Water Resources and Economics 43 (2023) 100229

Contents lists available at ScienceDirect

Water Resources and Economics

journal homepage: www.elsevier.com/locate/wre

Water value, irrigation policy, and implementation hazards in Vietnam's rural economy

Le Viet Phu

Natural Capital Management Program, Fulbright School of Public Policy and Management, Fulbright University Vietnam, 105 Ton Dat Tien, District 7, Ho Chi Minh City, Viet Nam

ARTICLE INFO

JEL classification:
Q12
Q15
Q25
Q51
D04

Keywords:
Water value
Irrigation policy
Principal–agent problem
Heckman selection
Instrumental variables

ABSTRACT

Irrigation plays a critical role in Vietnam's rural economy and the national food security priority. The Vietnamese government has developed an extensive irrigation system and waived irrigation costs for farmers to reduce rural poverty. However, excessive use of water in agriculture has become a major concern. It is important to evaluate the value of water in order to encourage economical use. We use a multi-model approach and plot-level data to indirectly estimate the value of irrigation water and address a majority of issues related to causal identification. Our results indicate that farmlands with access to irrigation have significantly higher productivity and land values. The high value of irrigation water in agricultural production is a premise for compulsory payment for irrigation water. We then investigate the design of Vietnam's irrigation policy and the hazards that have arose from the fee waiver policy. Finally, we explain why the current policy has failed to promote a sustainable long-term solution.

1. Introduction

Vietnam has made important achievements in food security and agricultural development over the past three decades. From a food importer, Vietnam has become one of the leading exporters of many agricultural products, particularly rice [1]. Land and irrigation policy play a critical role in the transition. The government interprets national food security as rice self-sufficiency, a goal achieved through explicit control over rice land [2]. The goal of producing enough rice to ensure food security is tied to the commitment to preserve 3.8 million hectares of agricultural land for rice production, of which 3.2 million hectares (which is equivalent to 10% of the country's total land area) for growing wet rice for two or more crops a year. This policy has been referred to as the "rice land designation policy" in various studies [3,4].

To support rice policy, the Vietnamese Government made massive investment in irrigation throughout the country, particularly in the Red River Delta and Mekong River Delta. Large investments and upgrading of hydraulic systems, the construction of dikes, sluices, and other irrigation infrastructure have led to the adoption of two and three rice crops a year, especially in the upstream area of the Mekong River Delta (Fig. 1). The significant increase in rice production and exports has been linked to the rapid growth of rice acreage over the past 20 years supported by the expansion and increase in the density of the irrigation system covering 9% of the area of the delta [5]. Currently, the Mekong River Delta, known as the "rice bowl" of Vietnam, is one of the most productive rice-producing regions in the world, providing more than 70% of Vietnam's rice exports to foreign countries [6].

Rice is a very water-intensive crop. Depending on growing seasons, water requirements vary. Winter–spring crops typically require about 8,000 cubic meters of water per hectare, while autumn–winter crops need about 6,500 cubic meters of water per hectare [7]. As a result, Vietnam has observed increasing demand for agricultural inputs, particularly water for crop production

E-mail address: phu.le@fulbright.edu.vn.

https://doi.org/10.1016/j.wre.2023.100229
Received 15 September 2022; Received in revised form 11 March 2023; Accepted 23 June 2023
Available online 28 June 2023
2212-4284/© 2023 Elsevier B.V. All rights reserved.

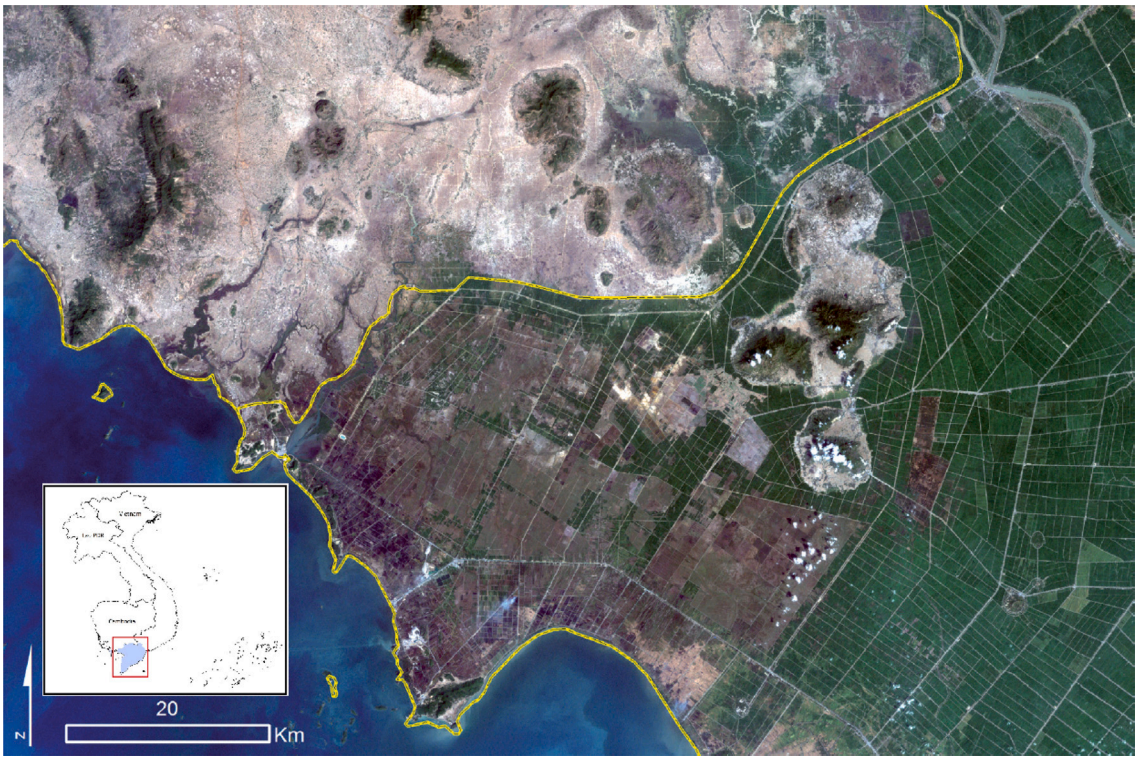


Fig. 1. Comparison of irrigated agriculture in the Mekong River Delta of Vietnam and Cambodia.
Different cultivation schemes between Cambodia (upper left corner) and the Mekong River Delta of Vietnam (lower right corner). Cropland is harvested once per year, while in Vietnam cropland is intensified up to three harvests per year due to extensive irrigation support. The figure reproduced with permission from [10].

which accounts for almost 73% of total water demand, most of which is surface water [8]. Despite efforts to divert from rice to other crops, rice still accounts for a half of the total cultivated area in 2020. Due to intensive rice cultivation, Vietnam has a much lower water productivity than that of regional countries such as China and India [9].

Prior to 2008, Vietnamese farmers had to pay an irrigation fee, which was set very low by the government. The government formulated the irrigation fee as a service charge collected from organizations and individuals that use water or services from irrigation projects for agricultural production. The collected fees help cover the cost of management, maintenance and operation of irrigation projects. However, as in most countries, only part of the operation and maintenance cost, typically less than 10% of the gross agricultural product, was collected [11]. From 2008 onward, the government has waived irrigation fees for most users, effectively encouraging farmers to cultivate water-intensive crops, especially rice. The government would indirectly subsidize water users by paying irrigation service providers instead of asking water users to pay the full cost of irrigation. The irrigation exemption policy helped to reduce the cost of production and raised household income [12]. For irrigation management companies, they will be directly compensated by the government. It is expected that ensuring a timely and stable source of revenue from the state budget helps reduce uncertainty with regard to fee collection and improves long-term commitments.

However, after a decade of irrigation fee exemption, this policy has continued to show many shortcomings. First, farmers do not directly pay for water, so they have no incentive to conserve it. Second, irrigation finance is dependent on a limited government budget while the demand for irrigation investment continues to increase. Furthermore, much of the exemption benefit goes to export markets while local people prefer high-quality rice imported from Cambodia and Thailand.[1] Complicated disbursement procedures and decentralized irrigation management also affect the efficiency of irrigation operations. Many locations have failed to provide sufficient irrigation and drainage services for rice production or alternative crops [9]. These have not taken into account the fact that Vietnam is among the countries most vulnerable to the impact of climate change.[2] Floods, droughts, and extreme weather events are forecast to pose significant risks to agricultural production [13]. Particularly, the Mekong River Delta is most susceptible due to the resonance of many factors, naturally from a flat terrain and very low elevation of only a few meters above the sea level, to an agrarian economy depending on water flows from outside of the country. In addition, upstream development involving the

[1] Upsurge in Vietnam imports of Cambodian farm produce. https://e.vnexpress.net/news/business/economy/upsurge-in-vietnam-imports-of-cambodian-farm-produce-4403716.html.

[2] ClimateLinks, A Global Knowledge Portal for Climate and Development Practitioners: https://www.climatelinks.org/countries/vietnam.

Table 1
Ministries and functions on water management.
Source: [23] and [21].

Ministry	Tasks and functions in water management
Ministry of Natural Resources and Environment (MONRE)	State management on water resources, meteorology and hydrology, integrated and unified management of the sea and islands
Ministry of Agriculture and Rural Development (MARD)	State management of agriculture, salt production, fisheries, irrigation, rural development, dyke, flood control
Ministry of Industry and Trade (MOIT)	Development of hydropower, building and operating hydropowers
Ministry of Science and Technology (MoST)	Prescription and guidance of water standard application
Ministry of Construction (MOC)	Implementation of planning for water supply and drainage in urban areas, industrial zones and densely populated areas
Ministry of Transport (MOT)	Management and development of waterway transportation, waterway works and harbors
Ministry of Health (MOH)	Management of drinking and daily life hygiene and safety standards
Ministry of Finance (MOF)	Guidance of water resource charges, fees and taxes
Ministry of Planning and Investment (MPI)	Coordination and submission of plans for investing funds in water management projects and for disaster caused by water

construction of many hydropower dams in the main-stream and tributaries of the Lower Mekong Basin may further change water flows, exacerbating water shortage [14].

In this context, estimating the value of irrigation water is needed as a basis for pricing and regulating irrigation services. To limit the use of water, irrigation water should be appropriately priced and paid for by users to efficiently and cost-effectively allocate scarce water resources to optimal uses [15,16]. Yet, very few attempts have been made to identify the value of irrigation in Vietnam. Because of this, estimated values vary widely, from as low as US1 cent/m3 in [17] to as high as US56 cent/m3 in [18], both using empirical crop modeling fitted to household survey data. Estimates of water values in different river basins using mechanistic approaches also carry vastly different results, from US6 cent/m3 in the central region to a high value of US77 cent/m3 in the central highland [19]. Meanwhile, a field measurement puts a value of US7.2 cent/m3 based on the cost savings from reduced demand for irrigation in coffee plantations in Dak Lak's plateau [20].

The paper makes two contributions to the literature. First, we provide an empirical estimate of the value of irrigation water in Vietnam at the plot level. We emphasize the causal interpretation of irrigation impact on farming economy, which has not been properly addressed in existing literature. We employ two separate models, one focusing on crop production and another on land value. Due to a unique feature of the national rice-first and rice land designation policy, we highlight a sample selection issue and employ a Heckman correction method to estimate the impact of irrigation on crop production. The endogeneity of irrigation is addressed by a two-staged instrumental variables approach. Second, we discuss the institutional arrangement of Vietnam's irrigation policy and the irrigation fee exemption, and explain why it has failed to achieve long-term sustainability. Then, we conclude with several recommendations for future irrigation policies.

2. Background

2.1. Vietnam's water sector and irrigation policy

Vietnam has a relatively comprehensive framework of institutions and polices for managing water, irrigation and drainage for both surface water and groundwater [21]. There are nine separate ministries, the Prime Minister's Office, a National Commission, and other agencies with direct and often overlapping jurisdiction over water [22]. Ministry of Agriculture and Rural Development (MARD) manages water resources including irrigation to support food security and rural development. As the largest water user, MARD drafted the latest Law on Irrigation, which was rectified by the National Assembly in 2017. Hydropower development is under the Ministry of Industry and Trade (MOIT). The Ministry of Natural Resources and Environment (MONRE) is responsible for environmental impacts. The organizational chart of water resource management is shown in Table 1.

The irrigation system is a major part of Vietnam's water sector, which is very extensive and serves multiple other purposes such as drainage, domestic water supply, fisheries, industrial production, electricity generation, transport and tourism, flood control and salinity prevention [19]. Investment in irrigation accounts for a major part of the government's budget in agriculture [22]. There are public components of the irrigation system such as large dams, lakes, main (primary) canals, pump stations, and private components such as locally built secondary and tertiary/field canals.

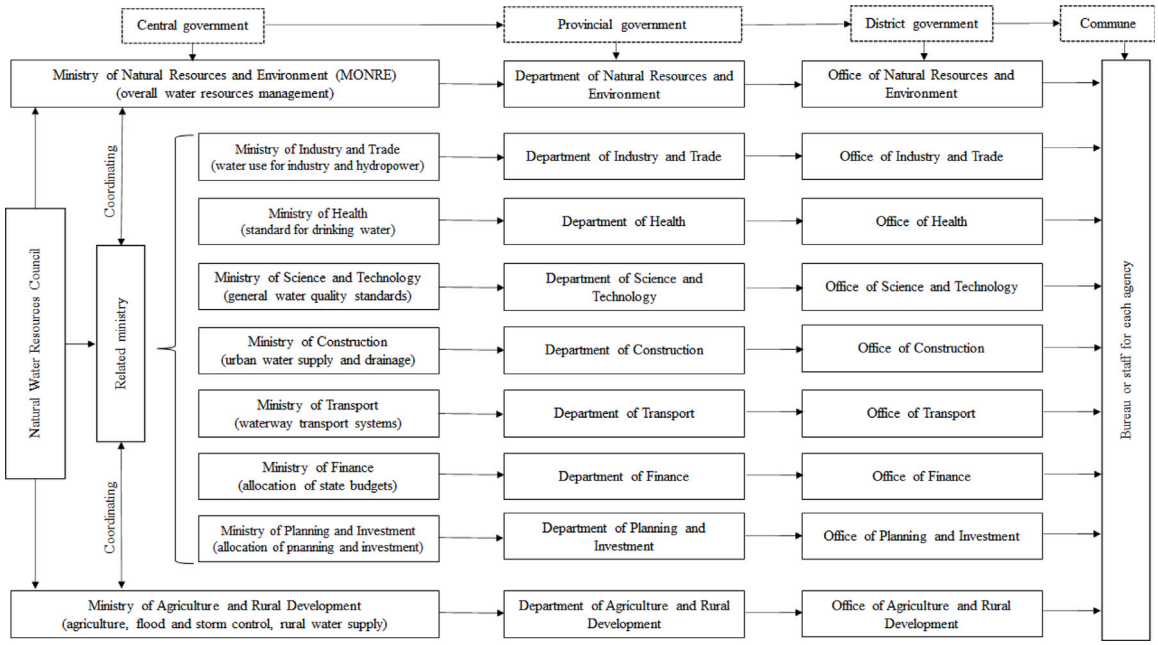


Fig. 2. Institutional arrangement from central to local levels for water sector in Vietnam.
Source: Adapted from [24].

Fig. 2 presents the institutional arrangement of irrigation management in Vietnam, from the central level (ministries) to local levels (province, district and commune). In the past, irrigation systems were managed by the Irrigation Management Section (IMS) under the Department of Water Resources at the provincial level and the Irrigation Station (IS) under the Water Resources Office (WRO) at the district level. Since 1977, Irrigation and Drainage Management Companies (IDMCs) were established. For large inter-provincial irrigation systems, an IDMC or a combination of many IDMCs is directly supervised by MARD or the Provincial People's Committee (PPC) of provinces where these systems are located. For irrigation systems within one province, depending on their size, IDMCs are established at provincial or district levels. Each IDMC is led by a Management Board chaired by a representative of MARD, PPC or the District People's Committee (DPC). With this structure, PPCs and DPCs are direct supervisors of IDMCs. Provincial Departments of Agriculture and Rural Development (DARD) are tasked with providing technical supports to IDMCs and advices to PPCs or DPCs [23].

Operating as independent business units, IDMCs build the irrigation system and collect water fees when providing services to water user groups or individual farmers. However, these fees were largely insufficient for operating expenses. There was no attempt to recover the cost of depreciation of physical assets, and funding for infrastructure maintenance was inadequate [25]. Therefore, a great part of their budget must come from central and provincial governments. From 2008, the government decided to waive irrigation fees for water users. Under the new scheme, IDMCs are responsible for delivering bulk water to primary canals and maintaining irrigation infrastructure within a province up to the commune boundary. Within the commune boundary, water user groups (WUGs) are responsible for maintaining and operating the field distribution system (internal canals and pumps) at their own cost. WUGs are also responsible for how irrigation water is allocated within the commune [23].

2.2. Irrigation fee exemption and consequences

Prior to 2008, IDMCs faced a difficult financial situation due to low irrigation fees and low collection rates. Revenues from other non-agricultural activities such as supplying water for domestic uses or tourism were often not collected due to the overlapping responsibilities for the same source of water among different government agencies. Since 2008, the irrigation fee exemption has been applied, and the government is responsible for paying most of the cost for irrigation activities [26,27]. Beneficiaries of the irrigation exemption policy are households and individuals using irrigation services for food and production, farmers growing vegetables and industrial crops, and aquaculture who meet certain land use quotas. The exemption policy also applies to poor households, and entities in charge of water drainage, with an exception for those in urban centers.

To implement the irrigation exemption, the provincial Department of Agriculture and Rural Development creates an irrigation plan based on irrigation contracts between water users and IDMCs, estimates the cost of granting exemption for irrigation fees, and submit it to the provincial Department of Finance. The Department of Finance then verifies the cost and seeks approval from the Provincial People's Committee. Exemption of irrigation fees is directly applied to IDMCs, meaning that the government will provide fund for management, maintenance, repair, and operation of irrigation projects [28]. IDMCs will not collect irrigation fees from

water users. However, farmers still have to pay for pumping water from commune canals into their fields and local management by a grassroot water user group. This fee varies significantly by river basins. The Mekong River Delta pays about VND800,000-1,500,000 hectare per crop (US35-67). For the rest of the country, it ranges from VND200,000 (USD9) per hectare in mountainous areas to VND600,000 (USD27) per hectare in the Red River Delta [29].

The exemption has had a positive impact on reducing production cost and increasing farmer's income [9]. Irrigation costs are reduced the most for farmers in the Red River Delta and the mountainous areas, while the Mekong Delta benefits the least.[3] On average, farmers could save 5%–10% of the total cost of production.[4] One critical impact of the exemption policy is that the irrigated area has been increasing steadily. In the past, farmers under-reported irrigated areas to reduce how much they would owe the government for use. Under the new scheme, irrigation area has increased likely because there is no longer an incentive to hide area along with IDMCs' incentives to expand the irrigation system to claim more revenue. Some IDMCs were even caught inflating the service area to receive more government funding.

Inadvertently, the irrigation exemption policy intensifies a typical principal–agent problem in allocating public expenditure [30]. This problem occurs when there is a conflict of priorities between the owner of an asset and the person to whom control of the asset has been delegated. The agent acting in its own interest may cause harm to the principal. Since exemption is granted directly toward IDMCs, water users have a poor experience of participation in the management and operation of irrigation projects. The principal, who is an indirect payer and beneficiary of irrigation services as represented by the government, is at the receiving end of the scheme. There is no binding mechanism between irrigation service providers and water user groups or farmers. Farmers have reflected poorly on the quality of the irrigation services [31]. This phenomenon is also observed in an earlier study by [32] of six developing countries including Bangladesh, China, India, Indonesia, Pakistan and Vietnam that a low irrigation charge could be disadvantageous to the poor as it adversely affects system performance.

Meanwhile, the agent, who is an irrigation service provider, is not tied to the quality of the service. The current mechanism does not motivate IDMCs to increase labor productivity and reduce costs. The contrasting picture of pre- and post-exemption is stark. In the 1990s, each irrigation worker would manage and operate about 200–300 hectare per year. Now the number of employees is much higher, and the average area managed by each irrigation worker is only 60–100 hectare/year or even lower [33]. IDMCs always report fully meeting the irrigation target post-exemption; whereas the completion rate was only 70%–75% pre-exemption [31]. [34] highlights the weak downward accountability between irrigation agencies and water users that existed even before the exemption. There is no formal mechanism to include local water users in the decision-making process involving irrigation planning. This issue has been further exacerbated by the exemption.

The exemption policy also causes inefficiencies due to misaligned responsibilities and incentives. The provision of exemption only covers the cost of operating culverts, regulating dams, siphons, primary canals, fixed electric pumping stations, dredging and upgrading primary canals [27]. Water users are responsible for managing and operating secondary canals and field pumping stations. Even for areas where 2nd- or 3rd-stage pumping is required, the exemption is still only applied to the primary canal. Because the physical extent of primary or secondary canals is not well defined, disputes have occurred [35]. In addition, irrigation exemption is only applicable to public projects. Irrigation works built with private investment are not eligible for exemption, which creates perverse incentives for stakeholders to further rely on the government's investment rather than encouraging private participation.

3. Method and data

3.1. Econometric framework

Many methods are available for valuing market and non-market commodities. Water, as an input to agricultural production, is not often traded explicitly. Therefore, the value of agricultural water must be measured indirectly through its contribution to the total value of agricultural 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. While this approach appears simple to implement, it requires very detailed household interviews to identify every aspect of production, including the types of outputs and inputs, volume of use, and price for each output and input, including those supplied by each household and thus do not have a market price. Ensuring data collection that entails all necessary inputs (both quantitative and qualitative) and values of non-market inputs, skills and expertise is challenging. Missing, unobserved or under-valued inputs can greatly affect the calculated value of water in the residual value approach, making this method less appealing in practice. Residual methods have been conducted mostly in developing countries, including [36–41], and [42].

Alternatively, water used for agriculture can be valued in a production function that transforms inputs into outputs. Farmers will choose the optimal level of inputs such that the net revenue (the revenue from crop sales less the cost of inputs) is maximized. Assuming farmers use the same technology and are fully efficient, the relative price of inputs is then equal to the marginal value of the product (crop) at its optimal level of production. Comparing farmlands with similar characteristics (demographics, soil characteristics, climate conditions, and input intensity) but with differing degrees of access to water, it is possible to attribute the production value to irrigation access. Empirical analysis using farm-level data shows that crop yields to be consistently higher in irrigated areas than in rainfed areas [43,44].

[3] Irrigation fee exemption: Farmers in the Mekong River Delta still pay the same. url: https://www.iwem.gov.vn/vn/mien--giam-thuy-loi-phi--nong-dan-nhieu-noi-phai-dong-muc-cu_496.html.

[4] Deficiency in irrigation fee waiver. url: https://www.qdnd.vn/quoc-te/binh-luan/bat-cap-khi-mien-giam-thuy-loi-phi-445715.

In the absence of farm output data, a hedonic valuation approach relies on observable land characteristics to predict the contribution of water access to farmland value [45–47]. Farms with better soil quality, a flat slope, and better access to water and transportation are expected to have a higher productivity or profit. A more productive farm often sells far more than a less productive one, assuming all other characteristics are the same. The hedonic regression approach then infers the capitalized value of water access in the total land value. An advantage of the hedonic valuation is that water value is identified through real estate price. Farmers are assumed to automatically switch to the most profitable production system in the long term. Thus, the value of water is the same across all types of production systems or land uses. This removes a potential issue facing other methods such as the residual valuation technique in which input and output prices are valued differently across farming systems.

3.1.1. Production model of crop yields

We first estimate a production function of crop yields to identify the contribution of irrigation to crop productivities. We assume a reduced-form log-linear function of inputs and the logarithm of outputs, following [47,48]:

$$log(Q_i) = \beta_0 + \beta_1 \times D_i + \sum_j \beta_j \times X^j{}_i + u_i \quad (1)$$

The crop yields Q_i is measured as the total amount of rice or maize in each unit of farmland. D_i is the state of irrigation, $D_i = 1$ for irrigated farms and $D_i = 0$ for non-irrigated farms. We include an extended list of variables X^j to control for input uses, land characteristics, and demographics representing the education level and ethnicity of a household's head. u_i is the unexplained residual. The impact of irrigation on the output is $[e^{\beta_1} - 1] * 100$ (%).

We define irrigation as having access to canal water, while non-irrigated farms are naturally irrigated, rain-fed or have no clearly defined source of water. Primary canals are public investment made by the government, while households are responsible for tertiary or field canals. They are capital intensive, most reliable, and designed to supply water to high-value crops. Meanwhile, rainfall, river, or pond water are natural irrigation with little investment. Since we do not observe the amount of water withdrawal, the value of having irrigation is interpreted as the value of having access to water per unit of agricultural land, regardless of the withdrawal amount or water quality. Farmers may decide to pump as much irrigation water as needed to maximize the value of crops grown on their land. This interpretation of the value of water is aligned with [49] that water is considered a fixed input in agricultural production.

We start with treating a household's decision to irrigate as random in a natural experiment as in [48]. This assumption likely holds, at least in the short run. Irrigation based on built structures such as water canals are often capital intensive and provided by the government. Natural irrigation such as river, pond or rainwater is a geographic or climatic characteristic rather than a household's choice. Groundwater access is also arguably random because its availability is dependent on specific locations and depths to underground aquifers. If irrigation is randomly assigned, then the difference in the outcome variables, or the unadjusted mean difference, is the average treatment effect of irrigation on farming. Because this effect is based on certain agricultural systems and land use types, we interpret it as the short-term value of water.

A potential problem with the production model is that the choice of crops, mainly rice or maize, may not be random. The choice of crops may be determined by restrictions placed on the land by the government. Because rice is considered a national food security issue, rice land is strictly regulated under various laws and regulations. Although the laws allow transfer, conversion, lease, mortgage and inheritance of land use rights, but in practice there are significant restrictions regarding both land conversion and land accumulation [50]. Landowners must not convert rice farms to other agricultural uses such as perennial crops, afforestation, aquaculture, or non-agricultural use without the permission of a relevant state agency. In addition, households and individuals that are not directly engaged in agricultural production may not receive the transfer or donation of rice farms. Conversions of rice farms from 10 hectares or more must be subject to approval of the Prime Minister, whereas conversions of smaller parcels require a resolution of the provincial people's council [51]. The national rice production and area targets are based on consideration of expected domestic consumption, export targets and planned land conversion. In addition to crop selection, the right to build permanent structures or to convert land away from agricultural use is severely restricted, representing another aspect of state-controlled land use [52].

In the literature, [53,54], examined the extent to which land designation policy influences crop choice, found that the policy had a significant effect on the proportion of agricultural land allocated to paddy production. [3] also concluded that the rice land designation policy could affect crop selection, although this comes at the expense of productive and allocative inefficiencies. If the best land is required to grow only rice, then we may observe that the most profitable farmlands pertaining to rice crops, while less fertile lands are used for less valuable crops such as maize, beans or peanuts. Then, rice models that use a restricted sample of the most profitable lands may overestimate the value of irrigation in rice farming, while underestimating the contribution of irrigation to other less valuable crops.

To correct for the potential sample selection issue, we propose a two-step Heckman sample correction method [55]. The Heckman procedure involves estimating two stages consecutively. In the first-stage selection model, we estimate the probability of observing a major crop being grown, either rice or maize, conditional on a set of explanatory variables R representing various land use designation requirements. The crop choice is heavily affected by government policies which restrict farm owners of what they could do on agricultural lands. Certain farms are required to grow rice in some season in a year. Rice farms are also protected by various conservation practices on soil or water, or prohibited from converting to other uses. Note that these requirements may affect a farmer's choice of what crop to grow, yet having obtained a conversion permit does not automatically raise the productivity of the farm. Therefore, the restrictions imposed on farmlands by the government satisfy the exclusion restriction to be used in the Heckman

two-step sample selection procedure. In the second stage, the inverse Mills ratio is added as an additional control variable in the farmland production function to adjust for the sample selection issue. The inverse Mills ratio 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:

$$\begin{cases} P(Rice_i = 1|R_i) = \Phi(R_i\gamma + v_i) & (H1) \\ log(Q_i|Rice_i = 1, X_i) = \beta_0 + \beta_1 \times D_i + \sum_j \beta_j \times X^j{}_i + \rho\lambda(R_i\gamma) + u_i & (H2) \end{cases}$$

where R_i is the set of explanatory variables of the selection equation $H1$. $\Phi(.)$ is the cumulative distribution function of the standard normal distribution. $\lambda(.)$ is the inverse Mills ratio, $\lambda(.) = \frac{\phi(.)}{\Phi(.)}$, measured at value $R_i\gamma$.

3.1.2. Hedonic valuation of the impact of irrigation on farmland value

A potential problem with using crop yields to estimate the value of irrigation is that it is dependent on crop choice and crop price. As the price fluctuates, the derived value of irrigation likely varies over time. Furthermore, government intervention may distort agricultural markets, particularly with respect to rice due to its relation to national food security. An alternative approach is to use the transacted values of farmland in the land market, starting with a seminal work of [45] proposing the Ricardian analysis to link climatic conditions with farmland values. [47] refine the approach to account for the impact of irrigation on crop productivity. 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.

The value of agricultural land is derived from its current and potential future use. It is also influenced by the institutional context that defines land use and limits its convertibility [56]. Farmers can raise the value of their land by improving its productivity such as investing in irrigation, drainage, soil practices, and fertilization. Because Ricardian hedonic valuation of farmland value assumes a long-term market equilibrium and that farmers automatically switch crops or inputs to maximize the income from their land, the value derived by the hedonic approach is independent of crop systems or land use purposes. If the land market is perfectly competitive, and farm owners have complete information about their land, then, the value function (logarithm of farmland value) could be constructed as a function of its attributes such as the climate, soil, and economic variables [45,46] as in Eq. (2):

$$log(V_i) = \beta_0 + \beta_1 \times D_i + \sum_j \beta_j \times Z^j{}_i + u_i \quad (2)$$

where V_i is the farmland value per unit if the land is sold at the time of survey. D_i is the irrigation status. Z_j is a vector of observable characteristics such as climate, soil, and economic characteristics.

We start by treating the decision to irrigate as random in a natural experiment. This helps circumvent the problem with omitted variables bias, which is the greatest threat to cross-sectional studies [57]. Despite the availability of panel data which could be used to control for farm-level unobserved heterogeneity, irrigation and other physical properties experience very little change during the survey period. As a result, a fixed-effect estimator cannot be used to separate the impact of irrigation from other field-level characteristics such as land quality or soil properties.

However, unlike the production model which measures the current contribution of irrigation in the output, the land value model is estimated for a long-term equilibrium in the land market. Therefore, it is no longer possible to assume irrigation as predetermined. The literature on endogenous irrigation suggests that the decision to irrigate may be a response to other drivers, notably weather shocks such as droughts or higher temperatures. Farms that have been subject to adverse shocks may require long-term adaptation measures such as investment in irrigation and other physical interventions. Because shocks tend to reduce farm outputs, the estimated coefficient of the irrigation variable is therefore negatively biased. As a result, [58] report that the impact of temperature change is less harmful to irrigated farms. [59] classify adaptations into micro-level adaptations such as crop diversification, alternative farming systems, shifting planting and harvesting dates, to macro-level adaptations such as national agricultural policy, reforms, and large-scale investment in infrastructure.

In Vietnam, endogenous irrigation may occur due to national agricultural policy priorities. On one hand, Vietnam's irrigation construction often leans toward supporting a pro-poor policy [60]. The government has used irrigation as a means to support socioeconomically disadvantaged communities through the construction of water storages, culverts, and canal systems. As poorer communities are often located in areas with less active real estate markets, the negative correlation between irrigation and land prices may produce a negative bias on the value of irrigation.[5] On the other hand, construction of irrigation and infrastructure to support rice farming also comes with improved access to roads, markets and services [61], which could raise local land value. Combining those opposing effects, it is unclear about the direction of bias on the impact of irrigation on farm values.

To address potential endogeneity of irrigation, we propose an instrumental variables approach with two-stage regression (2SLS/IV). We first estimate a household's decision to irrigate their farms with a set of instruments I^k. The second stage estimates

[5] When irrigation is endogenous, least-squares estimate of the coefficient of irrigation may be significantly underestimated:

$$\beta_1{}^{OLS} = \beta_1{}^{true} + \frac{Cov(Y,u)}{Var(D)}$$

because u includes unobservables that are negatively correlated with Y, $\beta_1{}^{OLS} < \beta_1{}^{true}$.

the impact of the instrumented irrigation on farmland values.

$$\begin{cases} P(D_i = 1|I_i, Z_i) = \gamma_0 + \sum_k \gamma_k \times I^k{}_i + \varepsilon_i & (I1) \\ log(V_i|Z_i) = \beta_0 + \beta_1 \times \widehat{D_i} + \sum_j \beta_j \times Z^j{}_i + u_i & (I2) \end{cases}$$

The instrument, or a set of instruments, is required to satisfy the relevance and the exclusion restriction conditions. First, the instruments must be correlated with the endogenous variable. Second, the instruments must not directly influence the dependent variable. In this study context, the first condition implies that the IVs must be related to the irrigation status of each farm, whereas the second condition stipulates that the IVs must not directly affect farming outcomes or farmland values. We have found a set of commune-level characteristics that potentially satisfy these two conditions. Specifically, we argue that commune-level irrigation characteristics are strongly related to farm-level irrigation status while having no direct impact on an individual farm's productivity or value.

Justification of the instruments

In Vietnam, the government is responsible for building primary canals to take water to communes. Water is provided free to the communal gate according to the irrigation fee exemption policy. Within a commune, farmers are responsible for irrigating their own farms. Vietnam's administrative hierarchy is delegated into province, district, and commune levels, respectively. Communal government is the lowest level of the government system. Commune authorities serve as the bridge between higher government levels and individuals in the commune. They represent the government and on behalf of the government exercises power, most importantly focusing on implementing guidelines and policies in the commune. We focus on a separate set of questions based on communal characteristics of the irrigation system. This set of questions was directed to commune leaders.

1. "Are there any public or cooperative irrigation facilities in this commune?", with the answer being Yes, Public/Cooperative/Both.
2. "What share (in percentage) of farming households in this commune use public sources of irrigation?"
3. "What share (in percentage) of farming households in this commune use private sources of irrigation (for example private wells)?"
4. "Where is the commune located in relation to the district's main irrigation facilities?", with answer being Head End/Middle/Tail End.
5. "Are there any water user group in this commune", with the answer being Yes/No.

These commune-level information are expected to be highly correlated with farm-level irrigation (the relevance condition). Having public or cooperative canals is expected to increase any given household's irrigation access. A higher percentage of irrigated farms (either by public or private canals) is also indicative that a specific farm more likely has access to irrigation. The position of a farm, whether it is at the head end of a water canal, tail end, or somewhere in between will affect water availability and therefore the private irrigation decision. And finally, the presence of a water user group is expected to increase the irrigation rate within the same commune.

The exclusion restriction must be justified on the policy ground. As commune-level irrigation investment is often made by higher governmental authorities, not by commune leaders or any individual household in the commune, we argue that communal irrigation characteristics do not directly affect plot-level land values within each commune, after conditioning on a set of fixed effects (province, district, and commune) in the land value regression. The three-way fixed effects capture local differences according to the administrative hierarchy, leaving behind random variations that are expected to be purely driven by farm-level productivity. The use of the commune-level instruments is motivated by [62,63] which instrument individual performance by group statistics because individual measurement error is arguably uncorrelated with group averages.

The validity of these instruments is dependent on having many water users and that there is no one dominating farm in the commune. This likely holds because most Vietnamese rural households are smallholders, and agricultural cropland is strictly limited to less than 2 hectares in most provinces by Vietnam's Land Law of 2013. Furthermore, agricultural lands in Vietnam are highly fragmented as a consequence of a communist-era land allocation policy that distributed land to commune members in a roughly egalitarian manner, so that no one household would have a concentration of plots in the most fertile parts of the commune, or near roads, water sources, or other essential services [50,64]. Many households had 7 to 8 fields, of which about 10% had an area of only 100 m2 or less [50]. Despite the total number of parcels of land has decreased recently due to land consolidation, but the problem is still widespread [65].

3.2. Calculating the annual and the capitalized value of water

The production model identifies the annual value of irrigation water in crop outputs; whereas the hedonic regression model estimates the long-run capitalized value of irrigation water in farmland value. The value of irrigation in either model can be identified as coefficient β_1. In a perfectly competitive market, the capitalized value is calculated as the present value of an infinite stream of annual values. Therefore, a discount rate r, assumed 5%, is applied to convert the capitalized value of irrigation to the flow of the annual value of irrigation, $Capitalized\ Value = Annual\ Value/r$. This allows us to directly compare the two models and check the robustness of the results.

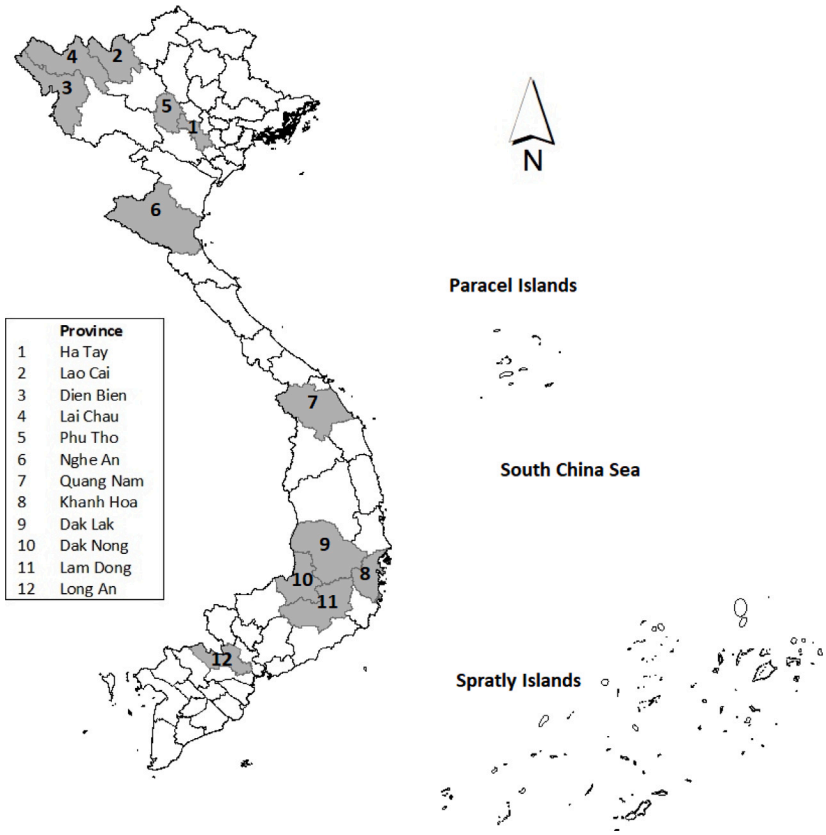


Fig. 3. Location of 12 provinces in the VARHS data.

3.3. Data and description

The Vietnam Access to Resources Household Survey (VARHS) has been conducted every two years since 2004 [66]. The survey, which focuses on the rural economy and rural livelihoods, serves as a complement for a more comprehensive Vietnam Household Living Standards Survey (VHLSS). VARHS is the only large-scale household survey that collects detailed information pertaining to production practices, farmland values, and irrigation systems, in addition to many household characteristics such as labor and income, land use, agricultural activities, risk and insurance, savings and credit, social capital and access to information. We use the latest available dataset of 2016, which was released to the public in 2020.[6] The VARHS 2016 survey has a sample of 2,669 households in 12 provinces from north to south of Vietnam (Fig. 3). We identify parcel-level information from a total of 11,182 land plots.

Dependent Variables

Our study examines two outcome variables: crop yield and farmland value. 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 popular unit of measurement of agricultural land in Vietnam is the "*công*" or "Vietnamese acre", which equals 1000 m2 in the South.[7] We observe that the most common crop is rice, followed by maize and vegetables, including cash crops, such as coffee, cassava and peanuts. In the first season, 4,492 farm plots grew rice, but only 3,711 did so in the second season, and 153 in the third season in the same 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. For administrative purposes, the farmland can be categorized as an agricultural, non-agricultural and unused land. Agricultural land includes land for annual crops and land for perennial crops. Land for annual crops is further divided into rice cultivation land and land for other annual crops [56]. To eliminate the impact of urban development on farmland values, we discarded all residential

[6] Viet Nam Access to Resources Household Survey, UNU-Wider: https://www.wider.unu.edu/database/viet-nam-data.

[7] However, 1 "*công*" equals to 360 m2 in the North, and 5000 m2 in the central region. We use this unit of measurement because most farms are less than one hectare in size.

Table 2
Estimated annualized values of irrigation calculated at sample mean/sample median, in million VND and USD equivalence per hectare/year.

Method	Crop production		Hedonic valuation
	Rice	Maize	
[1] Unadjusted Mean Difference	12.76/19.60	8.44/9.82	25.22/26.04
USD	570/876	377/439	1,127/1,164
[2] Regression-adjusted Mean Difference	10.66/11.43	2.25/1.78	28.95/20.22
USD	477/511	101/80	1,294/904
[3] Heckman Correction for Sample Selection	9.51/10.20	2.03/1.61	
USD	425/456	91/72	
[4] Instrumental Variables			52.18/39.30
USD			2,333/1,757

The official exchange rate in the year of the survey was USD/VND = 22,370.

land and garden houses. The analysis focuses on farmlands belonging to one of the following types: annual croplands, perennial croplands, forestland, fish and shrimp ponds, and grassland/pasture.

The reported farm values vary greatly, underscoring a potential issue with perceived values in the real estate market. In addition, up to 60% of the sample does not report a farm value. The reason is that the farmland market is not well established in Vietnam, and with very few actual transactions, the perceived price may not accurately reflect the actual value of agricultural land. Thus, we discarded observations below the 5th percentile or above the 95th percentile of the value spectrum. After this, we were left with 8,275 farm plots for our analysis.

Farmland Characteristics

Many factors may influence the productivity of farmland, such as the physical properties of the soil, the slope, the distance to market, infrastructure, the climate, and restrictions placed by the government on the land. 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 slope of the land 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 suffered any problem such as dry soil, if it is a low-lying land, and if the soil is stony or clay. In addition, we include the total land size in the model to examine whether farm productivity exhibits economies of scale.

Farmlands are also affected by various restrictions placed by the government. This could be soil and water conservation, crop choice, and conversion permits. In general, the Vietnamese government strictly stipulates that agricultural land must be used for agricultural production [51]. Conversion to built-up land could raise the land value significantly, which would create incentives for landowners to obtain conversion permission where possible. However, conversion from growing one crop to another, for example, from rice to upland crops, is more prevalent as long as the land remains classified as agricultural land.

In Ricardian hedonic regressions, climate conditions during growing seasons, such as temperature (or growing degree days), precipitation, and occasionally, extreme heating condition (or harmful degree days), are considered important inputs to crop agronomy [45,47]. However, these variables are highly correlated with geographic factors. To address this, we include a set of location fixed-effects representing communal differences in the climate conditions. We address intra-provincial correlations by clustering standard errors at the provincial level.

Irrigation Variable

The VARHS survey only provides information on the main source of water for each farm, although a farm could be irrigated by multiple sources, depending on seasons, crop types, and cost. The most common type of irrigation is canal, followed by water from a spring/river, groundwater (including both bore wells and dug wells), spring or river, a pond or lake, and other sources.

Other control variables

We control for the characteristics of household's head, including whether he/she belongs to the dominant Kinh ethnicity, age, and the type of education or training he/she has obtained at the time of survey.

The complete description of the variables and summary statistics are available in Tables SM1-SM6 in the attached Supplementary Materials.

4. Empirical findings

Table 2 summarizes estimated annualized values of irrigation. The first row is unadjusted mean differences in crop production or land values between irrigated farms and non-irrigated farms, which indicates a positive contribution of irrigation as expected (Fig. 4). To attribute the impact of irrigation to the farming economy, we rely on the estimation of the production function and the hedonic valuation. The second row corresponds to the regressions of Eqs. (1) and (2) without treating endogeneity. Crop production models adjusted for the sample selection issue is shown in the third row. Hedonic valuation of farmland values with endogenous irrigation is in the fourth row.

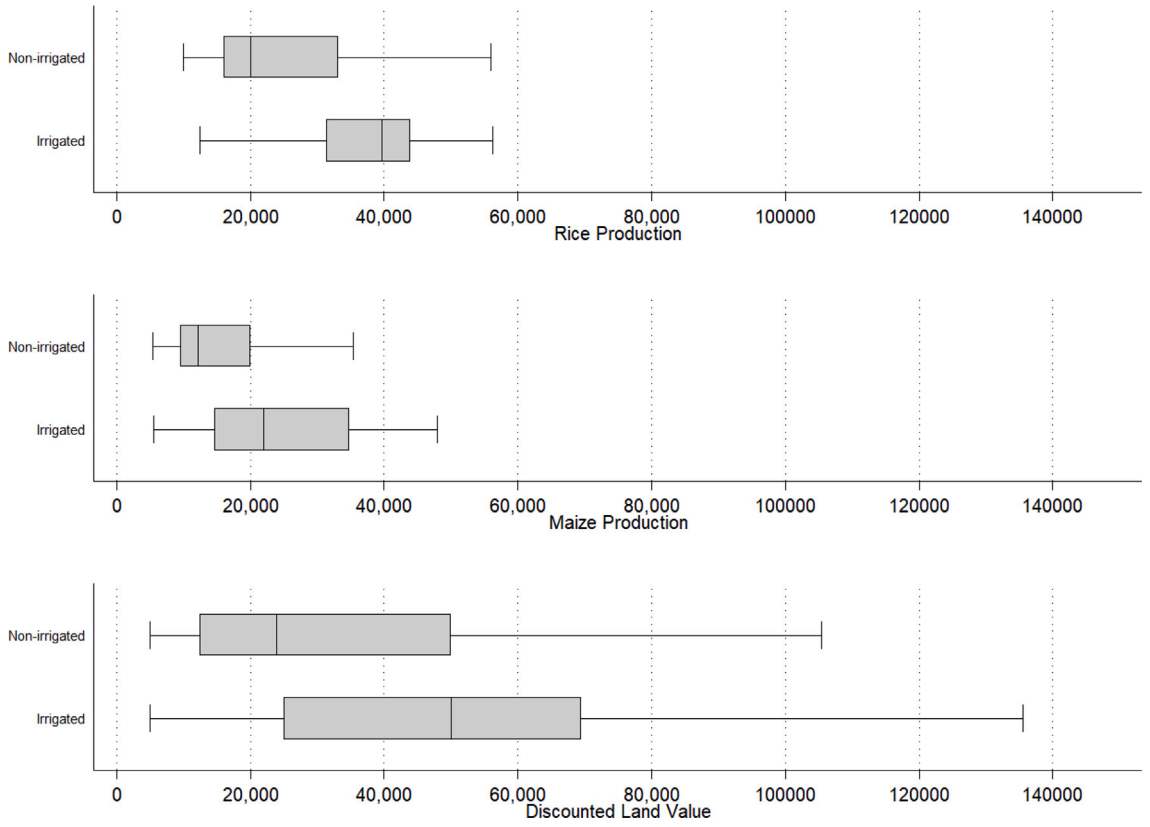


Fig. 4. Annualized values of irrigated versus non-irrigated farms (VND1000/ha).

4.1. Production model of crop yields

Estimation of crop production Eq. (1) shows that rice productivity is higher by up to 30% in farmlands that have access to irrigation. However, the impact of irrigation on maize yields is significantly smaller, is only 12% higher (Table SM7). In monetary terms, the added productivity is valued at approximately VND10.66 million (USD477) per hectare per year for rice.[8]

Other coefficients of interest are: the production input (+), the distance to home (−), juxtapose (+), land slope (−), and no land problem (+). These estimated coefficients are as expected. Using more inputs raise the amount of output. The longer the distance from farm to home, the higher the cost of production through transport and losses is. Adjacent farms may allow the use of tractors and other farming machines. Sloping land makes it difficult to retain water and is prone to runoffs, resulting in lower land productivity. Farmland without an issue such as stone, clay, or low-lying land may have a higher productivity. We observe that the coefficient of the plot area is negative, yet statistically insignificant.

To examine whether crop selection may affect the estimated coefficients in model (1), we examine the first stage of the Heckman two-step procedure (Table SM8). If there is no selection issue, the error terms from the selection equation ($H1$) and the production equation ($H2$) are independent. The LR test of independence ($\rho = 0$) is soundly rejected even at the 1% significance level, $\chi_2(1) =$ 28.18 and 8.76, for rice and maize crop, respectively, strongly confirming the presence of sample selection. The estimated parameters of the selection equations are all as expected: rice plots are significantly associated with having conservation measures, having a physical structure to support farming, not allowed to convert to non-agricultural use, not allowed to grow perennial crops, must grow rice in some seasons, and not restricted to grow certain crops. The opposite occurs with growing maize, although with a weaker association. The value of irrigation in farming, adjusted for the sample selection issue, is approximately VND9.51 million (USD425) per hectare per year for rice, and VND2.03 million (USD91) for maize, which is about 10% below the least-squares estimates.

[8] We assume paddy rice price is maintained at least VND4,000 per kilo by a government resolution which "...promulgates policies to ensure that commodity rice farmers earn a profit of at least 30% compared to production costs". [67]. Unlike rice, small-scale maize production is mostly used as cattle feeds and its price is not well established. If maize price is valued at VND4000 per kilo, the value of irrigation for maize is VND2.25 million (USD101) per hectare per year.

4.2. Hedonic valuation of the impact of irrigation on farmland value

Based on the least-squares estimate, irrigated lands are up to 48.52% more valuable than non-irrigated lands (Table SM9). If the mean farm price is VND1,193 million/hectare (USD53,300), having access to irrigation adds approximately VND579 million/hectare (USD25,883) to the value of irrigated farms compared to non-irrigated farms. Converting these into an annualized value of irrigation, assuming a constant discount rate of 5%, irrigation is valued at VND28.95 million (USD1,294) per hectare per year. However, considering irrigation to be endogenous, the value of irrigation is twice that of the least-squares estimate, reaching VND39.30 million (USD1,757) per hectare (median value) or VND52.18 million (USD2,333) per hectare (mean value). This confirms our initial suspicion that traditional hedonic valuation is biased downward when irrigation is considered an adaptation measure. Most importantly, the magnitude of bias is significant. Many studies have arrived at the same conclusion that irrigation has a moderating effect in research on the impact of global warming on farmland values [45,47,68]. These values are much higher than the maximum irrigation fees imposed by the Ministry of Finance. The highest price for public irrigation services is as low as VND1,811,000/ha/crop for pump operated irrigation, while gravity-fed irrigation is only VND1,267,000/ha/crop [69].

We present three tests, including the endogeneity test, the weak instruments test, and the over-identification test, to ensure the validity of the instrumental variables approach (Table SM10). For the Wu-Hausman's endogeneity test, rejection of the null implies endogenous irrigation. For the weak instruments test, if communal irrigation characteristics are only loosely correlated with farm-level irrigation status, IV estimates may be biased [70]. The weak instruments test with one endogenous variable and seven instruments, based on the first-stage F-statistics of 7.35, is rejected at a potential maximal bias of 20% relative to least-squares estimation. Examining the first-stage, we find that having cooperative irrigation facilities or a higher share of farming households using public irrigation increase the likelihood that a farm in this commune is irrigated. However, farms at the middle end of the district's irrigation facilities are marginally more likely to have irrigation. As [60] point out, water scarcities are more prevalent in the tail end of a water channel, thus the irrigation decision could be seen as a reaction to lack of water. We also find that the model does not suffer from over-identification. Of course, these tests are only valid if there is at least one valid instrument. Generally, the exclusion is often never fully justified.

To calculate the price per volumetric unit (m3) of water, we divide these values by the average volume of water used per hectare of rice. For example, if one typical hectare of rice needs approximately 6,000 cubic meters of water per season, and assuming that the average farmer grows rice twice a year, then the value of water is approximately VND793/m3 (US3.54 cent/m3) based on the production method. Based on hedonic valuation with endogenous irrigation, the value of irrigation could be as high as VND3,275 (median) or VND4,348 (mean) per cubic meter (US14.64-19.44 cent/m3). These figures are well in line with global estimates of water value in rice production of US12-16 cent/m3 (median/mean) in [71] (Table 3). Methodological differences aside, the estimates reinforce our conclusion that the value of irrigation water in Vietnam is high and consistent with what researchers have found in other countries.

The annualized value is derived 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 which the future income flow is discounted. Raising the discount rate will proportionately increase the value of water.

5. Discussion and policy implications

Irrigation fee exemptions have raised many interesting aspects on traditional government's investment and operation. For historical reasons, rice policy has always been considered a national food security issue in Vietnam. Vietnam's 2013 Land Law clearly stipulates the responsibilities of the government in protecting rice farms, supporting rice farming with irrigation infrastructure, and strictly demanding farmers to cultivate rice in some seasons of the year [51]. On the positive side, the exemption has limited the contribution of water users and increased farmer's profits. Due to more stable government funding, irrigation service coverage and irrigation access have increased every year since 2008. Building and providing access to irrigation can also improve the public image of the government in rural areas. Yet, over time, the exemption policy has been shown to be inefficient and susceptible to corruption. Because the funding is directly channeled toward irrigation service providers, the beneficiaries do not have any leverage over the quality of irrigation services.

Vietnam's irrigation development policy has always been driven by the country's goal of increasing rice production rather than a due concern for farmer's incomes [5]. For the world, Vietnam's rice policy benefits the world's food security by providing more and cheaper rice since 2012 [81]. However, as a national food security strategy, rice self-sufficiency is inefficient because it locks land and other resources such as labor, physical and financial capital into low-value rice cultivation [2]. Many studies show that hybrid systems such as rice-upland crops or rice-aquacultural production could yield a higher net revenue than a triple-rice intensive system [6,82].

Considering the high water intensity of the economy, massive investment in the irrigation system, and increasing awareness of potential impacts of climate change and extreme weather on future water supply, the high value of water warrants a new approach to irrigation policy. The new approach should require a shift from the traditional role of irrigation to support political and social stability toward a new role that highlights economic efficiency and long-term sustainability. The government should stop subsidizing irrigation water for water-intensive or low-value crops. To encourage economical uses and efficient allocations of water as a scarce resource, water must be considered a commodity, and its value be properly identified and paid by users as one of the inputs that producers have to pay, similar to other inputs such as seeds, fertilizer, energy, and labor. While a full cost recovery might not be

Table 3
Comparison of estimated values of irrigation water in selected countries.

Authors	Country	Method	Capitalized value	Annualized value	
			US$/hectare	US$/hectare	cent/m^3
[72]	USA	Hedonic	3,888	16–25/acre-foot	1.3–2
[73]	USA	Hedonic	1,507		
[74]	USA	Hedonic	12,395	620	
[75]	USA	Hedonic	1,270–7,207	31–153/acre-foot	2.5–12.4
[76]	Italy	Hedonic	9,391–10,399	680–684	18.9–34.3
[77]	Australia	Residual Method			12
[78]	India	Residual Method			4.5
[79]	China	Production			7.1
[71]	Cross-country	Biophysical model			12–16
Value of irrigation water in Vietnam					
[17]	Vietnam	Production			1
[80]	Vietnam	Production			12.85
[20]	Vietnam	Experiment			7.2
[18]	Vietnam	Crop choice modeling			56
This study	Vietnam	Production		425 (mean) 456 (median)	3.5 (mean) 3.8 (median)
		Hedonic		2,333 (mean) 1,757 (median)	19.4 (mean) 14.6 (median)

Due to different units of measurement, we convert all values to US Dollar per hectare at the year of the study.

justified, the Vietnamese Government could partially recover the cost of providing irrigation services estimated USD250 million as of 2012 [83].

Regarding fee collection mechanisms, past irrigation fees were assessed and collected per hectare per crop season. While they are easy to manage, they provide little or no incentive for farmers to use water efficiently [34]. A volume-based fee would provide a direct incentive to use water more efficiently. However, volumetric pricing worldwide is not widely adopted due to the high cost of implementation. Volumetric pricing requires installing and maintaining a water meter, which is an expensive operation [84]. In most advanced countries where tradeable rights of water access is established, water markets would ensure efficient use of water by internalizing the full opportunity cost of water [85]. However, the lack of constitutionally protected riparian rights (as all land, water, and resources belong to the people, and are stewarded by the government) does not allow the development of a water market in Vietnam. Vietnam should explore a middle-ground solution such as a two-part tariff in which a fixed fee per area is levied to cover the capital cost, operation and maintenance, and a volumetric fee for the actual usage [86]. Such a scheme could be implemented by combining the current area-based fee collection with water rationing locally managed by communal water user groups (WUG). WUGs are often close-knit members living in the same commune. There are successful models of communal groups managing local water pollution in aquacultural production [87]. In the past, unmonitored wastewater discharges by shrimp farmers could spread disease agents to neighboring farms. The formation of communal groups to watch over each other could enhance collaboration among water users to reduce bad behaviors.

Admittedly, water pricing and collection are often seen as a policy intervention that negatively affects poor farmers and will likely spark severe backlashes in the population. The Vietnamese Government must commit to transparency in irrigation expenditure, involve local stakeholders early in irrigation planning to build consensus, and keep irrigation subsidy for disadvantaged population as a social policy. At the same time, the government should facilitate an agricultural transformation that allows for the conversion of agricultural land from rice to other high-value crops. Rice should only be maintained in limited areas for national food security purposes.

6. Limitations

Like all econometric analysis of observational data, our results are prone to data quality concerns and mis-specifications. The agronomic production function is simplified to include only the most fundamental inputs. While it remains the mainstream in econometric analysis [48,57], mechanistic crop modeling would provide more insights on the biophysical process explaining the impact of water availability on productivity. The validity of the instrumental variables approach is dependent on finding a set of exogenous instruments that meet the relevance and the exclusion conditions. It is straightforward to use communal irrigation status to predict field irrigation, however the association could be a weak one. And weak instruments will produce even more bias than least squares estimates. It is also contentious to use land values to infer the value of irrigation, especially in a developing country without a mature real estate market. To alleviate those concerns, we use two methods with different assumptions and arrive at

the same conclusion about the high value of irrigation. Future research should explore large-scale datasets such as the decennial Vietnam's Agriculture, Forestry, and Aquaculture Census which is both much larger and more geographically comprehensive to assess irrigation values in other crop systems, for different river basins and crop seasons.

CRediT authorship contribution statement

Le Viet Phu: Study conception and design, Data processing, analysis and interpretation of results, Manuscript preparation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request

Acknowledgment

I am indebted to the journal editor and two reviewers for critical feedbacks on an earlier draft of this paper. I also benefited from working with colleagues and advisors at the former Fulbright Economics Teaching Program (FETP), particularly Chu Thai Hoanh, Le Thi Quynh Tram, and Malcolm McPherson. All remaining errors are my own.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.wre.2023.100229.

References

[1] Vinh B. Ngoc, Nguyen M. Hung, Phuong T. Pham, J. Nanomater. (2021) http://dx.doi.org/10.1155/2021/5801913, Article ID 5801913.
[2] Malcolm F. McPherson, Land policy in Vietnam: Challenges and prospects for constructive change, J. Macromarketing 32 (1) (2012) 137–146.
[3] James A. Giesecke, Nhi Hoang Tran, Erwin L. Corong, Rice land designation policy in Vietnam and the implications of policy reform for food security and economic welfare, J. Dev. Stud. 49 (9) (2013) 1202–1218, http://dx.doi.org/10.1080/00220388.2013.777705.
[4] Long Chu, Hoa-Thi-Minh Nguyen, Tom Kompas, Khoi Dang, Trinh Bui, Rice land protection in a transitional economy: The case of Vietnam, Heliyon 7 (2021) e06754.
[5] Chu T. Hoanh, Diana Suhardiman, Le A. Tuan, Irrigation development in the vietnamese mekong delta: towards polycentric water governance?, Int. J. Water Gov. 2 (2) (2014) http://dx.doi.org/10.7564/14-IJWG59.
[6] M.A. Van Aalst, E. Koomen, D.D. Tran, H.M. Hoang, H.Q. Nguyen, H.L.F. de Groot, The economic sustainability of rice farming and its influence on farmer decision-making in the upper Mekong Delta, Vietnam, Agricult. Water Manag. 276 (2023) (2023) 108018.
[7] Dang K. Nhan, Nguyen V. Be, Nguyen H. Trung, Water use and competition in the Mekong Delta, Vietnam, in: Challenges to Sustainable Development in the Mekong Delta: Regional and National Policy Issues and Research Needs, Stockholm Environment Institute, 2007, pp. 143–188.
[8] Ministry of Natural Resources and Environment (MONRE), Thuc trang khai thac su dung tai nguyen nuoc cua cac nganh o viet nam, in: Current state of water exploitation and consumption in Vietnam, 2021, http://cspl-tnmt.monre.gov.vn/tin-tuc/tin-tuc-su-kien/thuc-trang-khai-thac-su-dung-tai-nguyen-nuoc-cua-cac-nganh-o-viet-nam.html.
[9] World Bank, Transforming Vietnamese Agriculture: Gaining More from Less, Vietnam Development Report, World Bank, Washington, D.C, 2016.
[10] Patrick Leinenkugel, Natascha Oppelt, Claudia Kuenzer, A new land cover map for the mekong: Southeast Asia's largest transboundary river basin, Pac. Geogr. 41 (2014).
[11] Jean-Philippe Fontenelle, François Molle, The intricacies of water pricing in the red River Delta, Vietnam, in: Paper Presented At the Conference on Irrigation Water Policies: Micro and Macro Considerations, International Water Management Institute, Colombo, Sri Lanka, 2002.
[12] Jonathan R. Cook, et al., The irrigation service fee waiver in Viet Nam, ADB Briefs 12 (2013)
[13] M. Van Dijk, H. Hilderink, W. Rooij, M. Rutten, R. Ashton, K. Kartikasari, Vu Cong Lan, Land-use change, food security and climate change in Vietnam A global-to-local modelling approach, LEI report 2013-020, Project code 2271000204, LEI Wageningen UR, The Hague, 2013, ISBN/EAN: 978-90-8615-610-8.
[14] L.V. Phu, N.V. Giap, L.T.T. Tram, C.T. Hoanh, M. McPherson, Resource Governance, Agriculture and Sustainable Livelihoods in the Lower Mekong Basin, SIRD, Malaysia, ISBN: 978-967-2165-73-6, 2019.
[15] Cornish and Bosworth, et al., Water Charging in Irrigated Agriculture: An Analysis of International Experience, Food and Agriculture Organization of the United Nations, Rome, Italy, 2004.
[16] François Molle, Jeremy Berkoff, Irrigation water pricing: The gap between theory and practice, CAB Int. (2007)
[17] Ha D. Linh, Irrigation Valuation and Irrigation Policy in Vietnam (Master's of public policy thesis), Fulbright Economics Teaching Program, 2017.
[18] Long Chu, Quentin Grafton, Water pricing and the value-add of irrigation water in Vietnam: Insights from a crop choice model fitted to a national household survey, Agricult. Water Manag. 228 (2020) 105881.
[19] Asian Development Bank, Socialist Republic of Viet Nam: Water Sector Review, Kellogg Brown & Root Pty Ltd, Australia, 2009.
[20] Jeremy Cheesman, Tran V.H. Son, Jeff Bennett, Valuing irrigation water for coffee production in Dak Lak, Viet Nam: a marginal productivity analysis, in: Australian Centre for International Agricultural Research (ACIAR) Project: ADP/2002/015, (ISSN: 1832-7435) 2007.
[21] FAO, AQUASTAT Country Profile - Viet Nam, Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, 2011.
[22] Le T.Q. Tram, Malcolm F. McPherson, Agriculture in the lower mekong basin: current trends and policy challenges, in: Le Viet Phu, Nguyen Van Giap, Le Thi Quynh Tram, Chu Thai Hoanh, Malcolm McPherson (Eds.), Resource Governance, Agriculture and Sustainable Livelihoods in the Lower Mekong Basin, SIRD, Malaysia, ISBN: 978-967-2165-73-6, 2018.
[23] Chu T. Hoanh, Le V. Phu, Le T.Q. Tram, Governance of natural resources and restructuring of agricultural sector in the regional integration in the Mekong River Delta, Vietnam, in: The Lower Mekong Public Policy Initiative. Ho Chi Minh City, Vietnam, 2016.

[24] Nguyen T.P. Loan, Legal Framework of the Water Sector in Vietnam, in: ZEF Working Paper Series 52, Center for Development Research, (ISSN: 1864-6638) 2010.
[25] N. David Harris, Water management in public irrigation schemes in Vietnam, in: Impact Assessment Series Report, Vol. 43, Australian Centre for International Agricultural Research (ACIAR), 2006.
[26] Government of Vietnam, Decree 154 on Amendments and Supplements to Decree No. 143/2003/ND-CP on Exploitation of Irrigation Works, 154/2007/ND-CP, Hanoi, Vietnam, 2007.
[27] Government of Vietnam, Decree 115 on Amendments and Supplements to Decree No. 143/2003/ND-CP on Exploitation of Irrigation Works, 115/2008/ND-CP, Hanoi, Vietnam, 2008.
[28] Government of Vietnam, Decree on the Regulations on Financial Support for Use of Public Irrigation Services, No 62/2018/ND-CP, Hanoi, Vietnam, 2018.
[29] Doan D. Tuan, Tran V. Dung, Actual Situation of Using Irrigation Funds for Direct Compensation for Grassroots Irrigation Organizations to Manage and Exploit Small and In-Field Irrigation Works According to Decentralization, Center for Participatory Irrigation Management, Hanoi, Vietnam, 2020.
[30] Luc Leruth, Elisabeth Paul, A principal-agent theory approach to public expenditure management systems in developing countries, OECD J. Budg. (ISSN: 1608-7143) 7 (3) (2007).
[31] Do V. Quang, Nghien cuu cac bien phap nang cao hieu qua quan ly tuoi trong dieu kien mien giam thuy loi phi vung Dong bang song Hong (Research on efficient solutions to enhance irrigation services in Red River Delta) (Doctoral Thesis), University of Water Resources, 2016, http://tailieuso.tlu.edu.vn/handle/DHTL/6087.
[32] Intizar Hussain, Have Low Irrigation Service Charges Disadvantaged the Poor? ADB's Water Week: Irrigation Charges-2, International Water Management Institute, Colombo, Sri Lanka, 2004.
[33] Institute of Water Economics and Management, Bao cao thuc trang va kho khan thach thuc trong cong tac quan ly nuoc lien quan toi gia nuoc (Report on the current state and challenges in water management relating to water price), Ministry of Agriculture and Rural Development, Hanoi, Vietnam, 2015.
[34] Leslie E. Small, Irrigation operation and maintenance in Vietnam under economic restructuring: Institutional and financial considerations, Irrigation Drainage Syst. 10 (1996) 245–262.
[35] Nguyen X. Tiep, Y Kien Ve Cong Dau Kenh (on the Canal's Head Culvert), Vietnam Community on Large Dams, 2017.
[36] Julio Berbel, Azahara Mesa-Jurado, Juan Maximo Piston, Value of irrigation water in Guadalquivir basin (Spain) by residual value method, Water Resour. Manag. 25 (2011) 1565–1579.
[37] Jonah K. Kiprop, et al., Determining the economic value of irrigation water in Kerio Valley Basin (Kenya) by residual value method, J. Econ. Sustain. Dev. 6 (7) (2015) 102–107.
[38] Yusman Syaukat, Fitria Nur Arifah, Fahma Minha, Economic value and service fee of irrigation water in the districts Bogor and Kudus, Indonesia, J. ISSAAS 20 (2) (2014) 157–172.
[39] James MacGregor, et al., Estimating the economic value of water in Namibia, in: 1st WARFSA/Waternet Symposium: Sustainable Use of Water Resources, Maputo, 2000.
[40] M. Dinesh Kumar, Lokesh Singhal, Pabitra Rath, Value of groundwater: Case study in Banaskantha, Econ. Political Weekly (2004) 3498–3503, July 31, 2004.
[41] Ijaz Hussain, et al., Economic value of irrigation water: Evidence from a Punjab canal, Lahore J. Econ. 14 (1) (2009) 69–84.
[42] Glenn-Marie Lange, Rashid Hassan, The Economics of Water Management in Southern Africa: An Environmental Accounting Approach, 978-1-84376-472-4, Edward Elgar Publishing, Inc., 2006, ISBN-13.
[43] Songqing Jin, Winston Yu, Hans G.P. Jansen, Rie Muraoka, The impact of irrigation on agricultural productivity: evidence from India, in: International Association of Agricultural Economists (IAAE), Triennial Conference, Foz do Iguaçu, Brazil, 18-24 August, 2012, 2012.
[44] Alessandra Garbero, Tisorn Songsermsawas, Impact of modern irrigation on household production and welfare outcomes: Evidence from the participatory small-scale irrigation development programme (PASIDP) project in Ethiopia, IFAD Res. Ser. 31 (2018).
[45] Robert Mendelsohn, William D. Nordhaus, Daigee Shaw, The impact of global warming on agriculture: A ricardian analysis, Amer. Econ. Rev. 84 (4) (1994) 753–771.
[46] Robert Mendelsohn, Ariel Dinar, Climate Change and Agriculture: An Economic Analysis of Global Impacts, Adaptation and Distributional Effects, Edward Elgar, Cheltenham, UK, 2009.
[47] Wolfram Schlenker, Michael W. Hanemann, Anthony C. Fisher, Will U.S. agriculture really benefit from global warming? Accounting for irrigation in the hedonic approach, Amer. Econ. Rev. 95 (1) (2005) 395–406.
[48] Wolfram Schlenker, Michael J. Roberts, Nonlinear effects of weather on corn yields, Rev. Agric. Econ. 28 (3) (2006) 391–398.
[49] Robert A. Young, John B. Loomis, Determining the value of water: Concepts and methods, RFF Press, ISBN: 978-0-415-83850-4, 2014.
[50] Tom Kompas, Tuong Nhu Che, Hoa Thi Minh Nguyen, Ha Quang Nguyen, Productivity, net returns, and efficiency: Land and market reform in Vietnamese rice production, Land Econom. 88 (3) (2012) 478–495.
[51] Government of Vietnam, Decree on the Use and Management of Agricultural Land for Rice Production, 35/2015/ND-CP, Hanoi, Vietnam, 2015.
[52] Daley Kutzman, Of Rice and Men: Land-Use Restrictions in Vietnam, University of California, Berkeley, USA, 2015.
[53] T.D. To, P.L. Nguyen, S. Marsh, Agricultural land use flexibility in Vietnam, in: S. Marsh, T. Gordon MacAulay, Pham Van Hung (Eds.), Agricultural development and land policy in Vietnam, Australian Centre for International Agricultural Research, Canberra, 2006.
[54] T. Markussen, F. Tarp, K.V. Broeck, The forgotten property rights: Restrictions on land use in Vietnam, Discussion paper 09-21, University of Copenhagen, 2009.
[55] James J. Heckman, Sample selection bias as a specification error, Econometrica 47 (1) (1979) 153–161.
[56] Ho Dang Hoa, Malcolm McPherson, Land policy for socioeconomic development in Vietnam 2010, in: Fulbright Economics Teaching Program and Ash Center for Democratic Governance and Innovation, John F. Kennedy School, Harvard University, 2010.
[57] Wolfram Schlenker, Michael J. Roberts, Nonlinear temperature effects indicate severe damages to U.S. crop yields under climate change, Proc. Natl. Acad. Sci. 106 (37) (2009) 15594–15598.
[58] Pradeep Kurukulasuriya, Robert Mendelsohn, Endogenous Irrigation: The impact of climate change on farmers in Africa, World Bank Policy Research Working Paper 4278, 2007.
[59] Charles Nhemachena, Rashid Hassan, Micro-Level Analysis of Farmers' Adaptation to Climate Change in Southern Africa, IFPRI Discussion Paper 00714, 2007.
[60] Eric Biltonen, Doan Doan Tuan, Jinxia Wang, Making Irrigation Management Pro-Poor: Lessons from China and Vietnam, International Water Management Institute, 2004.
[61] Randolph Barker, Claudia Ringler, Nguyen Minh Tien, Mark Rosegrant, Macro policies and investment priorities for irrigated agriculture in Vietnam, Res. Rep. 6 (2004).
[62] Colin Camerer, Linda Babcock, Goerge Loewenstein, Richard Thaler, Labor supply of New York city cabdrivers: One day at a time, Q. J. Econ. 112 (2) (1997) 407–441.
[63] Henry S. Farber, Is tomorrow another day? The labor supply of New York city cabdrivers, J. Polit. Econ. 113 (1) (2005) 46–82.
[64] Sally P. Marsh, T. Gordon MacAulay, Pham V. Hung, Agricultural development and land policy in Vietnam: policy briefings 2007. Australia, 2007.
[65] Manh Hung Do, Trung Thanh Nguyen, Ulrike Grote, Is Land Consolidation Policy a Solution for Rice Production and Agricultural Transformation in Vietnam?, TVSEP Working Paper WP-028, Leibniz Universität Hannover, 2022.

[66] Finn Tarp, Growth, Structural Transformation, and Rural Change in Viet Nam, United Nations University World Institute for Development Economics Research (UNU-WIDER, 2017.
[67] Government of Vietnam, Resolution No. 03/NQ-CP of the Government: On the Main Solutions To Direct and Administer the Implementation of the Socio-Economic Development Plan and the State Budget Estimate in 2010, Hanoi, Vietnam, 2010.
[68] Thomas Chatzopoulos, Christian Lippert, Endogenous farm-type selection, endogenous irrigation, and spatial effects in ricardian models of climate change, Eur. Rev. Agric. Econ. 43 (2) (2015) 217–235.
[69] Ministry of Finance, Quyet Dinh Ve Gia Toi Da San Pham Dich Vu Cong Ich Thuy Loi Nam 2021 (Decision on the Maximum Price of Public Irrigation Services in 2021), No 1477/QD-BTC, Hanoi, Vietnam, 2021.
[70] Allison J. Sovey, Donald P. Green, Instrumental variables estimation in political science: A readers' guide, Am. J. Political Sci. 55 (1) (2011) 188–200.
[71] Paolo D'Odoricoa, et al., The global value of water in agriculture, Proc. Natl. Acad. Sci. 117 (36) (2020) 21985–21993.
[72] G.D. Swanepoel, Joleen Hadrich, Christopher Goemans, Estimating the contribution of groundwater irrigation to farmland values in Phillips county, Colorado, J. ASFMRA (2015) 165–178.
[73] L. Allen Torrell, James D. Libbin, Michael D. Miller, The market value of water in the Ogallala aquifer, Land Econom. 66 (2) (1990) 163–175.
[74] Monobina Mukherjee, Kurt A. Schwabe, Where's the salt? A spatial hedonic analysis of the value of groundwater to irrigated agriculture, Agricult. Water Manag. 145 (2014) 110–122.
[75] John Faux, Gregory M. Perry, Estimating irrigation water value using hedonic price analysis: A case study in Malheur county, Oregon, Land Econom. 75 (3) (1999) 440–452.
[76] Laura Mirra, Bernardo C. Gennaro, Giacomo Giannoccaro, Farmer evaluation of irrigation services. Collective or self-supplied? Land 10 (4) (2021) 415, http://dx.doi.org/10.3390/land10040415.
[77] M.E. Qureshi, M.D. Ahmad, S.M. Whitten, A. Reeson, M. Kirby, Impact of climate variability including drought on the residual value of irrigation water across the Murray-Darling Basin, Australia, Water Econ. Policy 4 (1) (2018) 1550020, http://dx.doi.org/10.1142/s2382624x15500204.
[78] Petra Hellegers, Brian Davidson, Determining the disaggregated economic value of irrigation water in the musi sub-basin in India, Agricult. Water Manag. 97 (6) (2010) 933–938, http://dx.doi.org/10.1016/j.agwat.2010.01.026.
[79] Tianhe Sun, Qiuqiong Huang, Jinxia Wang, Estimation of irrigation water demand and economic returns of water in Zhangye Basin, Water 10 (19) (2017) http://dx.doi.org/10.3390/w10010019.
[80] Joshua Dewbre, Improving Resource Allocation and Incomes in Vietnamese Agriculture: A Case Study of Farming in the Dong Nai River Basin, Discussion Paper 00984, International Food Policy Research Institute (IFPRI, 2010.
[81] T.M. Nguyen Hoa, Huong Do, Adrian Kay, Tom Kompas, Rice policy in a transitional economy: Balancing the social and political objectives, Food Secur. (2019) http://dx.doi.org/10.1007/s12571-019-01005-x.
[82] Nguyen H. Tin, Dang K. Nhan, Land-use strategies for triple-rice farmers in the floodplains of the Vietnamese Mekong Delta, in: Le Viet Phu, Nguyen Van Giap, Le Thi Quynh Tram, Chu Thai Hoanh, Malcolm McPherson (Eds.), Resource Governance, Agriculture and Sustainable Livelihoods in the Lower Mekong Basin, SIRD, Malaysia, ISBN: 978-967-2165-73-6, 2019.
[83] United Nations Environment Programme (UNEP), Resources and Markets Branch 2018, Pricing Reforms for Sustainable Water Use and Management in Vietnam. Working Paper, 2018.
[84] Yacov Tsur, Introduction to special section on irrigation water pricing, Water Resour. Res. 40 (2004) http://dx.doi.org/10.1029/2003WR002213, W07S01.
[85] Seamus Parker, Robert Speed, Agricultural Water Pricing: Australia, Organization for Economic Co-Operation and Development, 2010, 2010.
[86] Yacov Tsur, Economic aspects of irrigation water pricing, Canad. Water Resour. J. 30 (1) (2005) 31–46.
[87] Le C. Dung, Vo V. Tuan, Effects of seed quality on sustainable black tiger shrimp production in the Vietnamese Mekong Delta, in: Le Viet Phu, Nguyen Van Giap, Le Thi Quynh Tram, Chu Thai Hoanh, Malcolm McPherson (Eds.), Resource Governance, Agriculture and Sustainable Livelihoods in the Lower Mekong Basin, SIRD, Malaysia, ISBN: 978-967-2165-73-6, 2019.