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Irrigation in farmers' land-use choices: Panel-data evidence from Viet Nam

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Abstract: Irrigation and land use are crucial issues in rural sustainable development. The current study modifies the sustainable framework of livelihoods to clarify the role of irrigation management in farmers' land-use choices. A five-wave panel dataset of 1,534 farms for the period 2008–2016 in Viet Nam (with a total of 7,669 observations) is used for analyzing the influence of irrigation management on land-use selections, employing a fixed-effects model. Irrigation management is investigated in six aspects: (i) the physical conditions, (ii) the ownership of facilities, (iii) the operations, (iv) the management responsibility shift, (v) the decision-making, and (vi) the maintenance. The results reveal that the overall effects of irrigation management are so different, depending on the types of land uses. On top of that, different aspects of irrigation management have diversified influences on types of land uses. The findings lead to several important implications related to irrigation management that are relevant to farmers and policymakers. Different stakeholders, organizations/institutions, and farming households play differently effective roles in irrigation management. In general, policies can be conducted through the development of a lined irrigation network, and decision-making in operations of

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PUBLIC INTEREST STATEMENT

The current study examines the role of irrigation management in farmers' land-use choices in rural sustainable development. Irrigation management is investigated in six aspects: (i) the physical conditions, (ii) the ownership of facilities, (iii) the operations, (iv) the management responsibility shift, (v) the decision-making, and (vi) the maintenance. The results reveal that the overall effects of irrigation management are so different, depending on the types of land use. On top of that, different aspects of irrigation management have diversified influences on types of land uses. The findings lead to several important implications related to irrigation management that are relevant to farmers and policymakers. Different stakeholders, organizations/institutions, and farming households play differently effective roles in irrigation management. In general, policies can be conducted through the development of a lined irrigation network, and decision-making in operations of irrigation, maintenance of irrigation, and irrigation maintenance should give more power to farmers' groups.

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irrigation, maintenance of irrigation, and irrigation maintenance should give more power to farmers' groups.

Subjects: Development Studies; South East Asia; Rural Development; Economics and Development; Development Economics

Keywords: Irrigation; Land use decision making; panel data; fixed-effects model; Vietnam
JEL Codes: Q12; Q15; Q24; C33

1. Introduction

Irrigation and farmers' land use are central to rural sustainable development and of great concern to governments, NGOs, and academic researchers (Rutten et al., 2014), as global food security has existed as one of the most serious developmental concerns (De Janvry and Sadoulet (2010), FAO (2012)). Especially, the concerns are deepened in developing countries where small land endowment exists and deal with several physical and socioeconomic obstacles. Irrigation also plays a very important role in agricultural production (Buisson and Balasubramanya (2019), Alaofè et al. (2016)). Several studies related to the role of irrigation have been done. For example, studies have been conducted to examine the effect of irrigation on household welfare and income distribution by Van Den Berg and Ruben (2006), on poverty reduction by Burney and Naylor (2012). On the other hand, factors determining farmers' land use considerably include climate variability (Thulstrup, 2015), local good governance (Miratori & Brooks, 2015), law (Nguyen and Tran (2018), De Janvry et al. (2015)), state actors (Kyeyune & Turner, 2016), local institution (Marschke et al., 2014), economic conditions at the community level (Thulstrup, 2014), and information and communication technologies (Vong & Song, 2015).

Within the spectrum of irrigation and land uses, while several aspects of irrigation system have been studied, for example, the inefficiency and inequality in a government irrigation system (Ferguson, 1992), financial autonomy on irrigation system (Svendsen, 1993), technological investments and governance structure (Lam, 1996), the allocation of water rights to women (Zwarteveen, 1997), the indigenous model for successfully governing the commons (Trawick, 2003), collective action of local self-governance (Theesfeld, 2004), private investment in minor irrigation (Bardhan et al., 2012), and irrigation bureaucracies (Suhardiman & Giordano, 2014), little has been done to understand the influence of irrigation on land-use choices, given that irrigation contributes so significantly to land uses, agricultural production, agriculture productivity, environmental conditions and adaptation to climate change in developing countries (Dasgupta (1993), Sampath (1992), and Jodha (1986)).

The current study, thus, aims to identify the role of irrigation management in the land-use selections of Vietnamese farmers. Our key research question is how irrigation management at the community level drives their choices of land use. Specific six sub-research questions are then: (i) the irrigation physical conditions, (ii) the irrigation systems such as cooperatives or public ones, (iii) the irrigation operations, (iv) the management responsibility shift, (v) the decision-making, and (vi) the irrigation maintenance contribute to land-use choices.

Because irrigation is often considered as a system or a network, irrigation needs to be examined at least at the community level. We modify the framework developed by Scoones (1998) to incorporate the role of irrigation management at the commune level, and apply commune fixed-effects regression and employ panel data from recent Viet Nam Access to Resources Household Survey (VARHS) in five-wave surveys in 2008–2016 of 1,534 repeated farming households in 12 representative provinces of Viet Nam. To the authors' best knowledge, there is no study within this framework intensively examining the role of irrigation management on land use, given that the livelihoods framework has been so widely explored in a huge number of empirical studies.

The study makes both empirical and methodological contributions to the literature of land use, sustainable livelihood (see, Kokoye et al. (2013), Matthies and Karimov (2014)), and irrigation

management (Beg (2019) in different ways: Firstly, it extends the sustainable livelihoods framework by (i) covering a wider range of land use choices such as rice, other annual crops, perennial crops, forestry, and aquaculture thanks to the availability of data and (ii) paying more attention to the role of irrigation management to determine land-use selections. Secondly, the current study provides a comprehensive analysis of six components of irrigation management, namely: (i) irrigation physical conditions, (ii) ownership of irrigation facilities, (iii) irrigation operations, (iv) management responsibility shift, (v) decision-making, and (vi) maintenance.

The paper is structured into five sections. The following section, Section 2, provides a literature review. Section 3 presents a source of the dataset and methods as well. Section 4 are with empirical results and then Section 5 discussion. Section 6 concludes.

2. Literature review

Irrigation contribute so significantly to agricultural production and productivity, environmental conditions and adaptation to climate change in developing countries (Dasgupta (1993), Sampath (1992), Jodha (1986), and McCord et al. (2015)). Irrigation plays a very important role in agricultural production, especially in water intensive crops (such as rice, coffee, pepper, cashew nut and sugarcane), and in aquaculture. Several empirical studies investigate the impact of irrigation on, for example, household welfare, income distribution (Van Den Berg & Ruben, 2006), on poverty reduction (Burney & Naylor, 2012). In addition, many empirical researches analyzes the efficiency of various kinds of irrigation system, for example, Ferguson (1992) with the inefficiency and inequality in a government irrigation system, Svendsen (1993) with financial autonomy on irrigation system, Lam (1996) with technological investments and governance structure, Zwarteveen (1997) with the allocation of water rights to women, Trawick (2003) with an indigenous model for successfully governing the commons, Theesfeld (2004) with collective action of local self-governance, Bardhan et al. (2012) with private investment in minor irrigation in generating farm productivity, Suhardiman and Giordano (2014) with irrigation bureaucracies as prime actors in policy change.

Ferguson (1992) analyzed the efficiency and inequality from water allocation in a government irrigation system in the Philippines. She found that under the government management, water allocation is of inefficiency and inequality since the management typically follows simple, fixed rules of water allocation instead of management capabilities to respond to varying conditions. Svendsen (1993) showed that as a consequence of the shift to agency financial autonomy, staffing levels were reduced and operating expenses were lowered, while real irrigation fee-based income held constant. In addition, changes in operating rules and procedures led to an increase in equity of water distribution, resulting in a projected 13% increase in area irrigated had water supply remained constant. Zwarteveen (1997) examined the implications of changing water policies for women's water rights and access to water in irrigation systems. The author concluded that policies to privatize and devolve management of irrigation need to increase responsiveness to specific women's water needs and interests if they are to address efficiency as well as equity concerns. Trawick (2003), basing on the analysis of irrigation system among Andean communities in Peru, proposed an indigenous model for successfully governing the commons, instead of privatization of water. Theesfeld (2004) examined whether measures to facilitate local self-governance could be successful in Bulgaria. The author found that local actors use power asymmetries to maintain their opportunistic strategies, and the governance of information plays an especially important role. Moreover, distrust between community members plays a crucial role in constraining the evolution of social capital, which is a prerequisite for collective action. Bardhan et al. (2012) estimated the role of private investments in irrigation in farm productivity growth in West Bengal, India between 1982 and 1995. The authors found that the West Bengal Green Revolution of the 1980s benefited from complementarity between private investment incentives and state-led institutional reforms. Suhardiman and Giordano (2014) argued that many of interventions over irrigation system have failed, because government did not recognize irrigation bureaucracies as prime actors in policy change. So far, little has been done to understand the influence of irrigation on land-use choices, given that the livelihoods framework has been so widely explored in a huge number of empirical studies.

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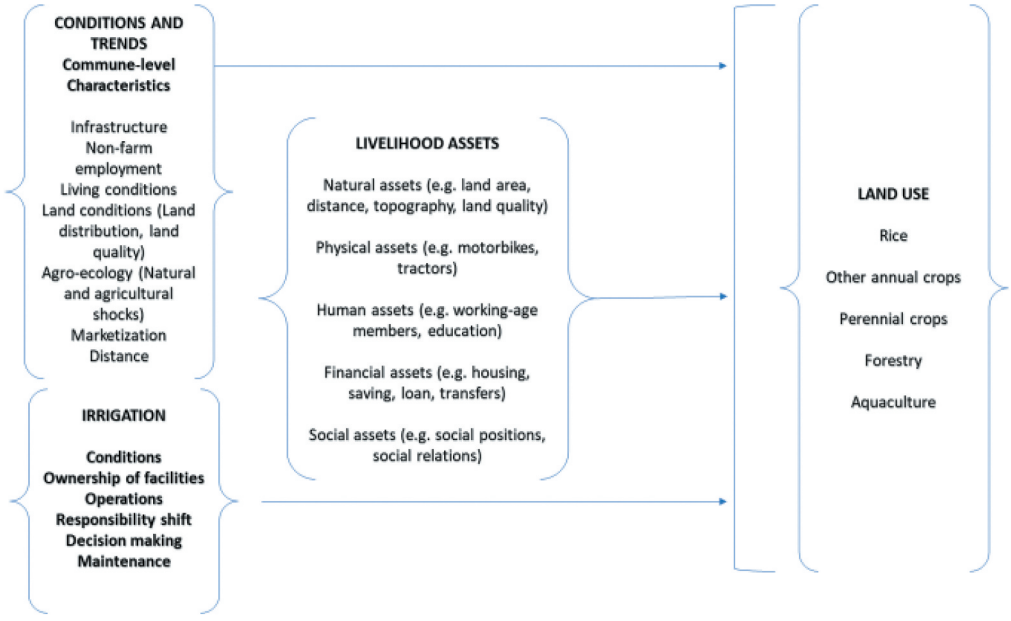

Figure 1. Livelihood framework: irrigation and land-use selections. Source: Modified from **Scoones (1998)** and (**Nguyen et al., 2017**).

Some relevant research questions occurred from the overview of previous studies, such as: (a) To what extent that the irrigation conditions contribute to land use choices, (b) To what extent that the irrigation systems such as cooperatives or public one contributes to land use choices, (c) To what extent that the irrigation operations explain land use choices, (d) To what extent that the management responsibility shift explain land use choices, (e) To what extent that the decision-making explain land use choices, and (f) To what extent that the irrigation maintenance explain land use choices.

Therefore, the results of our study can support policymakers and researchers in understanding the forces underlying farmers' land use decision making, especially the community characteristics such as irrigation. In the current paper, we modify the framework developed by Scoones (1998), focusing on irrigation roles and examining some aspects of irrigation management such as (i) irrigation conditions, (ii) ownership of irrigation facilities, (iii) irrigation operations, (iv) management responsibility shift, (v) decision-making, and (vi) maintenance, on land use. Based on the framework, it is argued that the choice of a specific livelihood strategy not only depends on the possession of, or access to, the livelihood platforms but also the conditions and trends with a focus on irrigation from which different productive streams are derived and livelihoods are constructed.

According to Ashley and Carney (1999), three connected stages of livelihood, namely platforms, strategies, and outcomes are embodied in the livelihood framework, which operates under a certain infrastructure and socio-economic living environment (Figure 1). Within this framework, a rural household is a basic unit of making the decision (Ellis, 2000).

3. Data and methods

3.1. Data

Data for our study are taken from VARHS. Details of VARHS can be found in CIEM, DOE, ILSSA and IPSARD (2009). The VARHS is the first survey in Viet Nam related to the attributes of rural markets for land, credit, and labor and households' access to these markets. Since 2006, the survey size was 2,324

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Figure 2. Site surveys. Source: Authors' creation.

households in 12 provinces, namely: Dak Lak, Dak Nong, Dien Bien, Ha Tay, Khanh Hoa, Lai Chau, Lam Dong, Lao Cai, Long An, Nghe An, Phu Tho, and Quang Nam (Figure 2). The VARHS covering these very same households had, by 2016 been carried out six times every two years. This is a high-quality panel data foundation for such a long period of nearly 15 years of study and policy work using the VARHS data. There were 2,131 households interviewed in all survey rounds over eight years. In this study, a balanced panel in 2008–2016 has been established and the number of panel households reduced to 1,534 because of missing data.

In addition to the household survey, the VARHS also included a commune-level survey. While households are 465 communes in total nationwide, the commune balanced panel data between 2008 and 2016 surveyed round was 418.

3.2. Methods

3.2.1. Model specification

Following the livelihood framework in Figure 1 set up in the Literature Review, a model of assessing the influence of irrigation on land-use choices is proposed, following Damon (2010). To capture the

effects of irrigation management on land-use selections, and given that a dataset of five waves (every two years in the period 2008–2016) is employed, the fixed-effects model is used to control for the invariant-unobserved characteristics at both household and commune levels (Damon, 2010). A most recent application of Damon (2010) can be found in T. T. Nguyen et al. (2017).

The following equation is used:

$$y_{itz} = f(x_{it}, v_{vt}, I_{it}) + \beta_{iz} + \mu_{itz}, (1)$$

Where i, t, v denote household i in year t and at commune v; z is a set of five land-use types; y is the mentioned land-use share, x is a vector of controlling explanatory variables at the household level, v is a vector of controlling variables for the characteristics of the commune, I is a vector of interested irrigation variables, β is the invariant-unobserved, and μ is the variant-unobserved characteristics of the household.

The following parts discuss the controlling explanatory variables at the household level in Equation (1):

Firstly, as indicated in Figure 1, the natural assets are measured by (a) the farmland area (ha), (b) the share of irrigated land (%), (c) the share of owned land (%; Markussen et al. (2011), Nguyen et al. (2014)), and (d) the average distance from the household to the plots (km).

Secondly, the human assets are expressed by (a) the dependency ratio (%), (b) the share of the household member at working ages (16–65 years old, %), (c) the educational level measured by the highest certificate (dummies), (d) the age average of working-age members (years), and (e) the share of the female head (%).

Thirdly, the physical assets are exhibited by (a) the numbers of tractors, motorbikes, and (b) the number of pesticide sprayers.

Fourthly, the financial assets are proxied by (a) the area of the house (squared meters), (b) the total saving (million Vietnamese currency-VND), (c) the total of the loan (million VND; Menkhoff & Rungruxsirivorn, 2011), (d) the private transfer and the public transfer (million VND).

Sixthly, social assets are typified by the relations of trust and connectedness in institutions (Pretty & Ward, 2001). The relations of trust are proxied by the choices of households when needing money (for example, they can choose to borrow from a relative, friend, neighbor, and other). Connectedness in institutions is proxied by the membership in a socio-political organization (dummy; Baird and Gray (2014), Forsyth and Evans (2013)) such as: being an office, head having a party membership, and being a member of Women Union, and the sources of help in case of needing money (dummies).

Lastly, other controlling variables such as the topography at the household level are measured by the shares of land with different slopes (in %), namely: flat, slight slope, moderate slope, steep slope. In addition, the quality of land at the household level is measured by the shares of land with various possible problems (in %) such as land with gullies, low-lying land, sedimentation land, stony soils/clay, land with no problem.

At the commune level, the following indicators are explored to serve as the controlling variables for physical and socio-economic environment:

First, land distribution: the shares of household with no land in the commune (in %), with land less than 0.5 ha in the commune (in %), with land between 0.5 ha and 1.0 ha in the commune (in

%), with land between 1.0 ha and 2.0 ha in the commune (in %), with land between 2.0 ha and 5.0 ha in the commune (in %), and with land larger than 5.0 ha in the commune (in %).

Second, land quality: the share of cropland with irrigation in the commune (in %).

Third, non-farm employment: the number of enterprises/firms/factories (including state agricultural farm) with at least 10 employees in the commune (Bezu et al., 2012), the number of enterprises/firms/factories (including state agricultural farm) with at least 10 employees in the neighboring commune where people can work there and come back within the day.

Fourth, markets: the availability of daily market, and periodic market (both in dummy, whether there is a daily market, a periodic market in a commune for local trade).

Fifth, social conditions: the existence of primary school, health-care center, clinic center, hospital, post office, secondary school (all in dummies).

Sixth, living conditions: the coverage of street light (in %), and the coverage of network for drinking water (in %).

Seventh, distance: and the distance (km) from the commune center to the nearest bus station, from the commune center to the main road.

Eighth, the climate variability takes its proxy by the frequency of weather shocks (Doss et al. (2008), Povel (2015)) that have been observed by households during the last three years (Barrett, 2014).

With respect to our interested variables related to irrigation, six dimensions of irrigation management are investigated in this paper, including (i) irrigation physical conditions, (ii) ownership of irrigation facilities, (iii) irrigation operations, (iv) management responsibility shift, (v) decision-making, and (vi) maintenance.

The following variables are used, respectively: Firstly, irrigation physical conditions: the status of the main irrigation canals in the commune lined with concrete or other solid materials, namely: (1) all lined, (2) mostly lined, (3) mostly not lined, (4) no lined (all in dummies) (Panel B1A); the status of the tertiary irrigation canals in the commune lined with concrete or other solid materials such as (1) all lined, (2) mostly lined, (3) mostly not lined, (4) no lined (all in dummies) (Panel B1B).

Secondly, ownership of irrigation facilities (Panel B2): the ownership status of irrigation facilities in the commune, namely: (1) public, (2) cooperative, (3) both public and cooperative, (4) none (all in dummies).

Thirdly, irrigation operations: the operations of irrigation managed by (1) cooperatives (in dummy) or (2) Commune Irrigation Groups (in dummy) (Panel B3).

Fourthly, management responsibility shift (Panel B4): the change in responsibility for irrigation management is given to farmers from commune- or higher-level authorities ((1) yes, substantial change, (2) yes, some change, and (3) no change, all in dummies).

Fifthly, decision-making: the most influence on decisions concerning irrigation facilities in the commune (namely: (1) farmers groups, (2) commune irrigation group, (3) cooperative, (4) irrigation and drainage company, (5) commune people's committee, (6) district people's committee, and (7) others, all in dummies). Decision-making is investigated in a range of activities: from (1) construction of new facilities (Panel B5A) to (2) operation of facilities (Panel B5B), and (3) maintenance of facilities (Panel B5C).

Sixthly, maintenance: The maintenance of tertiary canals and structures is conducted by (1) farmers themselves, irrigation and drainage company, (2) companies/individuals hired by irrigation and drainage company, (3) commune irrigation group/cooperative, (4) companies/individuals hired by commune irrigation group or cooperatives, and (5) others (Panel B6).

3.2.2. Estimation strategy

Since our key research questions are how their available farmland is allocated among several given land use alternatives under the changes in irrigation management, we follow two estimation steps as follow:

Step 1 (Panel A): Models are estimated with all of the household-level variables related to assets in the livelihood framework and topography and land quality at the household level. In addition, commune-level variables, namely: (i) land distribution, (ii) land quality, (iii) market, (iv) social conditions, (v) distance, (vi) non-farm employment, (vii) living conditions (viii) natural and agricultural shocks are included into the models.

Step 2 (Panel B): Variables related to irrigation management integrated into the models will be estimated. Several aspects of irrigation management are alternatively examined: (i) irrigation physical conditions (Panel B1), (ii) ownership of irrigation facilities (Panel B2), (iii) irrigation operations (Panel B3), (iv) management responsibility shift (Panel B4), (v) decision-making (Panel B5), and (vi) maintenance (Panel B6).

With respect to irrigation conditions, possible collinearity may exist between the main irrigation canals and the tertiary irrigation canals, therefore two separate models are estimated, Panel B1A and Panel B1B, respectively. Similarly, possible collinearity may exist among three stages of making the decision: (i) construction of new facilities, (ii) operation of facilities, and (iii) maintenance of facilities, therefore three separate models are estimated, Panel B5A, Panel B5B and Panel B5C, respectively.

4. Empirical results and discussions

4.1. Statistical analysis

Table 1 illustrate the livelihood assets of rural households in Viet Nam during 2008–2016. In terms of natural assets, the average farmland area per household decreases over the period. Similarly, the share of irrigated land decreases. The land value increases between 2008 and 2016, even though it is at the highest in 2014. The share of owned farmland increases between 2008 and 2016. The average distance to the field is more or less unchanged during the period.

In terms of human assets, the dependency ratio decreases between 2008 and 2016. Farm heads' percentage increases and farm households are older, and less in terms of working-age member percentage. In addition, farm heads are more educated in 2016.

Regarding physical assets, farmers have higher numbers of motorbikes, but fewer pesticide sprayers and tractors in 2016 compared to 2008. This is reasonable because, in general, higher income may lead to high consumption in valuable assets and convenient for daily activities such as motorbikes.

Regarding financial assets, farmers are better-off in 2016 compared to 2008, as they have more housing areas, higher saving volume, higher annual public, and private transfers. This is also partly because of achievement in economic development in Viet Nam during a decade from 2008 till 2016.

Regarding social assets, more social trust is found when farmers in Viet Nam rely more on relatives or friends. In addition, in terms of social networks, more farmers in Viet Nam are members of socio-political organizations, such as an officer, a party member, or a member of the Women Union.

Table 1. Comparison of household-level characteristics, 2008–2016

Variable	2008	2010	2012	2014	2016
Household-level					
Natural assets					
Land size (ha)	0.882	0.850	0.836	0.798^{a***}	0.777^{a**}
Land with irrigation	0.573	0.613^{b***}	0.620^{a***}	0.437^{d***}	0.420^{a***}
Land with LUC	0.761	0.731^{b**}	0.807 $^{c***, a***}$	0.807^{a***}	0.795^{a***}
Distance to plot (km)	1.050	0.970	1.083	0.958	0.978
Human assets					
Dependency ratio	0.646	0.646	0.645	0.630^{a*}	0.599$^{e***, a***}$
Female head (yes = 1)	0.075	0.082	0.090^{a**}	0.101^{a***}	0.108^{a***}
Age average of working-age members (years)	33.356	34.423^{b***}	38.350 $^{c***, a***}$	40.892$^{d***, a***}$	36.068$^{e***, a***}$
% of household member at working ages	0.646	0.646	0.645	0.594	0.599
% of "Cannot read and write"	0.087	0.081	0.077^{a*}	0.077^{a***}	0.063$^{e**, a***}$
% of "Completed Primary"	0.258	0.245	0.233^{a***}	0.187$^{d***, a***}$	0.161$^{e***, a***}$
% of "Completed Lower Secondary"	0.395	0.394	0.396	0.396	0.396
% of "Completed Upper Secondary"	0.236	0.266^{b***}	0.276^{a***}	0.318$^{d***, a***}$	0.360$^{e***, a***}$
% of "Can read and write "	0.023	0.014^{b***}	0.018^{a*}	0.022	0.020
Physical assets					
Number of motorbikes	0.720	0.770^{b***}	0.813 $^{c***, a***}$	0.869$^{d***, a***}$	0.832$^{e***, a***}$
Number of pesticide sprayers	0.349	0.373	0.299 $^{c***, a***}$	0.312^{a*}	0.292^{a***}
Number of tractors	0.032	0.019^{b***}	0.020^{a**}	0.016^{a***}	0.016^{a***}
Number of machines of all kinds	0.127	0.116	0.077^{a***}	0.067^{a***}	0.064^{a***}
Financial assets					
Housing area (m^2)	67.851	72.300^{b***}	79.619 $^{c***, a***}$	84.932$^{d***, a***}$	85.889^{a***}
Saving volume (mill. VND)	12,996.47	29,813.06^{b***}	44,730.87 $^{c***, a***}$	40,065.39^{a***}	39,918.89^{a***}
Loan size (mill. VND)	11,984.93	14,048.06	13,920.12	17,448.83^{a*}	12,037.33*
Private transfer (mill. VND)	3,288.15	3,891.48	6,502.14 $^{c***, a***}$	7,809.25$^{d**, a***}$	7,432.95^{a***}
Public transfer (mill. VND)	3,127.77	3,856.01^{b**}	4,836.24 $^{c***, a***}$	6,834.55$^{d***, a***}$	7,405.69^{a***}
Social assets					
In case of needing money:					
ask relative (yes = 1)	0.724	0.801^{b***}	0.797^{a***}	0.806^{a***}	0.766$^{e***, a***}$
ask friend (yes = 1)	0.117	0.109	0.196 $^{c***, a***}$	0.171$^{d**, a***}$	0.22$^{e***, a***}$
ask neighbor (yes = 1)	0.292	0.235^{b***}	0.229^{a***}	0.172$^{d***, a***}$	0.195$^{e*, a***}$
ask other (yes = 1)	0.063	0.032^{b***}	0.019 $^{c***, a***}$	0.024^{a***}	0.037$^{4**, a***}$
Being an officer (yes = 1)	0.056	0.059	0.045 $^{c**, a*}$	0.056	0.058

(*Continued*)

Table1. (*Continued*)

Variable	2008	2010	2012	2014	2016
Party membership of HH head (yes = 1)	0.057	0.069	0.065	0.077[a**]	0.078[a**]
Member of Women Union (yes = 1)	0.000	0.090[b***]	0.082[a***]	0.078[a***]	0.069[a***]
Topography					
% of land with flat	0.438	0.396	0.385	0.061[d***, a***]	0.027[e*** a***]
% of land with slight slope	0.240	0.254	0.258	0.142[d***, a***]	0.243[e***]
% of land with moderate slope	0.137	0.151	0.123	0.021[d***, a***]	0.019[a***]
% of land with steep slope	0.025	0.010[b**]	0.009[a***]	0.026[d**]	0.054[e*, a**]
Land quality					
% of land with gullies	0.070	0.073	0.062	0.052[a*]	0.050[a*]
% of dry land	0.140	0.214[b***]	0.138 [c***]	0.637[d***, a***]	0.647[a***]
% of low-lying land	0.100	0.078	0.037 [c**, a***]	0.038[a***]	0.034[a***]
% of sedimentation land	0.041	0.056	0.023 [c***, a*]	0.000[d*** a***]	0.000[a***]
% of land with landslide	0.015	0.012	0.013	0.000[a***]	0.000[a***]
% of land with stony soils/clay	0.052	0.019[b**]	0.032 [c**]	0.000[d***, a***]	0.000[a***]
% of land with no any problem	0.415	0.347[b**]	0.466 [c***]	0.000[d***, a***]	0.000[a***]

Note: [B, c, d, e]: compared with the years 2008, 2010, 2012, 2014, respectively. [a]: compared with the year 2008. Total observations in each year: 2,131. HH: households. *** p < 0.01, ** p < 0.05, * p < 0.1. Source: Authors' estimation from VARHS08-16

Regarding topography, the land is more in unfavorable conditions in 2016 than in 2008. However, in terms of the quality of land, the land is improved.

The descriptive statistics of the commune characteristics during 2008–2016 are presented in Table 2. As mentioned in the previous section, commune characteristics include (i) land distribution, (ii) land quality, (iii) marketization, (iv) social infrastructure, (v) distance, (vi) non-farm employment, and (vii) living conditions, and (viii) natural and agricultural shocks.

In terms of market, social conditions, most of the indicators are better in 2016 compared to 2008. The off-farm opportunities (represented by the number of firms with more than 10 laborers) are better in 2016 compared to 2008. With regard to living conditions, farmers living in communes with a higher percentage of coverages in terms of street lighting and network for drinking water between 2008 and 2016. Regarding climate variation, farmers in Viet Nam have experienced fewer weather shocks between 2008 and 2016.

The descriptive statistics of the irrigation at the commune level during 2008–2016 are presented in Table 3. As mentioned in the previous section, some aspects of irrigation, namely: (i) irrigation physical conditions, (ii) ownership of irrigation facilities, (iii) assessments of facilities, (iv) irrigation operations, (v) management responsibility shift, (vi) decision-making, and (vii) maintenance, are surveyed.

In general, between 2008 and 2016, lined canals including main canals and tertiary canals are almost better, public irrigation facilities or both public and cooperative irrigation facilities increase,

Table 2. Comparison of commune-level characteristics, 2008–2016

Variable	2008	2010	2012	2014	2016
Land distribution					
% of HHs with no land (base)	0.054	0.007^{b***}	0.005 ^{c*}, ^{a***}	0.006^{a***}	0.003^{e***}, ^{a***}
% of HHs with 0.5 ha or less	0.559	0.154^{b***}	0.039 ^{c***}, ^{a***}	0.031^{d***}, ^{a***}	0.033^{e**}, ^{a***}
% of HHs with 0.5–1.0 ha	0.186	0.141^{b***}	0.019 ^{c***}, ^{a***}	0.021^{a***}	0.013^{e***}, ^{a***}
% of HHs with 1.0–2.0 ha	0.126	0.133	0.015 ^{c***}, ^{a***}	0.015^{a***}	0.009^{e***}, ^{a***}
% of HHs with 2.0–5.0 ha	0.058	0.01^{b***}	0.007 ^{c***}, ^{a***}	0.005^{d***}	0.005^{e*}, ^{a***}
% of HHs with > 5.0 ha	0.015	0.003^{b***}	0.004 ^{c***}, ^{a***}	0.002^{d***}, ^{a***}	0.001^{e**}, ^{a***}
Land quality					
% of crop land with irrigation	0.240	0.445^{b***}	0.311 ^{c***}, ^{a***}	0.388^{d*}, ^{a***}	0.238^{e***}
Market					
Having daily market (yes = 1)	0.511	0.516	0.593 ^{c***}, ^{a***}	0.729^{d***}, ^{a***}	0.797^{e***}, ^{a***}
Having periodic market (yes = 1)	0.256	0.202^{b***}	0.223^{a**}	0.293^{d***}, ^{a***}	0.363^{e***}, ^{a***}
Social conditions					
Having primary school (yes = 1)	0.998	0.99^{b***}	0.997 ^{c***}	0.997	0.995^{a*}
Having health care center (yes = 1)	0.989	0.955^{b***}	0.958^{a***}	0.989^{d***}	0.998^{e***}, ^{a***}
Having clinic center (yes = 1)	0.058	0.056	0.072 ^{c**}, ^{a*}	0.102^{d***}, ^{a***}	0.139^{e***}, ^{a***}
Having hospital (yes = 1)	0.052	0.02^{b***}	0.048 ^{c***}	0.064^{d**}	0.081^{e**}, ^{a***}
Having post office (yes = 1)	0.000	0.000	0.814 ^{c***}, ^{a***}	0.922^{d***}, ^{a***}	0.950^{e***}, ^{a***}
Having secondary school (yes = 1)	0.849	0.905^{b***}	0.913^{a***}	0.951^{d***}, ^{a***}	0.962^{e*}, ^{a***}
Distance					
Distance 1 (km)	9.978	9.927	10.898	9.939	11.196
Distance 2 (km)	2.745	3.412^{b*}	2.529 ^{c***}	2.025	3.067^{e***}, ^{a***}
Distance 3 (km)	12.453	11.482	11.522 ^{c***}, ^{a***}	11.493^{a***}	11.225^{a***}
Distance 4 (km)	5.932	6.358^{b***}	7.989 ^{c***}, ^{a***}	7.397^{d***}, ^{a***}	5.44^{e*}
Non-farm employment					
Non-farm employment 1	8.458	19.230^{b***}	17.028^{a***}	21.466^{d**}, ^{a**}	27.711^{e**}, ^{a***}
Non-farm employment 2 (yes = 1)	0.337	0.207^{b***}	0.258 ^{c***}, ^{a***}	0.243^{a***}	0.251^{a***}
Living conditions					
Coverage of street lighting (%)	28.880	35.504^{b***}	26.620 ^{c***}, ^{a*}	32.985^{d***}, ^{a***}	50.552^{e***}, ^{a***}
Coverage of drinking water (%)	22.500	25.682^{b***}	37.140 ^{c***}, ^{a***}	35.926^{d***}, ^{a***}	53.128^{e***}, ^{a***}
Natural and agricultural shocks					

(*Continued*)

Table2. (*Continued*)

Variable	2008	2010	2012	2014	2016
Flood last year (yes = 1)	0.437	0.396[b***]	0.319 [c***, a***]	0.322[a***]	0.202[e***, a***]
Drought last year (year = 1)	0.412	0.499[b***]	0.331 [c***, a***]	0.349[a***]	0.407[e***]
Typhoon last year (yes = 1)	0.293	0.365[b***]	0.250 [c***, a***]	0.336[d***, a***]	0.163[e***, a***]
Land slide last year (yes = 1)	0.188	0.175	0.128 [c*** a***]	0.080[d***, a***]	0.068[a***]
Animal/livestock epidemics last year (yes = 1)	0.389	0.420[b*]	0.400	0.358[d***, a**]	0.243[e***, a***]
Plant disease last year (yes = 1)	0.410	0.480[b***]	0.392 [c***, a***]	0.348[d***, a***]	0.241[a***]
Insects/rats last year (yes = 1)	0.298	0.283	0.260	0.190[d***, a***]	0.118[e***, a***]
Flood two years ago (yes = 1)	0.383	0.584[b***]	0.358 [c***]	0.331[d*, a***]	0.211[e***, a***]
Drought two years ago (year = 1)	0.410	0.415	0.328 [c***, a***]	0.335[a***]	0.362[e*, a***]
Typhoon two years ago (yes = 1)	0.289	0.335[b***]	0.291 [c***]	0.306	0.174[e***, c***]
Land slide two years ago (yes = 1)	0.145	0.187[b***]	0.130 [c***]	0.087[d***, a***]	0.076[a***]
Animal/livestock epidemics two years ago (yes = 1)	0.348	0.344	0.426 [c***, a***]	0.408[a***]	0.246[e***, a***]
Plant disease two years ago (yes = 1)	0.449	0.432	0.439	0.322[d***, a***]	0.213[e***, a***]
Insects/rats two years ago (yes = 1)	0.269	0.292	0.272	0.140[d***, a***]	0.130[a***]

Note: [B, c, d, e]: compared with the years 2008, 2010, 2012, 2014, respectively. [a]: compared with the year 2008. *** p < 0.01, ** p < 0.05, * p < 0.1. Distance 1: Distance from the commune center to the nearest bus station (km); Distance 2: Distance from the commune center to the main road (km); Distance 3: Distance from the commune center to the extension center; Distance 4: Distance from the commune center to the extension shop (km). Non-farm employment 1: Number of enterprises with 10 or more employees in the commune; non-farm employment 2: Having enterprises with 10 or more employees in the neighboring communes where people can work there and come back within the day (dummy). Source: Authors' estimation from VARHS08-16

Cooperatives dealing with irrigation operation and Commune Irrigation Groups also increase. In terms of shift for irrigation management: given to farmers, most of the changes have been conducted.

In terms of decision-making related to the construction of new facilities, farmers group, commune irrigation group, cooperatives, irrigation, and drainage company have more power whereas Commune People's committee becomes less powerful. Interestingly, District People's committee gains more power.

In terms of decision-making related to the operation of new facilities, commune irrigation group, irrigation, and drainage company, and District People's committee have more power whereas farmers group, cooperatives, Commune People's committee becomes less powerful.

Similarly, in terms of decision-making related to the maintenance of new facilities, commune irrigation group, irrigation, and drainage company, have more power whereas farmers group, cooperatives, becomes less powerful. In addition, the roles of the Commune People's committee and District People's committee are more or less the same in the period.

Table 3. Comparison of commune-level characteristics of irrigation, 2008–2016

Variable	2008	2010	2012	2014	2016
Panel B1A: Physical conditions: Irrigation canals with concrete or other solid materials					
All canals lined (yes = 1)	0.341	0.309$^{\alpha^{**}}$	0.261$^{\beta^{***},\ a^{***}}$	0.372$^{\chi^{***},\ b^{*}}$	0.366
Mostly lined (yes = 1)	0.258	0.293$^{\alpha^{**}}$	0.342$^{\beta^{***},\ a^{***}}$	0.372$^{\chi^{*},\ b^{***}}$	0.389 $^{c^{***}}$
Mostly not lined (yes = 1)	0.146	0.105$^{\alpha^{***}}$	0.227$^{\beta^{***},\ a^{***}}$	0.086$^{\chi^{***},\ b^{***}}$	0.165$^{\delta^{***}}$
No canal lined (yes = 1) (base)	0.255	0.293$^{\alpha^{**}}$	0.170$^{\beta^{***},\ a^{***}}$	0.170$^{b^{***}}$	0.080$^{\delta^{***},\ c^{***}}$
Panel B1B: Physical conditions: Tertiary canals with concrete or other solid materials					
All canals lined (yes = 1)	0.064	0.062	0.114$^{\beta^{***},\ a^{***}}$	0.129$^{b^{***}}$	0.161$^{\delta^{***},\ c^{***}}$
Mostly lined (yes = 1)	0.294	0.274	0.215$^{\beta^{***},\ a^{***}}$	0.357$^{\chi^{***},\ b^{***}}$	0.424$^{\delta^{***},\ c^{***}}$
Mostly not lined (yes = 1)	0.309	0.363$^{\alpha^{***}}$	0.358$^{a^{***}}$	0.279$^{\chi^{***},\ b^{*}}$	0.288
No canal lined (yes = 1) (base)	0.333	0.301$^{\alpha^{**}}$	0.313	0.235$^{\chi^{***},\ b^{***}}$	0.127$^{\delta^{***},\ c^{***}}$
Panel B2: Ownership of Irrigation facilities: Public, cooperative, both or none					
Public irrigation facilities (yes = 1)	0.548	0.514$^{\alpha^{**}}$	0.546$^{\beta^{*}}$	0.638$^{\chi^{***},\ b^{***}}$	0.539$^{\delta^{***}}$
Cooperative irrigation facilities (yes = 1)	0.124	0.138	0.159$^{\beta^{*},\ a^{***}}$	0.106$^{\chi^{***},\ b^{*}}$	0.014$^{\delta^{***},\ c^{***}}$
Both public and cooperative irrigation facilities (yes = 1)	0.222	0.268$^{\alpha^{***}}$	0.243$^{\beta^{*}}$	0.223	0.430$^{\delta^{***},\ c^{***}}$
None of public and cooperative irrigation facilities (yes = 1) (base)	0.105	0.080$^{\alpha^{***}}$	0.052$^{\beta^{***},\ a^{***}}$	0.032$^{\chi^{***},\ b^{***}}$	0.017$^{\delta^{***},\ c^{***}}$
Panel B3: Irrigation operations: Cooperatives and Commune Irrigation Groups					
Cooperatives dealing with irrigation (yes = 1)	0.106	0.232$^{\alpha^{***}}$	0.247$^{a^{***}}$	0.331$^{\chi^{***},\ b^{***}}$	0.287$^{\delta^{***},\ c^{***}}$
Commune Irrigation Groups in this commune (yes = 1)	0.506	0.584$^{\alpha^{***}}$	0.606$^{a^{***}}$	0.593$^{b^{***}}$	0.598 $^{c^{***}}$
Panel B4: Responsibility shift for irrigation management: given to farmers					
Substantial change (yes = 1)	0.210	0.240$^{\alpha^{**}}$	0.257$^{a^{***}}$	0.240$^{b^{**}}$	0.255 $^{c^{***}}$
Some change (yes = 1)	0.178	0.220$^{\alpha^{***}}$	0.307$^{\beta^{***},\ a^{***}}$	0.254$^{\chi^{***},\ b^{***}}$	0.263 $^{c^{***}}$
No change (yes = 1) (base)	0.612	0.540$^{\alpha^{***}}$	0.437$^{\beta^{***},\ a^{***}}$	0.506$^{\chi^{***},\ b^{***}}$	0.482 $^{c^{***}}$
Panel B5A: Irrigation decision making: Construction of new facilities					
Farmers group (yes = 1) (base)	0.055	0.054	0.060	0.072$^{b^{**}}$	0.069 $^{c^{*}}$
Commune irrigation group (yes = 1)	0.011	0.023$^{\alpha^{***}}$	0.046$^{\beta^{***},\ a^{***}}$	0.062$^{\chi^{**},\ b^{***}}$	0.064 $^{c^{***}}$
Cooperative (yes = 1)	0.053	0.127$^{\alpha^{***}}$	0.169$^{\beta^{***},\ a^{***}}$	0.107$^{\chi^{***},\ b^{***}}$	0.073$^{\delta^{***},\ c^{**}}$
Irrigation and drainage company (yes = 1)	0.059	0.035$^{\alpha^{***}}$	0.063$^{\beta^{***}}$	0.049$^{\chi^{*}}$	0.064$^{\delta^{*}}$
Commune People's committee (yes = 1)	0.438	0.276$^{\alpha^{***}}$	0.237$^{\beta^{***},\ a^{***}}$	0.298$^{\chi^{***},\ b^{***}}$	0.325$^{\delta^{*},\ c^{***}}$

(*Continued*)

Table3. (*Continued*)

Variable	2008	2010	2012	2014	2016
District People's Committee (yes = 1)	0.353	$0.481^{\alpha***}$	$0.412^{\beta***, a***}$	0.411^{b***}	0.392^{c**}
Others (yes = 1)	0.031	$0.005^{\alpha***}$	$0.013^{\beta***, a***}$	$0.000^{\chi***, b***}$	$0.013^{\delta***, c***}$
Panel B5B: Irrigation decision making: Operation of facilities					
Farmers group (yes = 1) (base)	0.067	0.079	$0.060^{\beta**}$	0.069	$0.055^{\delta*}$
Commune irrigation group (yes = 1)	0.157	$0.136^{\alpha*}$	$0.112^{\beta**}$	0.119^{b***}	$0.200^{\delta***, c***}$
Cooperative (yes = 1)	0.218	0.235	0.215^{a***}	$0.181^{\chi***, b***}$	$0.151^{\delta**, c***}$
Irrigation and drainage company (yes = 1)	0.097	$0.123^{\alpha**}$	0.121^{a**}	0.131^{b***}	0.128^{c***}
Commune People's committee (yes = 1)	0.346	$0.302^{\alpha***}$	$0.336^{\beta**}$	$0.388^{\chi***, b***}$	$0.319^{\delta***, c*}$
District People's Committee (yes = 1)	0.075	$0.124^{\alpha***}$	$0.156^{\beta***, a***}$	$0.108^{\chi***, b***}$	$0.137^{\delta***, c***}$
Others (yes = 1)	0.039	$0.001^{\alpha***}$	0.000^{a***}	$0.003^{\chi**, b***}$	$0.009^{\delta***, c***}$
Panel B5C: Irrigation decision making: Maintenance of facilities					
Farmers group (yes = 1) (base)	0.070	0.071	$0.054^{\beta**, a**}$	$0.078^{\chi***}$	$0.050^{\delta***, c**}$
Commune irrigation group (yes = 1)	0.127	$0.100^{\alpha**}$	0.108^{a*}	$0.152^{\chi***, b**}$	$0.204^{\delta***, c***}$
Cooperative (yes = 1)	0.203	$0.243^{\alpha***}$	$0.217^{\beta*}$	$0.179^{\chi***, b*}$	$0.141^{\delta***, c***}$
Irrigation and drainage company (yes = 1)	0.103	0.095	$0.159^{\beta***, a***}$	$0.119^{\chi***}$	0.134^{c***}
Commune People's committee (yes = 1)	0.345	0.363	$0.304^{\beta***, a***}$	$0.351^{\chi***}$	0.340
District People's Committee (yes = 1)	0.126	0.127	$0.155^{\beta**, a**}$	$0.116^{\chi***}$	0.121
Others (yes = 1)	0.027	$0.002^{\alpha***}$	0.002^{a***}	0.004^{b***}	$0.010^{\delta***, c***}$
Panel B6: Irrigation maintenance: Tertiary canals and structures					
Farmers themselves (yes = 1) (base)	0.361	$0.221^{\alpha***}$	$0.175^{\beta***, a***}$	$0.219^{\chi***, b***}$	$0.147^{\delta***, c***}$
Irrigation and drainage company (yes = 1)	0.056	$0.132^{\alpha***}$	0.141^{a***}	0.145^{b***}	$0.187^{\delta***, c***}$
Companies/individuals hired by irrigation and drainage company (yes = 1)	0.016	0.016	0.018	$0.030^{\chi**, b***}$	$0.063^{\delta***, c***}$
Commune irrigation group/cooperative (yes = 1)	0.389	$0.498^{\alpha***}$	0.486^{a***}	$0.438^{\chi***, b***}$	$0.405^{\delta**}$
Companies/individuals hired by commune irrigation group or cooperative (yes = 1)	0.075	0.073	$0.093^{\beta**, a*}$	0.095^{b**}	0.093^{c*}
Other (yes = 1)	0.102	$0.06^{\alpha***}$	$0.087^{\beta***}$	0.074^{b***}	$0.105^{\delta***}$

Note: α, β, χ, δ: compared with the years 2008, 2010, 2012, 2014, respectively. $^{a, b, c}$: compared with the year 2008. *** p < 0.01, ** p < 0.05, * p < 0.1. Source: Authors' estimation from VARHS08-16

Table 4. Average farmland area (ha) and land-use types, 2008–2016

	2008	2010	2012	2014	2016
Land size (ha)	0.882	0.850	0.836	0.798^{b*}	0.777 c**
Share of rice	0.603	0.595	0.596	0.597	0.549$^{\delta***,\ c***}$
Share of other annual crops	0.219	0.236	0.238$^{\beta*}$	0.223	0.246$^{\delta**,\ c**}$
Share of perennial crops	0.116	0.117	0.123	0.140^{b**}	0.166$^{\delta**,\ c***}$
Share of forestry	0.039	0.032	0.019$^{\beta***,\ a***}$	0.017^{b***}	0.016 ^{c***}
Share of aquaculture	0.024	0.021	0.024	0.024	0.023

Note: α, β, χ, δ: compared with the year 2008, 2010, 2012, 2014, respectively. $^{a, b, c}$: compared with the year 2008. *** p < 0.01, ** p < 0.05, * p < 0.1. Source: Authors' estimation from VARHS08-16

In terms of irrigation maintenance, farmers group becomes less powerful while other organizations such as irrigation and drainage companies and commune irrigation groups/cooperatives become more powerful.

Table 4 presents the uses of farmland in Viet Nam during 2008–2016 and indicates that (i) rice is still considered as the predominant crop in Viet Nam; (ii) the land share of other annual crops increases; (iii) the land share of perennial crops also increases, (iv) the land share of forestry crops decreases, and (v) the land share of aquaculture tends to stand still in the studied period.

4.2. Irrigation and land-use choices

4.2.1. Basic model

The results of estimating the basic model (Panel A) are presented in Table 5. The F test of residuals equal to zero for each equation is significant at f the 1% level, suggesting that the FE model is of validity (as shown at the seventh line from the bottom of Table 5). Specific models explain 4–17% of the variation in the dependent variables (as shown at the fifth line from the bottom of Table 5). As Table 5 presents, various factors have statistically significant effects on the land shares of rice, other annual crops, perennial crops, forestry, and aquaculture area. Interestingly, different effects have been found across land-use purposes.

With regard to natural capital, the farmland size has a statistically significant effect (at 1% level) in most equations, except for the land of other annual crops. Land size has a negative effect on the land share of rice, and a positive effect on the land shares of perennial crops, forestry, and aquaculture area. The share of irrigated land has a statistically significant influence on the land shares of rice, other annual crops, forestry, and aquaculture area; it has a positive effect on the land shares of rice, but a negative one on the land share of other annual crops, forestry, and aquaculture area. This finding makes sense since the irrigation systems mostly serve rice production in Viet Nam. Other types of crops also need water and mostly depend on water pumping. If the irrigated land share increases, then farmers in Viet Nam would reduce the area of other annual crops and change to cultivate rice. The share of owned land has a significantly negative effect on the land share. The distance from the homestead to the fields has a significantly negative effect on the land share of rice, and aquaculture area but a significantly positive effect on the land share of perennial crops.

For human capital, female-head household has a statistically significant negative effect on the land share of rice. The average age of household members in working ages has a statistically significant positive effect on the land share of perennial crops. This might be explained by the fact that the production of perennial crops requires more labor forces. Farmers with a high education

Table 5. Irrigation and land-use choices: Basic model (Panel A)

Variable	Rice land (%)	Other annual lands (%)	Perennial land (%)	Forestry land (%)	Aquaculture area (%)
Household-level variables					
Natural assets					
Land size (ha), ln	−0.2340***	0.0077	0.0937***	0.1140***	0.0188***
	(0.0171)	(0.0175)	(0.0117)	(0.0081)	(0.0050)
Land with irrigation (%)	0.1840*** (0.0129)	−0.1110*** (0.0133)		−0.0486*** (0.0061)	−0.0270*** (0.0037)
Land with LUC (%)				−0.0117** (0.0052)	
Distance to plot (km)	−0.0018** (0.0007)		0.0027*** (0.0005)		−0.0005** (0.0002)
Human assets					
Female head (yes = 1)	−0.0683* (0.0357)				
Age average of working-age members (years)			0.0005** (0.0003)		
% of "Cannot read and write" (%)	−0.0882** (0.0420)				
% of "Completed Primary"	−0.1100*** (0.0404)				
% of "Completed Lower Secondary"	−0.0794* (0.0413)				
% of "Completed Upper Secondary"	−0.0554 (0.0432)				
Physical assets					
Number of motorbikes	0.0311*** (0.0092)	−0.0240** (0.0094)			
Number of tractors			−0.0454*** (0.0141)		
Financial assets					
Loan size (mill. VND), ln			0.0011* (0.0006)		
Private transfer (mill. VND), ln	−0.0038*** (0.0009)	0.0026*** (0.0009)			
Social assets					
In case of needing money: ask relative (yes = 1)					0.0034* (0.0020)
In case of needing money: ask a friend (yes = 1)					0.0050** (0.0024)
Topography					
% of land with flat	0.0101 (0.0220)	0.191*** (0.0227)	−0.0013 (0.0144)	0.0080 (0.0104)	−0.1980*** (0.0063)
% of land with slight slope	−0.0560** (0.0225)	0.207*** (0.0234)	0.0245 (0.0150)	0.0125 (0.0107)	−0.186*** (0.0065)
% of land with moderate slope	−0.1050*** (0.0251)	0.1870*** (0.0261)	0.0345** (0.0169)	0.0584*** (0.0119)	−0.1820*** (0.0073)
Land quality					
Land share with gullies (%)		0.0445*** (0.0173)		0.0163** (0.0079)	−0.0096** (0.0049)
Dryland share (%)		0.0200**		0.0008	−0.0056**
		(0.0099)		(0.0045)	(0.0028)
Low-lying land share (%)		0.0199 (0.0180)		−0.0073 (0.0083)	−0.0062 (0.0052)

(*Continued*)

Variable	Rice land (%)	Other annual lands (%)	Perennial land (%)	Forestry land (%)	Aquaculture area (%)
Sedimentation land share (%)		−0.0202 (0.0233)		0.0052 (0.0108)	−0.0058 (0.0066)
Share of land with a landslide (%)		0.0185 (0.0478)		0.0505** (0.0221)	−0.0256** (0.0129)
Land share with stony soils/clay (%)		0.0552* (0.0284)		0.0371*** (0.0129)	−0.0145* (0.0079)
Commune-level variables					
Land quality					
Share of cropland with irrigation (%)					−0.0023*** (0.0008)
Market					
Having periodic market (yes = 1)		−0.0237** (0.0118)	0.0141* (0.0078)		
Social conditions					
Having primary school (yes = 1)			−0.0935** (0.0441)		
Having a health care center (yes = 1)	0.0433** (0.0195)				
Having a clinic center (yes = 1)				−0.0232*** (0.0066)	
Having a hospital (yes = 1)	0.0611*** (0.0167)	−0.0537*** (0.0172)			
Having a post office (yes = 1)	−0.0751*** (0.0072)	0.0660*** (0.0081)	0.0348*** (0.0048)		
Having a secondary school (yes = 1)			0.0241** (0.0096)		
Distance					
Distance from the commune center to the main road (km)				−0.0001* (6.16×10^{-5})	
Distance from the commune center to the extension shop (km)		-1.64×10^{-5}* (8.51×10^{-6})			
Non-farm employment					
Number of enterprises with 10 or more employees			−0.0110** (0.0047)		
Living conditions					
Coverage of street lighting (%)				−0.0002*** (4.50×10^{-5})	
Natural and agricultural shocks					
Flood last year (yes = 1)				−0.0110*** (0.0040)	
Typhoon last year (yes = 1)				0.0097** (0.0045)	
Landslide last year (yes = 1)			−0.0228** (0.0092)		
Plant disease last year (yes = 1)				0.0058* (0.0032)	

(*Continued*)

Table5. (*Continued*)

Variable	Rice land (%)	Other annual lands (%)	Perennial land (%)	Forestry land (%)	Aquaculture area (%)
Flood two years ago (yes = 1)				0.0126*** (0.0038)	
Typhoon two years ago (yes = 1)				−0.0134*** (0.0044)	
Landslide two years ago (yes = 1)			0.0263*** (0.0094)		
Animal/livestock epidemics two years ago (yes = 1)				−0.0106*** (0.0033)	
Plant disease two years ago (yes = 1)			0.0072* (0.0044)		
Insects/rats two years ago (yes = 1)	−0.0144** (0.0071)	0.0174** (0.0073)			
Year dummies	Yes	Yes	Yes	Yes	Yes
Constant	0.653***	0.108***	0.109**	0.0045	0.206***
	(0.0487)	(0.0238)	(0.0464)	(0.0110)	(0.0064)
Observations	7,675	7,675	7,675	7,806	8,517
Number of HH	1,747	1,747	1,747	1,759	1,945
F statistic	37.67	11.13	12.98	23.71	86.39
F for u (i) = 0	7.864***	5.216***	10.33***	2.539***	5.884***
Log likelihood	1893	1667	4801	7626	12,106
R^2 within model	0.108	0.038	0.038	0.080	0.165
R^2 between model	0.224	0.062	0.177	0.135	0.437
R^2 overall model	0.228	0.065	0.155	0.099	0.305
AIC	−3746.041	−3290.739	−9564.859	−15,206.77	−24,179.04
BIC	−3607.127	−3137.933	−9432.89	−15,046.63	−24,066.24

Standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.1. Source: Authors' estimation from VARHS08-16

level such as a level of "completed lower secondary school" would plant less rice than the group of "Can read and write but never went to school or did not finish primary school" does.

In terms of physical capital, the number of motorbikes has a positive association with the land share of rice but a negative one on the land share of other annual crops. The number of tractors has a negative effect on the land share of perennial crops. It can be explained by the nature of planting perennial does not go effectively with the tractor.

Regarding financial capital, loan volume has a positive effect on the land share of perennial crops. This finding indicates that investment into perennial crops may require more capital investment that sometimes goes out of the hand of the household. Considering private transfer, it has a negative effect on the land share of rice but a positive one on the land share of other annual crops.

With respect to social capital, relative and friend trusts have positive effects on the share of the aquaculture area. This may be a traditional custom in aquaculture production where investment and working capital are high and seasonal variation.

For topography and land quality, their effects reflect the priority given to each land-use type in the sample. Farmers who have experienced more share of land with flat would allocate more land

to other annual crops, and less to aquaculture. Farmers who have experienced more share of land with slight slope would allocate less land to rice, aquaculture, and more to other annual crops. Farmers who have experienced more share of land with a moderate slope would allocate less land to rice, aquaculture, and more to other annual crops, perennial crops, and forestry. With regard to land quality, farmers who have experienced more share of land with gullies would allocate more to other annual crops, and forestry, and less to aquaculture.

At the commune level, in a commune with more cropland with irrigation, farmers would less likely to give land to aquaculture activity.

With regard to market at the commune level, farmers in commune with the periodic market are negatively correlated with the share of land for other annual crops, and a positive correlation with perennial crops.

In terms of social conditions, such as schooling, health care, post office, farmers in commune, having primary school would decrease the land share of perennial crops, whereas in commune having secondary school would increase the land share of perennial crops. Farmers in commune having health-care center and the hospital would increase the land share of rice and reduce the land share of other annual crops, whereas farmers in commune having clinic center would increase the land share of perennial crops.

With regard to distance variables at the commune level, distance to the main road would reduce the probability that farmers allocate more land for forestry. Distance to the extension center would decrease the chance that farmers allocate more land for perennial crops.

The off-farm wage employment opportunities inside the commune would reduce the possibility that farmers plant more perennial crops.

With respect to living conditions at the commune level, the level of lighting coverage is negatively correlated with the probability that farmers plant forestry. A plausible explanation: lighting coverage is more related to a higher level of urbanization and less agricultural activities.

The effects of the weather shock experience also reflect the priority given to each land-use type in Viet Nam. Farmers living in a commune that experienced floods last year would allocate less land to forestry. This is because forestry requires a high level of initial investments and a long period to get the returns. In addition, the shocks might lead to income losses and, as a consequence, farmers are unable to invest in forestry. Farmers in a commune that experienced typhoons last year would allocate more land to perennial crops. Farming households in a commune that experienced a landslide last year would allocate less land to forestry. Farmers in a commune that experienced animal/livestock epidemics last year would allocate more land to forestry.

When the time occurrence of shocks is longer, from one year to two years, farmers in a commune that experienced flood two years ago would allocate more land to forestry. An explanation may be flooding two years ago may bring more land nutrition, so as a result, farmers are eager to plant more in the survey year. Second, farmers in a commune that experienced typhoons two years ago would allocate less land to forestry. This may be the long-term effect of typhoons. Third, farmers in a commune that experienced a landslide two years ago would allocate more land to other annual crops. While farming households in a commune that experienced animal/livestock epidemics two years ago would allocate less area to aquaculture, farmers in a commune that experienced plant disease two years ago would allocate more land to perennial crops. Unlike the cases of animal/livestock epidemics and plant disease, farmers in a commune that experienced insects/rats two years ago would allocate less land to rice and more land to perennial crops.

4.2.2. Irrigation physical conditions

The results of estimating the influence of irrigation physical conditions on land-use selections are presented in Table 6. The models explain 4–16% and 4–17% of the variation in the land proportions for (a) a set of variables relating to main canals, and (b) a set of variables relating to tertiary, respectively.

Specifically, farmers in a commune with all canals lined have less percentage of other annual crops than households in a commune with no canal-lined (column 2). The percentage is 3.0 percentage points lower than the cases of the commune with no canal-lined. Second, farmers in a commune with canals mostly lined with concrete (or other solid materials) have more percentage of aquaculture than households in a commune with no canal-lined (column 5). The percentage is 1.0 percentage point higher than the cases of the commune with no canal-lined. Third, farmers in a commune with canals mostly not lined with concrete (or other solid materials) have less percentage of forestry than households in a commune with no canal-lined (column 4). The percentage is 1.0 percentage point lower than the cases of the commune with no canal-lined. In addition, for perennial land, there are no statistically significant differences between the three types of canals (column 3). This may be because the farmers can use water from wells or other sources for perennial crops. We also do not find statistically significant differences between the three types of canals on land for rice (column 1).

Regarding the influence of irrigation physical conditions of tertiary canals, the effects are similar to the case of main canals for other annual crops. Specifically, farmers in a commune with all canals lined (or canals mostly lined) with concrete (or other solid materials) have less percentage of other annual crops than farmers in a commune with no canal-lined, with the percentages of 2.8 percentage points and 2.3 percentage points, respectively (column 2). On top of that, farmers in a commune with canals mostly lined with concrete (or other solid materials) have more percentage of perennial crops than households in a commune with no canal lined (column 3). Last but not least, for rice, forestry, and aquaculture, there are no statistically significant differences among these types of canals (columns 1, 4, and 5).

4.2.3. Ownership of irrigation facilities

The results of estimating the influence of ownership of irrigation facilities are presented in Table 7. The models explain 4–17% of the variation in all four types of land use. As Table 7 presents, farmers in a commune with cooperative irrigation facilities are more likely to cultivate perennial crops than households in a commune with the public or none of the public and cooperative irrigation facilities. The percentage is 2.0 percentage points higher than the cases of the commune with none of the public and cooperative irrigation facilities.

4.2.4. Irrigation operations

The results of estimating the influence of irrigation operations on land uses are presented in Table 8. We observe that farmers in a commune with Commune Irrigation Groups are less likely to cultivate rice, other annual crops, and forestry than households in a commune with no cooperative involved in irrigation operations. The percentages are 1.9 percentage points, 2.0 percentage points, and 1 percentage point, respectively, lower than the cases of the commune with no cooperative involved in irrigation operations. Moreover, households in a commune with cooperatives involved in irrigation operations are more likely to plant forestry than households in a commune with no cooperatives involved in irrigation operations or with commune irrigation groups (column 4) (which is more or less similar with Buisson and Balasubramanya (2019)). The respective percentage is 1.0 percentage point.

4.2.5. Management responsibility shift

The results of estimating the influence of the management responsibility shift are presented in Table 9.

Table 6. Irrigation and land-use choices: Irrigation physical conditions (Panel B1)

Variable	Rice land (%)	Other annual lands (%)	Perennial land (%)	Forestry land (%)	Aquaculture area (%)
	(1)	(2)	(3)	(4)	(5)
Household-level variables	Yes	Yes	Yes	Yes	Yes
Commune-level variables	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
Panel B1A: Main canals lined with concrete or other solid materials (base: No canal-lined)					
All canals lined (yes = 1)	0.0145 (0.0110)	−0.0279** (0.0114)	0.0105 (0.0074)	−0.0025 (0.0047)	0.0004 (0.0032)
Mostly lined (yes = 1)	0.0023 (0.0102)	−0.0127 (0.0106)	0.0028 (0.0069)	−0.0020 (0.0044)	0.0055* (0.0030)
Mostly not lined (yes = 1)	0.0133 (0.0113)	−0.0098 (0.0117)	0.0037 (0.0076)	−0.0103** (0.0048)	0.0034 (0.0033)
Observations	7,252	7,252	7,252	7,364	7,364
Number of HH	1,740	1,740	1,740	1,752	1,752
F statistic	31.03	9.708	11.42	17.39	48.72
F for u (i) = 0	7.370***	4.916***	9.715***	2.851***	5.643***
Log likelihood	1828	1604	4741	7969	10,722
R^2 within model	0.111	0.041	0.042	0.075	0.161
R^2 between model	0.220	0.051	0.185	0.119	0.442
R^2 overall model	0.221	0.060	0.163	0.091	0.302
AIC	−3609.967	−3158.815	−9438.398	−15,884.26	−21,397.1
BIC	−3451.519	−2986.59	−9286.839	−15,697.85	−21,238.3
Panel B1B: Tertiary canals lined with concrete or other solid materials (base: No canal-lined)					
All canals lined (yes = 1)	0.0126 (0.0121)	−0.0280** (0.0125)	0.0112 (0.0083)	−0.0019 (0.0057)	0.0027 (0.0037)
Mostly lined (yes = 1)	0.0081	−0.0232**	0.0153**	−0.0051	0.0011
	(0.0089)	(0.0092)	(0.0061)	(0.0042)	(0.0027)
Mostly not lined (yes = 1)	−0.0004 (0.0083)	−0.0133 (0.0085)	0.0088 (0.0057)	−0.0023 (0.0039)	0.0041 (0.0025)
Observations	7,267	7,267	7,267	7,375	7,375
Number of HH	1,739	1,739	1,739	1,749	1,749
F statistic	30.64	9.282	11.62	20.27	49.75
F for u (i) = 0	7.534***	5.053***	9.407***	2.587***	5.499***
Log likelihood	1879	1677	4626	7333	10,579
R^2 within model	0.109	0.039	0.042	0.083	0.170

(*Continued*)

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Table6. (*Continued*)

Variable	Rice land (%)	Other annual lands (%)		Perennial land (%)	Forestry land (%)	Aquaculture area (%)
	(1)	(2)		(3)	(4)	(5)
R^2 between model	0.223	0.049	0.175		0.139	0.440
R^2 overall model	0.223	0.054	0.153		0.106	0.311
AIC	−3712.974	−3303.889	−9207.914		−14,614.89	−21,110.15
BIC	−3554.479	−3131.612	−9056.31		−14,435.34	−20,944.41

Note: Standard errors in parentheses; *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Source: Authors' estimation from VARHS08-16

Table 7. Irrigation and land-use choices: Ownership of irrigation facilities (Panel B2)

Variable	Rice land (%)	Other annual lands (%)	Perennial land (%)	Forestry land (%)	Aquaculture area (%)
	(1)	(2)	(3)	(4)	(5)
Panel B2: Ownership of irrigation facilities (base: None of the public and cooperative irrigation facilities)					
Household-level variables	Yes	Yes	Yes	Yes	Yes
Commune-level variables	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
Public (yes = 1)	−0.0043 (0.0141)	−0.0129 (0.0146)	0.0158 (0.0097)	0.0009 (0.0067)	0.0064 (0.0043)
Cooperative (yes = 1)	−0.0089 (0.0159)	−0.0078 (0.0166)	0.0202* (0.0109)	−0.0011 (0.0076)	0.0028 (0.0048)
Both public and cooperative (yes = 1)	−0.0013 (0.0150)	−0.0143 (0.0154)	0.0138 (0.0103)	0.0042 (0.0071)	0.0020 (0.0045)
Observations	7,672	7,672	7,672	7,802	7,804
Number of HH	1,747	1,747	1,747	1,759	1,759
F statistic	32.52	9.847	11.30	20.45	55.71
F for u (i) = 0	7.789***	5.198***	10.27***	2.508***	5.837***
Log likelihood	1892	1661	4800	7627	11,165
R^2 within model	0.108	0.0370	0.0386	0.0812	0.169
R^2 between model	0.224	0.0671	0.175	0.137	0.452
R^2 overall model	0.228	0.0673	0.154	0.101	0.310
AIC	−3737.322	−3274.997	−9556.994	−15,199.94	−22,284.67
BIC	−3577.579	−3108.309	−9404.197	−15,011.96	−22,124.53

Note: Standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.1. Source: Authors' estimation from VARHS08-16

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Table 8. Irrigation and land-use choices: Irrigation operations (Panel B3)

Variable	Rice land (%)	Other annual lands (%)	Perennial land (%)	Forestry land (%)	Aquaculture area (%)
	(1)	(2)	(3)	(4)	(5)
Panel B3: Irrigation operations: Cooperatives and Commune Irrigation Groups					
Household-level variables	Yes	Yes	Yes	Yes	Yes
Commune-level variables	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
Cooperatives (yes = 1)	0.0032 (0.0077)	0.0013 (0.0077)	0.0002 (0.0051)	0.0061* (0.0035)	0.0020 (0.0023)
Commune Irrigation Groups (yes = 1)	−0.0186*** (0.0070)	−0.0200*** (0.0070)	0.0057 (0.0046)	−0.0058* (0.0032)	0.0004 (0.0020)
Observations	7,675	7,669	7,675	7,806	7,802
Number of HH	1,747	1,747	1,747	1,759	1,759
F statistic	10.70	10.36	11.76	21.98	55.55
F for u (i) = 0	5.223***	5.185***	10.31***	2.517***	5.848***
Log likelihood	1668	1674	4802	7630	11,160
R^2 within model	0.0383	0.0388	0.0383	0.0805	0.169
R^2 between model	0.0540	0.0618	0.174	0.135	0.452
R^2 overall model	0.0596	0.0646	0.153	0.0990	0.310
AIC	−3290.871	−3300.142	−9562.823	−15,209.94	−22,273.58
BIC	−3131.119	−3133.463	−9416.963	−15,035.87	−22,113.45

Note: Standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.1. Source: Authors' estimation from VARHS08-16

As Table 9 presents, farming households in a commune with substantial responsibility changes is more likely to cultivate rice than households in a commune with no change. This may be because farmers with more autonomy can manage better irrigation operations (Svendsen, 1993). In other cases, we do not find any statistically significant difference in management responsibility shift.

4.2.6. Decision-making

The results of estimating the influence of decision-making are presented in Table 10: the effects of decision-making related to the construction of new facilities in Panel B5A, decision-making related to the operation of new facilities in Panel B5B, and decision-making related to maintenance of facilities in Panel B5C.

Regarding the construction of new facilities, we observe no significant difference in agents' decision-making for the cases of cultivating rice, other annual crops, perennial crops, and aquaculture (columns 1, 2, 3, and 5). However, farmers in a commune where decision-making mostly influenced by Commune Irrigation Group, Cooperative, irrigation and drainage companies, and Commune People's Committee at both district and commune levels are less likely to plant forestry than households in a commune where decision-making mostly influenced by farmers' groups (column 4).

With respect to the operation of new facilities in Panel B5B, farmers in a commune where decision-making mostly influenced by the Commune Irrigation Group and District People's Committee are more likely to cultivate other annual crops than farmers in a commune where decision-making mostly influenced by farmers' groups (Column 2). The percentage is 2.5 percentage points higher in both two cases. Moreover, farmers in a commune where decision-making mostly influenced by Commune Irrigation Group are less likely to plant perennial crops than farmers in a commune where decision-making mostly influenced by farmers group (1.6 percentage

Table 9. Irrigation and land-use choices: Management responsibility shift (Panel B4)

Variable	Rice land (%)	Other annual lands (%)	Perennial land (%)	Forestry land (%)	Aquaculture area (%)
	(1)	(2)	(3)	(4)	(5)
Panel B4: Responsibility shift in irrigation management: given to farmers (base: No change)					
Household-level variables	Yes	Yes	Yes	Yes	Yes
Commune-level variables	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
Substantial change (yes = 1)	0.0166** (0.0075)	−0.0064 (0.0078)	−0.0048 (0.0051)	−0.0017 (0.0036)	−0.0024 (0.0023)
Some change (yes = 1)	0.0006 (0.0074)	−0.0007 (0.0076)	−0.0065 (0.0050)	0.0009 (0.0035)	0.0011 (0.0022)
Observations	7,537	7,537	7,537	7,665	7,667
Number of HH	1,745	1,745	1,745	1,757	1,757
F statistic	34.79	10.21	11.39	22.33	58.24
F for u (i) = 0	7.632***	5.091***	9.802***	2.527***	5.719***
Log likelihood	1866	1637	4730	7505	10,923
R^2 within model	0.112	0.0375	0.0380	0.0835	0.172
R^2 between model	0.224	0.0616	0.181	0.134	0.446
R^2 overall model	0.229	0.0653	0.157	0.100	0.314
AIC	−3687.327	−3228.489	−9418.426	−14,960.79	−21,802.54
BIC	−3534.92	−3069.154	−9272.947	−14,787.18	−21,649.76

Note: Standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.1. Source: Authors' estimation from VARHS08-16

points lower) (column 3). Besides, farmers in a commune where decision-making mostly influenced by irrigation and drainage company are less likely to plant forestry than farmers in a commune where decision-making mostly influenced by the farmers' group (1.2 percentage points lower) (column 4). Finally, farmers in a commune where decision-making mostly influenced by Commune Irrigation Group, cooperatives, Commune People's Committee are more likely to cultivate aquaculture than farmers in a commune where decision-making mostly influenced by farmers group (1.0 percentage point lower in all cases) (column 5).

The effects of decision-making related to maintenance of facilities are presented in Table 10, Panel B5C. Farmers in a commune where decision-making mostly influenced by District People's Committee have a higher 3.4 percentage points to cultivate other annual crops than those in a commune where decision-making mostly influenced by farmers' groups (column 2). Besides, farmers in a commune where decision-making mostly influenced by irrigation and drainage companies, and the People's Committee at both district and commune levels are less likely to plant forestry than those in a commune where decision-making mostly influenced by farmers' groups (column 4). Finally, farmers in a commune where decision-making mostly influenced by farmers' groups have more percentage of aquaculture than those in a commune where decision-making mostly influenced by other agents (column 5).

4.2.7. Maintenance

The results of estimating the influence of irrigation maintenances are presented in Table 11. While we find no different roles of ownership in management with respect to other annual crops (column 2), and aquaculture (column 5), farmers in a commune where irrigation maintenances conducted by either irrigation and drainage company, commune irrigation groups/cooperative, or companies/individuals hired by commune irrigation groups/cooperatives are less likely to cultivate

Table 10. Irrigation and land-use choices: Decision-making (Panel B5)

Variable	Rice land (%)	Other annual lands (%)	Perennial land (%)	Forestry land (%)	Aquaculture area (%)
	(1)	(2)	(3)	(4)	(5)
Household-level variables	Yes	Yes	Yes	Yes	Yes
Commune-level variables	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
Panel B5A: Irrigation decision-making: Construction of new facilities (base: Farmers group)					
Commune irrigation group (yes = 1)	0.0170 (0.0182)	0.0086 (0.0188)	0.0001 (0.0125)	−0.0167* (0.0086)	−0.0066 (0.0056)
Cooperative (yes = 1)	0.0153 (0.0155)	0.00705 (0.0160)	−0.00157 (0.0107)	−0.0227*** (0.0073)	0.0006 (0.0047)
Irrigation and drainage company (yes = 1)	−0.0089 (0.0183)	0.0147 (0.0190)	0.0148 (0.0126)	−0.0216** (0.0087)	0.0035 (0.0056)
Commune People's Committee (yes = 1)	0.0200 (0.0132)	0.0068 (0.0137)	0.0010 (0.0091)	−0.0226*** (0.0062)	−0.0032 (0.0041)
District People's Committee (yes = 1)	−0.0018 (0.0129)	0.0161 (0.0133)	0.0092 (0.0088)	−0.0247*** (0.0060)	0.0012 (0.0039)
Others (yes = 1)	0.0037	0.0424	−0.0044	−0.0283**	−0.0065
	(0.0290)	(0.0300)	(0.0199)	(0.0136)	(0.0089)
Observations	7,411	7,411	7,411	7,529	7,531
Number of HH	1,736	1,736	1,736	1,748	1,748
F statistic	29.25	8.822	9.851	19.96	48.78
F for u (i) = 0	7.553***	4.999***	9.526***	2.502***	5.573***
Log likelihood	1891	1651	4687	7531	10,729
R^2 within model	0.115	0.0390	0.0402	0.0885	0.175
R^2 between model	0.229	0.0590	0.194	0.137	0.454
R^2 overall model	0.231	0.0644	0.171	0.103	0.320
AIC	−3729.966	−3247.805	−9324.996	−15,004.03	−21,405.39
BIC	−3550.288	−3061.215	−9152.228	−14,803.16	−21,225.3
Panel B5B: Irrigation decision-making: Operation of facilities (base: Farmers group)					
Commune Irrigation Group (yes = 1)	0.0021 (0.0135)	0.0258* (0.0140)	−0.0159* (0.0093)	−0.0030 (0.0065)	−0.0091** (0.0041)
Cooperative (yes = 1)	0.0071 (0.0138)	0.0014 (0.0142)	−0.0045 (0.0094)	0.0012 (0.0066)	−0.0076* (0.0042)
Irrigation and drainage company (yes = 1)	0.0002 (0.0146)	0.0093 (0.0150)	0.0043 (0.0010)	−0.0122* (0.0070)	−0.0053 (0.0044)
Commune People's Committee (yes = 1)	−0.0051 (0.0123)	0.0142 (0.0127)	0.0065 (0.0085)	−0.0094 (0.0059)	−0.0078** (0.0037)
District People's Committee (yes = 1)	−0.0080 (0.0142)	0.0252* (0.0146)	−0.0082 (0.0097)	−0.0084 (0.0068)	−0.0031 (0.0043)
Others (yes = 1)	−0.0081	0.0148	0.0129	0.0135	−0.0112
	(0.0316)	(0.0327)	(0.0219)	(0.0151)	(0.0096)
Observations	7,402	7,402	7,402	7,521	7,523
Number of HH	1,736	1,736	1,736	1,748	1,748
F statistic	28.97	9.025	9.865	20.39	51.09
F for u (i) = 0	7.587***	5.010***	9.572***	2.430***	5.811***
Log likelihood	1902	1680	4698	7433	10,808
R^2 within model	0.114	0.0399	0.0403	0.0904	0.176

(*Continued*)

Variable	Rice land (%)	Other annual lands (%)	Perennial land (%)	Forestry land (%)	Aquaculture area (%)
	(1)	(2)	(3)	(4)	(5)
R^2 between model	0.226	0.0559	0.185	0.137	0.457
R^2 overall model	0.231	0.0623	0.162	0.106	0.323
AIC	−3751.108	−3305.32	−9346.464	−14,807.56	−21,565.51
BIC	−3571.461	3118.763	−9173.727	−14,606.73	−21,392.37
Panel B5C: Irrigation decision making: Maintenance of facilities (base: Farmers group)					
Commune Irrigation Group (yes = 1)	0.0018 (0.0139)	0.0166 (0.0143)	−0.0049 (0.0095)	−0.0092 (0.0066)	−0.0069* (0.0042)
Cooperative (yes = 1)	−0.0022 (0.0139)	0.0130 (0.0141)	0.0013 (0.0095)	−0.0074 (0.0065)	−0.0112*** (0.0042)
Irrigation and drainage company (yes = 1)	0.0046 (0.0146)	0.0081 (0.0150)	0.0093 (0.0101)	−0.0169** (0.0069)	−0.0115*** (0.0044)
Commune People's Committee (yes = 1)	−0.0055 (0.0128)	0.0127 (0.0131)	0.0096 (0.0087)	−0.0119** (0.0060)	−0.0106*** (0.0038)
District People's Committee (yes = 1)	−0.0210 (0.0140)	0.0342** (0.0145)	0.0056 (0.0096)	−0.0128* (0.0067)	−0.0074* (0.0042)
Others (yes = 1)	−0.0218	0.0509	−0.0067	−0.0073	−0.0062
	(0.0329)	(0.0340)	(0.0226)	(0.0156)	(0.0099)
Observations	7,391	7,391	7,391	7,509	7,511
Number of HH	1,738	1,738	1,738	1,750	1,750
F statistic	29.14	9.171	9.495	20.03	51.49
F for u (i) = 0	7.568***	5.013***	9.519***	2.448***	5.750***
Log likelihood	1896	1673	4672	7433	10,793
R^2 within model	0.115	0.0407	0.0389	0.0891	0.177
R^2 between model	0.228	0.0555	0.182	0.136	0.449
R^2 overall model	0.231	0.0621	0.161	0.104	0.319
AIC	−3739.441	−3291.166	−9293.339	−14,807.84	−21,535.11
BIC	−3559.833	−3104.649	−9120.639	−14,607.05	−21,362.01

Note: Standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.1. Source: Authors' estimation from VARHS08-16

rice than those in a commune where irrigation maintenances conducted by farmers themselves (column 1). Similar results are found for forestry (column 4).

On the other side, farmers in a commune where irrigation maintenances conducted by either irrigation and drainage company, companies/individuals hired by irrigation and drainage company, commune irrigation groups/cooperative, or companies/individuals hired by households in a commune irrigation groups/cooperatives are less likely to plant perennial trees than households in a commune where irrigation maintenances conducted by farmers themselves (column 3).

5. Discussions

The results in this paper support and add more empirical evidence to the existing empirical literature on the effects of irrigation on land-use decisions in developing countries recently, such as Yao et al. (2017), Huang (2014) for China, Chaudhry (2018) for Pakistan, and Buisson and Balasubramanya (2019) for Tajikistan. In most of developing countries such as Vietnam, China and India, water user association (WUA) is one of important institutions to manage irrigation efficiently. WUAs, among its various definitions, were designed to set up schedules, allocate water use to farmers, and the financial autonomy.

With respect to irrigation operation, as Buisson and Balasubramanya (2019) observer in Tajikistan, improvements in irrigation services through utilizing WUAs affect the cultivation of cotton and wheat, or perennial crops in general. Other researchers also indicate that irrigation services are crucial for enhancing agricultural production in general (see the review by Darko et al. (2016); Buisson and Balasubramanya (2019)). In terms of leadership, according to Yao et al. (2017), irrigation system managed by WUA with the director as village leader proves to be more efficient in allocating water sources to individual farmers from the perspectives of increased water fee collection and less water conflicts. Other studies also confirm that communities performing better in managing local irrigation have the following features such as good leaders (Fujiie et al. (2005), Khwaja (2009), and Mishra et al. (2011)), educated leadership, better status of irrigation infrastructure, and higher water scarcity (Nagrah et al., 2016),

On top of that, cooperation also has its own advantages in irrigation management as shown in our results that households in a commune with cooperatives involved in irrigation operations are more likely to plant forestry than households in a commune with no cooperatives involved in irrigation operations or with commune irrigation groups. Chaudhry (2018), for example, finds higher degree of cooperation is common in smaller communities because it can reduce transaction costs in terms of communication and enforcement, confirming results from previous studies by Araral (2009), Bardhan (2000), and Mekonnen et al. (2015). However, the low level of community participation is found with the degree of water scarcity in the community, that is, salience of the resource (Araral (2009), Meinzen-Dick et al. (2002)).

Recent studies show that changes in management responsibility from the state to cooperatives, farmers can improve the efficiency of irrigation management. Chaudhry (2018) concludes that irrigation management institutions such as Irrigation Management Transfer (IMT), Participatory Irrigation Management (PIM), or Farmer Managed Irrigation Systems (FMIS) have been expanded to give more responsibility to farmers or groups of farmers in developing countries. In a country that Vietnam shares many similar features of system of irrigation management, China, state-established organizations in irrigation management such as WUAs, have little autonomous power because of either the central control of the government and the farmers' reluctancy in taking more responsibilities and rights in water management (Yao et al., 2017). As shown in our empirical results, farming households in a commune with substantial responsibility changes is more likely to cultivate rice than households in a commune with no change. Yao et al. (2017) also suggest that a more incentive of political participation in the rural area may encourage farmers to take the extra responsibilities in self-governance.

Huang (2014) examines the effects of management transfer to WUAs or contractors from the village committee in northern China and finds that WUAs have improved the timeliness of water deliveries, the percent of irrigated area. Contractors have also improved the irrigation systems managed but with magnitudes smaller than in the case of WUAs. This observation is, more or less, reflected in our result which indicate that substantial change does have significant effect on land use whereas some changes may not reach the full targets.

In reference to decision making, Yao et al. (2017) conclude that efficiency in water management does not depend much on the involvement of individual farmers in to decision-making. On top of that, farmers in the case of Chinese WUAs highly care about the official decisions of the irrigation quota, fees, and time, indeed. In our study, we find that a complex picture. For example, regarding the construction of new facilities, we observe no significant difference in agents' decision-making for cultivating rice, other annual crops, perennial crops, and aquaculture, but the significant influence of decision-making by farmers' groups in forestry. With respect to the operation of new facilities, more significant effects in other annual crops are found with the Commune Irrigation Group and District People's Committee rather than farmers' groups. However, more significant role of farmers' groups in perennial crops and forestry rather than Commune Irrigation Group and irrigation and drainage company, respectively. More significant influence of farmers' groups in aquaculture is evidenced rather than Commune Irrigation Group, cooperatives, Commune People's Committee. In relation to decision making on maintenance of

Table 11. Irrigation and land-use choices: Irrigation maintenance (Panel B6)

Variable	Rice land (%)	Other annual lands (%)	Perennial land (%)	Forestry land (%)	Aquaculture area (%)
	(1)	(2)	(3)	(4)	(5)
Panel B6: Irrigation maintenance: Tertiary canals and structures (base: Farmers themselves)					
Household-level variables	Yes	Yes	Yes	Yes	Yes
Commune-level variables	Yes	Yes	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes	Yes	Yes
Irrigation and drainage company (yes = 1)	−0.0245** (0.0106)	0.0071 (0.0109)	0.0245*** (0.0072)	−0.0131*** (0.0050)	0.0040 (0.0032)
Companies/individuals hired by irrigation and drainage company (yes = 1)	−0.0083 (0.0182)	0.0035 (0.0187)	0.0034 (0.0123)	−0.0022 (0.0086)	0.0027 (0.0055)
Commune irrigation group/cooperative (yes = 1)	−0.0190** (0.0081)	0.0033 (0.0083)	0.0188*** (0.0055)	−0.0079** (0.0038)	0.0016 (0.0025)
Companies/individuals hired by commune irrigation group or cooperative (yes = 1)	−0.0204* (0.0119)	0.0002 (0.0123)	0.0280*** (0.0081)	−0.0098* (0.0057)	−0.0039 (0.0036)
Other (yes = 1)	0.0022	−0.0103	0.0258***	−0.0135**	−0.0047
	(0.0131)	(0.0135)	(0.0089)	(0.0062)	(0.0040)
Observations	7,443	7,443	7,443	7,561	7,563
Number of HH	1,738	1,738	1,738	1,750	1,750
F statistic	30.56	9.061	10.79	20.45	52.86
F for u (i) = 0	7.477***	4.990***	9.537***	2.402***	5.656***
Log likelihood	1857	1644	4743	7440	10,773
R^2 within model	0.114	0.0384	0.0418	0.0871	0.174
R^2 between model	0.225	0.0599	0.201	0.144	0.452
R^2 overall model	0.229	0.0628	0.175	0.108	0.320
AIC	−3664.897	−3236.267	−9438.883	−14,824.51	−21,497.93
BIC	−3492.022	−3056.477	−9272.923	−14,630.45	−21,331.58

Note: Standard errors in parentheses; *** p < 0.01, ** p < 0.05, * p < 0.1. Source: Authors' estimation from VARHS08-16

facilities, District People's Committee shows more power in other annual crops, while farmers' groups prove more influences in forestry and aquaculture. We find no different effect in rice cultivation and perennial land. In short, diversified effects may come from the differences of land-use purposes, institutional conditions and farm characteristics that may need for further deep analysis in the future.

On maintenance of irrigation, Buisson and Balasubramanya (2019) show that infrastructure maintenance and improvements of, such as the watercourse, or the condition of the distributary canal are important for crops cultivation. Chaudhry (2018) also stresses that watercourse maintenance by contributing labor is important.

The common agreement is that government agencies are less efficient in the operation and maintenance of scattered irrigation systems (Coward et al. (1988), Woodhouse et al. (2017)). As shown in our study, irrigation maintenance by farmers from the perspective of rice land and forestry is superior than that by irrigation and drainage company, companies/individuals hired by irrigation and drainage company, commune irrigation group or cooperative, and companies/

individuals hired by commune irrigation group or cooperative. However, it is not the case with perennial land. One plausible explanation is perennial cultivation often requires a large amount of water that usually is supplied by companies or state-owned irrigation works. Empirical evidence of our study generally supports the view that if farmers have ownership over the land, they will take better care of the land (Bruns (1993), Oates et al. (2015)).

6. Conclusion and Implications

The current study modifies the livelihoods framework to examine the influence of irrigation management on farmers' land-use selections in the rural areas of Viet Nam, using a unique panel five-waves dataset in 2008–2016. Seemingly, unrelated regressions and fixed-effects models are estimated. A wide range of irrigation management is investigated, namely: (i) the irrigation physical conditions, (ii) the ownership of irrigation facilities, (iii) the irrigation operations, (iv) the management responsibility shift, (v) the decision-making, and (vi) the irrigation maintenance. In general, we find that the overall effects of irrigation management are so different, depending on the types of land uses. On top of that, different aspects of irrigation management have diversified influences on types of land uses.

Specifically, the results reveal that irrigation physical conditions such as main canals lined (or mostly lined) with concrete (or other solid materials) have less favorable to cultivate other annual crops, forestry, but more supportive to aquaculture. The effects of tertiary canals mostly lined with concrete (or other solid materials) are favorable to other annual crops, and perennial crops.

Secondly, with respect to ownership of irrigation facilities, cooperative irrigation facilities are more likely to support perennial crops.

Thirdly, in regard to irrigation operations, rice cultivation, other annual crops, and forestry are not benefited from Commune Irrigation Groups. In addition, cooperatives involved in irrigation operations are less likely to support forestry land.

Fourthly, as to the management responsibility shift, substantial responsibility changes given to farmers in irrigation management, thus more autonomy, are favorable to cultivate rice. We do not find any statistically significant difference in management responsibility shift across alternatives of land use.

Fifthly, in relation to the decision-making of the construction of new facilities, Commune irrigation group, cooperative, irrigation and drainage companies, and Commune People's Committee at both district and commune levels are less likely to plant forestry.

With respect to the decision-making of the operation of new facilities, Commune Irrigation Group and District People's Committee are more likely to support other annual crops; Commune Irrigation Group is less likely to help the cultivation of perennial crops; irrigation and drainage company is less likely to support forestry; and Commune Irrigation Group, cooperatives, Commune People's Committee are more likely to cultivate aquaculture. With reference to decision-making related to maintenance of facilities, the District People's Committee is more favorable to cultivate other annual crops; the irrigation and drainage company and People's Committee at both district and commune levels are less likely to plant forestry; farmers' groups have more probability to choose aquaculture.

Last but not least, with regard to irrigation maintenances by actors, irrigation maintenances conducted by either irrigation and drainage company, commune irrigation groups/cooperative, and companies/individuals hired by commune irrigation groups/cooperatives are less likely to cultivate rice and forestry. In addition, irrigation maintenances conducted by either irrigation and drainage company, companies/individuals hired by irrigation and drainage company, commune irrigation groups/cooperative, and companies/individuals hired by households in a commune irrigation groups/cooperatives are more likely to plant forestry.

The findings of our study lead to several important implications related to irrigation management that are relevant to farmers and policymakers. Different stakeholders, organizations/institutions, and farming households play differently effective roles in irrigation management. Firstly, investments in irrigation conditions such as main canals and tertiary canals need to be promoted to support other annual crops, perennial crops, and crop diversification. Secondly, development of irrigation facilities based on the public, cooperative, or both, stimulation of irrigation operations with cooperative involved, more autonomy in terms of farmers' responsibility in irrigation management are needed for perennial crops. Thirdly, the decentralization of irrigation facilities in fields of land for rice, other annual crops, and forestry is accompanied along the way. Fourthly, more decision-making power in terms of the construction of new facilities, the operation of new facilities, maintenance of facilities should be released toward farmer's group. Fifthly, irrigation maintenances by actors such as the Commune Irrigation Group and District People's Committee should be given to the field of other annual crops, and aquaculture. In general, policies can be conducted through the development of a lined irrigation network, and decision-making in operations of irrigation, maintenance of irrigation, and irrigation maintenance should give more power to farmers' groups.

The current paper bears some limitations. Given the availability of dataset, six dimensions of irrigation management are investigated, including (i) irrigation conditions, (ii) ownership of irrigation facilities, (iii) irrigation operations, (iv) management responsibility shift, (v) decision-making, and (vi) maintenance. However, it is difficult to assess the possible mechanisms that may underline the interaction between these components within the set-up framework. Secondly, although the paper tries to control for topography, land quality and climate conditions, various systems of irrigation in Vietnam between the North and the South, plains vs. mountainous areas, different types of handling irrigation operations may hide the choices of land uses. Thirdly, no specific information household members 'powers and thus on how decisions are made within households also may lead to a concealed picture from the perspective of households.

Future studies may enhance the topic to examine the empowerment within households and its interactions with bargaining power in the exploration of irrigation systems. Some qualitative analyses with relevant stakeholders may shed more lights on the hidden mechanisms of irrigation operations.

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