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ABSTRACT

This paper investigates the impacts of inequality access to irrigation on rice farming productivity as measured by rice yield and revenue per hectare and on food insecurity among rice farmers in rural Cambodia. Using our own household survey administered in 2014 to 251 rice farming households in 32 rural villages in four provinces, we show that better irrigation access, particularly reservoir, dike, or canal irrigation, provide households with significantly higher rice production and revenue. We also show that productivity of rice farming is significantly and negatively associated with household food insecurity. Hence, developing irrigation networks such as reservoirs, dikes, or canals to reduce irrigation inequality is a key policy option to tackle food insecurity in Cambodia.

Keywords: irrigation, inequality, rice farming productivity, food insecurity

JEL: D33, I31, O12, Q15, Q18

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INTRODUCTION

Good quality water irrigation systems are key to improving the productivity of rice farming (Barker, Herdt, and Rose 1985; Tao et al. 2015; Thakur et al. 2016). However, 'irrigation inequality' or the inability to provide good quality water irrigation systems to all farmers remains a critical issue in many developing countries, including Cambodia.

In 2011, only 24 percent of the 4.65 million hectares of cultivable land in Cambodia was irrigated (MOWRAM 2012). Additionally, most irrigation systems in Cambodia are not efficient: Among approximately 2,000 irrigation schemes, only seven percent are fully functional, 34 percent are partly functional, while 59 percent are unusable due to lack of maintenance (Levidow et al. 2014).

Between 70 and 80 percent of rural Cambodians rely on rice farming for income and food (USAID 2016). Most of these poor people spend 70 percent of their income on food (CDRI 2008; Chan 2011). Meanwhile, rice consumption constitutes about two-thirds of the daily caloric intake for the poorest 40 percent in Cambodia (Kiple and Ornelas 2000; Maltsoglou, Dawe, and Tasciotti 2010). Thus, irrigation inequality due to shortages in irrigation networks can be among the major drivers of rural income inequality and food insecurity.

Food insecurity, defined as having an insufficient nutrition and dietary intake to ensure a healthy and productive life,[1] is a critical issue for Cambodia. The prevalence of rural food

[1] Food (in)security is measured on a yearly basis. It means having unobstructed social and economic access to sufficient intakes of affordable, nutritious food to ensure a healthy and productive life (Naylor 2014; Wegren, Nikulin, and Trotsuk 2017; Wegren 2013).

insecurity during the mid-2010s has been as high as 25 to 28 percent (NIS 2011; USAID 2016). Furthermore, food insecurity affects almost every social facet (Jones et al. 2013), and over an extended period affects health, labor productivity, and child mortality.

However, the quantifiable impacts of irrigation inequality on household food insecurity in Cambodia have not been previously analyzed. Many existing studies conducted in other countries have argued for the importance of irrigation in crop production and rural livelihoods, and some even suggest for reducing food insecurity (Mueller et al. 2012; Pradhan et al. 2015; Rosegrant et al. 2009; Wassman et al. 2009a; Kang, Khan, and Ma 2009). Irrigation contributes to the greater availability of food, improved nutritional intake, diverse and balanced diets, and income and improved nutritional and health outcomes (Von Braun, Puetz, and Webb 1989; Sampath 1992; Rockström et al. 2010; Namara et al. 2010; Lall 2013; Domènech 2015).

One of the few studies quantitatively investigating the impacts of irrigation inequality on household food insecurity is conducted by Chheng and Resosudarmo (2021). When analyzing the correlation between land property right and food insecurity in Cambodia, they could not observe the direct correlation between general measure of irrigation availability and food insecurity. This paper differs than that of Chheng and Resosudarmo (2021), since this paper particularly focuses on searching for possible indirect impact of irrigation inequality on food insecurity. While Chheng and Resosudarmo (2021) conduct a household-level analysis, this paper focuses its analysis at the rice plot-level data. Furthermore, this paper utilizes different measures of irrigation availability.

This paper examines the impact of a lack of access to good irrigation systems or irrigation inequality on rice farming productivity at rice plot level. Rice farming productivity is measured by yield and revenue per hectare per harvest. This paper then observes the correlation between rice farming productivity and household food insecurity. This paper uses a primary data, similar to that of Chheng and Resosudarmo (2021), from a household survey administered to 251 households in 32 rural villages across four provinces in Cambodia. The different disaggregated types of water irrigation systems are classified into three groups: (1) reservoir, dike, and canal (RDC) irrigation; (2) river, lake, and pond (RLP) irrigation; and (3) ground water (GW) pumping irrigation. The performance of these water irrigation systems is compared to rice production with no irrigation system.

IRRIGATION SYSTEMS IN CAMBODIA

The establishment of irrigation systems in Cambodia date back to the 9th and 10th centuries (Frenken 2012; Fletcher et al. 2008). By the 13th century, a vast network of reservoirs, canals, and embankments were built in the northern provinces, covering over 1,000 km^2 for use in flood control, agriculture, and rituals (Fletcher et al. 2008). A system of overflows and bypasses was built to carry surplus water into the Tonle Sap Lake. However, these systems ceased being used in about the 14th to the 15th centuries. Massive rebuilding of these irrigation systems occurred in the mid-1950s; the systems remained functioning till the Khmer Rouge war in the mid-1970s. Most of these irrigation systems were destroyed during the conflict.

After the restoration of the monarchy system in the early 1990s, the Cambodian government began to construct irrigation canals and dikes throughout the country as part of a massive project to improve rice production and food security (USDA 2010; Frenken 2012). In the 1990s, the government committed USD 1 billion to develop the irrigation sector (USDA 2010). More than 10 dams and irrigation systems were planned in four north-western provinces to supply irrigation for wet- and dry-season rice production (Frenken 2012). It was expanded to cover 650,000 ha of rice farming area during 1996–2007. Figure 1 shows that by 2007, only 24 percent of all agricultural land was irrigated in Cambodia. This government irrigation project has also been expanded to irrigate another 800,000 ha during 2008–2017 (USDA

2010).[2] Meanwhile, since the mid-1990s, there has been a growing number of ground water pumping irrigation systems developed by individual farmers (IDE 2005). The unplanned growth of this irrigation system has been suspected to cause water table decline, land subsidence, and making groundwater more difficult to access and costlier to lift (Erban and Gorelick 2016).

Irrigation in Cambodia is mainly used for dry-season rice and to irrigate wet-season rice in times of poor rainfall (Smith and Hornbuckle 2013). It has been argued that in general, these irrigation systems have played a minor role in food production (Tully 2005). Compared to Thailand and Vietnam, Cambodia has about 50 percent less physical and water productivity (Smith and Hornbuckle 2013; USAID 2016).

Despite the continuing progress in developing modern irrigation systems since the early 1990s, the irrigation sector in Cambodia continues to face several challenges. First, most irrigation facilities have been concentrated only in major rice-growing regions, creating unequal distribution of water access for agriculture in the country. Second, increasing human settlements on irrigation structures have affected the functionality of canals and subsidiary networks. Third, insufficient investment and maintenance of the irrigation systems have left major irrigation schemes in limbo.

DATA COLLECTION

Data utilized for this paper come from our own household survey conducted between March and May 2014, which was administered to 251 rice farming households in 32 rural villages across four provinces in Cambodia.[3] The survey was funded by the Economic Research

[2] The Cambodian government has prioritized irrigation infrastructure development to increase paddy production and rice productivity as laid out in its Rectangular Strategy and Policy Document for Paddy Rice Production and Rice Export (Frenken 2012). Cambodia's National Strategy for Agriculture and Water aims to develop and rehabilitate large-scale irrigation infrastructure (Johnston, Try, and De Silva 2013).

[3] See also Chheng and Resosudarmo (2021).

Institute for ASEAN and East Asia (better known as ERIA) and supported by Cambodia's Council for Agriculture and Rural Development (or CARD). Stratified random sampling was adopted in this survey to represent sufficient socioeconomic variations in the villages. The four surveyed provinces are Kampong Thom in the central region, Banteay Meanchey and Battambang in the north-western region, and Prey Veng in the southern region. The 251 rice farmer households were randomly selected across the 32 villages (marked by # in Figure 2). Eight households were selected from each village and two villages from each of the 16 communes. Two districts were chosen from each of the four provinces. Table 1 lists the names of villages, communes, districts, and provinces.

Of the 32 villages, 16 are in floodplains prone to annual flooding while the other 16 are in areas less vulnerable to annual floods. The collected data displays sufficient variation in landholding sizes, both within and between villages. The three main sets of questions asked during this survey are the following:

1. Irrigation questions:
   a. "Among all the plots your household cultivated, is plot i irrigated (i = 1–6)?"
   This is a binary question (1 = yes; 0 = no)
   b. "What are the sources of water your household uses for rice cultivation?"
   Multiple choices (rainwater, ground water, pumped water from rivers, natural ponds or lakes, and water from reservoirs, dams, or canals) are supplied to the question.
2. Questions on other shocks
   a. "What types of serious shocks occurred to your household over the past ten years, i.e., from 2005–2014, which affected your household's rice production?"
   Multiple choices (flood, drought, insect, pest, disease, and others [specify] are provided).

b. “When (month and year) did it/they happen? How did it/they affect your rice production/rice income?”

We restricted the shocks to short-run shocks (agricultural and non-agricultural) that directly impact rice yields in a particular year.

3. Food insecurity questions:

a. “In the past 12 months, were there any days and weeks that your household had very little, not enough, or no food (was hungry)?”

b. “If YES, how many weeks of the past 52 weeks did the household have so little food or no food at all that the household was hungry?”

Two dimensions of food insecurity are examined: incidence of food insecurity and length of food insecurity.

The data collected displays variation in plot characteristics and sources of irrigation (Table 2). In selecting households, there was no prior information about household irrigation sources, access, and choices. We grouped farmers’ irrigation systems into RDC or canal, RLP, and GW irrigation systems. The first category pertains to government-built irrigation systems, which need large capitals to construct. They are, however, the least expensive for individual farmers to operate as they are managed collectively. The second category is typically built and managed by individual households. It is generally costly because it requires investing in personal pumping equipment since RLPs and ponds are distant from farmers’ rice fields. The third category are also built and managed by individual households, but more likely less costly than pumping water from rivers, lakes, or ponds.

The measures of rice farming productivity are computed at plot and household levels. Other variables taken during the surveys are:

- **At rice plot level:** Yield of previous harvest season in tons per hectare, total rice revenue from previous harvest season in billion Cambodian Riels (KHR) per hectare, cost of chemical inputs in rice production in billion KHR per hectare, cost of other inputs in rice production in billion KHR per hectare, dummy on secure land property rights, dummy on having soil quality problem, dummy on ever flooded during 2010–2014 period, different types of rice quality and number of crop seasons per year.

- **At household-level:** Number of household members, whether household experienced external economic shocks during 2010–2014 period, whether household has non-rice farming based income, number of years of household head experience in cultivating rice, highest degree that household head has, whether household has good relations with other village members and whether household has good relations with local government officials. Note that a single household can own multiple plots. Therefore, all variables collected at plot level for each household can be combined to become variables at household level, or vice versa.
- **At village level:** distance in kilometers to the closest village town.
- **At provincial level:** annual average precipitation rate measured in inches.

Table 3 provides the summary statistics for all variables collected. Several variables at household level are weighted summation from the rice plot variables.

BASIC MODEL

In observing the indirect links between irrigation inequality and household food insecurity, we adopt a two-step estimation model. First, we observe the correlation between type of irrigation system and rice farming productivity; second, we examine the correlation between rice farming productivity and food insecurity. The main reason for doing this is that the main channel, if not the only channel, for having access to an irrigation system to affect household food insecurity is through household rice farming productivity (Mueller et al. 2012;

Pradhan et al. 2015; Rosegrant, Ringler, and Zhu 2009; Wassman et al. 2009a; Kang, Khan, and Ma 2009).

In observing the correlation between type of irrigation system and rice farming productivity, we estimate the following models both at rice plot and household levels.

$$Y_i = \alpha_0 + \alpha_1 . D_i^{RDC} + \alpha_2 . D_i^{RLP} + \alpha_3 . D_i^{UP} + \alpha_4 . X_i + \varepsilon_i \quad (1)$$

$$Y_i = \beta_0 + \beta_1 . D_i^{IP} + \beta_2 . X_i + \mu_i \quad (2)$$

Index i will be at rice plot level. Y_i measures rice farming productivity as (*i*) rice yields in tons per hectare from the latest harvest, or (ii) revenue in billion KHR per hectare. D_i^{RDC}, D_i^{RLP} and D_i^{UP} are dummies for having RDC, RLP, and GW irrigation systems. D_i^{IP} is a dummy for having any type of irrigation system. X_i is a vector of control variables at rice plot. These controls include having secure land property rights, cultivating in a flooding risk area, having soil problems, having any short-run economic shock, size of cultivated crops, number of crops per year, cost of per-hectare chemical input in rice production, cost of other inputs in rice production per hectare, quality of rice planted, household head's years of rice-growing experience, size of household, closest distance between village and a major district town and annual average provincial precipitation rate. The variables ε_i and μ_i are random errors.

An ordinary least squares (OLS) estimation technique is applied to equations (1) and (2). It is important to note that majority of irrigation systems in Cambodia were destroyed during the Khmer Rouge war in the mid-1970s. Only since the early 1990s has the Cambodian government rebuilt irrigation infrastructures in the country. Households have no control over government investment decisions in the construction and expansion of reservoirs, dikes, and canals. Land transfers, buying, or selling among households is historically restricted; for a household to strategically buy a plot that has been irrigated is difficult. Most surface (river, lake, or pond) and ground water pumping irrigation are built individually. However, whether there are sources of surface or ground water nearby is relatively random. It is therefore reasonable to assume that household access to an irrigation system is exogenously determined.

For observing the correlation between rice farming productivity and food insecurity, the food insecurity variable is only available at household level and so we estimate the following model at household level only:

$$F_h = \gamma_0 + \gamma_1 . Y_h + \gamma_2 . Z_h + \zeta_h \qquad (3)$$

Where F_h is food insecurity and it is either (1) household has ever experienced any days with very little, not enough or no food in the last 12 months; or (2) number of weeks a household has experienced any day with very little, not enough or no food in the last 12 months. Y_h is rice farm productivity in tons per-hectare rice yields or in billion KHR per-hectare rice revenues. $\mathrm{Z_h}$ is a vector of control variables at household level. These variables are household head's highest education, size of household, having non-rice farming based income, having any short-run external economic shock, having good relations with other village members, and having good relations with local government officials. ζ_h is a random error term.

An OLS estimation and Maximum likelihood estimation (MLE) of a Probit model are applied to estimate the link between whether a household has ever experienced any day with very little, not enough or no food in the last 12 months, and with rice farming productivity.[4] An OLS estimation and MLE of Tobit model are utilized to estimate the relationship between rice farming productivity and number of weeks with food insecurity. γ_1 is the variable of interest.

[4] Implementing an MLE estimation of a negative binomial model might be necessary in this case. However, almost 26 percent of our samples mentioned that they have experienced food insecurity situation. This suggests that an MLE estimation of Probit model is adequate.

RESULTS AND DISCUSSION

Table 4 shows the impact of having an irrigation system on rice farming productivity, measured either by rice yield (in tons per hectare) or rice revenue (in million KHR per hectare). Columns 1–3 show the estimation results for rice yield and columns 4–6 for rice revenue. Columns 1 and 4 are the results without any irrigation variable. Columns 2 and 5 are the results with three different types of irrigation systems, while columns 3 and 6 are with any type of irrigation system as part of the control variables. All are at plot level. Note that in general, one household manages two to three plots, discontinuous to one another, and each plot could have a different irrigation system.

Comparing the results in columns 1, 2, and 3,[5] the coefficients of control variables (X_i) are relatively stable across the three estimation results, indicating that the models adopted for rice yield are relatively robust, and having an irrigation system does not correlate strongly with those control variables. Given these control variables are the most readily available from the survey, it can be argued that having a certain irrigation system is relatively exogenous.

In general, some control variables (X_i) are significantly associated with rice yield. These include having secure land property rights, cultivating in a flooding risk area, having a soil problem, number of crops per year, cost per hectare of chemical input in rice production, cost per hectare of other inputs in rice production, and household head's years of rice-growing experience. Except for the household head's rice cultivation experience, the effects of these variables on rice yield are expected. The negative association between the household head's rice cultivation experience and rice yield was unexpected. Generally, the longer experience in cultivation could equate to better productivity. This negative association results because this variable represents age rather than actual cultivation skill, and because most household heads

[5] Or among results in columns (4), (5), and (6)

are of older ages. There is a tendency to see a decline in rice farming productivity attributable to this increased age.

Secure land rights and agricultural land grabbing are prominent issues in Cambodia given the changes to the system of government during the last three decades. Private property rights in Cambodia have undergone critical transitions under unstable political regimes. They were abruptly abolished by the genocidal Khmer Rouge regime that took power in 1975 (Oldenburg and Neef 2014). The current property rights are largely underdeveloped, fragmented, and fragile. An estimated 70 percent of agricultural land held by rural households was not titled in 2015 (USAID 2016). Having no land title presents a high risk of land dispossession or expropriation by the state or private elites. However, registered or titled farmland in rural Cambodia does not guarantee exemption from these risks either (Sekiguchi and Hatsukano 2013). It can be seen in Table 4 that more secure land property rights are positively correlated with higher rice yield. This could indicate that those with more secure property rights are more willing or have a greater chance to do their best in cultivating their rice fields, leading to significantly higher rice yield and revenue per hectare than those with less secure land rights.

While annual floods provide water for agriculture, bring nutrients, and stabilize soil conditions, floods can have negative effects on rural sectors as well. Existing evidence has shown that excessive flooding undermines food production and reduces crop production, food availability, and rural income (Malla 2008; Douglas 2009). Our results also show that rice farming productivity in flood prone areas tends to be lower than in non-flood prone areas. This finding is important given that approximately 12 percent of the total rice area in Cambodia is in flood prone areas (ADB 2012).

On the relationship between irrigation inequality and rice farming productivity, the following were observed: Compared to no irrigation, formal irrigation (RDC) produces higher rice yield and revenue per hectare by approximately 1.2 t and KHR 0.9 million, respectively.

Compared to no irrigation, RLP irrigation produces higher rice yield and revenue per hectare by approximately 0.4 t and KHR 0.3 million, respectively. However, there is no significant difference in rice yield and revenue per hectare for those with GW irrigation and those without irrigation.

On average, access to irrigation is significantly positively associated with rice farming productivity and rice revenues (Table 4, columns 3 and 6).[6] Compared to plots without irrigation, irrigated plots have higher per-hectare yield by approximately 0.7 t and higher per-hectare revenue by approximately KHR 0.6 million (≈USD 150).

Tables 5 and 6 show the correlations of rice farming productivity, measured either by rice yield (in tons per hectare) or rice revenue (in million KHR per hectare), and household food insecurity, measured by (1) whether a household has ever experienced any days with very little, not enough or no food in the last 12 months; or (2) number of weeks a household has experienced any day with very little, not enough or no food in the last 12 months. Columns (1) to (4) in Table 5 depict the estimated results for whether a household has ever experienced any day with very little, not enough or no food in the last 12 months (have experienced food insecurity) using the OLS technique and columns (5) to (6) using the Probit technique. Columns (1) to (4) in Table 6 show the estimation results for number of weeks a household has experienced any day with very little, not enough or no food in the last 12 months (length of food insecurity) using the OLS technique and columns (5) to (6) using Tobit technique. All results in both Tables 5 and 6 are at household level. Rice yield and revenue per hectare as well as other variables are calculated from all plots owned by each household.

The OLS and Probit estimates in Table 5 show that household heads with senior high school degrees and good relations with local government officials are significantly less likely

[6] The results are consistent with Wokker, Santos, and Ros (2014) and Rosegrant, Ringler, and Zhu (2009): irrigation affects rice yields and productivity.

to experience food insecurity in the last 12 months. These results are expected. Households with family heads that have high school degrees tend to not experience food insecurity compared to those with household heads having lower education degrees. Furthermore, it is also expected that households with good relations with local government officials would less likely experience food insecurity than those without good connection with local officials.

In Table 5, it can also be seen that rice farming productivity is significantly and negatively associated with food insecurity. As rice yield and revenue per hectare increase, household food insecurity is significantly reduced. Based on the Probit estimations, favourable effects result from the household's ability to increase rice farming productivity by a ton per hectare or by million KHR per hectare. This productivity would be associated with approximately a 5 percent reduction in the probability of experiencing food insecurity. Comparing results from columns (1) and (2), as well as from (3) and (4), it can be argued that our results are relatively robust. The coefficient of rice farming productivity in column (1) is relatively similar with that in column (2), as well as between those in (3) and (4).

A different situation resulted from observing the correlation between rice farming productivity and the length of food insecurity in the last 12 months (Table 6). None of the control variables are significantly associated with the length of food insecurity. Rice framing productivity, on the other hand, is significantly associated with the length of food insecurity. Since the length of food insecurity would never be negative, the results from the Tobit estimation are preferable. From columns (5) and (6) in Table 6, it can be concluded that an increase in rice farming productivity by a ton per hectare or by million KHR per hectare would reduce the length of food insecurity by approximately 1.3 weeks. In many cases, this would eliminate food insecurity.

Overall, this paper yields important implications for the effect of irrigation inequality and rice farming productivity. Rice farming productivity is the intermediate link through which irrigation inequality affects household food insecurity. In other words, improving rice farming productivity through expanding access and availability of irrigation systems, particularly access to reservoir, dike, or canal irrigation systems can potentially lower the level of household food insecurity for rural households in rice-growing regions in Cambodia.

CONCLUSIONS

We surveyed 251 households in 32 rural villages across four provinces in Cambodia to show the link between irrigation inequality and food insecurity. This paper aims to contribute to the debates on the impact of irrigation inequality, or inequality in access to irrigation, on rice production and food insecurity in Cambodia. This paper, nevertheless, is an attempt to provide a final conclusion on this issue.

Our findings are as follows. Except for piping ground water, access to irrigation systems could translate to varying socioeconomic and food security outcomes for rural Cambodians. Irrigation of any type increases rice yield and, eventually, revenue. Controlling other household characteristics, an increase in rice farming productivity is associated with a decrease in household food insecurity, as measured by whether a household has ever experienced food insecurity or number of weeks with lack of food in the last 12 months. Linking the impact of irrigation on rice farming productivity with the association between rice farming productivity and household food insecurity, it can also be concluded that lack of access to irrigation could increase household food insecurity in rural Cambodia.

Hence, the findings of this paper suggest that a policy to reduce irrigation inequality among rural rice farmers could improve food security in rural Cambodia. Providing access to irrigation will significantly improve rice farming productivity and revenue, effectively reducing household food insecurity. Among the irrigation systems, particularly important are the reservoir, dike, or canal systems. Developing this kind of system nationally could be expected to significantly boost national rice productions and so reduce incidents of food insecurity. The next important type of irrigation systems is river, lake, or pond type of irrigation.

This paper, on the other hand, does not support encouraging the development of irrigation from pumping out ground water. There is no evidence that it significantly improves rice farming productivity. More importantly, groundwater pumping irrigation results in adverse impacts on the environment (Erban and Gorelick 2016).

This research was conducted in 2014, some changes might have occurred in Cambodia that might also change how the results can be interpreted. Further research, hence, is required to establish the means to cost-effectively implement such a policy. This topic, however, is beyond the scope of this paper.

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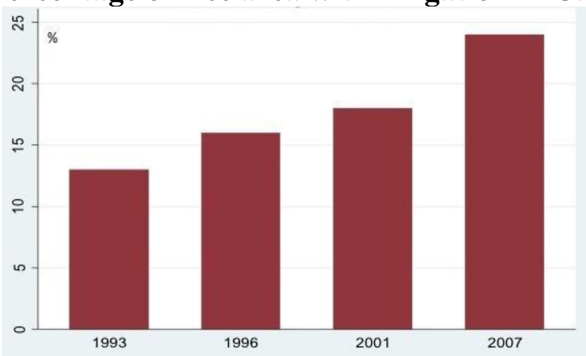
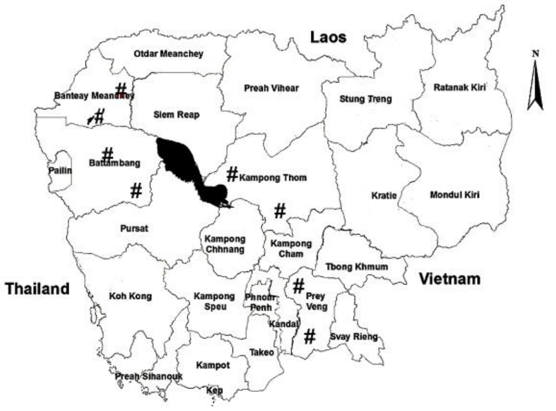
Figure 1. Percentage of rice area with irrigation in Cambodia



Source: USDA (2010)

Figure 2. Map of the survey fields



Note: The sign # are locations of the household survey.

Table 1. List of the survey areas

Province	District	Commune	Village
Kampong Thom	Krong Steung Saen	Srayov	Bramatdei
			Srayov Thboung
		Aur Kanthor	Prek Sbov
			Aur Kanthor Thbong
	Kampong Svay	Sankor	Kra Sang
			Balang
		Kdei Doung	Peam Kreng
			Kdei Doung
Banteay Meanchey	Preach Netr Preah	Preach Netr Preah	Sresh Lech
			Tapen
		Chab Vari	Kouk Lorn
			Brasat
	Mongkul Borey	Banteay Neang	Kouk Kduoch
			Kouk Trolerb
		Russei Kroak	Aur Takol
			Chamkeav
Battambong	Thmor Koul	Boeng Pring	Snoul Koang
			Boeng Pring
		Tapung	Ta Pung
			Kouk Kdouch
	Moung Russei	Robos Mongkol	Prey Prom I
			Prey Prom II
		Prey Touch	Prey Touch
			Kon Khlong
Prey Veng	Preah Sdach	Rom Jek	Chongros
			Tropoeng Chhuk
		Bateay Chakrey	Brobos Rolauy
			Rorka Jour II
	Kampong Trabek	Peam Montea	Takeo
			Krocham Luer
		Cham	Cham
			Sdach

Table 2. Plot-level and household-level basic survey data

	Variable	Description	# of HHs or plots	% of total sample
1	Food insecurity	1 = food insecurity; 0 = no food insecurity	65 HHs = 1 186 HHs = 0	25.90 74.10
2	Length of food insecurity	1 to 26 weeks; mean weeks of food insecurity = 1.04	32 HHs = 1 week 17 HHs = 2–4 weeks 8 HHs = 5–8 weeks 8 HHs > 8–26 weeks	12.75 6.77 3.19 3.19
3	Irrigation type	RDC irrigation	58 plots	10.18
		RLP irrigation	134 plots	23.51
		GW irrigation	37 plots	5.61

Note: Numbers of plots and households in this sample are 570 and 251. Our data shows that farmers use a single irrigation system (including no irrigation) for each of their plots. On average, each household cultivate 2–3 plots. Each of these plots could have a different irrigation system.

Table 3. Summary statistics of variables collected

Variable	At Rice Plot Level		At Household Level	
	Mean	Standard Deviation	Mean	Standard Deviation
Food insecurity (1 = yes, 0 otherwise)	n.c.	n.c.	0.24	0.43
Length of food insecurity (weeks)	n.c.	n.c.	1.04	3.25
Rice yield (tonnes per hectare)	2.43	1.99	2.38	1.87
Rice revenue (million Riels per hectare)	1.94	1.64	1.99	1.55
Having RDC irrigation (1 = yes, 0 otherwise)	0.1	n.c.	n.c.	n.c.
Having RLP irrigation (1 = yes, 0 otherwise)	0.23	n.c.	n.c.	n.c.
Having UP irrigation (1 = yes, 0 otherwise)	0.06	n.c.	n.c.	n.c.
Having any irrigation (1 = yes, 0 otherwise)	0.42	n.c.	n.c.	n.c.
Secure land property right (0 = not secure, 10 = secure)	8.41	3.26	n.c.	n.c.
Flood risk area (1 = yes, 0 otherwise)	0.67	0.47	n.c.	n.c.
Having soil problem (1 = yes, 0 otherwise)	0.58	0.49	n.c.	n.c.
Cultivated land size (hectare)	1.22	1.41	n.c.	n.c.
Number of crop season per year	1.33	0.49	n.c.	n.c.
Cost of chemical input (billion Riels per hectare)	0.01	0.08	n.c.	n.c.
Cost of other inputs (billion Riels per hectare)	0.03	0.37	n.c.	n.c.
Rice quality (thousand Riels per ton)	0.8	0.13	n.c.	n.c.
Household head's rice cultivation experience (years)	27.23	12.15	n.c.	n.c.
Short-run external economic shocks (1 = yes, 0 otherwise)	0.69	n.c.	0.69	n.c.
Household size (person)	5.19	2.01	5.18	1.99
Household head having no degree (1 = yes, 0 otherwise)	n.c.	n.c.	0.21	n.c.
Household head having elementary school degree (1 = yes, 0 otherwise)	n.c.	n.c.	0.45	n.c.
Household head having junior high school degree (1 = yes, 0 otherwise)	n.c.	n.c.	0.23	n.c.
Household head having senior high school degree (1 = yes, 0 otherwise)	n.c.	n.c.	0.11	n.c.
Having non-rice farming based income (1 = yes, 0 otherwise)	n.c.	n.c.	0.78	n.c.
Good relations with other village members (1 = yes, 0 otherwise)	n.c.	n.c.	0.87	n.c.
Good relations with local government (1 = yes, 0 otherwise)	n.c.	n.c.	0.4	n.c.
Distance to district town (km)	11.58	6.16	n.c.	n.c.
Annual average precipitation rate (inches)*	54.67	0.53	n.c.	n.c.

Source: *Weather & Climate (2021)

Note: Numbers of plots and households in this sample are 570 and 251. On average, each household cultivated 2 to 3 plots. The n.c. is not calculated.

Table 4. Rice farming productivity at plot levels

	Rice Yield (Tons per Hectare)			Rice Revenue (Million KHR per Hectare)		
	(1)	(2)	(3)	(4)	(5)	(6)
Having RDC irrigation (1 = yes, 0 otherwise)		1.201***			0.933***	
		(0.286)			(0.234)	
Having RLP irrigation (1 = yes, 0 otherwise)		0.378*			0.342*	
		(0.223)			(0.184)	
Having GW irrigation (1 = yes, 0 otherwise)		0.503			0.380	
		(0.365)			(0.288)	
Having any irrigation (1 = yes, 0 otherwise)			0.676***			0.563***
			(0.194)			(0.158)
Secure land property right (0 = not secure, 10 = secure)	0.039*	0.049**	0.046**	0.030*	0.037**	0.036**
	(0.022)	(0.021)	(0.021)	(0.018)	(0.017)	(0.017)
Flood risk area (1 = yes, 0 otherwise)	-0.344*	-0.303*	-0.350**	-0.260*	-0.228	-0.265*
	(0.177)	(0.172)	(0.174)	(0.144)	(0.140)	(0.142)
Having soil problem (1 = yes, 0 otherwise)	-0.034	0.014	-0.016	-0.014	0.022	0.002
	(0.162)	(0.162)	(0.163)	(0.134)	(0.135)	(0.135)
Short-run external economic shocks (1 = yes, 0 otherwise)	0.02	-0.028	-0.023	0.017	-0.019	-0.019
	(0.179)	(0.171)	(0.175)	(0.147)	(0.141)	(0.144)
Cultivated land size (hectare)	-0.081	-0.078	-0.08	-0.059	-0.058	-0.058
	(0.064)	(0.066)	(0.066)	(0.051)	(0.052)	(0.052)
Number of crop season per year	1.351***	1.172***	1.049***	1.100***	0.946***	0.849***
	(0.175)	(0.202)	(0.197)	(0.144)	(0.162)	(0.158)
Cost of chemical input (billion KHR per hectare)	1.724	2.404*	2.383**	0.915	1.464	1.464
	(1.447)	(1.256)	(1.167)	(1.187)	(1.020)	(0.947)
Cost of other inputs (billion KHR per hectare)	0.769***	0.666***	0.671***	0.533**	0.450**	0.451**
	(0.287)	(0.248)	(0.229)	(0.237)	(0.202)	(0.187)
Rice quality (thousand KHR per ton)	0.011	0.049	0.024	1.599***	1.629***	1.609***
	(0.561)	(0.562)	(0.545)	(0.551)	(0.551)	(0.536)
Household head's rice cultivation experience (years)	-0.021***	-0.018***	-0.017***	-0.015***	-0.013***	-0.013**
	(0.006)	(0.006)	(0.006)	(0.005)	(0.005)	(0.005)
Household size (person)	0.02	0.001	-0.001	0.009	-0.005	-0.008
	(0.037)	(0.036)	(0.036)	(0.029)	(0.028)	(0.028)
Distance to district town (km)	0.009	0.012	0.013	0.007	0.009	0.01
	(0.011)	(0.011)	(0.011)	(0.009)	(0.009)	(0.009)
Annual average precipitation rate (inches)	-0.097	-0.068	-0.065	-0.083	-0.057	-0.057
	(0.151)	(0.152)	(0.152)	(0.121)	(0.123)	(0.122)
N	570	570	570	570	570	570
R^2	0.197	0.228	0.218	0.191	0.22	0.213

Note: Robust standard errors are reported in parentheses. ***, **, * mark statistical significance at the 1, 5 and 10% level. Dependent variables at columns (1) to (3) are rice yield, and at columns (4) to (6) are rice revenue. Columns (1) and (4) are the results without any irrigation variable. Columns (2) and (5) are the results with three different types of irrigation, while columns (3) and (6) are with any type of irrigation as part of the control variables. Constant parameters are not reported.

Table 5. Household food insecurity

	OLS				Probit	
	(1)	(2)	(3)	(4)	(5)	(6)
Rice yield (tonnes per hectare)	-0.049***	-0.046***			-0.184***	
	(0.013)	(0.013)			(0.057)	
Rice revenue (million Riels per hectare)			-0.052***	-0.050***		-0.193***
			(0.016)	(0.016)		(0.067)
Household head having elementary school degree (1 = yes, 0 otherwise)		-0.059		-0.060	-0.184	-0.185
		(0.074)		(0.073)	(0.235)	(0.235)
Household head having junior high school degree (1 = yes, 0 otherwise)		-0.056		-0.060	-0.127	-0.144
		(0.086)		(0.086)	(0.274)	(0.273)
Household head having senior high school degree (1 = yes, 0 otherwise)		-0.180*		-0.183*	-0.616*	-0.623*
		(0.094)		(0.094)	(0.358)	(0.357)
Household size (person)		-0.020		-0.021	-0.077	-0.079
		(0.013)		(0.013)	(0.051)	(0.051)
Having non-rice farming based income (1 = yes, 0 otherwise)		0.049		0.048	0.180	0.184
		(0.062)		(0.063)	(0.229)	(0.229)
Short-run external economic shocks (1 = yes, 0 otherwise)		-0.051		-0.050	-0.171	-0.167
		(0.060)		(0.061)	(0.204)	(0.203)
Good relations with other village members (1 = yes, 0 otherwise)		-0.111		-0.115	-0.288	-0.306
		(0.112)		(0.112)	(0.327)	(0.325)
Good relations with local government (1 = yes, 0 otherwise)		-0.092*		-0.095*	-0.341*	-0.340*
		(0.054)		(0.054)	(0.197)	(0.195)
N	251	251	251	251	251	251
R^2	0.046	0.089	0.036	0.081		
Average marginal effect						
Rice yield (tonnes per hectare)					-0.052***	
					(0.015)	
Rice revenue (million Riels per hectare)						-0.055***
						(0.018)

Note: Robust standard errors are reported in parentheses. ***, **, * mark statistical significance at the 1, 5 and 10% level. Marginal effects are reported in the Probit models. Constant parameters are not reported.

Table 6. Length of household food insecurity

	OLS				Tobit	
	(1)	(2)	(3)	(4)	(5)	(6)
Rice yield (tonnes per hectare)	-0.260**	-0.245**			-1.267***	
	(0.107)	(0.107)			(0.418)	
Rice revenue (million Riels per hectare)			-0.278*	-0.252*		-1.322***
			(0.142)	(0.145)		(0.497)
Household head having elementary school degree (1 = yes, 0 otherwise)		-0.558		-0.568	-1.545	-1.567
		(0.665)		(0.667)	(1.691)	(1.701)
Household head having junior high school degree (1 = yes, 0 otherwise)		-0.875		-0.907	-2.307	-2.430
		(0.664)		(0.669)	(2.024)	(2.035)
Household head having senior high school degree (1 = yes, 0 otherwise)		0.088		0.071	-1.737	-1.862
		(1.197)		(1.195)	(2.458)	(2.477)
Household size (person)		-0.015		-0.019	-0.169	-0.190
		(0.073)		(0.072)	(0.350)	(0.353)
Having non-rice farming based income (1 = yes, 0 otherwise)		0.045		0.041	1.346	1.398
		(0.604)		(0.609)	(1.688)	(1.699)
Short-run external economic shocks (1 = yes, 0 otherwise)		-0.886		-0.877	-2.182	-2.179
		(0.605)		(0.606)	(1.465)	(1.471)
Good relations with other village members (1 = yes, 0 otherwise)		0.549		0.524	0.039	-0.121
		(0.479)		(0.476)	(2.357)	(2.368)
Good relations with local government (1 = yes, 0 otherwise)		0.340		0.324	-0.615	-0.638
		(0.466)		(0.470)	(1.408)	(1.413)
N	251	251	251	251	251	251
R^2	0.023	0.051	0.018	0.045		

Note: Robust standard errors are reported in parentheses. ***, **, * mark statistical significance at the 1, 5 and 10% level. Constant parameters are not reported.