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Effectiveness of Irrigation Access on Sticky Rice Productivity: Evidence from Lao PDR

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Abstract: This study estimates the impact of irrigation on household sticky rice productivity in Lao People's Democratic Republic (Lao PDR) by applying propensity score matching (PSM) and the difference-in-differences (DID) method. This paper utilizes panel data from the Lao Expenditure and Consumption Survey (LECS) from 2003 to 2013. The results show that the average sales value and total production of sticky rice for irrigated households is greater than those for non-irrigated households by around 36 to 38% per season. Moreover, irrigated households experience improved sticky rice productivity of approximately 2.44 tons per hectare, per season, compared to non-irrigated households. In particular, compared to households with access to irrigation in one period of the surveys, households with access to irrigation in two periods of the surveys have nearly double the sticky rice productivity. Therefore, long-term access to irrigation is more effective for sticky rice productivity. However, we cannot find any evidence to support the impact of irrigation on household consumption. Some policy implications that can be derived from this research are that farmers should be intensively promoted to make the most use of irrigation, development of irrigation system is highly needed, and to ensure effectiveness of irrigation utilization local farmer involvement in monitoring procedure of irrigation is necessary.

Keywords: irrigation; sticky rice production; propensity score matching (PSM); difference-in-differences (DID)

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1. Introduction

The agriculture sector is the key driving force that stimulates economic development in developing countries. The growth of this sector generates significant economic spillover effects in terms of employment and income generation in remote areas. One of the most important agricultural products is rice. According to the World Bank [1], the agricultural sector needs to increase its production by approximately 70% by 2050. Generally, global rice production is estimated to grow by 1.4% by 2018, of which Asia accounts for 1.2% of this growth. Specifically, rice production in the world increased from 504.6 million tons in 2017 to 511.4 million tons in 2018. Whereas, rice production in Asia increased from 456.3 million tons in 2017 to 461.9 million tons in 2018. The Asian region is well-known as the largest rice producer and consumer in the world. Among Asian countries, China, India, Indonesia, Bangladesh, Vietnam, Thailand, Myanmar, and the Philippines are the leading rice producers, accounting for 90.8% of Asian production [2].

The sustainability of agricultural development depends on the effective policies and sufficient concern in the environmental, economic, cultural, social, and political issues associated with the technological availability [3]. To increase agricultural production and productivity, improvements can be made in a variety of ways, for example, by targeting seed quality, fertilizer use, pesticide use, agrochemical use, or irrigation systems. Irrigation is considered one of the most effective techniques [1,4–6]. In 2012, only one-fifth, or over 275 million hectares, of total cultivated land was irrigated globally, accounting for 40% of the global food supply [7].

Irrigation development has played a crucial role for supporting global food production and contributed to the economic development and well-being of many countries. A mechanism for stabilizing agricultural production is in overcoming issues associated with drought and allowing for diversification of crop production [8]. Irrigation is the single most important component of sustainable agricultural production as it improves agricultural production and indirectly improves the diversity of household food consumption and food security, which reduce poverty [9–12]. Upgrading irrigation systems has become a priority for governments, particularly in developing countries.

Many studies have found that irrigation is the main driving force for enhancing agricultural production and productivity. For example, Nguyen [13] indicated that irrigation increases the land area for rice, corn, and potato in Vietnam. Yu and Fan [14] revealed that in Cambodia, households that use irrigation could increase their rice production by approximately 10.6% and 23% in the wet, and dry seasons, respectively. Moreover, Nonvide [15] suggests that households with irrigation in Benin can increase their rice productivity by approximately 57%, compared to non-irrigation households. Nonvide [16] also showed that, compared to households without access to irrigation, households with access to irrigation could increase rice productivity by 2746 kg per hectare. In addition, Dillon [17] found that irrigation in Northern Mali improves the total household consumption by around 1635 to 1725 USD, total agricultural production by about 1.25 to 1.90 tons per household, and productivity by approximately 2.5 to 3.8 tons per hectare. Furthermore, another work of Dillon [18] shows that irrigation has a positive impact on agricultural income, ranging from 279 to 294 USD, and irrigation increases agricultural productivity on average from 1.96 to 2.1 tons per hectare and improves household consumption per capita by approximately 89 to 111 USD. Babatunde et al. [19] studied in Nigeria and he found that households with irrigated rice is higher, about 17,798 Naira (Nigerian currency) per hectare, compared to non-irrigated households.

However, some researchers reported mixed results on the impacts of irrigation on agricultural products, such as Dillon et al. [20] applied two cross-sections in Nepal and found that access to irrigation can improve land values by approximately 5.3% points from 1996 to 2003. Then, they applied panel data to estimate the impacts of public infrastructure on household welfare and found no significant impact on households' consumption growth, poverty, and agricultural income growth. Furthermore, Urama and Hodge [21] found mixed results on the impact of irrigation on rice productivity in Nigeria. Irrigated plots experienced improved annual rice productivity when they used irrigation in both dry and rainy seasons from 1984 to 1998. In contrast, the results from the cross-section estimation showed that the partial elasticity of rice productivity with respect to other variable input costs, such as fertilizers and pesticides in irrigated plots was lower than that in non-irrigated plots by around 18%. On the other hand, many empirical studies in the past, such as Travers and Ma [22], Zhu [23], Fan et al. [24], and Jin et al. [25] have failed to find a link between irrigation and agricultural products. As these studies defined the proxies of irrigation as the share of irrigated land and public investment in irrigation, they did not determine the impact of using irrigation on agricultural production.

Based on those studies, the impact of irrigation on agricultural production and productivity, especially for rice, is not clear. The results were different for different countries, geographies, management styles, irrigation methods, and crop mixes. The characteristics of the countries likely caused different results. Therefore, this study seeks to confirm the impacts of irrigation on rice production in the Lao People's Democratic Republic (Lao PDR) by employing propensity score matching (PSM) and the difference-in-differences (DID) method. Since our data is not random, PSM can help researchers to reconstruct the counterfactuals to mitigate the endogeneity problem [26]. Moreover, the significant advantage of the difference in differences (DID) method is that the observed and unobserved time-invariant confounding variables, which might be correlated with the treatment and outcomes of interest, are canceled out in the regression.

To the best of our knowledge, there has been a limited previous quantitative evaluation of the impact of irrigation on rice productivity in Lao PDR. Unlike previous papers, rice is the main staple food crop of Lao, more than 75% of arable land is used for growing rice and 80% out of total rice production is sticky rice [27]. These are reasons why we take sticky rice in our account. This study utilizes a large set of panel data, based on the Lao Expenditure and Consumption Survey (LECS) from 2003 to 2008. The main questions addressed in this paper include the following: Has irrigation played an important role in improving sticky rice productivity in the case of Lao PDR? Is any increase in sticky rice productivity attributable to sustainable irrigation if households maintain long-term to access irrigation? The objective of this study is to examine the impacts of irrigation systems on sticky rice production. The impact is expected to be positive. In any case, given the results of previous studies, it is unclear what effect irrigation has.

The remainder of this paper is organized as follows: The next section provides a brief discussion of agricultural production, rice production, and irrigation in Lao PDR. Section 3 describes the data source and the descriptive statistics. Next, Section 4 discusses the methodology and model selection. Section 5 presents the empirical results. Finally, Section 6 provides conclusions and policy recommendations.

2. Agricultural Production, Rice Production, and Irrigation in Lao PDR

Lao PDR is a small landlocked country in Southeast Asia with a population of 6.85 million in 2017. The country is surrounded by five neighboring countries, namely, Thailand, Vietnam, Cambodia, Myanmar, and China. Lao PDR has been one of the fastest-growing economies in East Asia and the Pacific region, and over the past decade, its GDP has expanded at an average growth rate of 7.8% per year [1]. In 2016, GDP per capita was 2338 USD, and GDP was 2740 million USD (Table 1). The agriculture, industry, and service sectors account for 19.48%, 32.52%, and 48%, respectively, of the country's GDP. Lao PDR is rich in natural resources, with a total planted area of 1.80 million hectares in 2017 [28]. A large planted area has transformed this country into a potentially important area for agricultural production in the ASEAN region.

Table 1. Agricultural production in Lao PDR.

Item	2010	2011	2012	2013	2014	2015	2016
GDP growth (%)	8.53	8.04	8.03	8.03	7.61	7.27	7.02
Per capita income (USD)	1141	1381	1589	1839	2018	2159	2339
Agricultural production (Million USD)	1944	2196	1890	2141	2334	2531	2740
Share of agriculture to GDP (%)	30.63	28.91	20.35	19.74	19.43	19.66	19.48
Share of labor force in agricultural sector (%)	77.10	77.39	77.61	77.81	77.99	78.14	78.27
Rice paddy production (Million ton)	3.07	3.07	3.49	3.41	4.00	4.10	4.15
Total rice export (Million USD)	1.90	2.33	9.64	12.36	8.74	23.52	33.67
Share of rice to total agriculture export (%)	1.48	1.43	4.55	3.91	4.01	6.85	5.63

Sources: [28–31].

Therefore, promoting agricultural production is a top priority of governmental policy to ensure national food security, and to generate sustainable income and employment for local farmers. The total agricultural production of Lao PDR has rapidly increased from 1943 million USD in 2010 to 2740 million USD in 2016. Although, the value of agricultural output has slightly increased every year, the share of agricultural production to GDP has declined from 30.63% in 2010 to 19.48% in 2016. The rapid growth of industrial and service sectors has made the share of agricultural production relatively small. However, agriculture is more vital for the local population and economic development than its contribution to GDP. This sector significantly contributes to local employment, as indicated by the share of the labor force in the agricultural sector, which was over 70% during the period from 2010–2016 (Table 1).

More specifically, rice is an important staple food crop of Lao: Almost all farmers are involved in rice production, and approximately 75% of arable land is used for growing rice [1]. Since rice plantation ensures food security and serves as a primary source of income, the government has invested significant efforts toward improving rice productivity throughout the country. Since 2000, rice production in Lao PDR has transformed from self-sufficient production to commercialization, after the government introduced a national strategy for promoting rice production for export. As a result, rice production increased from 3.07 million tons in 2010 to 4.14 million tons in 2016, leading to an increase in total rice exports from 1.9 million USD in 2010 to 33.67 million USD in 2016, accounting for 3.98% of total agricultural production (Table 1).

However, the rice productivity of Lao PDR is relatively low, compared to other ASEAN countries [32]. The main determinants of this slow progress are low and/or insufficient application of modern technology in plantation procedures, lack of rice varieties and limited access to sufficient irrigation [1,28,33,34]. Additionally, the Ministry of Agriculture and Forestry (MAF) [28] points out that only 20% of farming households have access to irrigation. In addition, some existing irrigation systems still have a problem with sufficient water supply, due to a lack of operational and maintenance costs.

To address the problem of rice plantation in Lao PDR, the government has organized irrigation projects by region. Irrigation in Lao PDR can be classified according to three types of regions: (1) Community-managed gravity irrigation in the northern area of the country; (2) pump irrigation in the Vientiane plain; and (3) pump irrigation along the Mekong River. In 2005, more than 90% of rice plantations used surface water for irrigation [2]. In 2015, it was estimated that the irrigation area covered around 473,756 hectares, accounting for 31% of arable land in the whole country. Approximately 54% of the irrigated area was in the central region, which is the largest region of rice production in the Lao PDR. The southern region accounted for 25% of the rice production area, and 21% of this area was in the northern region. Of the total irrigation area, 293,536 hectares (around 62%) are wet-season irrigated areas, and 180,220 hectares (about 38%) are dry-season irrigated areas [34]. The irrigated area in the wet season increased from 138,077 hectares in 1995 to 293,536 hectares in 2015, while in the dry season, the area increased from 36,282 hectares in 1995 to 180,220 hectares in 2015 [2,34].

Figure 1 shows that rice paddy production and productivity have a strong relationship with irrigation, as indicated by total rice paddy production, which increased from 2.84 million tons in 2010 to 3.83 million tons in 2017, while the total irrigation area expanded from 386 thousand hectares in 2010 to 438 thousand hectares in 2016. Moreover, the productivity of rice also increased by 0.62 tons per hectare during the same period. Therefore, irrigation has played a significant role in supporting rice production and improving rice productivity in Lao PDR.

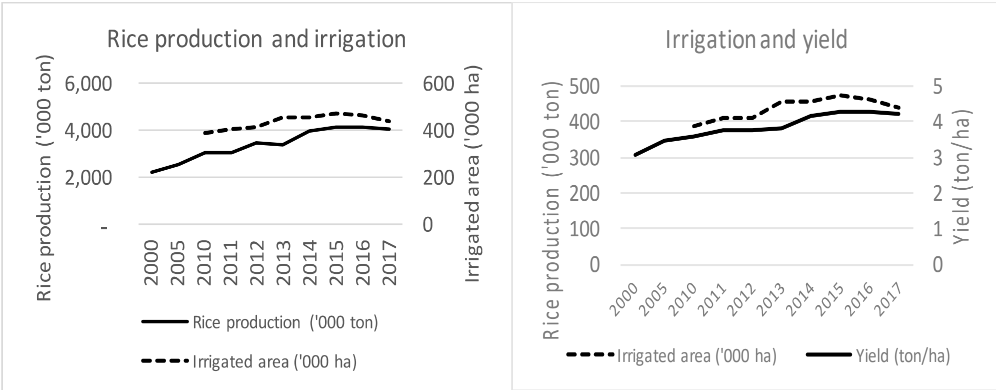

Figure 1. The relation among rice paddy production, yield and irrigation areas. *Source:* [28].

3. Data

This study utilizes the data from the Lao Expenditure and Consumption Survey (LECS). The survey is conducted every five years by the National Statistical Bureau [35]. The first round of the LECS was conducted in 1992/1993 (known as LECS 1) and the latest round was conducted in 2012/2013 (LECS 5). Due to the availability of the data of interest, this study can only utilize the data from LECS 3, LECS 4, and LECS 5, which include 8092, 8296, and 8226 households, respectively (Table 2).

Table 2. Number of households with and without irrigation in each survey.

Household	LECS3 (8092)	LECS4 (8296)	LECS5 (8226)	Panel (2241) [a]
No irrigation	4287	4414	2001	936
Irrigation	1689	1582	1673	516
Total	5976	5996	3674	1452
Sticky rice	6007	6091	5671	747

Data source: The Lao Expenditure and Consumption Survey (LECS) from 2002/2003–2012/2013. Note: [a] The total panel data in three round surveys reduce from 2241 to 1452 households according to existing data of irrigation.

To estimate the impacts of irrigation on household sticky rice production, this study uses pooled cross-section data by assuming three periods of time as one cross-sectional data set (three periods of time are omitted). First, we include the total number of households that grow sticky rice in each survey: There are 6007 households, accounting for 74.23% of the total observations, in LECS 3; 6091 households (73.42%) in LECS 4; and 5671 households (69%) in LECS 5 (Table 2). Then, the data are converted into a panel data set. Finally, 747 households match in LECS 3, LECS 4 and LECS 5. This research also uses the village-level questionnaire in each LECS to collect the paddy sticky rice prices.

To examine the impacts of irrigation on household sticky rice production, we divided panel data into four groups—G0 to G3. G0 is the control group. The households in G0 do not irrigate in any of the three periods of the LECS. G1 to G3 are the treatment groups in which the households irrigate in all three periods of the LECS namely G1, G2, and G3 are consisting of households that have access to irrigation during one and two periods of the surveys, respectively (Table 3).

Table 3. Four subgroups of panel data (G0 to G3).

Group's Name	1 = Access to Irrigation, 0 = No Irrigation		
	LECS3 (2003)	LECS4 (2008)	LECS5 (2013)
G0	0	0	0
G1	1	1	1
G2		0	1
G3	0	1	1

The mean difference test of the potential covariates and outcomes are shown in Table 4. The imbalance of some household characteristics between comparison groups arises from sample selection bias, as irrigation is not randomly selected. The heads of irrigated households hold greater Lao Lum ethnic status and are relatively more educated than those of non-irrigated households. In contrast, non-irrigated households have larger households than their counterparts. However, the imbalance can be seen in the observed variables and might occur in unobserved variables as well [36]. For instance, unobserved variables, such as households that are more motivated, skilled or experienced in sticky rice cultivation, might tend to participate in the irrigation system since they can anticipate it being a better practice. However, no significant difference is found between the comparison groups with regard to the household head age, gender, and status and the harvest area. For potential outcomes, such as the sticky rice sale value, total production and productivity and household consumption, irrigated households have greater values than non-irrigated households.

Table 5 shows the mean difference in the potential covariates and outcomes between households with irrigation (G2) and without irrigation (G0). The imbalances for harvest areas were found, which the t-test is negatively significant, meaning that the harvest area in the control group is greater than the corresponding treatment group. For potential outcomes variables, only the mean productivity difference in the treatment group is significantly greater than that of the control group.

Table 6 presents the mean difference test of potential covariates and outcomes between the treatment group (G3) and control group (G0). The mean differences in the households' ethnic group and harvest area are significant. Irrigated households are less likely to include individuals from the Lao Lum ethnic group and have less harvest area compared to non-irrigated households. Regarding potential outcomes, only the sticky rice productivity of irrigated households is found to be higher than non-irrigated households.

To conclude, despite the small landholdings of irrigated households compared to non- irrigated households, sticky rice productivity of the treatment group is higher than that of the control group in three comparisons (G1 versus G0 to G3 versus G0).

The definition and measurement of potential outcomes and a set of covariate variables in estimating the impact of irrigation on sticky rice production are in Appendix A Table A1.

Table 4. The mean difference of households with irrigation (G1) and without irrigation (G0).

Variables	Irrigation			No Irrigation			Difference			
	Obs	**Mean**	**S.D**	**Obs**	**Mean**	**S.D**	**Obs**	**Mean**		**S.E**
Potential covariates										
Household size (year)	516	5.78	2.14	936	6.12	2.44	1452	−0.34	***	0.13
Age of household head (year)	516	47.38	10.97	936	46.80	11.94	1452	0.59		0.64
Education of household head [a] (year)	459	7.13	2.70	783	6.24	2.29	1242	0.90	***	0.14
Ethnic of household head (1 = Lao Lum)	516	0.91	0.29	936	0.66	0.48	1452	0.25	***	0.02
Gender of household head (1 = male)	516	0.95	0.21	936	0.96	0.20	1452	0.00		0.01
Status of household head (1 = married)	516	0.95	0.23	936	0.95	0.22	1452	−0.01		0.01
Harvest area (Hectares)	516	1.62	1.26	936	1.70	1.29	1452	−0.08		0.07
Potential outcome										
Sales value ('000 LAK)		8535.43	9651.76		6282.26	5723.63		2253.17	***	403.71
Total production (Kg)		4326.12	4094.10		3190.64	2545.79		1135.48	***	174.53
Productivity (Kg/ha)		4881.57	4620.79		2281.14	1420.39		2600.43	***	163.43
Consumption ('000 LAK)		1450.99	1171.41		1298.84	1101.61		152.15	***	61.79
		N = 516			N = 936			N = 1452		

Data source: The author's calculations from the Lao Expenditure and Consumption Survey (LECS) from 2002/2003–2012/2013. Note: [a] Due to missing data on the education variable, the total observations decreased from 1452 to 1242 households: 459 irrigated households and 783 non-irrigated households. *** Significant at 1% level; 1 USD = 8700 LAK.

Table 5. The mean difference of households with irrigation (G2) and without irrigation (G0).

Variables	Irrigation			No Irrigation			Difference			
	Obs	**Mean**	**S.D**	**Obs**	**Mean**	**S.D**	**Obs**	**Mean**		**S.E**
Potential covariates										
Household size (member)	288	5.97	2.50	624	5.95	2.41	912	0.03		0.18
Age of household head (year)	288	48.19	10.92	624	48.72	11.64	912	−0.53		0.79
Education of household head[a] (year)	266	6.51	2.28	530	6.32	2.34	796	0.20		0.17
Ethnic of household head (1 = Lao Lum)	288	0.68	0.47	624	0.66	0.47	912	0.02		0.03
Harvest area (Hectares)	288	1.24	0.79	624	1.77	1.39	912	−0.53	***	0.07
Potential outcome										
Sales value ('000 LAK)		7333.18	4369.37		7847.56	6225.89		−514.38		358.34
Total production (Kg)		3108.79	1846.52		3329.63	2659.01		−220.84		152.22
Productivity (Kg/ha)		3646.74	2782.56		2339.27	1475.22		1307.47	***	174.28
Consumption ('000 LAK)		1581.05	1213.01		1584.56	1223.02		−3.50		86.64
	N = 288			N = 624			N = 912			

Data source: The author's calculations from the Lao Expenditure and Consumption Survey (LECS) from 2002/2003–2012/2013. Note: [a] Due to missing data on the education variable, the total observations decreased from 912 to 796 households: 266 irrigated households and 530 non-irrigated households. *** Significant at 1% level; 1 USD = 8700 LAK.

Table 6. The mean difference of households with irrigation (G3) and without irrigation (G0).

Variables	Irrigation			No Irrigation			Difference			
	Obs	Mean	S.D	Obs	Mean	S.D	Obs	Mean		S.E
Potential covariates										
Household size (year)	132	6.11	2.47	936	6.12	2.44	1068	−0.01		0.23
Age of household head (year)	132	48.14	12.01	936	46.80	11.94	1068	1.34		1.12
Education of household head [a] (year)	98	6.56	2.59	783	6.24	2.29	881	0.32		0.27
Ethnic of household head (1 = Lao Lum)	132	0.52	0.50	936	0.66	0.48	1068	−0.13	***	0.05
Harvest area (Hectares)	132	1.15	0.69	936	1.70	1.29	1068	−0.55	***	0.07
Potential outcome										
Sales value ('000 LAK)		5967.67	4312.70		6282.26	5723.63		314.59		419.41
Total production (Kg)		2953.73	1729.44		3190.64	2545.79		−236.91		172.00
Productivity (Kg/ha)		3884.13	3505.82		2281.14	1420.39		1602.99	***	308.65
Consumption ('000 LAK)		1315.24	1018.03		1298.84	1101.61		16.40		95.64
		N = 132			N = 936			N = 1068		

Data source: The author's calculations from the Lao Expenditure and Consumption Survey (LECS) from 2002/2003–2012/2013. Note: [a] Due to missing data on the education variable, the total observations decreased from 1068 to 881 households: 98 irrigated households and 783 non-irrigated households. *** Significant at 1% level; 1 USD = 8700 LAK.

4. Methodology

4.1. Propensity Score Matching (PSM)

Propensity score matching was introduced by Rosenbaum and Rubin [37]: It has been well used in recent years in many fields to evaluate causal treatment effects. The main idea of PSM is to focus on the different outcomes between treatment and control groups with respect to the treatment condition, and the control variables are not random. Therefore, there may be large differences in their observed covariates, and these differences can lead to biased estimations of the treatment effect. In other words, the self-selection problem can lead to overestimations and underestimations of the outcome of interest. To mitigate the self-selection problem, this study assumes that the Lao government provides irrigation schemes based on household and land characteristics. Therefore, to evaluate the impact of irrigation on households' sticky rice production, comparing the mean outcomes between irrigated and non-irrigated households can lead to self-selection bias since the statuses or likelihoods of the two groups are different, even without treatment [38]. In this paper, in order to mitigate the bias from the treatment effect, we estimated the observational data by balancing the observed covariates in the pretreatment between the comparison groups by matching the propensity scores.

First, we obtain the status or likelihood (a set of covariates) of each treatment and the control variables to estimate the propensity score by using the probit model to get the balanced matched sample. Then, we apply the nearest neighbor matching technique by matching with a 0.01 distance (caliper) to match the one to one nearest neighbor of each treated observation with a control observation. To avoid bad matches, we prune the treated observations that are matched with no control observations and the pairs that have matching distances greater than 0.01. PSM can help researchers to reconstruct the counterfactuals by using observational data to remove bias [39].

To reinforce the findings of the impacts of irrigation and to address the selection bias, this study applies PSM to estimate the average treatment effect on the treated (ATT). Based on Rosenbaum and Rubin [37], Caliendo et al. [38], and Khandker et al. [40], the ATT can be estimated as follows:

$$ATT_{PSM} = E_{P(X)|T_i=1}\Big\{E\Big[Y_i(1)\Big|T_i = 1, P(X)\Big] - E\Big[Y_i(0)\Big|T_i = 0, P(X)\Big]\Big\} \quad (1)$$

where $p(x)$: propensity score of a set of observed covariates x, ATT: average treatment effect for treated households with irrigation, T_i: treatment variable if $T = 1$ and $T = 0$ for control variable, Y_i: outcome variable of household i (sales value, production, and productivity of sticky rice; and household consumption), and X: a set of observed covariates (household size; household head's age, education, ethnic group, gender and marital status and household harvest area).

4.2. Difference-in-Differences (DID)

To test the hypothesis that irrigation improves sticky rice productivity among participating households, this study applies the DID estimation method since the intervention was not randomly employed in each village. The DID method compares the changes in the measured outcomes pre- and post-treatment among the comparison groups (treatment and control groups), while controlling for observed covariates. The significant advantage of the DID method is that the observed and unobserved time-invariant confounding variables, which might be correlated with the treatment and outcomes of interest, are addressed and eliminated in the regression. To estimate the impact of irrigation on sticky rice productivity, this paper employs the DID method with a fixed-effect estimator [40,41], since the fixed-effect estimator controls are not only for unobserved time-invariant heterogeneity, but also for the heterogeneity in observed characteristics over multiple periods. More specifically, any time-invariant variables will be dropped from the fixed-effect estimation. Therefore, the treatment effect can be rewritten as follows:

Let i and t indicate household i and year t, respectively. The DID regression specification can be written as follows:

$$Y_{it} = \beta_0 + \beta_1 Irrigation\ group_i + \beta_2 Time_t + \beta_{DID}(Irrigation\ group_i * Time_t) + \beta X_{it} + \alpha(year) + a_i + \mu_{it} \quad (2)$$

where Y_{it} represents the outcome variables of interest: sales value, total production, productivity, and household consumption. $Irrigationgroup_i$ is a dummy that takes the value of 1 if the household status is irrigated. $Time_t$ is a dummy for the irrigation in year t. X_{it} is a vector of control variables for sociodemographic characteristics: household size; age, education, and ethnic group of household head; and harvest area. The term *year* is a year dummy to capture the time fixed effect which addresses unobserved factors that changed during the survey periods: 2003 takes a value of 0 as the baseline and one otherwise. The term a_i represents unobserved time-invariant individual household heterogeneity that may be correlated with both the treatment and other unobserved characteristics (μ_{it}). Household-level error is captured by μ_{it}. Finally, β_{DID} is the interaction coefficient between $Irrigation\ group_i$ and $Time_t$, which is the casual estimate of our interest in capturing the effect of irrigation on the measured outcomes.

5. Empirical Results

This section is divided into two parts. The first shows results for the impact of irrigation on sticky rice production which comparison between G1 versus G0. In the second part, we report the results of the impact of irrigation on sticky rice productivity when households extend their irrigation access from one period to two periods.

5.1. The Impact of Irrigation on Sticky Rice Production (G1 vs. G0)

Table 7 presents the set of covariates before and after matching. It is evident that after matching, all the imbalances of the covariates are removed. The magnitudes of all the mean differences for the household characteristic variables are dramatically reduced and are closer to zero compared to before matching. This result confirms our estimation that was performed by using the propensity score is well-matched.

Table 7. Balance checking before and after matching.

Potential Covariates	Before Matching			After Matching	
	Mean		S.E	Mean	S.E
Household size (member)	−0.34	***	0.13	0.194	0.174
Age of household head (year)	0.59		0.64	0.467	0.887
Education of household head (year)	0.90	***	0.14	−0.048	0.107
Ethnic of household head (1 = Lao Lum)	0.25	***	0.02	0.004	0.007
Gender of household head (1 = male)	0.00		0.01	0.007	0.016
Status of household head (1 = married)	−0.01		0.01	0.002	0.017
Harvest area (Hectares)	−0.08		0.07	0.062	0.078
Treated units	459			458	
Control units	783			783	
Total matched	-			458	
Total matched	1242			916	

Data source: The author's calculations from the Lao Expenditure and Consumption Survey (LECS) from 2002/2003–2012/2013. *** Significant at the 1% level.

Before the PSM estimation, an OLS estimation is conducted to check the correlation between the irrigation treatment with each outcome—sales value, total production, and productivity of sticky rice products and household consumption. The OLS results show that irrigation is positively correlated with the sales value, production, and productivity of sticky rice products, but not with household consumption, see Table 8. The main findings of the ATT from PSM, except for household consumption, all the coefficients of interest are significant and have their expected signs. This result shows that the set of covariates that we selected to estimate the propensity score achieve a good balance between households with irrigation and with no irrigation. The finding indicates that irrigated households improve their sticky rice sales value by an average of 2.37 million LAK (around 273 USD), representing an increase of 38% compared to non-irrigated households. Furthermore, irrigated households produce approximately 1138 kg more sticky rice, corresponding to 36% more per season. For sticky rice productivity, irrigation also has a strong impact on productivity, as irrigated households improve their sticky rice productivity by approximately 2.44 tons per hectare per season compared to non-irrigated households. Similar to the works of Bidzakin et al. [42]), Nonvide [15], Babatunde et al. [19], Bell et al. [5], and Dillon [17,18], our findings provide robust evidence of the positive impacts of irrigation on household sticky rice production.

Table 8. The results of the PSM estimation.

Potential Outcome	**OLS**			**PSM**			**Entropy Balance**		
	Coef.		**S.E**	**ATT**		**S.E**	**ATT**		**S.E**
Sales value ('000 LAK)	2213.46	***	374.23	2375.16	***	676.99	2168.34	***	525.99
Total production (Kg)	1114.26	***	161.09	1138.42	***	274.34	1051.94	***	222.54
Productivity (Kg/ha)	2595.63	***	191.92	2446.60	***	294.02	2527.51	***	230.88
Consumption ('000 LAK)	45.5677		66.47	66.52		99.54	33.28		81.39
Control variables		YES			-			-	
Year dummy		YES			-			-	
Treated units		-			458			459	
Control units		-			783			783	
Total matched		-			458			459	
Total observation		1242			916			918	

Data source: The author's calculations from the Lao Expenditure and Consumption Survey (LECS) from 2002/2003–2012/2013. *** Significant at 1% level; 1 USD = 8700 LAK.

For household consumption, no evidence is found by estimation. There are several reasons that might explain this result, as follows. Most of local households mainly grow sticky rice for self-consumption, only the surplus portion is sold to the market. This might be the reason why increases of sticky rice productivity and sales value have no direct effect on households consumption. Moreover, household main income sources may not be earned from sticky rice cultivation solely, but also other sources, such as livestock husbandry, wage, salaries, non-timber forest products, and other agricultural products. More importantly, the sales value used in this study is measured by the expected value of total productions if households sell total sticky rice cultivation (sales values = value of total productions). In other words, sales value is not the actual amount of money that households earn from sticky rice production sale. This result is in line with the previous finding by Dillon et al. [20], whose findings suggest no evidence for the impact of irrigation on household consumption growth in Nepal.

To check the robustness of the impacts of irrigation on sticky rice production, we also utilize the entropy balancing method [43]. The entropy balancing method creates balanced samples by reweighting the data set to adjust the control covariates for matching the covariates in a treatment using a set of specified moment conditions. Then, the weights are utilized in a regression model. This procedure will mitigate model dependency. The findings show strong significance levels for three out of four outcome variables. Even though the magnitudes of all coefficients of the selected outcomes are greater than those of PSM, the results are consistent.

5.2. The Impact of Irrigation on Sticky Rice Productivity when Households Extend their Irrigation Access from one Period to two Periods

In this section, we report on the estimation results for the impacts of irrigation on sticky rice productivity by using the DID methods. The results are divided into two comparison groups including G2 versus G0 in two periods of surveys and G3 versus G0 in three periods of surveys.

The results of the G2 versus G0 comparison groups are reported in Table 9. The control group is not irrigated in both the LECS 4 and LECS 5 surveys, whereas the treatment group is not irrigated in LECS 4, but is irrigated in LECS 5. The OLS and fixed effect models are applied to estimate Equation (2) for all four potential outcome variables. The findings show that, except for household consumption, all the coefficient of interest shows positive signs in both OLS and fixed effect estimations, meaning that irrigated households have larger sales value, total production, and productivity of sticky rice than non-irrigated households. However, only one out of three outcome variables are significant at the 5% and 10% level in both OLS and fixed effect estimators. In addition, the OLS estimator reports that sticky rice productivity is positively associated with irrigation. Furthermore, a fixed-effect estimator shows evidence of a positive impact of irrigation on sticky rice productivity. The sticky rice productivity of irrigated households is, on average, 647 kg per hectare, corresponding to 1.40 million LAK (approximately 161 USD), higher than that for non-irrigated households per season. Our finding is consistent with those of Babatunde et al. [19], Nonvide [15], and Bell et al. [5], whose findings suggest that irrigation has a positive impact on rice productivity in Nigeria, Benin, and Bangladesh, respectively.

For household consumption, no evidence is found in either the OLS or fixed effect estimations. There are several reasons that might explain this result as we explained in paragraph 3 of Section 5.1. To sum up, except for sticky rice productivity, we cannot find any evidence to support the hypothesis regarding the impact of irrigation access on sticky rice sales value, total production, and household consumption.

In this section, we would like to further investigate whether the impact of irrigation on sticky rice productivity (if any) is sustainable when households extend their irrigation access from one period to two periods. The treatment group is newly defined as households without irrigation in LECS 3, but are irrigated in LECS 4 and LECS 5 (two periods of surveys). Table 10 presents the estimation results of the comparison between G3 versus G0. Similar to the results of the comparison between G2 versus G0, we cannot find any evidence of the impact of irrigation on the sales value and total production of sticky rice, as well as household consumption. Although, the coefficient of total sticky rice production is not significant in OLS estimation, the fixed effect estimator shows the coefficient of interest is positively significant at the 10% level, meaning that, when households have longer access to irrigation, it improves their sticky rice production on average, by 478 kg, which is equivalent to 1.13 million LAK (130 USD). Our findings suggest that instead of initial access, households need to time to realize the benefits of irrigation access, as they need more time to manage the optimal volume of water from the irrigation system. Furthermore, the coefficients for sticky rice productivity in both the OLS and fixed effect estimations are positively significant at the 1%, and 10% levels, respectively. This result shows that households with irrigation can increase their sticky rice productivity by 1560 kg per hectare, or approximately 3.68 million LAK (423 USD). Interestingly, we can find that the productivity coefficient is nearly double in both the OLS and fixed effect estimations, compared to the results for households with access to irrigation for one period. In other words, households' access to irrigation for two periods can increase their sticky rice productivity by approximately 913 kg per hectare, or 2.28 million LAK (262 USD), more than household access to irrigation for one period of time. It can be concluded that the productivity gains from irrigation are sustainable in the case of sticky rice production in Lao PDR.

Table 9. Estimated results comparing G2 and G0 with household access to irrigation in 2013 (LECS5).

Variables	Sales Value		Total Production		Productivity		Consumption	
	OLS	Fixed Effect	OLS	Fixed Effect	OLS	Fixed Effect	OLS	Fixed Effect
Year dummy (year 2013 = 1)	−1434.75 ***	−1224.43 ***	−54.05	62.29	24.54	225.64	443.8 ***	490.79 ***
	(388.12)	(451.41)	(166.31)	(193.57)	(176.32)	(184.79)	(108.95)	(119.89)
Treat G2 vs. G0	638.77	-	298.67	-	827.12 ***	-	4.79	-
	(463.16)	-	(198.47)	-	(210.41)	-	(130.02)	-
*Treat G2 vs. G0 * Time 2013*	541.24	432.08	189.31	134.15	*708.78* **	*647.00* *	−109.48	−104.72
	(655.89)	(514.73)	(281.06)	(218.64)	*(297.97)*	*(366.25)*	(184.13)	(162.64)
Household size (member)	80.72	104.05	35.03	49.92	29.72	−27.70	82.02 ***	95.45 **
	(69.65)	(138.95)	(29.84)	(60.08)	(31.64)	(75.44)	(19.55)	(43.01)
Age of household head (year)	24.42 *	27.14	9.40	5.90	−2.30	−42.25	7.83 *	1.99
	(14.67)	(45.28)	(6.28)	(18.49)	(6.66)	(36.98)	(4.12)	(9.40)
Education of household head (year)	167.68 **	−99.11 *	68.33 **	−38.72	−14.29	−50.70	73.77 ***	20.76
	(68.14)	(103.25)	(29.20)	(43.03)	(30.95)	(42.32)	(19.13)	(40.75)
Ethnic of household head (1 = Lao Lum)	1750.88 ***	3,051.95 ***	738.37 ***	1154.83	583.21 ***	1392.48	304.98 ***	−125.01
	(367.32)	(1682.33)	(157.40)	(738.23)	(166.87)	(845.00)	(103.12)	(482.33)
Harvest area (Hectares)	2820.00 ***	2581.29	1218.80 ***	1159.54 ***	−248.34 ***	−114.25	−2.22	5.81
	(131.90)	(315.63)	(56.52)	(134.70)	(59.92)	(98.13)	(37.03)	(75.60)
Constant	−311.84	736.12	−384.48	238.46	2391.45 ***	4299.51 *	−104.57	696.67
	(996.35)	(2829.07)	(426.95)	(1168.36)	(452.64)	(2280.33)	(279.70)	(675.55)
Household Fixed Effect	-	YES	-	YES	-	YES	-	YES
Year Fixed Effect	-	YES	-	YES	-	YES	-	YES
R-squared	0.42	0.30	0.42	0.30	0.13	0.05	0.08	0.08
Observations	796	796	796	796	796	796	796	796

Data source: The author's calculations from the Lao Expenditure and Consumption Survey (LECS) from 2002/2003–2012/2013. *, **, *** Significant at 10%, 5% and 1% level, 1 USD = 8700 LAK.

Table 10. Estimated results comparing G3 and G0 with household access to irrigation in 2008 & 2013.

Variables	Sales Value		Total Production		Productivity		Consumption	
	OLS	**Fixed Effect**	**OLS**	**Fixed Effect**	**OLS**	**Fixed Effect**	**OLS**	**Fixed Effect**
Year dummy 2008 (year 2008 = 1)	4779.70 ***	4986.09 ***	111.50	171.04	226.56	233.07 *	635.49 ***	791.19 ***
	(348.74)	(300.48)	(163.86)	(119.81)	(157.66)	(123.90)	(89.02)	(109.78)
Year dummy 2013 (year 2013 = 1)	3385.09 ***	3754.86 ***	27.33	145.56	194.45	259.37	1134.52 ***	1433.65 ***
	(371.95)	(378.59)	(174.76)	(158.50)	(168.15)	(175.78)	(94.94)	(143.11)
Treat G3 vs. G0	1025.89	-	288.14	-	1057.41 ***	-	−51.10	-
	(809.94)	-	(380.55)	-	(366.15)	-	(206.74)	-
*Treat G3 vs. G0 * Time 2008 & 2013*	577.21	645.48	485.22	*477.86* *	*1342.23* ***	*1559.58* *	70.50	−20.92
	(953.87)	(606.59)	(448.18)	*(286.06)*	*(431.22)*	*(930.88)*	(243.47)	(156.62)
Household size (member)	22.88	66.94	12.71	44.36	−6.09	7.21	65.39 ***	92.54 ***
	(59.96)	(98.40)	(28.17)	(39.46)	(27.10)	(65.92)	(15.30)	(30.44)
Age of household head (year)	8.43	9.92	6.41	14.18	−3.36	1.05	4.68	−18.27
	(13.03)	(27.36)	(6.12)	(11.37)	(5.89)	(15.30)	(3.33)	(11.15)
Education of household head (year)	156.11 ***	−36.51	89.58 ***	−14.33	19.77	−48.81	72.4 ***	5.50
	(58.51)	(85.66)	(27.49)	(33.75)	(26.45)	(45.01)	(14.94)	(29.98)
Ethnic of household head (1 = Lao Lum)	1563.19 ***	879.03	700.34 ***	133.50	731.65 ***	0.17	253.74 ***	−55.76
	(310.01)	(1392.17)	(145.66)	(737.67)	(140.15)	(1142.63)	(79.13)	(402.18)
Harvest area (Hectares)	2516.46 ***	2239.90 ***	1266.13 ***	1100.29 ***	−169.06 ***	−48.02	1.55	−32.20
	(113.74)	(241.24)	(53.44)	(118.13)	(51.42)	(60.66)	(29.03)	(48.94)
Constant	−3255.39 ***	−1558.05	−399.43	325.03	1994.70 ***	2500.76 **	−480.76 **	941.32 *
	(805.54)	(1765.93)	(378.48)	(808.92)	(364.16)	(1225.96)	(205.61)	(570.16)
Household Fixed Effect	-	YES	-	YES	-	YES	-	YES
Year Fixed Effect	-	YES	-	YES	-	YES	-	YES
R-squared	0.51	0.52	0.45	0.34	0.16	0.04	0.22	0.28
Observations	881	881	881	881	881	881	881	881

Data source: The author's calculations from the Lao Expenditure and Consumption Survey (LECS) from 2002/2003–2012/2013. *, **, *** Significant at 10%, 5% and 1% level, 1 USD = 8700 LAK.

6. Conclusions and Policy Implications

This study focuses on analyzing the impacts of irrigation on sticky rice production by employing PSM and DID method. In the panel data, three LECS surveys—2002/2003, 2007/2008, and 2012/2013—were divided into four subgroups to examine the effects of irrigation on the sales value, total production, and productivity of sticky rice, as well as household consumption. Our findings suggest that irrigation has positive impacts on the sales value, total production, and productivity of sticky rice. More specifically, the average sticky rice sales value of irrigated households is greater than that of non-irrigated households by an average of 2.37 million LAK per season. Furthermore, irrigated households have higher sticky rice production of approximately 1138 kg per season and have higher sticky rice productivity on an average of 2.44 tons per hectare per season, compared to non-irrigated households. In addition, households with access to irrigation in two periods of the surveys have higher sticky rice productivity than households with access to irrigation in one period of the surveys by approximately 913 kg per hectare. We found that long-term access to irrigation leads to higher sticky rice productivity. However, no evidence was found to support the impact of irrigation on household consumption in this study, as households in Lao PDR mainly grow sticky rice for self-consumption rather than sale, and household income is usually earned from various sources apart from sticky rice cultivation. This might, to some extent, be able to explain the reason why an increase in sticky rice productivity does not reflect in household consumption.

To conclude, our findings show positive impacts of irrigation on sticky rice productivity in the case of the Lao PDR. However, the determinants of sticky rice productivity is not only in relation to irrigation, but also the adoption of technology innovation, seed quality, agrochemical use, etc. However, the factors driving the success of aforementioned determinants also depends on country characteristics, geographical location, and weather condition. Some policy implications can be derived from this research are that farmers should be intensively promoted to make use of irrigation more, development of agricultural infrastructure, especially irrigation system expansion is highly needed, and to ensure effectiveness of irrigation utilization local farmer involvement in monitoring procedure of irrigation is necessary.

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Appendix A

Table A1. Definitions and units of variables.

Variables	Explanation	Unit
Potential covariates		
Household size	Total members in the household	Members
Age of household head	Age of household head	Years
Education of household head	Year of education of the household head	Years
Ethnic of household head	Dummy variable for ethnic group of the household head; 1 for Lao Lum, 0 otherwise	
Gender of household head	Dummy variable for gender of the household head; 1 for male, 0 otherwise	
Status of household head	Dummy variable for status of the household head; 1 for married, 0 otherwise	
Harvest area	Area for harvested sticky rice production	Hectares
Potential outcomes		
Sales value	Sticky rice production multiplied by average price in each year survey	1000 LAK
Total production	Sticky rice production	Kg
Productivity	Sticky rice production divided by harvested area	Kg/ha
Consumption	Household consumption	1000 LAK

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