Doctoral Dissertation

Agricultural Production, Irrigation and Interdependency through Transactions in Rural Village: Evidence from Developing Countries

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Executive Summary

In developing country, over half of total workers get involved in agricultural sector and most poor people make money from agricultural production. Agricultural sector generates significant economic spillover effects in terms of employment and income generation to local people in remote areas. Inevitably, irrigation is the single most important component of sustainable agricultural production. It improves agricultural production and indirectly improves the diversity of household food consumption and food security leading to poverty reduction.

More specifically, rice is one of the most important agricultural products and its plantation needs more water than many types of agricultural products. Most cases are rainfed rice cultivation which is directly affected by climate change. In developing countries, approximately 60% of total rice production come from irrigated area. Therefore, the government in many countries try to introduce irrigation to ensure the growing of rice in both dry and raining seasons as well as to improve rice productivity and production.

In the case of Lao People's Democratic Republic (Lao PDR), rice is an important staple food crop which is planted over 75% of arable land. Especially, sticky rice has the share of approximately 80% of total rice production and over 80% of rice cultivation occurs via rainfed farming which changes year by year and results in fluctuating rice production. In 2018, only 20% of households accessed to irrigation. However, some existing irrigations cannot be regularly used due to insufficient water supply, lack of operational and maintenance costs. As a result, some farmers avoid to grow rice in dry reason.

Whether irrigation can improve agricultural production and productivity or not, we cannot measure the magnitude of its effect on poverty reduction. Interdependency among households could be another factor leading to poverty reduction, especially isolated villages, where the villagers become more specialized and economic interdependence by products' transaction. The level of economic interdependence can vary depending on type of products and village setting. The interdependency mainly occurs in households that cannot access regular market. So access to adequate consumption could lead to household livelihood improvement and poverty reduction in the long run. The interdependency among households in rural areas is a crucial factor to better understanding the rural households' characteristic,

pattern of their production and trade transactions. This issue is useful information for local government to formulate district or villages' poverty eradication strategy.

To address this problem, three main empirical studies of this dissertation focus on: (1) examining the impacts of irrigation systems on sales value, total production and productivity of sticky rice, as well as household consumption; (2) estimating the impact of households access irrigation in different period of times on sticky rice productivity; and (3) analyzing key characteristics of interdependency among households in the same community through agriculture transactions in order to capture village economy's performance pattern. The findings of this dissertation expect to contribute to a greater improvement of rice productivity, and a better understanding interdependency among households in village, as a result lead to poverty reduction.

To estimate the impacts of irrigation on household sticky rice production and productivity in Lao PDR of the first and second empirical chapters, this research utilizes panel data of the Lao Expenditure and Consumption Survey (LECS) 2002/2003, 2007/2008, and 2012/2013.

The first empirical study evaluates the impacts of irrigation on sticky rice production and productivity. Panel data are divided into two groups, in which the treatment group has 459 irrigated households in all three periods of the LECS. The second group is control group including 783 non-irrigated households in any of the three periods of the LECS. Since irrigation is not randomly selected, PSM can help researchers to reconstruct the counterfactuals to mitigate the endogeneity problem. The results show that with irrigation access, households can improve sales value, total production and productivity of sticky rice. However, no any evidences are found in the impact of irrigation on household consumption. In Lao PDR, households mainly grow sticky rice for self-consumption rather than sale, and household income is usually earned from various sources apart from sticky rice cultivation. In addition, majority of rural areas in developing countries including Lao PDR, where households cannot access regular markets. Therefore, when the production of households increases or the production surplus, they will be stocked them as wealth or capital accumulation. Furthermore, sticky rice product is considered to be necessary goods which has a small elasticity of demand when the production of household or income increases, they will have a minor change on the amount of stick rice consumption. This might, to some extent, be able to explain the reason why an increase in sticky rice productivity does not reflect in household consumption.

The second empirical study aims to further investigate whether the impacts of irrigation on sticky rice productivity (if any) is sustainable when households extend their irrigation access from one period to two periods applying the difference-in-differences (DID) method with a fixed-effect model to analyze the impact of irrigation access in different period of times on sticky rice productivity. 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 canceled out in the regression. Meanwhile, the fixed-effect model accounts for not only the unobserved time-invariant heterogeneity but also the heterogeneity in observed characteristics over multiple periods. Panel data are divided into two comparison groups to evaluate the impact of irrigation on sticky rice productivity when households access irrigation in one period and two periods of LECS. The first comparison group, in which the treatment group has 266 households with irrigation access in LECS 5 but no longer in LECS 4 and the control group includes 530 households without irrigation in any of the LECS. The second comparison group comprise of 98 households with irrigation in LECS 4 and 5, but without irrigation in LECS 3 and the control group has 783 households with no irrigation access in any of the LECS. The finding points out that irrigation has positive impact on sticky rice productivity when households access to irrigation in both one period and two periods of the LECS. Moreover, comparing with households access irrigation in one period of the LECS, households with access to irrigation in two periods of the LECS have nearly double sticky rice productivity. We found that long-term access to irrigation leads to higher sticky rice productivity, since a longer access to irrigation made farmers have learnt more experience in using irrigation for supporting their sticky production such as good irrigation practice, intensive irrigation management and good water arrangement.

The third empirical study of this dissertation focuses on investigating household interdependency through their transactions. Two village surveys were conducted in two developing countries in March 2018. By focusing on agricultural transactions, 75 households are conducted in Dang village in Vietnam and 70 households in Houey Nambak village in Lao PDR. Using data from two household surveys, two expanded VIOTs are constructed. The expanded VIOT shows the amount or value of household transactions in each village. Therefore, to examine the number of transactions for each product for each consumer and producer, two expanded QVIOTs are transformed to binary information from two expanded VIOTs. The findings show that poultry is the subject of most transactions

because it is cheap and widely consumed by households in the two villages. Specifically, in Houey Nambak village, nearly poor and middle-income households have stronger interdependency than poor and rich households in terms of poultry transactions with over 70% of total transactions conducted within the village, but no such evidence is found in Dang village.

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. To improve household livelihoods and to lead to sustainable development, adopting commercialization is necessary to raise transaction volume and poultry productivity.

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Abbreviations

ASEAN	Association of Southeast Asian Nations
ATT	Average Treatment Effect for Treated
CI	Centrality Index
DID	Difference-In-Differences
GDP	Gross Domestic Product
IO	Input-Output
IOT	Input-Output Table
LAK	Lao Kip
LECS	Lao Expenditure and Consumption Survey
MAF	Ministry of Agriculture and Forestry
OLS	Ordinary Least Squares
PSM	Propensity Score Matching
QIOT	Qualitative Input-Output
QVIOT	Qualitative Village Input-Output Table
VIOT	Village Input-Output Table

Chapter 1

Introduction

1.1 Background of the Study

Poverty eradicate is one of the top priorities of government policy in developing country, where are most poor people involving in agricultural production. Agricultural sector is not only a key driving force to stimulate economic development in developing country, but it also generates significant economic spillover effects in terms of employment and income to local people in remote area. The share of labor force involving in agriculture sector has accounted more than half of total workers in developing country. According to the World Bank (2018), the agricultural sector needs to increase its production by approximately 70% by 2050. 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 (Shady, 1991). 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 and irrigation systems.

Irrigation is considered one of the most effective techniques (Stirzaker and Pittock, 2014; Bell et al., 2015; Van Rooyen et al., 2017 and World Bank, 2018). Irrigation development has played a crucial role for supporting global food production and contributed to the economic development and well-being of many developing countries. A mechanism for stabilizing agricultural production is in overcoming issues associated with drought and allowing for diversification of crop production (Tollefson and Hogg, 1997). 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 (Nonvide, 2018a; Khan & Shah, 2012; Gebregziabher et al., 2009 and Hussain and Hanjra, 2004). Upgrading irrigation systems has become a priority for governments, particularly in developing countries. In 2012, only one-fifth of total cultivated land were globally irrigated and accounted for 40% of the global food supply (Food and Agriculture Organization (FAO) of the United Nations, 2016).

Rice is one of the most important agricultural products, especially in Asia region, where is well-known as the largest rice producer and consumer in the world. Meanwhile, Rice plantation needs more water than many types of agricultural products. Most cases are rainfed rice cultivation which is directly affected by climate change. In developing countries, approximately 60% of total rice production come from irrigated area (Bhattarai et al., 2002). Therefore, the government in many countries try to introduce irrigation to ensure the growing of rice in both dry and raining seasons as well as to improve rice production and productivity.

In Lao People's Democratic Republic (Lao PDR), agriculture is more vital for the local population and economic development. As evidence shown the share of the labor force in the agricultural sector is around 77% in yearly from 2010 to 2016. Agricultural production increased 41% of total national output in which rice account for 35% from 2010 to 2016 according to Ministry of Agriculture and Forestry (MOAF), 2018. Rice is an important staple food crop which is planted over 75% of arable land. Especially, sticky rice has the share of approximately 80% of total rice production (Yoshida et al., 2003 and World Bank, 2018). In the Lao PDR since 2000, rice production has transformed from self-sufficient production to commercialization. In 2007, one of the highest per capita rice consumptions in the world was in the Lao PDR (163kg/year). Over 80% of rice cultivation occurs via rainfed farming which changes year by year and results in fluctuating rice production (Yoshida et al., 2003 and Welcher and Prasertsri, 2019).

From 2015 to 2017, irrigated area decreased 34,763 ha (7.34%) of total irrigated area, and in 2018 only 20% of households accessed to irrigation (MOAF, 2018). However, some existing irrigations cannot be regularly used due to insufficient water supply, lack of operational and maintenance costs. As a result, some farmers avoid to grow rice in dry reason.

Whether irrigation can improve agricultural production and productivity or not, we cannot measure the magnitude of its effect on poverty reduction. Interdependency among households could be another factor leading to poverty reduction, especially isolated villages, where the villagers become more specialized and economic interdependence by products' transaction. The level of economic interdependence can vary depending on type of products and village setting. The interdependency mainly occurs in households that cannot access regular market. So, access to adequate consumption could lead to household livelihood improvement and poverty reduction in the long run. The interdependency among households in rural areas is a crucial factor to better understanding the rural households' characteristic,

pattern of their production and trade transactions. This issue is useful information for local government to formulate district or villages' poverty eradication strategy.

1.2 Problem Statement

To mitigate poverty, this research focuses on analyzing agricultural production and productivity, especially sticky rice, and enhance the interdependency among households through agricultural transactions in isolated village. This research focuses on three main questions as following: (1) Has irrigation played an important role in improving sticky rice production and productivity in the case of Lao PDR? (2) Is any increase in sticky rice productivity attributable to sustainable irrigation if households maintain long term to access irrigation? (3) Do households have interdependencies within/outside the village? (if any) in which agricultural products? And Who have the most tendency in agricultural transactions within/outside the village?

1.3 Objective of the Study

This dissertation focuses on analyzing the impact of irrigation on production and productivity of sticky rice and enhance the interdependency among households through agricultural transactions in isolated village. the main aims of this dissertation are:

(1) to examine the impacts of irrigation systems on sales value, total production, and productivity of sticky rice, as well as household consumption;

(2) to estimate the impact of households' access irrigation in different period of times on sticky rice productivity;

(3) to analyze key characteristics of interdependency among households in the same community through agriculture transactions in order to capture village economy's performance pattern.

1.4 Significance and Limitation

1.4.1 Significant of this Dissertation

This research will benefit the Lao and Vietnam government, including their policy makers as well as researchers. For the policy makers, 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. This kind of study is essentially crucial for rural development as sticky rice plantation which has been the main income source of the majority of the Lao population. Nonetheless, in compare to other ASEAN countries sticky rice production still remains low. Therefore, the government has spent more efforts on irrigation system improvement aiming at increasing the sticky rice productivity.

The knowledge of an analysis interdependency among households in rural areas is a crucial factor to better understanding the rural households' characteristic, pattern of their production and trade transactions. This study is useful information for local government to formulate district or villages' poverty eradication strategy, especially isolated villages, where households cannot access regular market. As a result, it will lead to an improvement of households' livelihood and sustains poverty eradication in developing country. This study will provide a great support on poverty reduction in rural areas for both in Lao PDR and Vietnam by elaborating the interdependency among households within and outside the villages, this information will shed some lights for local government to better understanding the potential production and the shortage of each local area. As a result, they can formulate the suitable poverty eradication in each area. Finally, the author hopes that this research can be used to contribute to academic research and discussion for future scholars who are interested in this problem.

1.4.2 Scope and Limitation

This dissertation will focus on two points, first, the impact of irrigation on sticky rice production and productivity. There are still limited quantitative evidences on the impacts of irrigation on the rice production in Lao PDR. This dissertation not only fills the gap but it also utilizes a large set of panel data based on the Lao Expenditure and Consumption Survey (LECS) conducted every five years (2002/2003, 2007/2008 and 2012/2013). Second, the interdependency among households through village transactions. This work uses qualitative village input-output tables are constructed by two village input-output tables of Dang village in Vietnam and Houey Nambak village in Lao PDR surveyed 2018. To the best of our knowledge, there has been a limited previous empirical studies. As we known, there is only one work written by Hongsakhone and Ichihashi (2018). This paper has three differences from previous studied as (1) it compares transactions conducted within and outside the villages in Lao PDR and Vietnam; (2) it is able to identify which households are real suppliers and demanders in agricultural products in two countries; and (3) it provides precise counts of the total transactions of each trading partner.

1.5 Structure of Dissertation

The structure of dissertation consists of five chapters which is demonstrated as in Figure 1.1:

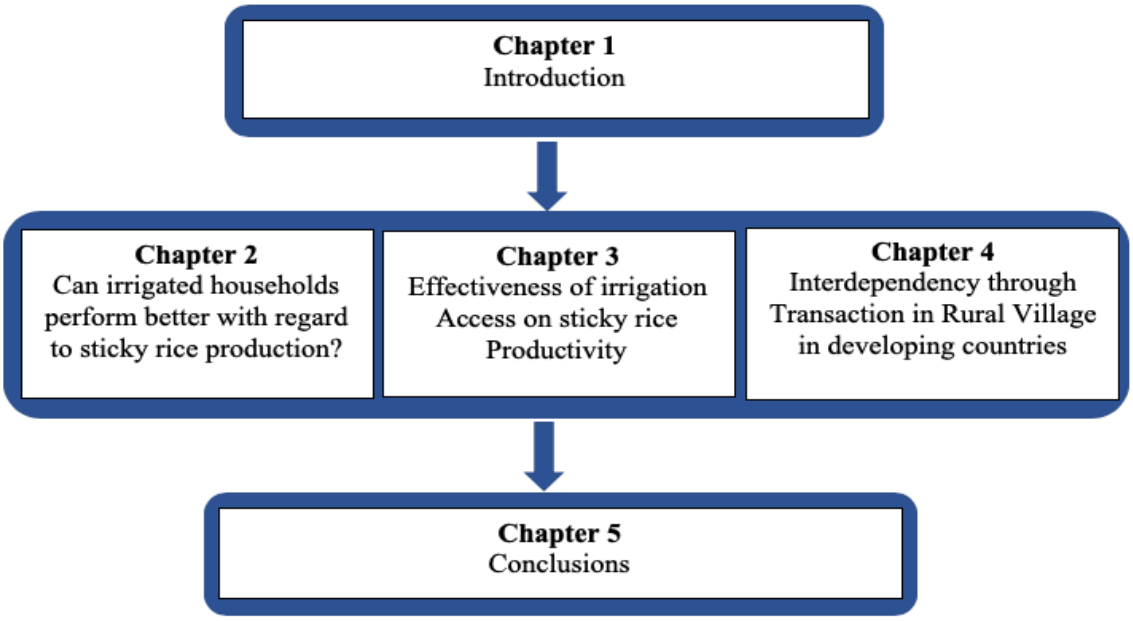


Figure 1.1: Structure of dissertation

Chapter 1 provides the background of study, problem statement, research objective, significant of the research and scope limitation of dissertation. For Chapter 2 and 3 use the same data source from LECS to estimate the impact of irrigation on sticky rice production and productivity by applying PSM and DID method. First, the comparison of the impact of irrigated households and non-irrigated households on sticky rice production and productivity. Then, second, continuing to investigate the impact of irrigation on sticky rice productivity when households extend their irrigation access from one period to two period of surveys. Chapter 4 aims to examine household interdependency through village transactions by using the qualitative input-output tables of Dang village (Vietnam) and Houey Nambak village (Lao PDR) surveyed 2018. Finally, Chapter 5 provides a summary of core findings in three empirical Chapters of dissertation. Then gives some policy implications.

Chapter 2

Can Irrigated Households Perform Better with regard to Sticky Rice Production? Evidence from Lao PDR

2.1 Introduction

The agriculture sector is the key driving force that stimulates economic development in developing countries, especially in African and Asian regions. 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, and the Asian region is the largest rice producer and consumer in the world. In Asian countries, total rice production was approximately 461.9 million tons in 2018, corresponding to 90.32% of the global rice production (Food Outlook, 2018). Meanwhile, rice plants need more water than many other types of agricultural products and most rice cultivation is rainfed, which is directly affected by climate change. Therefore, the governments in many countries introduce irrigation to ensure rice growth in both seasons and to improve rice production and productivity.

Irrigation is the single most important component of sustainable agricultural production as it improves agricultural productivity and indirectly improves the diversity of household food consumption, food security, and income generation, which reduce poverty (Nonvide, 2018a; Khan & Shah, 2012; Gebregziabher et al., 2009 and Hussain and Hanjra, 2004). For instance, Nonvide (2018a) applied the ordered probit model with sample selection to examine the impact of irrigation on reducing food insecurity among rice farmers in Benin, and the author found that food security in irrigated households is 14% greater than that in non-irrigated households. Gebregziabher et al. (2009) applied propensity score matching (PSM) to estimate the impact of irrigation on poverty reduction by using the average household income in Ethiopia. Their findings suggest that irrigated household income is, on average, 50% higher than that of non-irrigated households, which is equivalent to 462 to 520 USD per year. Hence, access to irrigation reduces food insecurity. In addition, Hussain and

Hanjra (2004) and Khan and Shah (2012) found strong linkages (direct and indirect linkages[1]) between irrigation and poverty reduction.

Most literatures focus on the impacts of irrigation on agricultural production and productivity in African countries. For example, Dillon (2011a) estimated the effects of irrigation on household consumption, agricultural production, and productivity in Northern Mali. The PSM and Difference-in-differences with PSM (DID_PSM) were applied using data in two periods from 1997/98 to 2005/2006. It is found that irrigation positively affects all outcome variables in both estimators, but the effect of the DID_PSM estimator is less than that of the PSM estimator. In general, irrigation improves total household consumption by approximately 1,635 to 1,725 USD, total agricultural production by approximately 1.25 tons to 1.90 tons per household, and productivity by approximately 2.5 tons and 3.8 tons per hectare. Furthermore, another work of Dillon (2011b) assessed whether differences in the scale of irrigation have different impacts on poverty and agricultural production. The PSM results show that irrigation has a positive impact on agricultural income that ranges 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. Even though small scale irrigation has larger impacts on agricultural production and income than large scale irrigation, large scale irrigation has a larger impact on consumption per capita. In addition, another study by Nonvide (2017) tested the impact of irrigation on rice productivity in Benin by applying the Heckman selection model. The results report that irrigated households can improve rice productivity by approximately 57% compared to their non-irrigated counterparts. Furthermore, in 2018, the same author re-examined the impact of irrigation on rice productivity by employing an endogenous switching model and found that households with irrigation can increase their rice productivity by approximately 2,746 kg per hectare or approximately 790 USD compared to their non-irrigation counterparts. Babatunde et al. (2017) estimated the determinants of the productivity gap[2] of rain-fed and irrigated rice plantations in Nigeria. Rice productivity increased with both non-irrigated and irrigated rice, but the magnitude of irrigated rice is

[1] Direct linkages between irrigation and poverty reduction mean that irrigation has a positive impact on poor farmers by increasing their agricultural productivity, income, consumption, and saving; indirect linkages means the impacts occur through regional, national and economic effects. (Hussain and Hanjra, 2004 and Khan &Shah, 2012).

[2]The yield gap is the difference between potential and actual yields (Babatunde et al., 2017).

higher than that of non-irrigated rice. On average, households with irrigated rice can gain 45,945 Naira (Nigerian currency) per hectare, whereas households with no irrigated rice only gain 28,147 Naira per hectare. Moreover, Bidzakin et al. (2018) suggests that irrigation utilization should be intensely promoted to rice farmers to increase rice productivity and profits. Additionally, a study by Mutiro and Lautze (2015) showed that 59% of the irrigation in southern Africa was considered to be successful because of their performance, especially their management measures, irrigation systems, and crop mixes.

In Asian countries, the impacts of irrigation on agricultural productions have also been examined by some researchers. Bell et al. (2015) analyzed the benefits of irrigation on rice productivity in Bangladesh using the logarithmic form of the Cobb-Douglas production function with a selection of plot-level data and found that access to irrigation has a larger influence on rice productivity in the dry season than in other seasons. By using a similar method, Yu and Fan (2011) investigated rice production in Cambodia from 2004 to 2007 and found that households with access to irrigation experienced significantly increased rice production by an average 16% in a wet season and 23% in the dry season. Huang et al. (2006) applied a fixed-effects model to study the impacts of irrigation on agricultural performance in China by using different types of agricultural products such as wheat, maize, and cotton and found that irrigation increases the productivity of all products. Particularly, irrigation improves wheat, maize, and cotton productivity by an average of 17.7%, 29.4%, and 28.4%, respectively.

However, some researchers reported mixed results on the impacts of irrigation on agricultural products both in African and Asian regions. Dillon et al. (2011) applied the hedonic method[3] to estimate the impacts of irrigation on plot values in two cross-sections (1996 and 2003) in Nepal and found that access to irrigation had a positive impact on land values; notably, the land values in 1996 were increased by approximately 14.3%, and those in 2003 were increased by 19.6%. In other words, 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 (2004) found mixed results on the impact of irrigation on

[3] The hedonic method is used to measure of value of farmlands after they gain access to public investments such as roads, irrigation and so on (Dillon et al., 2011).

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 (1999/2000) 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 approximately 18%.

Meanwhile, there are some studies that did not find a linkage between irrigation and agricultural products. Travers and Ma (1994) found that in 1987 in poor areas of China, machinery and fertilizer raised the incomes of farmers, but the benefits of irrigation investments are lower than their costs. By using the share of irrigated areas as a proxy for irrigation, Zhu (2004) found no evidence of the impacts of irrigation on the productivity of wheat and corn in China from 1979 to 1997. In addition, Fan et al. (2000) suggested that public investments in irrigation in a rural area of India are not efficient. Jin et al. (2002) found a negative impact of irrigation on the total factor productivity of rice and maize and no evidence of a linkage between irrigation and the total factor productivity of wheat in China from 1980 to 1995.

Due to the mixed results on the impacts of irrigation on agricultural production and limited related research in Lao PDR. This study seeks to confirm the impacts of irrigation on sticky rice production and productivity in the Lao PDR by employing propensity score matching (PSM) using a large data set of panel data from LECS (2002/2003, 2007/2008 and 2012/2013). The main question and objective of this chapter addressed in this research including the following: Has irrigation played an important role in improving sticky rice production and productivity in the case of Lao PDR? The objectives of this study is to examine the impacts of irrigation systems on sales value, total production and productivity of sticky rice, as well as household consumption.

The next section details the agricultural production, rice production and irrigation systems in the Lao PDR. Section 2.3 provides the data source and descriptive analysis of the comparison groups. The methodology and model are described in Section 2.4. Section 2.5 discusses the estimated results of the impacts of irrigation on sticky rice production and productivity. The last section sums up the main findings in this chapter and provides possible policy implications.

2.2 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 (World Bank, 2018). In 2016, GDP per capita was 2,338 USD, and GDP was 2,740 million USD (Table 2.1). 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 (Ministry of Agriculture and Forestry (MAF), 2018). A large planted area has transformed this country into a potentially important area for agricultural production in the Association of Southeast Asian Nations (ASEAN) region.

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 1,943 million USD in 2010 to 2,740 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 become 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 2.1).

Table 2.1: 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 (%)	77.1	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	4.1	4.15
Total rice export (Million USD)	1.9	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: UNCTAD Stat database, 2018; ADB, 2017; MAF and MoIC, 2018.

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 (World Bank, 2018). Since rice plantation ensures food security and serves as a primary source of income, the government has invested significant effort toward improving the 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 2.1).

However, the rice productivity of Lao PDR is relatively low compared to other ASEAN countries, especially Vietnam, Indonesia, and Malaysia. More specifically, the productivity of Lao rice was 4.02 tons per hectare in 2014 and increased slightly to 4.34 tons per hectare in 2018 (see Table 2.2). 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 (Pandey, 2001; Sipaseuth et al., 2001; MAF, 2018; and World Bank, 2018). Additionally, MAF (2018) 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, with service area sizes ranging from 1 hectare to over 300 hectares; (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 (FAO, 2018)

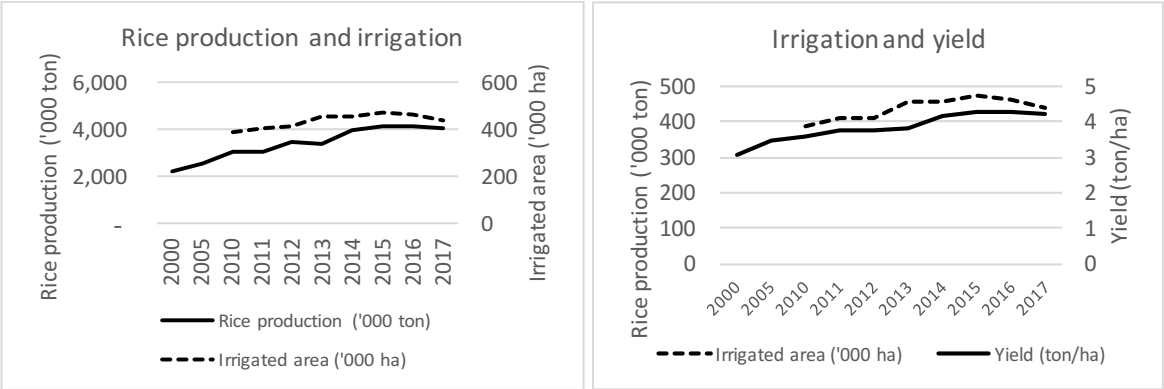
Table 2.2: Rice productivity in ASEAN countries from 2014 to 2018

Country	**2014**	**2015**	**2016**	**2017**	**2018**
Vietnam	5.64	5.67	5.6	5.58	5.64
Indonesia	5.13	5.17	5.24	5.24	5.39
Malaysia	4.29	4.37	3.98	4.26	4.5
Lao PDR	4.02	4.04	4.26	4.26	4.34
Myanmar	3.9	3.97	3.91	3.86	4
Philippines	3.98	4.02	3.86	3.93	3.98
Thailand	3.15	3.04	2.85	3.03	3.12
Cambodia	3.16	3.17	3.09	3.12	3.1
Brunei	1.45	1.45	1.75	1.94	1.95
Singapore	-	-	-	-	-
ASEAN	**4.31**	**4.32**	**4.33**	**4.35**	**4.42**

Source: ASEAN plus three food security information system, annual ACO report 2018. Available: http://www.aptfsis.org/publication

In 2015, it was estimated that the irrigation area covered approximately 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 (approximately 62%) are wet-season irrigated areas, and 180,220 hectares (approximately 38%) are dry-season irrigated areas (MAF, 2017). 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 (MAF, 2017 and FAO, 2018).



Source: Ministry of Agriculture and Forestry, 2018.

Figure 2.1: The relation among rice production, productivity (yield) and irrigation areas

Figure 2.1 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.

2.3 Data Source

This chapter utilizes the data from the "Lao Expenditure and Consumption Survey" (LECS). The purpose of the LECS is to observe poverty and income distribution by using household consumption, investments, production and income from agriculture and household businesses. The survey is conducted every five years by the National Statistical Bureau (NSB). The first round of the LECS was conducted in 1992/1993 (known as LECS 1), the second round was conducted in 1997/1998 (LECS 2), the third round was conducted in 2002/2003 (LECS 3), the fourth round was conducted in 2007/2008 (LECS 4), and the fifth round was conducted in 2012/2013 (LECS 5). In each LECS, approximately 15 to 16 households per village are selected, of which 8 households are randomly selected from the

previous LECS, and another 8 households are randomly selected among the remaining households in the village. The selection of the sample households is based on the number of existing households in the village at the time of the survey. 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 8,092, 8,296, and 8,226 households, respectively (Table 2.3).

Table 2.3: Summary of LECS 3, LECS 4, and LECS 5

LECS 3 (2002/2003)	**LECS 4 (2007/2008)**	**LECS 5 (2012/2013)**
136 districts	135 districts	135 districts
540 villages	518 villages	515 villages
8,092 households	8,296 households	8,226 households

Data source: The Lao Expenditure and Consumption Survey (LECS) from 2002/2003 - 2012/2013.
Note: The number of villages decreased from 540 to 518 villages due to the allocation and unification of smaller villages into larger villages in every province (LECS 5 report, 2016).

To estimate the impacts of irrigation on household sticky rice production and productivity, this chapter uses panel data. First, we include the total number of households that grow sticky rice in each survey: there are 6,007 households, accounting for 74.23% of the total observations, in LECS 3; 6,091 households (73.42%) in LECS 4; and 5,671 households (69%) in LECS 5 (Table 2.4). Then, the data are converted into a panel data set (not repeated cross-sectional data). Finally, 747 households match in LECS 3, LECS 4 and LECS 5, and 487 villages match in each survey. This research also uses the village-level questionnaire in each LECS to collect the paddy sticky rice prices.

Table 2.4: Number of households with and without irrigation in each survey

Household	**LECS3 (8,092)**	**LECS4 (8,296)**	**LECS5 (8,226)**	**Panel (2,241)**
No irrigation	4,287	4,414	2,001	936
Irrigation	1,689	1,582	1,673	516
Total	5,976	5,996	3,674	1,452
Sticky rice	6,007	6,091	5,671	747

Data source: The Lao Expenditure and Consumption Survey (LECS) from 2002/2003 - 2012/2013.

By using the panel data from three time periods, we can compare 936 households with no irrigation and 516 households with irrigation at the same time in the statistical analysis. The panel data are divided into two groups - G0 and G1. G0 is the control group. The households in G0 do not irrigate in any of the three periods of the LECS. G1 is the treatment group in which the households irrigate in all three periods of the LECS, as shown in Table 2.5.

Table 2.5: Comparison groups of panel data

Groups	Group's name	1 = Access to irrigation, 0 = No irrigation		
		LECS3 (2003)	LECS4 (2008)	LECS5 (2013)
G0	Control	0	0	0
G1	Treatment	1	1	1

2.3.1 Descriptive Statistics

The mean difference test of the potential covariates and outcomes are shown in Table 2.6. The imbalance of some household characteristics between comparison groups exists due to the existence of 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 (Tran and Goto, 2019). 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 or the harvest area. For potential outcomes, such as the sticky rice sales value, total production and productivity and household consumption, irrigated households have greater values than non-irrigated households.

The definition and measurement of the potential covariates and outcomes are explained in Table 2.7. Based on the literature, factors that possibly affect a household's decision to access irrigation can be household and land characteristics such as the household head's age, education, and gender that were used in Nonvide (2018b) and Khor and Feike

(2017); and household size, ethnicity, and land characteristics (harvest area is used to represent land characteristics in this paper) that were used in Bidzakin et al. (2018), Dillon (2011b), and Huang et al. (2006). In addition, the potential outcomes of this study are the sales value, total production and productivity of sticky rice and household consumption, which were also used in Dillon (2011a) and Dillon et al. (2011)

Table 2.6: Descriptive statistics

Variables	Irrigation			No irrigation			Difference			
	Observations	**Mean**	**S.D**	**Observations**	**Mean**	**S.D**	**Observations**	**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 (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= 1,452			

Data source: The author's calculations from the Lao Expenditure and Consumption Survey (LECS) from 2002/2003 - 2012/2013.*** Significant at the 1% level; 1 USD = 8,700 LAK. Note: [a] Due to missing data on the education variable, the total observations decreased from 1,452 to 1,242 households: 459 irrigated households and 783 non-irrigated households.

Table 2.7: Definition and unit 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	1,000 LAK
Total production	Sticky rice production	Kg
Productivity	Sticky rice production divided by harvested area	Kg/ha
Consumption	Household consumption	1,000 LAK

2.4 Methodology

Propensity score matching (PSM) was introduced by Rosenbaum and Rubin (1983): 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 and productivity, 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 (Caliendo et al., 2005). In this paper, in order to mitigate the bias from the treatment effect, we estimate observational data by balancing the observed covariates in the pretreatment between the comparison groups by matching 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. Propensity score matching can help researchers to reconstruct the counterfactuals by using observational data to remove bias (Li, 2012).

To reinforce the findings of the impacts of irrigation and to address the selection bias, this chapter applies PSM to estimate the average treatment effect on the treated (ATT). Based on Rosenbaum and Rubin (1983), Caliendo et al. (2005), and Khandker et al., (2010), the ATT can be estimated as follows:

$$ATT_{PSM} = E_{P(X)|T_i=1}\{E[Y_i(1)|T_i = 1, P(X)] - E[Y_i(0)|T_i = 0, P(X)]\} \quad (2.1)$$

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 production 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).

2.5 Empirical Results

Table 2.8 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 that our estimation performed by using the propensity score is well matched.

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, total production and productivity of sticky rice, but not with household consumption see Table 2.9. 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 coefficient of the sales value of sticky rice is positive and significant at the 1% level. The finding indicates that irrigated households improve their

Table 2.8: 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.

sticky rice revenue or sales value by an average of 2.37 million LAK (approximately 273 USD[4]), representing an increase of 38% compared to non-irrigated households. Furthermore, the coefficient of sticky rice production (total production) is also positive and significant at the 1% level. Irrigated households produce approximately 1,138 kg more sticky rice production, 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, representing an increase from 106% per season compared to non-irrigated households. Similar to the works of Bidzakin et al., (2018), Nonvide (2017), Babatunde et al. (2017), Bell et al. (2015), and

[4] Based on the exchange rate on 2nd August 2019 from the Bank of the Lao PDR, where 1 USD = 8,700 LAK (https://www.bol.gov.la/)

Dillon (2011), our findings provide robust evidence of the positive impacts of irrigation on household sticky rice production and productivity.

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. Additionally, majority of rural areas in developing countries including Lao PDR, where households cannot access regular markets. Therefore when the production of households increase or the production surplus, they will be stocked them as wealth or capital accumulation (Bhattarai et al., 2001). Furthermore, sticky rice product is considered to be necessary goods which has a small elasticity of demand when the production of household or income increases, they will have a minor change on the amount of stick rice consumption. This result is in line with the previous finding by Dillon et al. (2011), 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 and productivity, we also utilize the entropy balancing method (Hainmueller and Xu, 2013). 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.

Table 2.9: 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)	2213.456	***	374.2327	2375.16	***	676.99	2168.34	***	525.99
Total production (Kg)	1114.259	***	161.093	1138.42	***	274.34	1051.94	***	222.54
Productivity (Kg/ha)	2595.632	***	191.9188	2446.60	***	294.02	2527.51	***	230.88
Consumption ('000 LAK)	45.56766		66.46959	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	1,242			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 = 8,700 LAK.

2.6 Conclusions and Policy Implications

This chapter focuses on analyzing the impacts of irrigation on sticky rice production and productivity by employing PSM method. In the panel data, three LECS surveys- 2002/2003, 2007/2008, and 2012/2013- were divided into two groups to examine the effect 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. 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 1,138 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. However, no evidence was found to support the impact of irrigation on household consumption in this chapter, 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. Additionally, majority of rural areas in Lao PDR, where households cannot access regular markets. Therefore when the production of households increase or the production surplus, they will be stocked them as capital accumulation. Furthermore, sticky rice product is considered to be necessary goods which has a small elasticity of demand when the production of household increases, they will have a minor change on the amount of stick rice consumption. 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 production and productivity in the case of the Lao PDR, which is consistent with theory and the previous literature review. Some policy implications can be derived from this chapter 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.

Chapter 3

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

3.1 Introduction

Providing a food supply to meet the demands of rapidly growing populations, as well as economic development, is an emerging issue. According to the World Bank (2018), 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. 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 (Food Outlook, 2018).

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 (Stirzaker and Pittock, 2014; Bell et al., 2015; Van Rooyen et al., 2017 and World Bank, 2018). 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 (Food and Agriculture Organization (FAO) of the United Nations, 2016).

Upgrading irrigation systems has become a priority of governments, particularly in developing countries. For instance, from 1969 to 1990, the Indonesian government invested a large amount of money in research to increase the use of irrigation for agricultural production. As a result, the share of output growth was 85% for rice, 93% for cassava, and 71% for soybeans (Rosegrant et al., 1998). Improving agriculture and enhancing productivity as a result of irrigation could lead to income generation and poverty alleviation (Nakawuka et al., 2018; Van Rooyen et al., 2017; Mutiro and Lautze, 2015; Domenech,

2015; Bacha et al., 2011 and Hussain and Hanjra, 2004). For example, in Sub-Saharan Africa, households with irrigation can generate a large potential income of approximately 14 billion USD to 22 billion USD per year (Xie et al., 2014).

Many studies, including Huang et al. (2006); Watto and Mugera (2015); Nguyen et al. (2017), Yu and Fan (2011); Nonvide (2017) and Nonvide (2018), have found that irrigation is the main driving force for enhancing agricultural production and productivity. For instance, Huang et al. (2006) found that in China, irrigation increased productivity for wheat by approximately 17.7%; for maize, irrigation increased productivity by 29.4%; and for cotton, irrigation increased productivity by 28.4%, irrigation increased household and village revenues by 76% and 42.9%, respectively. Similarly, in Pakistan, Watto and Mugera (2015) showed that irrigation could increase cotton production by 19%. Nguyen et al. (2017) indicated that irrigation increases the land area for rice, corn, and potato in Vietnam. Yu and Fan (2011) 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 (2017) examines the effect of irrigation on rice productivity in Benin. His finding suggests that households with irrigation can increase their rice productivity by approximately 57% compared to non-irrigation households. Moreover, Nonvide (2018) also showed that, compared to households without access to irrigation, households with access to irrigation could increase rice productivity by 2,746 kg per hectare, or by approximately 789.54 USD.

In southern Africa, 59% of irrigation systems have been considered successful as a result of the management systems and irrigation methods employed, the geography and the cultivation of mixed-crops (Mutiro and Lautze, 2015). Furthermore, in Ghana, Adeoti (2009) found that a unit increase in the irrigated area led to a 74.9% increase in per capita income. Household access to irrigation technology increased per capita income by 28.1% compared to households that did not access this technology. In Nigeria, Babatunde et al. (2017) showed that an average rice farmer with access to irrigation earns a gross margin greater than the average rice farmer without access to irrigation (45,945 N[5] per hectare compared to 28,147 N per hectare).

[5] N is currency of Nigeria (Naira)

On the other hand, many empirical studies in the past have failed to find a strong linkage between irrigation and agricultural production and/or income from production. As these studies used public investment to examine the effect of irrigation on agricultural production, they did not determine the impact of using irrigation on agricultural production. For instance, Dillon et al. (2011) estimated the impact of public investment in irrigation in Nepal. They applied different data sources and methodologies. Based on panel data with generalized method via the moments (GMM) approach, they found that irrigation did not have a significant impact on consumption growth, poverty, or agricultural income.

Similarly, Zhu (2004) proxied irrigation by irrigated area divided by arable land area. This study did not find evidence of a relationship between irrigation and the output of wheat and corn production between 1979 and 1997 in China. Moreover, Travers and Ma (1994) applied data from 1980-1987 in China to estimate the influence of various factors on total agricultural production. They found that the factors that increase total agricultural production include technology and fertilizer, but not irrigation. Additionally, Jin et al. (2002) found that irrigation did not have a significant impact on wheat, but it had a significant negative impact on China's total factor productivity for rice and maize from 1980 to 1995.

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 paper attempts to estimate the impact of irrigation on sticky rice productivity in Lao PDR. The impact is expected to be positive. In any case, given the results of previous studies, it is unclear what effect irrigation has.

Compared to the existing literature on irrigation and its impact on any type of agricultural product, this study is different in several aspects. First, most studies mentioned above used ordinary least square (OLS) to estimate effects, and the methodologies that they used exhibited selection bias toward the treatment group because the outcome can be overestimated or underestimated, thus leading to misleading policy implications (Mendola, 2007 and Li, 2012). This chapter applies the difference-in-differences (DID) method with a fixed-effect model to analyze the impact of irrigation on sticky rice productivity. 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 canceled out in the regression. Meanwhile, the fixed-effect model accounts for not only the unobserved time-invariant heterogeneity but also the heterogeneity in observed characteristics over multiple periods. Second, 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. Third, this study utilizes panel data based on LECS, which is conducted every five years (2002/2003, 2007/2008 and 2012/2013), and sticky rice production is taken to account. The main question and objective of this chapter addressed in this research include the following: Is any increase in sticky rice productivity attributable to sustainable irrigation if households maintain long term to access irrigation? The objectives of this study is to estimate the impact of households' access irrigation in different period of times on sticky rice productivity.

The remainder of this paper is organized as follows: the next section provides a brief discussion of rice production and irrigation in Lao PDR. Section 3.3 describes the data source and the descriptive statistics. Next, section 3.4 discusses the methodology and model. Section 3.5 presents the empirical results. Finally, section 3.6 provides conclusions and policy recommendations.

3.2 Rice Production and Irrigation in the Lao PDR from 2010-2017

Lao PDR is the landlocked country with 236,800 km2 of the land area, of which 9,000 km2, corresponding to 4%, is cultivatable land area. Of this, approximately 75% of the cultivatable land area is used for rice production (Yoshida et al., 2003 and World Bank, 2018). According to IRRI (2012) and FAO (2013), in 2007, one of the highest per capita rice consumptions in the world was in the Lao PDR, accounting for 163 kg per year, and sticky rice is the main food crop of the Lao people. Therefore, rice is a main staple food crop that has experienced rapid growth in the past two decades, and the country has been transformed from an importer to an exporter (Welcher and Prasertsri, 2019).

Regarding Table 3.1, during the 2010-2017 period, rice production in the Lao PDR significantly increased, which was the result of expanded cultivation areas and productivity improvements. Agricultural land increased from 2.22 million hectares in 2010 to 2.49 million hectares in 2017, leading to an increase in rice production from 3.07 million kg in

2010 to 4.06 million kg in 2017. Due to the higher production, the Lao PDR could achieve self-sufficiency in rice, and it experienced a surplus that could be exported. In 2016, the export value of Lao rice was 33.67 million USD, which accounted for 5 percent of total agricultural product exports (MoIC, 2018). Although rice production has been increasing since 2010, the productivity was relatively low at only 3.59 tons per hectare in 2010. The growth rate of rice productivity was negligible at only 2.22 % per year during the 2010-2013 period. However, the trend of the irrigated area is consistent with the changes in rice productivity (Table 3.1). In other words, an increase in the irrigated land area from 0.41 million hectares in 2012 to 0.46 million hectares in 2014 resulted in an increase in productivity from 3.74 tons per hectares in 2012 to 4.18 tons per hectares in 2014. In 2015, the total irrigated area was estimated at 473,756 hectares, accounting for 31% of the arable land in the whole country.

Table 3.1: Rice production, productivity and irrigated areas from 2010-2017

Year	2010	2011	2012	2013	2014	2015	2016	2017
Agricultural land (Million ha)	2.220	2.277	2.299	2.335	2.369	2.369	2.369	2.487
Irrigated area (Million ha)	0.386	0.408	0.413	0.458	0.455	0.473	0.461	0.438
Rice production (Million kg)	3.070	3.065	3.489	3.414	4.002	4.102	4.148	4.055
Productivity (Ton/ha)	3.59	3.75	3.74	3.83	4.18	4.25	4.26	4.21

Source: Ministry of Agriculture and Forestry, 2018.

Over 80% of rice cultivation occurs via rainfed farming; however, rainfall changes year by year and results in fluctuating rice production (Yoshida et al., 2003 and Welcher and Prasertsri, 2019). Therefore, the Lao government has introduced irrigation systems to stabilize the rice production in wet and dry seasons and to increase rice productivity. Irrigation development is one government strategy to expand rice cultivation and to diversify agricultural production. The total irrigated area has continuously increased from 408,676 hectares in 2011 to 473,756 hectares in 2015 and slightly decreased to 438,993 hectares in 2017 (Table 3.2). Due to lack of proper maintenance measures, some irrigation systems cannot be regularly used. Additionally, high electricity costs are another problem and account for 10% of the crop production cost per hectare, on average (Sacklokham, 2016). As a result, some farmers do not grow rice in dry reason. The largest irrigated area is in the central region of the Lao PDR, which accounted for 56.18% of the total irrigated area during the 2011-2017 period. Among 18 provinces, Savannakhet has the largest irrigated area of

74,860 hectares, which covers 17.05% of the total irrigated area in 2017. It is followed by Vientiane and Attapeu provinces, accounting for 13.62% and 8.94%, respectively.

Table 3.2: Total irrigated area by province from 2011-2017 (Unit: hectare)

Province name	**2011**	**(%)**	**2013**	**(%)**	**2015**	**(%)**	**2017**	**(%)**
Northern region	**104,018**	**25.45**	**107,134**	**23.38**	**99,945**	**21.10**	**102,565**	**23.36**
Phongsaly	8,657	2.12	9,028	1.97	9,553	2.02	10,214	2.33
Luangnamtha	10,296	2.52	19,580	4.27	17,399	3.67	14,455	3.29
Oudomxay	14,464	3.54	16,002	3.49	15,489	3.27	15,530	3.54
Bokeo	17,529	4.29	14,793	3.23	17,156	3.62	14,594	3.32
Luangprabang	14,268	3.49	15,560	3.39	8,121	1.71	14,632	3.33
Huaphanh	18,749	4.59	15,326	3.34	15,560	3.28	16,340	3.72
Xayabury	20,055	4.91	16,845	3.68	16,667	3.52	16,800	3.83
Central region	**238,169**	**58.28**	**269,087**	**58.71**	**256,667**	**54.18**	**235,179**	**53.57**
Vientiane. C	59,270	14.50	63,132	13.77	45,645	9.63	37,617	8.57
Xiengkhuang	12,576	3.08	17,097	3.73	11,117	2.35	11,323	2.58
Vientiane	50,890	12.45	54,108	11.81	86,000	18.15	59,786	13.62
Borikhamxay	12,223	2.99	16,543	3.61	55,089	11.63	14,246	3.25
Khammuane	28,703	7.02	29,277	6.39	15,918	3.36	28,859	6.57
Savannakhet	74,507	18.23	88,930	19.40	34,059	7.19	74,860	17.05
Xaysomboun	-	-	-	-	8,839	1.87	8,488	1.93
Southern region	**66,489**	**16.27**	**82,104**	**17.91**	**117,144**	**24.73**	**101,249**	**23.06**
Saravanh	28,310	6.93	33,621	7.34	28,790	6.08	27,196	6.20
Sekong	4,800	1.17	5,322	1.16	8,876	1.87	19,359	4.41
Champasack	29,853	7.30	38,461	8.39	40,341	8.52	15,464	3.52
Attapeu	3,526	0.86	4,700	1.03	39,137	8.26	39,230	8.94
Total	**408,676**	**100**	**458,325**	**100**	**473,756**	**100**	**438,993**	**100**

Source: Ministry of Agriculture and Forestry, 2018.

3.3 Data Source

This chapter applied dataset from three periods of the LECS which is the same data source used in Chapter 2. To estimate the impact of households' access irrigation in different period of times on sticky rice productivity, we apply panel data techniques by dividing the households into three subgroups, namely, G0, G1, and G2. The group G0 is defined as the control group because the household status in G0 has no access to irrigation for all the three periods of surveys. G1 and G2 are treatment groups consisting of households that have access to irrigation during one and two periods of the surveys, respectively, as shown in Table 3.3.

Table 3.3: Three subgroups of panel data (G0 to G2)

Group	**Group's name**	**1 = Access to irrigation, 0 = No irrigation**		
		LECS3 (2003)	**LECS4 (2008)**	**LECS5 (2013)**
G0	Control	0	0	0
G1	Treatment		0	1
G2	Treatment	0	1	1

3.3.1 Descriptive Statistics

The total sample size is 912 households, of which 288 households have access to irrigation and 624 households have no access to irrigation, as shown in Table 3.4. The t-test shows that the mean difference in the potential covariates and outcomes between households with irrigation (G1) and without irrigation (G0). Since irrigation interventions were not randomly implemented in each village, selection bias occurred in our sample size, and imbalances in the selection covariates were found, especially for harvest areas in 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 3.4: The mean difference of households with irrigation (G1) and without irrigation (G0)

Variables	Irrigation			No irrigation			Difference			
	Observations	Mean	S.D	Observations	Mean	S.D	Observations	Mean		S.E
Potential covariates										
Household size	288	5.97	2.50	624	5.95	2.41	912	0.03		0.18
Age of household head	288	48.19	10.92	624	48.72	11.64	912	-0.53		0.79
Education of household head (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
Gender of household head (1= male)	288	0.98	0.15	624	0.96	0.20	912	0.02		0.01
Status of household head (1= married)	288	0.97	0.16	624	0.95	0.21	912	0.02		0.01
Harvest area (Hectares)	288	1.24	0.79	624	1.77	1.39	912	-0.53	***	0.07
Potential outcomes										
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. *** Significant at 1% level;

1 USD = 8,700 LAK.

Table 3.5: The mean difference of households with irrigation (G2) and without irrigation (G0)

Variables	Irrigation			No irrigation			Difference			
	Observations	Mean	S.D	Observations	Mean	S.D	Observations	Mean		S.E
Potential covariates										
Household size	132	6.11	2.47	936	6.12	2.44	1068	-0.01		0.23
Age of household head	132	48.14	12.01	936	46.80	11.94	1068	1.34		1.12
Education of household head (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
Gender of household head (1= male)	132	0.98	0.15	936	0.96	0.20	1068	0.02		0.01
Status of household head (1= married)	132	0.94	0.24	936	0.95	0.22	1068	-0.01		0.02
Harvest area (Hectares)	132	1.15	0.69	936	1.70	1.29	1068	-0.55	***	0.07
Potential outcomes										
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. *** Significant at 1% level; 1 USD = 8,700 LAK.

Table 3.5 presents the mean difference test of potential covariates and outcomes between the treatment group (G2) 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.

Despite the small landholdings of irrigated households compared to non-irrigated households, the sticky rice productivity of the treatment group is higher than that of the control group in both comparisons (G1 vs G0 and G2 vs G0).

Table 3.6 reports the definition and measurement of potential outcomes and a set of covariate variables in estimating the impact of irrigation on sticky rice productivity. The estimation consists of five potential covariates: age, education, and ethnic group of household head; household size; and harvest area of sticky rice. The previous literature suggests that all five covariates can explain the decision of households to access the irrigation (Nonvide, 2017; Khor and Feike, 2017 and Dillon, 2011a). Based on the literature review, this paper also selects the sales value, total production, and productivity of sticky rice, in addition to the household consumption, as potential outcomes (Dillon, 2011b and Dillon et al., 2011).

Table 3.6: 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	
Harvest area	Area for harvested sticky rice production	Hectares
Potential outcome		
Sales value	Sticky rice production multiplied by average price in each year survey	1,000 LAK
Production	Sticky rice production	Kg
Productivity	Sticky rice production divided by harvested area	Kg/ha
Consumption	Household consumption	1,000 LAK

3.4 Methodology

To test the hypothesis that irrigation improves sticky rice productivity among participating households, this study applies the difference-in-differences (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 posttreatment 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 (Khandker et al., 2010 and Gertler et al., 2016) since the fixed-effect estimator controls 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:

$$Y_{it} = \beta_0 + \beta_1 Irrigation\ group_i + \beta_2 Time_t + \beta_{DID}(Irrigation\ group_i * Time_t) + \beta X_{it} + \alpha(year) + a_i + \mu_{it} \quad (3.1)$$

where Y_{it} represents the outcome variables of interest: sales value, total production and productivity of sticky rice, as well as 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.

3.5 Empirical Results

In this section, we report the estimation results for the impacts of irrigation on the sales value, total production and productivity of sticky rice, in addition to the household consumption, by using the OLS and DID-fixed effect methods. The results are divided into two comparison groups including G0 vs G1 in two periods of surveys and G0 vs G2 in three periods of surveys.

Firstly, the author estimates the impact of irrigation on households sticky rice productivity when households access to irrigation in one period of the LECS survey- only LECS5. The results of the G1 vs G0 comparison groups are reported in Table 3.7. 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 3.1 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. (2017), Nonvide (2017), and Bell et al. (2016), 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 the author explained in section 2.5

in Chapter 2. 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.

Secondly, 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 that are irrigated in LECS 4 and LECS 5 (two periods of surveys). Table 3.8 presents the estimation results of the comparison between G0 vs G2. Similar to the results of the comparison between G0 vs G1, we cannot find any evidence of the impact of irrigation on the sales value of sticky rice and household consumption. Although the coefficient of total sticky rice production is not significant in the 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 1,560 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. We found that long-term access to irrigation leads to higher sticky rice productivity, since a longer access to irrigation made farmers have learnt more experience in using irrigation for supporting their sticky production such as good irrigation practice, intensive irrigation management and good water arrangement (Bhattarai et al., 2001 and; Mutiro and Lautze, 2015). It can be concluded that the productivity gains from irrigation are sustainable in the case of sticky rice production in Lao PDR.

Table 3.7: Estimated results comparing G0 and G1 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)	-1,434.75	***	-1,224.43	***	-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 G01	638.77		-		298.67		-		827.12	***	-		4.79		-	
	(463.16)		-		(198.47)		-		(210.41)		-		(130.02)		-	
Treat G01 * 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)	1,750.88	***	3,051.95	***	738.37	***	1,154.83		583.21	***	1,392.48		304.98	***	-125.01	
	(367.32)		(1,682.33)		(157.40)		(738.23)		(166.87)		(845.00)		(103.12)		(482.33)	
Harvest area (Hectares)	2,820.00	***	2,581.29		1,218.80	***	1,159.54	***	-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		2,391.45	***	4,299.51	*	-104.57		696.67	
	(996.35)		(2,829.07)		(426.95)		(1,168.36)		(452.64)		(2,280.33)		(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 = 8,700 LAK.

Table 3.8: Estimated results comparing G0 and G2 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)	4,779.70	***	4,986.09	***	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)	3,385.09	***	3,754.86	***	27.33		145.56		194.45		259.37		1,134.52	***	1,433.65	***
	(371.95)		(378.59)		(174.76)		(158.50)		(168.15)		(175.78)		(94.94)		(143.11)	
Treat G02	1,025.89		-		288.14		-		1,057.41	***	-		-51.10		-	
	(809.94)		-		(380.55)		-		(366.15)		-		(206.74)		-	
Treat G02 * Time 2008 & 2013	577.21		645.48		485.22		477.86	*	1,342.23	***	1,559.58	*	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)	1,563.19	***	879.03		700.34	***	133.50		731.65	***	0.17		253.74	***	-55.76	
	(310.01)		(1,392.17)		(145.66)		(737.67)		(140.15)		(1,142.63)		(79.13)		(402.18)	
Harvest area (Hectares)	2,516.46	***	2,239.90	***	1,266.13	***	1,100.29	***	-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	-3,255.39	***	-1,558.05		-399.43		325.03		1,994.70	***	2,500.76	**	-480.76	**	941.32	*
	(805.54)		(1,765.93)		(378.48)		(808.92)		(364.16)		(1,225.96)		(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 = 8,700 LAK.

3.6 Conclusions and Policy Implications

This study focuses on analyzing the impact of households' access irrigation in different period of times on sticky rice productivity by employing the DID-fixed effect method. In the panel data, three LECS surveys - 2003/2003, 2007/2008, and 2012/2013 - are divided into three subgroups to examine the effects of irrigation on the sales value, total production and productivity of sticky rice, as well as the household consumption. The findings are consistent with theoretical and previous literature, which suggests that irrigation has a positive impact on sticky rice productivity. Even though irrigated households have smaller land areas than non-irrigated households, they can produce more sticky rice than non-irrigated households. In addition, 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. Because a longer access to irrigation made farmers have learnt more experience in using irrigation such as good irrigation practice, intensive irrigation management and good water arrangement. To conclude, long term access to irrigation leads to higher sticky rice productivity. However, no evidence to support the impact of irrigation on the sales value of sticky rice and household consumption was found in this chapter. Therefore, to encourage more access of rice farmers to irrigation aiming at enhancing productivity, the government should provide some subsidies for electricity fees leading to lower burden of farmers. In the long run, development of agricultural infrastructure especially irrigation system expansion along with improvement monitoring system of irrigation utilization are essential.

Chapter 4

Interdependency through Transactions in Rural Villages in Developing Countries: Applying the Qualitative Village Input - Output Table

4.1 Introduction

An input-output table (IOT) is the fundamental framework of economic structures, and it has been well known since the late 1930s when it was proposed by Wassily Leontief. The so-called Leontief model, which is constructed using observed economic data from a whole country or from a particular economic region (Miller and Blair, 2009), captures the interrelationships among various producing and demanding industries of an economic structure in a particular year (Keogh and Quill, 2009, Morrissey and Donoghue, 2013). One fundamental concept of the IOT is interdependence among production structures. For example, to produce the output of industry i, industry i must buy its inputs from industry k, and industry k buys inputs from industry j; that is, the output or production of the industry i indirectly depends on inputs from industry j. This relationship holds for all industries or sectors in the whole economic system and means that each industry directly and/or indirectly depends on other industries (Dietzenbacher, 2005).

In recent years, IOTs have been used for analysis in many fields of study. For example, Nakano et al. (2018) developed an interregional IOT to analyze a next-generation energy system in Japan. Additionally, many papers, including Li et al. (2018), Pan et al. (2018) and Song et al. (2018), focused on environmental issues, especially pollutant emissions, using IO analysis to illustrate carbon emissions in China. Furthermore, Lee et al. (2014) and Morrissey and Donoghue (2013) applied IOTs to analyze linkage and production effects in marine sectors.

In contrast, in research on various economic activities or economic structures, there is some literature focusing on the measurement of economic structures and interdependency among industries. Analysis of an economic structure in a regional study using qualitative data provides greater insight into the cases of developing countries (Ghosh and Roy, 1998).

One famous technique to examine direct and indirect interrelationships between sectors in economic structures is a qualitative input-output table (QIOT), which transforms quantitative information from an IOT into qualitative information (Titze et al., 2011). Moreover, Aroche-Reyes and Muniz (2018) employed a QIOT to examine the economic structure by identifying sectoral linkages or direct and indirect connections among several sectors in the economic system.

A QIOT utilizes methods, concepts, and techniques of a directed graph or digraph theory (Aroche-Reyes, 2003). Many previous studies have applied this method to identify various direct and indirect transactions among sectors or products in many developed and developing countries; these studies include Nijkamp et al. (1992), Ghosh and Roy (1998), Aroche-Reyes (2003), Aroche (2006), Titze et al. (2011) and Aroche-Reyes and Muniz (2018). For instance, Ghosh and Roy (1998) analyzed economic structural changes in Indian by applying the concept of important coefficients by drawing a graph to determine changes to the economic structure from 1983/84 to 1989/90. The authors found that the degree of interdependence among sectors had significantly increased, indicating that the Indian economy had become more dynamic during the 1980s. Furthermore, Aroche-Reyes (2003) described a method for identifying the set of interindustry relationships in the Mexican economy. Aroche-Reyes proposed graphing theoretical concepts. The results showed that a graph of relationships represents the characteristics of the productive structure of the Mexican economy as a whole. The structure of the graph also shows how information relates to the main paths of influence between sectors and the complexity of the economic system. Later, Aroche-Reyes utilized the same method to recognize the set of basic interindustry relationships in the US and Mexico. The results show that even though both economies have highly intensive on energy sectors, the structures of the U.S. and Mexican economies are different. Additionally, each fundamental economic structure concentrates different amounts of the total intermediate demand in the economy, which leads to unequal dynamics in each economic system (Aroche-Reyes, 2006). Moreover, Reyes and Muniz (2018) identified the economic structure in Greece using graph and network theory. These authors found that the economic structure is relatively scattered and identified a lack of systematic connectivity among industries. The service sector, in which technological intensity plays an important role in weaving the economic pattern, and manufacturing industries are also input-intensive and have more complex connectivity structures. The study concluded that industries play different roles depending on the relative numbers of their transactions. Meanwhile, Titze et

al. (2011) identified regional industrial clusters through a national IOT in Germany by applying minimal flow analysis to determine the intermediate relations between certain regional industrial clusters. These authors found that regional industrial clusters influence regional economic development. In addition, there are eleven regions with multiple important production locations and multiple vertical linkages. Sixteen regions contain multiple concentrated important production locations but only one vertical industrial linkage. In contrast, Nijkamp et al. (1992) examined the reliability and suitability of ordinal data methods at the province level in the Netherlands by means of a stochastic approach. This technique was developed as a method for transforming a quantitative IOT into the ordinal ranking of the coefficients; the authors then investigated whether the ordinal data method could be used with a high degree of reliability. The authors found that the error of ordinal IOTs appears to be relatively small compared to the error when alternative updating procedures are used. Therefore, the ordinal data method provides a fairly reliable analysis of the underlying quantitative IO data. Only Hongsakhone and Ichihashi (2018) focused on the qualitative village input-output table (QVIOT) to measure the interdependency among households through their transactions in Lao PDR by using a household survey. The authors found that the four richest households are the main players in the Phonxay village economy and that the interdependency among these four highest-income households is stronger than that among other households. The highest number of transactions involved rice, and transaction involving poultry ranked fourth. The findings of that study showed that most transactions occurred only inside the village. Except for Hongsakhone and Ichihashi (2018), previous literature reviews have been limited to mentioning the above-applied QIOT to capture the methodology application and theoretical framework. This paper utilizes the QIOT to capture the village's actual economic situations in Vietnam and Lao PDR. Agricultural production in the two developing countries has unique characteristics; in Lao PDR, most current agricultural production is for farmers' own use, and only 33% of farmers produce mainly for sale (FAO, 2019), whereas in Vietnam, households have mainly implemented the commercialization of agricultural production in rural areas (Mcky et al., 2015).

This research applies concepts and techniques of graph theory to extend the structure of village analysis in the context of the VIOT. In other words, the QVIOT can be summarized in graphs or tables and it aims to identify the basic features of the villages' economic structures by defining the VIOT. The QVIOT examines the connectivity between households

based on their products; as a result, it transforms the technical coefficients table into binary data to show whether households exchange products in the village economic structure. Herein, we assume that whether households are connected with one another and/or whether they have different connections with other households, connectivity among households is essential to explaining a village economy's performance pattern. Moreover, more connections, or larger numbers of transactions, drive demand for products, therefore furthering economic development and forming a more complex economic structure (Aroche-Reyes and Muniz, 2018). Unlike Hongsakhone and Ichihashi (2018), the aim of this research is to present qualitative information by applying the expanded QVIOT to capture both dependencies outside the villages and interdependency among the production and demand of households within the villages. An analysis interdependency among households in rural areas for both Lao PDR and Vietnam is a crucial factor to better understanding the rural households' characteristic, pattern of their production and trade transactions. This study is vital information for local government to formulate district or villages' poverty eradication strategy, especially isolated villages, where households cannot access regular market. As a result, it will lead to an improvement of households' livelihood and sustains poverty eradication in Lao PDR and Vietnam.

Regarding structure, the paper is organized into four sections. After this introduction, the second section, on data collection, describes the characteristics of the Dang and Houey Nambak villages, which are the target areas of our household surveys. Following the methodology, the third section discusses how we construct two village input-output tables (VIOTs) from two household surveys and transform them into two QVIOTs. The empirical results are presented in the last section, in which we illustrate the simplicity of the village economic structure; in this last section, we also explain the results of analyzing interrelationships among households and networks in Dang villages in Vietnam and show the more complex economic structure of Houey Nambak village in Lao PDR.

4.2 Data Collection

To examine the interdependency among households and network analysis in the villages, two village surveys were conducted in two developing countries in March 2018. These two villages were selected by the local government at the province level. One of the two villages surveyed was Dang village, which is located in Thai Nguyen Province in the northern part of Vietnam (Figure 4.1). Dang village is not an isolated village, and therefore,

villagers conduct more transactions outside the village, especially in the market. Since the Samsung factory was established in 2014, the population of this village has shifted from agricultural cultivators to manufacturing workers. Therefore, the village's main income source is workers' salaries. Another survey was conducted in Houey Nambak village in Lao PDR (Figure 4.2), which is approximately 27 km from the city. This village is one of 81 villages of the Long district in Luang Namtha Province, in the northwestern part of Lao PDR. Houey Nambak village is a rural, isolated village located in a mountainous area. All of the households are of the Akha ethnic group, which is the largest ethnic group in Luang Namtha Province. The village's main income source is agricultural products, especially sugarcane, which villagers have contracted to farm for a Chinese investor. Therefore, most of the sugarcane is sold to a Chinese investor.

The household questionnaire survey comprised of 4 sections. The first section described household characteristics (age, sex, education, and occupation). The second section requested information about household transactions for all products, such as household consumption, stock, selling and purchasing of goods, receiving in kind from and giving to other households in the last three months (12/2017-02/2018). The third section focused on agricultural input expenditures. Finally, information was requested on the household income and consumption expenditures in the last three months.

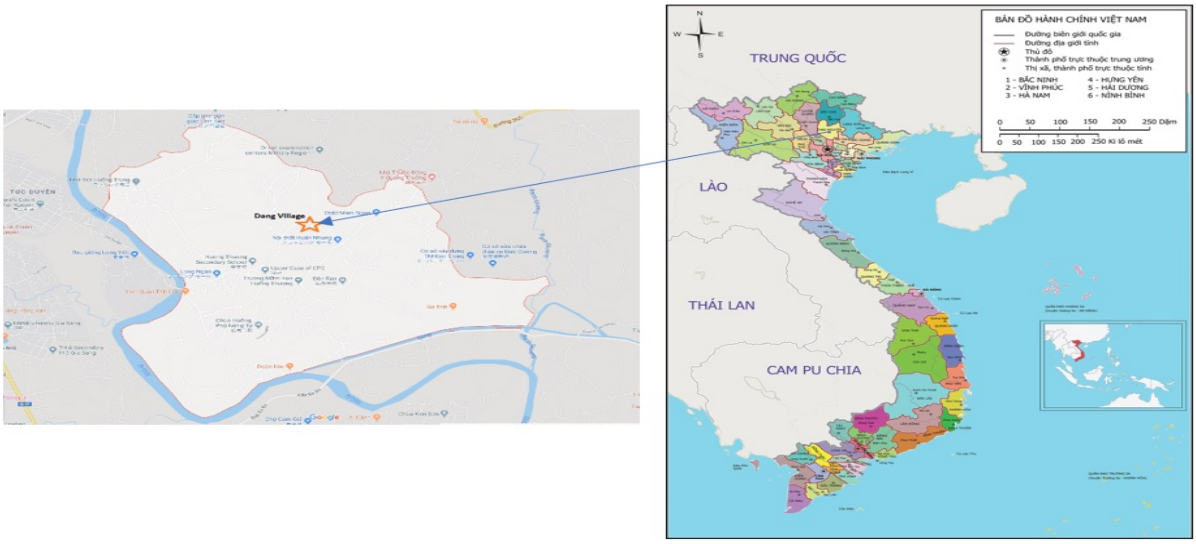


Figure 4.1: Map of Dang village in Vietnam

Source: https://medium.com/@north.vietnam/map-of-northern-vietnam-919ff8beae47

http://investinvietnam.vn/report/parent-region/91/94/Thai

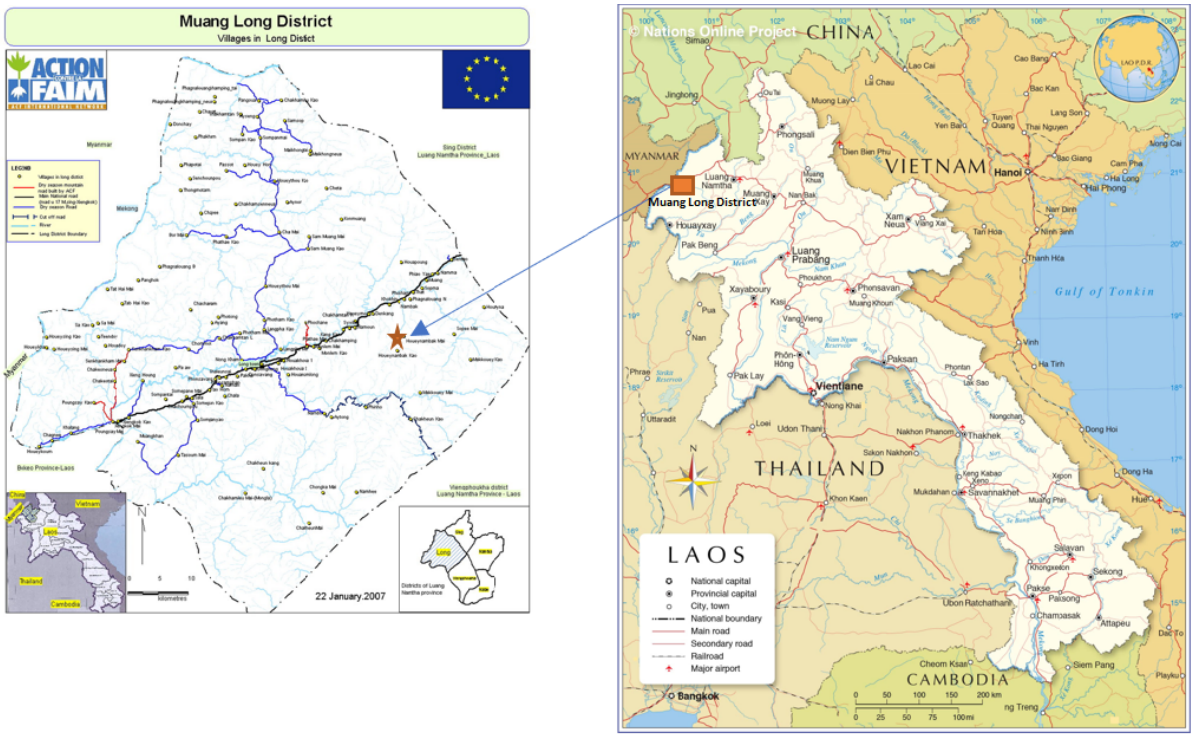


Figure 4.2: Map of Houey Nambak village in Lao PDR

Source: https://www.nationsonline.org/oneworld/map/Laos-politicalmap.htm?fbclid=IwAR2zUgiilU6hwVXuYXlcqtWELA9sU_lqKOtNopu1AdGh_lx4Qg2GquEp0nA.
https://www.researchgate.net/figure/Map-of-Long-District-in-Luang-Namtha-Province-The-circle-marks-the-location-of-Ban_fig1_282847756.

Summaries of the household characteristics in Dang village and Houey Nambak village are shown in Table 4.1. Seventy-five and 70 households were surveyed in Dang village (Vietnam) and Houey Nambak village (Lao PDR), respectively. In particularly, 306 residents lived in Dang village, and approximately 56% of the households, had 4 to 6 members. Most of the household heads were aged 41 to 60 years, accounting for 56%, while only 26.67% of household head above 60 years. The majority of the household heads had completed secondary school and high school, which accounted for 53.33% and 30.67%, respectively, and more than half of the household heads were farmers. In Houey Nambak village (Lao PDR), which had 415 residents, approximately 56% of household had 4 to 6 members. Household heads aged under 40 years old accounted for 52.86% of the sample, while 4.29% had heads above 61 year old. Most of the household heads, 68.57%, had completed primary school. All of the household heads were farmers.

Table 4.1: Characteristics of Dang village and Houey Nambak village

HH Characteristics	Dang village		Houey Nambak village	
	Frequency	%	Frequency	(%)
Total HH	75	100	70	100
Total population	306	100	415	100
HH size				
1-3	27	36	9	13
4-6	42	56	39	56
7+	6	8	22	31
HHH gender				
Male	43	57.33	-	-
Female	32	42.67	-	-
HHH age				
<40	13	17.33	37	52.86
41-60	42	56	30	42.86
61+	20	26.67	3	4.29
HHH education				
Non-education	1	1.33	15	21.43
Primary school	5	6.67	48	68.57
Secondary school	40	53.33	6	8.57
Higher	29	38.67	1	1.43
HHH occupation				
Farmer	51	68	70	100
Others	24	32	-	-

Note: HHH is household head, and HH is household.

Table 4.2 reports the values of products sold within and outside Dang village in the last three months from 12/2017 to 02/2018. The data in the third column indicate that products sold outside the village were more than double those sold within the village; this means that this village greatly depended on the outside in terms of selling products. The village's main income source was derived from livestock (cattle and pigs), which accounted for 59.20% of its total income last season. Livestock was followed by rice and poultry, which accounted for 18.21% and 11.26%, respectively. Only a small proportion of income was derived from other products, including meat, eggs, fish, vegetables, and flowers.

Table 4.2: Total agricultural products sold within and outside Dang village.

Products	Value sold (Unit: VND)		Total value in		(%)
	Inside village	Outside village	VND	USD	
Cattle and pigs	59,500,000	129,000,000	188,500,000	8,125	59.20
Rice	28,270,000	29,700,000	57,970,000	2,499	18.21
Poultry	10,950,000	24,900,000	35,850,000	1,545	11.26
Sticky rice	3,125,000	10,200,000	13,325,000	574	4.19
Other	6,920,000	4,825,000	11,745,000	506	3.69
Other agriculture	-	11,000,000	11,000,000	474	3.45
Total	108,765,000	209,625,000	318,390,000	13,724	100

Note: Total value of products that were sold within and outside the village. Other includes meat, eggs and fish. Other agriculture includes vegetables and flowers. Based on the exchange rate in the state bank of Vietnam, 1 USD = 23,504VND (31/01/2019).

Table 4.3 presents the values of products sold within and outside Houey Nambak village in the three months from 12/2017 to 02/2018. The village's income came mainly from selling its products both within and outside the village. Sugarcane was the largest source of income of village households, contributing 2,208 million LAK (approximately 258,907 USD) or approximately 89.36% of the total village income in the last season. Even though sugarcane was the main product generating income for the villagers, based on production output level, only 21.4% of sugarcane's seed transactions occurred within the village. In terms of income, sugarcane was followed by rice, poultry and livestock (cattle and pigs), which contributed 10,727 USD, 9,931 USD, and 9,068 USD, respectively.

Table 4.3: Total agricultural products sold within and outside Houey Nambak village

Products	Value sold (Unit: LAK)		Total value in		(%)
	Inside village	Outside village	LAK	USD	
Sugarcane	472,570,000	1,735,910,000	2,208,480,000	258,907	89.36
Rice	84,000,000	7,500,000	91,500,000	10,727	3.70
poultry	67,825,000	16,890,000	84,715,000	9,931	3.43
Cattle and pigs	32,620,000	5,625,000	77,350,000	9,068	3.13
Other	5,520,000	2,995,000	8,515,000	998	0.34
Bamboo shoots	618,000	400,000	1,018,000	119	0.04
Total	663,153,000	1,769,320,000	2,471,578,000	289,751	100

Note: Total values of products that were sold within and outside the village. Other includes meat, eggs, vegetables and other crops. Based on the exchange rate in the bank of Lao PDR, 1 USD = 8,530 kip (31/12/2018).

Table 4.4 shows household status by per capita income in Dang village, according to the national poverty line for rural areas in Vietnam, with household status classified using four criteria. The data in column 2 show that 34 of 75 households, or approximately 45.33% of the total households, remained poor, while 16 households (21.33%) were considered to be nearly poor. Meanwhile, only a small proportion of the households surveyed were classified as middle- and high-income households, accounting for 14.67% and 18.67%, of the total sample, respectively.

Table 4.4: Household status in Dang village

Income per capita (VND)	Number of HH	HHID classification	(%)	Household status
≤ 700,000	34	1-34	45.33	Poor
700,001-1,000,000	16	35-50	21.33	Nearly poor
1,000,001-1,500,000	11	51-61	14.67	Middle
>1,500,001	14	62-75	18.67	Rich
Total	75		100	

Note: Household status was identified according to the national poverty line for rural areas in Vietnam from 2016 – 2020 (2015).

Based on the Lao national poverty line for rural areas and income per capita of households in Houey Nambak village, we classified household status using four criteria (Table 4.5). Of the total number of households, 48.57% were considered nearly poor households; they were classified from household ID 7 to 40, and their income per capita ranged from 180,001 to 560,000 LAK. Meanwhile, middle-income households accounted for 31.43%, with household ID from 41 to 62. Only 6 of 70 households were considered poor, with incomes per capita below the national poverty line for rural areas -180,000 LAK per person, per month.

Table 4.5: Household status in Houey Nambak village

Income per capita (LAK)	Number of HH	HHID classification	(%)	Household status
≤ 180,000	6	1-6	8.57	Poor
180,001-560,000	34	7-40	48.57	Nearly poor
560,001-999,999	22	41-62	31.43	Middle
>1,000,000	8	63-70	11.43	Rich
Total	70		100	

Note: According to the Lao national poverty line for rural areas and income per capita of households in Houey Nambak village.

4.3 Research Methodology

4.3.1 Construction of Two Expanded VIOTS from Two Household Surveys

We portray the structural characteristics of the economies of Dang and Houey Nambak villages by constructing two expanded VIOTs from the data from two household surveys. The expanded VIOT is constructed in a two-dimensional matrix, in which the first dimension concerns consumers, and the second dimension concerns producers. Two matrix forms are constructed, namely, (450+1) x (450+1), which is {(75 households x 6 products)+ inflow/outflow} for Dang village and (420+1) x (420+1), which is {(70 households x 6 products)+ inflow/outflow} for Houey Nambak village. The expanded VIOT is considered for the flows of each product from each household, as a producer, to other households, as consumers. In each expanded VIOT, each consumer and producer must buy or sell six products, such as poultry, rice, cattle and pigs, sticky rice, other (meat, eggs, and fish) and other agriculture (vegetables and flowers) in the case of Dang village, and six products, such as sugarcane, rice, poultry, cattle and pigs, bamboo shoots and other (meat, eggs, vegetables, and crops), in the case of Houey Nambak village.

The column (first dimension) in the VIOT shows consumer transactions by buying inputs as intermediate demand for products to produce their outputs. The additional column is final demand, which records the sale by each household of their products, such as consumption, investment (or stock), selling products outside the village (outflow or export) and giving products to other households both within and outside the village.

The row (second dimension) in the VIOT shows the transactions of producers by selling their products (or outputs) to other households and the other inputs to production via value-added, which includes inflow or import of products from outside to village, receiving in-kind from outside and wage payment to other households. The additional row is the household surplus, which increased from each transaction of each product by each household. After we construct each matrix form, we can calculate the input coefficient matrix based on the Leontief input-output model (Miller and Blair, 2009; Galbusera and Giannopoulos, 2018) as follow:

$$X = AX + f \tag{4.1}$$

where X = [x_1…..x_n] is the total output vector, A= [a_{ij}] is the technical coefficient matrix or input coefficient matrix and $f = [f_1, \ldots\ldots, f_n]$ is the final demand, which is the one column vector of size n.

With the input coefficient matrix, it is: $a_{ij} = \frac{x_{ij}}{X_j}$ (4.2)

where $x_{ij} = q_{ij}p_j$ is specific sales from producers i to consumers j as a function of quantities q_{ij} and price p_j at an equilibrium point, and X_j is the total input of consumers j. From the household survey data, we cannot distinguish between the households' consumption and investment ratios for both intermediate and final demand. Based on macroeconomic theory, we assume a fixed consumption and investment ratio of 0.7 and 0.3, respectively, with all products. Consequently, after we calculate the input coefficient, then we can add the consumption and investment ratios for intermediate and final demand to the expanded VIOT.

Table 4.6 and Table 4.7 provides total value of the cumulative transactions in each agricultural product in Dang and Houey Nambak villages from the first or direct transaction up to the third round of transactions. The results in Table 4.6 and Table 4.7 can be interpreted that the amount of money that households in village have transactions within and outside village. The highest value of direct household transactions in Dang village is cattle and pigs which account for 394 million VND; following by poultry is 147 million VND . In case of Houey Nambak village, sugarcane has the highest value of direct household transactions which account for 2,507 million LAK, then cattle and pigs is 191 million LAK. The highest amount of money in a certain product transaction does not indicate that households have more frequency trade to each other. The findings suggest that we cannot observe the

interdependency of the households through amount of transactions by using the Expended VIOT. Another reason, some households may not remember the exact amount of money that they had transaction in last three months.

4.3.2 Transformation of the Expanded VIOT to the Expanded QVIOT

The expanded VIOT shows the number and value of the transactions between consumers and producers for each product. The expanded VIOT cannot identify which household has the most transactions, even though the households are ordered and sorted by income per capital in Dang village and Houey Nambak village.

To examine the number of transactions for each product for each consumer and producer, two expanded QVIOTs are constructed. The expanded QVIOT is a binary or Boolean matrix (Q), which transforms all the values of transactions for all the products in the input coefficient matrix (A) by 1 if $a_{ij} \neq 0$, and 0 elsewhere (Miller and Blair, 2009), see Figure A1 in Appendix A .

From equation 4.1, we can derive the Leontief inverse matrix below:

$$f = X\,[I - A]$$
$$X = [I - A]^{-1} f$$

We have $$[I - A]^{-1} = I + A + A^2 + A^3 + \cdots \quad (4.3)$$

where $[I - A]^{-1}$ is the Leontief inverse matrix, which is a cumulation of the exponent of input coefficient matrix A from power zero to infinity, $I=A^0$ is a unit matrix, and A is the input coefficient matrix. Based on Holub and Schnabl (1985) and equation 3, we derive the qualitative input-output model as:

$$S = I + Q + Q^2 + Q^3 \quad (4.4)$$

where S is the summation of the qualitative input coefficient matrix or the cumulative matrix of the total (direct and indirect) transactions between consumers and producers. Q is a binary (Boolean) matrix, in which 1 is used for a household with a transaction and 0 otherwise.

Table 4.6: Total value of cumulative transactions in each agricultural product in Dang village (Unit: Mil. VND)

Transactions	Poultry	Rice	Cattle and pigs	Sticky rice
Direct transactions	147	117	394	21
Indirect transactions	4,608,717,798,321,190	596,149,521,088,597	154,239,394,188,127,000	65,672,279,242,500
Total transactions	4,608,717,798,321,340	596,149,521,088,713	154,239,394,188,128,000	65,672,279,242,521
Transactions	Other agriculture	Other	Cumulative transactions	
Direct transactions	14	32	724	
Indirect transactions	25,120,597,488,415	324,144,333	159,535,054,708,412,000	
Total transactions	25,120,597,488,428	324,144,365	159,535,054,708,413,000	

Source: Calculated by the author from the expanded VIOT of Dang village.

Note: Other agriculture includes vegetables and flowers; other includes meat, eggs and fish.

Table 4.7: Total value of cumulative transactions in each agricultural product in Houey Nambak village (Unit: Mil. LAK)

Transactions	Poultry	Sugarcane	Cattle and pigs	Rice
Direct transactions	109	2,507	191	64
Indirect transactions	27,439,881	483,022,592,859	2,316,410,004	31,886,291
Total transactions	27,439,989	483,022,595,365	2,316,410,194	31,886,354
Transactions	Other	Bamboo	Cumulative transactions	
Direct transactions	14	3	2,888	
Indirect transactions	9,970	46	485,398,339,051	
Total transactions	9,984	49	485,398,341,935	

Source: Calculated by the author from the expanded QVIOT of Houey Nambak village in the third round.

Note: Other includes meat, eggs, vegetables and other crops.

Based on Ghosh and Roy (1998), we can calculate the centrality index (CI) of a household to determine which households are the main suppliers and demanders of each product in the village. If the inflow to a household is less than the outflow from it, then the household is considered more of a supplier. Similarly, if a household's inflow is greater than its outflow, then we conclude that the household is more of a demander in the village. The center is defined as a household's inflow being equal to its outflow as in the following equation:

$$CI = \frac{Inflow}{Outflow} \tag{4.5}$$

The CI is greater than, equal to or less than unity if a household is categorized as a demander, central or a supplier, respectively, with regard to a product.

4.4 Empirical Results

Our presentation of the empirical results in this chapter is divided into two parts, beginning with the findings regarding simple transactions in Dang village in Vietnam and followed by those regarding complicated transactions in Lao PDR.

4.4.1 Interdependency through Transactions of Agricultural Products in Dang Village in Vietnam

To identify interdependency among households in this village, first, converging processes are needed. The cumulative ratio is computed by input coefficient (A) from the expanded VIOT. This ratio indicates how many rounds of agricultural product transactions close to the Leontief inverse matrix will be selected from the expanded QVIOT. The converging process of the expanded VIOT in Dang village is shown in Table 4.8. From the input coefficient matrix in round three (A^3), the cumulative ratio obtains 99.49% of the sufficient level -close to the Leontief inverse matrix- to summarize the total transactions in the village. Therefore, the product transactions will utilize the expanded QVIOT from the first round to the third round to calculate the interdependency among households in Dang village.

Table 4.8: Converging process of Dang VIOT

Input coefficient Matrix	I	A	A^2	A^3
Multiproduct multiplier	1	0.08	0.03	0.01
Cumulative ratio	89.57	96.35	98.65	99.49

Source: Calculated by author from the intermediate portion of the expanded VIOT of Dang village.

Table 4.9 shows the total number of transactions of each product as the cumulative transactions from the first to the third rounds in the expanded QVIOT of Dang village. Each column shows the main products regarding which households had transactions, and the rows show the cumulative numbers of transaction paths, including direct transactions (first round), indirect transactions (second round) and total transactions (third round). The transactions for each product slightly increase in each round of the expanded QVIOT. In the converging process for this village, we except the sufficient level to the third round, which had 969 of the total cumulative transaction paths, with poultry accounting for the highest number of cumulative transaction paths, at approximately 289, followed by 227 and 142, for rice and cattle and pigs cumulative transactions, respectively. In addition, other agricultural products (vegetables and flowers) and other products (meat, eggs, and fish) have the fewest cumulative transaction paths, accounting for only 90 and 11 of transactions in the village, respectively.

Table 4.9: Cumulative transaction paths for each product in Dang village

Transactions	Poultry	Rice	Cattle and pigs	Sticky rice	Other agriculture	Other	Cumulative transactions
Direct transactions	140	127	104	90	84	106	651
Indirect transactions	149	100	38	20	6	5	318
Total transactions	289	227	142	110	90	11	969
Share (%)	29.82	23.43	14.65	11.35	9.29	1.14	100

Source: Calculated by the author from the expanded QVIOT of Dang village in the third round. *Note:* Other agriculture includes vegetables and flowers; other includes meat, eggs and fish.

Table 4.10 reports the top ten of the total pair transactions of all products in Dang village. Except for middle-income households, as a seller -a poor household- had to sell products, namely, poultry, rice, cattle and pigs, sticky rice, other agricultural products, and

other products, to households within the village. A poor household tends to have smaller transactions with buyers outside the village than with those within the village. Specifically, the total number of transactions in which a poor household sold products to outsiders was only 62, which was fewer than such transactions inside the village. Additionally, a poor household tended to sell more products to poor households than nearly poor and rich households.

Table 4.10: Top ten product transactions in Dang village

Rank	Seller		Buyer		Total transactions
	HHID	HH status	HHID	HH status	
1	1	Poor	Outflow		62
2	1	Poor	12	Poor	24
3	1	Poor	63	Rich	23
4	1	Poor	1	Poor	21
5	1	Poor	35	Nearly poor	20
6	1	Poor	19	Poor	20
7	1	Poor	15	Poor	19
8	1	Poor	13	Poor	19
9	1	Poor	43	Nearly poor	19
10	1	Poor	5	Poor	18

Source: Calculated by the author from the expanded QVIOT of Dang village in the third round.

Note: HHID1-34, 35-50, 51-61 and 62-75 are poor, nearly poor, middle-income and rich households, respectively.

A pair of transactions of a specific product, poultry, in Dang village is shown in Table 4.11. Even though the sell value of poultry is ranked third behind those of cattle and pigs and rice (Table 4.2), poultry was the subject of the highest total number of transactions in Dang village. Compared to cattle and pigs, poultry is a less expensive product. Therefore, poultry was involved in more transactions than other products. The data report that as sellers, rich and poor households tended to trade their products with poor households. In addition, middle-income households sold their products to poor and nearly poor households. To conclude, rich, middle-income and poor households seemed to be sellers, while poor and nearly poor households demanded intermediate products for their production.

Table 4.11: Poultry transactions in Dang village

Rank	Seller		Buyer		Poultry
	HHID	HH status	HHID	HH status	
1	58	Middle	35	Nearly poor	6
1	69	Rich	1	Poor	6
1	6	Poor	5	Poor	6
1	71	Rich	33	Poor	6
1	6	Poor	15	Poor	6
1	59	Middle	19	Poor	6
1	53	Middle	43	Nearly poor	6

Source: Calculated by the author from the expanded QVIOT of Dang village in the third round.

Note: HHID1-34, 35-50, 51-61 and 62-75 are poor, nearly poor, middle-income and rich households, respectively.

In the case of rice and cattle and pigs transactions, poor households tended to use their own products, meaning that they produced rice and raised cattle and pigs for their own consumption. In rural areas, rice is a very important product that is consumed daily, and almost all households have rice fields; therefore, they grow rice for their own consumption. In addition, cattle and pigs are considered the most expensive products in the village. Households consider these products to be valuable products and properties, to be sold only when households need money (Table A1 in Appendix A). As a result, transactions of cattle and pigs were relatively few in this village.

Following Ghosh and Roy (1998), equation 4.5, the centrality index, is shown in Table 4.12. The inflow shows how many times households bought a certain product as an intermediate product within and outside the village. In addition, outflow signifies how many times households sold a certain product to villagers or outsiders. Table 4.12 indicates that suppliers of poultry included poor, middle-income and rich households and that demanders were almost all poor and nearly poor households. These results are consistent with those in Table 4.11, which presents the pair transactions of poultry.

Table 4.12: Suppliers and demanders of poultry in Dang village

Rank	HH		Sell	Buy	Supply	Rank	HH		Sell	Buy	Demand
	ID	Status	Unit: Times				ID	Status	Unit: Times		
1	6	Poor	19	4	15	1	1	Poor	4	10	-6
1	59	Middle	19	4	15	1	5	Poor	4	10	-6
2	69	Rich	16	4	12	1	33	Poor	4	10	-6
3	71	Rich	13	4	9	1	35	Nearly poor	4	10	-6
4	58	Middle	10	4	6	1	15	Poor	4	10	-6
4	53	Middle	10	4	6	1	19	Poor	4	10	-6
						1	43	Nearly poor	4	10	-6

Source: Calculated by the author from the expanded QVIOT of Dang village in the third round.

Note: If CI = (Sell/Buy) > 1, that indicates supplier; if CI = (Sell/Buy) < 1, that indicates demander. HHID1-34, 35-50, 51-61 and 62-75 are poor, nearly poor, middle-income and rich households, respectively.

Figure 4.3 shows the network of poultry transactions in Dang village, with key sellers including poor, middle-income and rich households. In particular, a poor household sold poultry to poor households. A middle-income household sold poultry not only to poor and rich households within the village but also to outsiders. A rich household tended to sell more poultry to poor households within than outside the village. In addition, outsiders bought poultry from poor, middle-income and rich households as the average number of transactions of each type of household was 3. Moreover, poor households are frequently trading within the village; as Figure 4.3 shows, the average number of transactions per household was 6.

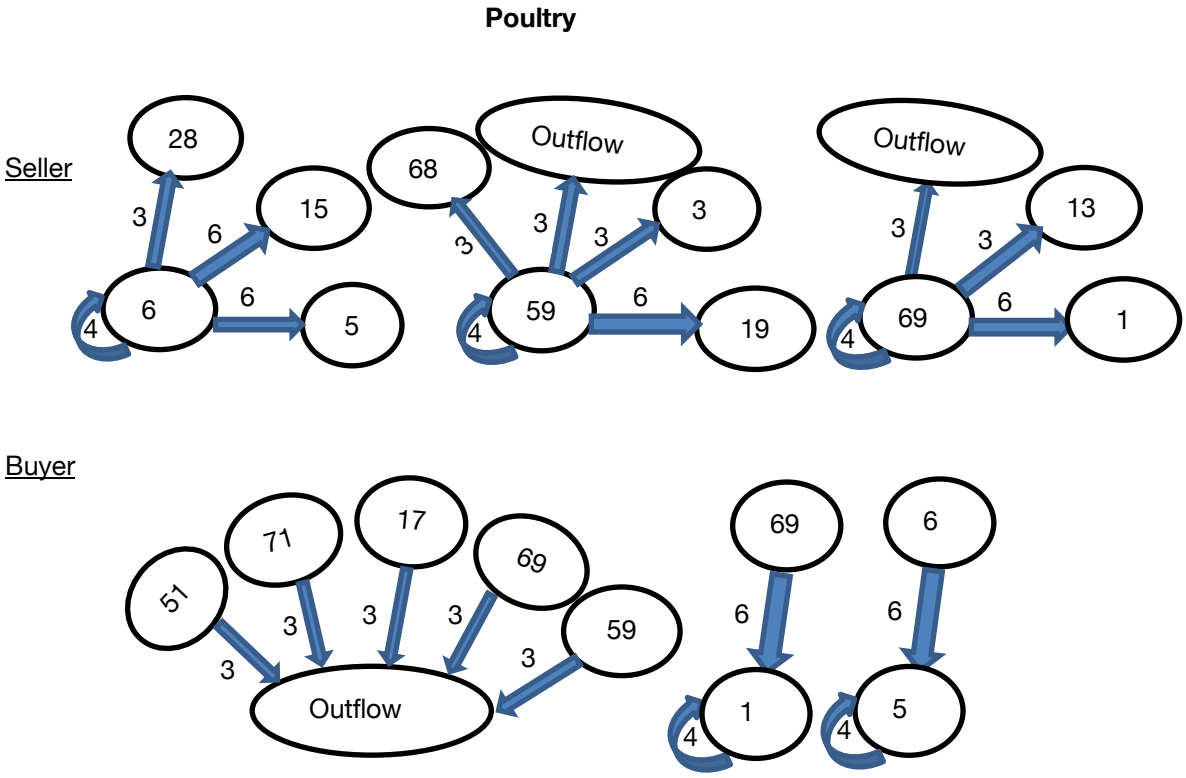


Figure 4.3: Network of poultry transactions in Dang village

Source: Calculated by the author from the expanded QVIOT of Dang village in the third round.

Note: The number in the circles indicated the household IDs, and the numbers nearby arrows are the numbers of transactions of each household. HHID1-34, 35-50, 51-61 and 62-75 are poor, nearly poor, middle-income and rich households, respectively.

To conclude, most households' incomes have become based on wages rather than agricultural products, since the population in Dang village has shifted from agricultural workers to manufacturing workers. A poor household sold all products within and outside the village; in addition, poor, nearly poor and rich households bought intermediate products from a poor household. Although most of these transactions were small, poultry was the subject of the most transactions within the village compared to the other five products. Poor, middle-income and rich households were the main suppliers for poultry, and demanders were poor and nearly poor households. The network analysis confirms that there were not specific households that were the main trading partners in terms of poultry transactions. Since the number of transactions was very low, there was no tendency among households in poultry transactions in the village.

4.4.2 Interdependency through Transactions of Agricultural Products in Houey Nambak Village in Lao PDR

By analyzing the village economic structure by households' transactions of agricultural products, this research applies the expanded QVIOT, which is derived from the expanded VIOT. The cumulative ratio is calculated from the expanded VIOT to select the round of product transactions in the expanded QVIOT. From the input coefficient matrix (A), the cumulative ratio is calculated from one round to the third round of transactions. The cumulative ratio is approximately 93.13% (close to the Leontief inverse matrix), which is sufficient to summarize the total transactions in Houey Nambak village (Table 4.13).

Table 4.13: Converging process of Houey Nambak VIOT

Input coefficient Matrix	**I**	**A**	**A^2**	**A^3**
Multiproduct multiplier	1	0.21	0.09	0.05
Cumulative ratio	68.49	83.13	89.61	93.13

Source: Calculated by author from the intermediate portion of the expanded VIOT of Houey Nambak village.

The expanded QVIOT focuses only on the intermediate part of the expanded VIOT; based on equation 4.4 and Table 4.13, the cumulative transaction paths for each product were calculated from the QVIOT from the first to the third rounds of transactions (Table 4.14). The third round of cumulative transactions was 20,040, which includes 2,025 and 18,015 of the total cumulative direct transactions (first round) and indirect transactions (second round). In particular, poultry was the highest-ranked, contributing 15,687 or approximately 78% of the total transactions, followed by sugarcane, cattle and pigs, and rice, constituting approximately 2,283, 850 and 821 of the total transactions, respectively. Meanwhile, bamboo shoots (a forestry product) was the lowest-ranked product, with only 161 transactions, due to the village being surrounded by mountains and forests, so every household can easily access forest products, especially in the rainy season. Moreover, in rural areas in Lao PDR, the household livelihoods has highly depended on forestry products.

Table 4.14: Cumulative transaction paths for each product in Houey Nambak village

Transactions	Poultry	Sugarcane	Cattle and pigs	Rice	Other	Bamboo	Cumulative transactions
Direct transactions	895	294	288	222	175	151	2,025
Indirect transactions	14,792	1,989	562	599	63	10	18,015
Total transactions	15,687	2,283	850	821	238	161	20,040
Share (%)	78.28	11.39	4.24	4.10	1.19	0.80	100

Source: Calculated by the author from the expanded QVIOT of Houey Nambak village in the third round.
Other includes meat, eggs, vegetables and other crops.

Table 4.15 shows the total transactions among households of all products in Houey Nambak village. Of the top ten, the greatest number of transactions involved rich, middle-income and nearly poor households, who tended to sell products (poultry, sugarcane, cattle and pigs, rice, other products, and bamboo shoots) outside the village. Meanwhile, middle-income and nearly poor households invested in intermediate products from outsiders. Even though the top ten transactions shows only households' trade with outsiders, after the top one hundred, the data show interdependencies among households within the village.

Table 4.15: Top ten product transactions in Houey Nambak village

Rank	Seller		Buyer		Total transactions
	HHID	HH status	HHID	HH status	
1	63	Rich	Outflow		69
2	45	Middle	Outflow		64
3	Inflow		60	Middle	59
4	30	Nearly poor	Outflow		59
5	Inflow		21	Nearly poor	58
6	Inflow		38	Nearly poor	58
7	47	Middle	Outflow		57
8	Inflow		55	Middle	56
9	Inflow		9	Nearly poor	56
10	Inflow		37	Nearly poor	56

Source: Calculated by the author from the expanded QVIOT of Houey Nambak village in the third round.
Note: HHID1-6, 7-40, 41-62 and 63-70 are poor, nearly poor, middle-income and rich households, respectively.

The number of transactions of poultry is reported in Table 4.16. Poultry was one of the six products with the most transactions in Houey Nambak village, although it was the third-ranked sources of income from agricultural products (Table 4.3). In particular, in the top ten, a nearly poor household sold poultry products to outsiders. Nearly poor, middle-income and rich households bought intermediate poultry (young poultry) from outside the village. Therefore, to raise poultry, these households must buy young poultry from outsiders. The data in Table 4.16 show that transactions involving purchase of young poultry from outside the village exceed those involving sales of poultry products outside the village.

Even though the data in the top ten do not show transactions among households in the village, after the top one hundred, transactions among households within the village occurred. As, with Dang village in Vietnam, Houey Nambak village also had poultry as the subject of the most transactions. Since poultry is a major source of food consumed daily, especially in mountainous areas where fishing is difficult, it is the main source of protein and is less expensive than other agricultural products in the village.

Unlike in Hongsakhone and Ichihashi (2018), the top ten of poultry transactions in Houey Nambak village, households tended to conduct transactions outside the village. As a result, over 90% of households were above the national poverty line (Table 4.5), while Phonexay village in Hongsakhone and Ichihashi's paper had only 10.48% of households above the poverty line. Therefore, Houey Nambak village is richer than Phonexay village, and households with the most transactions tended to trade outside rather than within the village. Another reason for this difference is the method of analysis of the QVIOT; Hongsakhone and Ichihashi did not show the number of households that conducted transactions outside the village.

Table 4.16: Top ten households conducting poultry transactions in Houey Nambak village.

Rank	Seller		Buyer		Poultry
	HHID	HH status	HHID	HH status	
1	Inflow		38	Nearly poor	56
2	Inflow		21	Nearly poor	55
3	Inflow		60	Middle	55
4	Inflow		37	Nearly poor	54
5	Inflow		69	Rich	52
6	30	Nearly poor	Outflow		52
7	Inflow		9	Nearly poor	51
8	Inflow		57	Middle	50
9	Inflow		68	Rich	49
10	Inflow		50	Middle	47

Source: Calculated by the author from the expanded QVIOT of Houey Nambak village in the third round.
Note: HHID1-6, 7-40, 41-62 and 63-70 are poor, nearly poor, middle-income and rich households, respectively.

In the case of sugarcane, households transacted with outsiders, especially a Chinese investor. In addition, cattle and pigs transactions, shown in Table A2 (Appendix A), were among the top ten highest subjects of transactions. Nearly poor and middle-income households raised and consumed their own products; in other words, to raise cattle and pigs, they must invest in their own young cattle and piglets. As shown in Table 4.14, the number of cattle and pigs transactions was relatively low, since cattle/pigs are the most expensive products in the village. Therefore, households consider these products assets or property (Phonvisay et al. 2015) and these transactions occur only if households urgently need money. Unlike cattle and pigs, there are some transactions of rice in the village (Table A2 in Appendix A). Rice is an important staple food crop, needed for daily consumption by households in rural areas in Lao PDR (Sengsourivong and Ichihashi, 2019). Therefore, most rural households have rice fields, so they can grow and consume their own products. As a result, there were fewer rice transactions than of poultry and cattle and pigs.

Based on Ghosh and Roy's (1998) concept of the centrality index, the results of equation 4.5 are reported in Table 4.17, which indicates that nearly poor and middle-income households were the main suppliers and demanders (purchasers) of poultry in Houey Nambak village. Specifically, nearly poor households were the greatest suppliers of poultry, and the greatest demanders were middle-income households.

Table 4.17: Suppliers and demanders of poultry in Houey Nambak village.

Rank	HH		Sell	Buy	Supply	HH		Sell	Buy	Demand
	ID	status	Unit: Times			ID	status	Unit: Times		
1	24	Nearly poor	295	86	209	60	Middle	109	307	-198
2	30	Nearly poor	366	190	176	69	Rich	105	288	-183
3	27	Nearly poor	221	79	142	50	Middle	88	258	-170
4	40	Nearly poor	281	158	123	21	Nearly poor	146	310	-164
5	12	Nearly poor	253	149	104	8	Nearly poor	85	222	-137
6	52	Middle	185	85	100	53	Middle	60	190	-130
7	64	Rich	268	176	92	41	Middle	4	131	-127
8	45	Middle	352	265	87	17	Nearly poor	85	211	-126
9	43	Middle	230	145	85	38	Nearly poor	212	338	-126
10	4	Poor	149	80	69	55	Middle	157	276	-119

Source: Calculated by the author from the expanded QVIOT of Houey Nambak village in the third round.

Note: If CI = (Sell/Buy) > 1, that indicates supplier; if CI = (Sell/Buy) < 1, that indicates demander. HHID1-6, 7- 40, 41-62 and 63-70 are poor, nearly poor, middle-income and rich households, respectively.

Table 4.18 presents the total numbers of traders and transactions of poultry. In the top three poultry-transaction networks, the main players in selling and buying poultry were outsiders, a nearly poor and a middle-income household. Most households bought and sold poultry outside the village, and the total numbers of transactions were 2,443 (buying) and 1,959 (selling). Therefore, the total number of poultry transactions with outsiders was 4,402 or approximately 28% of total poultry transactions; in addition, the total number of poultry transactions both within and outside the village was 15,687 (Table 4.14). As shown, poultry transactions within the village (11,285 or approximately 72%) exceeded those outside the village (4,402), indicating that households within the village are interdependent. The network analysis shows strong evidence that the main trading partners of purchases and sale of poultry outside village were nearly poor and middle-income households.

As sellers, nearly poor and middle-income households sold poultry not only outside the village but also within the village and their trading partners were nearly poor and middle-income households. In addition to outsiders, the key buyers of poultry were nearly poor households who conducted transactions within and outside the village, and their main trading partners were nearly poor and middle-income households. The interdependency among nearly poor and middle-income households was very strong in terms of poultry, and Table 4.5 also confirms that in Houey Nambak village, approximately 80% of the total households were nearly poor and middle-income households.

In summary, according to the data on the top ten, rich, middle-income and nearly poor households tended to sell and buy all products outside the village. In particular, all of these households bought more poultry outside the village. However, nearly poor households tended to sell poultry outside the village. In Houey Nambak village, the main suppliers and demanders of poultry were nearly poor and middle-income households. The network analysis shows strong evidence that the key players were nearly poor and middle-income households in terms of poultry transactions, and they are very interdependent compared to poor and rich households.

Table 4.18: Top three of poultry-transaction networks in Houey Nambak village.

HHID as seller	HHID as buyer														Tot. No. of HH (Tot. No. of transactions)
Inflow	38	21	60	37	69	9	57	68	50	55	32	59	42	45	
	(56)	(55)	(55)	(54)	(52)	(51)	(50)	(49)	(47)	(47)	(46)	(45)	(44)	(42)	
	25	31	51	3	39	65	61	2	34	46	54	47	23	36	
	(41)	(41)	(41)	(40)	(40)	(40)	(40)	(39)	(39)	(39)	(39)	(38)	(38)	(38)	
	17	26	70	8	19	62	11	35	56	18	49	33	28	66	
	(37)	(37)	(37)	(36)	(36)	(36)	(35)	(35)	(35)	(34)	(34)	(34)	(34)	(34)	
	67	13	53	22	58	6	63	12	30	64	48	15	44	29	
	(34)	(33)	(33)	(33)	(33)	(32)	(32)	(31)	(31)	(30)	(30)	(29)	(29)	(29)	
	5	10	41	14	40	43	4	16	27	24	52	7	20		*69*
	(26)	(26)	(26)	(25)	(24)	(21)	(20)	(20)	(19)	(18)	(18)	(12)	(9)		(2,443)
30	Outflow	45	38	30	48	37	55	46	40	56	62	9	34	33	
(Nearly	(52)	(23)	(21)	(18)	(15)	(14)	(13)	(12)	(11)	(11)	(11)	(9)	(9)	(9)	
poor)	36	63	54	15	69	25	49	44	60	6	5	43	31	22	
	(9)	(9)	(8)	(7)	(7)	(6)	(5)	(5)	(5)	(4)	(4)	(4)	(4)	(4)	
	68	39	7	21	59	64	42	67	18	13	28	35	47	57	
	(4)	(3)	(3)	(3)	(3)	(3)	(3)	(3)	(2)	(2)	(2)	(2)	(2)	(2)	
	65	61	70	2	4	3	8	14	32	19	17	53	23	52	
	(2)	(2)	(2)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	
	29	26	66												*59*
	(1)	(1)	(1)												(336)
45	Outflow	46	45	55	40	30	60	38	62	39	25	37	36	28	
(Middle)	(45)	(19)	(19)	(16)	(15)	(15)	(12)	(11)	(11)	(10)	(9)	(9)	(9)	(8)	
	48	67	49	15	32	34	56	61	63	26	42	13	19	31	
	(8)	(8)	(7)	(7)	(6)	(6)	(6)	(6)	(6)	(5)	(5)	(4)	(4)	(4)	
	17	53	57	65	64	9	8	50	23	66	5	33	51	21	
	(4)	(4)	(4)	(4)	(4)	(3)	(3)	(3)	(3)	(3)	(2)	(2)	(2)	(2)	
	69	54	68	6	7	14	43	10	11	41	47	22	58	59	
	(2)	(2)	(2)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	
	44	29													*58*
	(1)	(1)													(352)
Total transactions															(15,687)

HHID as buyer	HHID as seller														Tot. No. of HH (Tot. No. of transactions)
Outflow	30	47	45	36	63	28	24	48	40	34	19	64	6	31	
	(52)	(45)	(45)	(41)	(40)	(38)	(38)	(38)	(37)	(37)	(37)	(37)	(36)	36	
	52	59	54	26	70	39	43	33	51	42	57	12	35	61	
	(36)	(36)	(36)	(36)	(35)	(34)	(34)	(34)	(34)	(34)	(33)	(32)	(32)	(32)	
	27	67	9	46	22	62	32	38	68	2	49	66	25	58	
	(32)	(32)	(31)	(31)	(31)	(31)	(30)	(30)	(30)	(29)	(29)	(29)	(28)	(28)	
	21	11	23	29	4	37	55	14	56	15	44	65	13	18	
	(27)	(26)	(26)	(26)	(25)	(25)	(25)	(24)	(23)	(22)	(22)	(21)	(20)	(17)	
	17	60	8	50	10	1	3	7	5	53	69	16	20	41	*70*
	(17)	(17)	(15)	(15)	(14)	(13)	(13)	(13)	(13)	(13)	(13)	(10)	(6)	(2)	(1,959)
38	Inflow	30	38	33	39	32	49	34	45	25	19	47	23	52	
(Nearly	(56)	(21)	(20)	(18)	(17)	(17)	(15)	(15)	(11)	(9)	(9)	(9)	(9)	(9)	
poor)	55	70	40	46	42	9	16	14	11	17	57	68	63	31	
	(6)	(6)	(5)	(5)	(5)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	(3)	
	28	51	54	61	1	12	37	22	48	26	66	2	6	4	
	(3)	(3)	(3)	(3)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(1)	(1)	(1)	
	10	24	21	58	59	69	36	64	29	62	60	67			*54*
	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)			(338)
21	Inflow	63	49	35	59	11	48	12	2	39	33	57	40	43	
(Nearly	(55)	(17)	(14)	(14)	(12)	(11)	(10)	(9)	(9)	(9)	(9)	(9)	(8)	(8)	
poor)	21	3	38	24	70	17	26	9	7	13	34	31	36	67	
	(8)	(6)	(6)	(6)	(6)	(5)	(5)	(4)	(4)	(4)	(4)	(4)	(4)	(4)	
	30	61	62	6	18	14	15	46	51	23	45	69	55	27	
	(3)	(3)	(3)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	
	42	4	8	5	16	32	20	10	53	22	58	54	64	66	*56*
	(2)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(1)	(310)
Total transactions															(15,687)

Source: Calculated by the author from the expanded QVIOT of Houey Nambak village in the third round.

Note: The numbers in parenthesis () are the numbers of transactions. HHID1-6, 7-40, 41-62 and 63-70 are poor, nearly poor, middle-income and rich households, respectively.

4.5 Conclusions and Policy Implications

The analysis of economic structures in regional studies using qualitative data provides greater insight into the cases of developing countries. One well-known technique to examine direct and indirect relationships among industrial sectors in the economic structure of a certain region/country is a qualitative input-output table which is derived from a usual type of input-output table.

This research aimed to examine key characteristics of interdependency among households in the same community through the application of the expanded QVIOT, based on village transactions in Vietnam and Lao PDR. These expanded QVIOTs were constructed using two VIOTs of Dang village, in Vietnam, and Houey Nambak village, in Lao PDR, using data from household surveys conducted in 2018. Our findings illustrate that in Dang village, households' main income was based on wages rather than agricultural products. A poor household sold products within and outside the village, while poor, nearly poor and rich households bought intermediate products from a poor household. Although most transactions, involving poultry were small, poultry was the highest-ranked in terms of numbers of transactions within the village compared to other products. Poor, middle-income and rich households were the main suppliers of poultry, and demanders were poor and nearly poor households. The network analysis confirmed that there were no specific households that were the main trading partners in terms of poultry transactions. Since there were very few transactions, there was no tendency among households in terms of poultry transactions in the village. Unlike in Dang village, the main income source of Houey Nambak village was based on agricultural products, especially sugarcane. In the highest top ten transactions, rich, middle-income and nearly poor households tended to sell and buy products outside the village. In particular, all of the households bought more poultry outside the village. However, nearly poor households tended to sell poultry outside the village. In Houey Nambak village, the main suppliers and demanders of poultry were nearly poor and middle-income households. The network analysis showed strong evidence that the key players were nearly poor and middle-income households in terms of poultry transactions with over 70% of total transactions conducted by these households within the village. And they were very interdependent compared to poor and rich households.

Our findings differ from Hongsakhone and Ichihashi (2018). First, because we used the expended QVIOT, we could compare transactions within and outside the village. Second, with the centrality index, we could easily identify which households were the real suppliers and demanders. Finally, the network analysis provided precise total numbers of transactions by each trading partner, and we could also identify the number of transactions that involved trade with outsiders.

Strengthening information networks is necessary to ensure sustainable rural development. This research sheds light on another perspective on rural development in Vietnam and Lao PDR, and we note some policy implications.

- Most households in the two villages have planted rice and raised cattle and pigs for their own consumption, which generates little added value. Transforming to commercialization is essential to increase the numbers of internal and external village transactions. This transformation will lead to an increase in household income and mitigate poverty.
- In Houey Nambak village, sugarcane is the main source of household income and has a certain market. Consequently, expanding the area of the production of sugarcane, together with increased productivity of this product, is important to raise household income.

Chapter 5

Conclusions and Policy Implications

5.1 Conclusions

The finding of this dissertation is divided into two parts, the first part concludes the results of impact of irrigation on sticky rice production and productivity. The second part shows interdependencies among households through their agricultural transactions.

5.1.1 Main Finding from Impact Evaluation of Irrigation on Sticky Rice Production and Productivity

This result focuses on analyzing the impacts of irrigation on sticky rice production and productivity by employing PSM and DID method. The panel data 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 in PSM (Chapter 2) 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 1,138 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. However, no evidence are found in the impact of irrigation on household consumption. In Lao PDR, households mainly grow sticky rice for self-consumption rather than sale, and household income is usually earned from various sources apart from sticky rice cultivation. In addition, majority of rural areas in developing countries including Lao PDR, where households cannot access regular markets. Therefore when the production of households increase or the production surplus, they will be stocked them as wealth or capital accumulation (Bhattarai et al., 2001). Furthermore, sticky rice product is considered to be necessary goods which has a small elasticity of demand when the

production of household or income increases, they will have a minor change on the amount of stick rice consumption. This might, to some extent, be able to explain the reason why an increase in sticky rice productivity does not reflect in households' consumption.

In addition, the result of DID (Chapter 3) points out that irrigation has positive impact on sticky rice productivity when households access to irrigation in both one period and two periods of the LECS. In particularly, 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. Additionally, the 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, per season. We found that long-term access to irrigation leads to higher sticky rice productivity, since a longer access to irrigation made farmers have learnt more experience in using irrigation for supporting their sticky production such as good irrigation practice, intensive irrigation management and good water arrangement (Bhattarai et al., 2001 and; Mutiro and Lautze, 2015).

To conclude, our findings show positive impacts of irrigation on sticky rice production and 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.

5.1.2 Main Finding from Interdependencies among Households through their Transactions

This part examines the interdependency among households through village transactions. These expanded QVIOTs were constructed using two VIOTs of Dang village in Vietnam and Houey Nambak village in Lao PDR using data from household surveys conducted in 2018. The findings illustrate that in Dang village, households' main income was based on wages rather than agricultural products. Although most transactions, involving poultry were small, poultry was the highest-ranked in terms of numbers of transactions within the village compared to other products. The network analysis confirmed that there were no specific households that were the main trading partners in terms of poultry

transactions. Unlike in Dang village, the main income source of Houey Nambak village was based on agricultural products, especially sugarcane. Rich, middle-income and nearly poor households tended to sell and buy products outside the village according to the list of top ten highest transaction. In particular, all households status bought poultry outside the village. However, nearly poor households tended to sell poultry outside the village. In Houey Nambak village, the main suppliers and demanders of poultry were nearly poor and middle-income households. The network analysis showed strong evidence that the key players were nearly poor and middle-income households in terms of poultry transactions with over 70% of total transactions conducted by these households within the village. And they were very interdependent compared to poor and rich households.

5.2 Policy Implications

According to the findings in Chapter 2 and 3, irrigation has positive effect on sticky rice production and productivity. Therefore, in order to improve rice productivity leading to higher income generation, the government needs to not only consider more access to irrigation of the farmers but also improved monitoring of irrigation systems to ensure the efficiency of irrigation utilization. Especially those who live in distant areas. In the long run, development of agricultural infrastructure especially irrigation system expansion is highly needed,

The result from Chapter 4 suggests that to improve household livelihoods and to lead to poverty reduction in the long run, adopting commercialization is necessary to raise transaction volume and poultry productivity.

5.3 Further Discussions

The discussion in Chapter 2 and 3, even though the results shown that irrigation have positive effect on sticky rice production and productivity, this impact may not only from irrigation solely but also many factors such as the adaptation of technology innovation, fertilizer used, seed quality, the amount of rain fall, etc. Additionally, the impact of irrigation on agricultural products may have different for different countries, geographies, irrigation management styles, irrigation method, and crop mixes. For further study, the author highly

recommend observe those factors to get more precise of the impact of irrigation on agricultural products.

There is no evidence of the impact of irrigation on household consumption are found in Chapter 2 and 3. Since many developing countries include Lao PDR, majority of households who live in rural areas, still cannot access regular markets. Therefore, when sticky rice production of household increases or the production surplus, they tend to stock them as wealth or capital accumulation (Bhattarai et al., 2001). For future study, the author highly recommends to add amount of self-consumption and agricultural stock to see the real impact on irrigation.

Appendix A

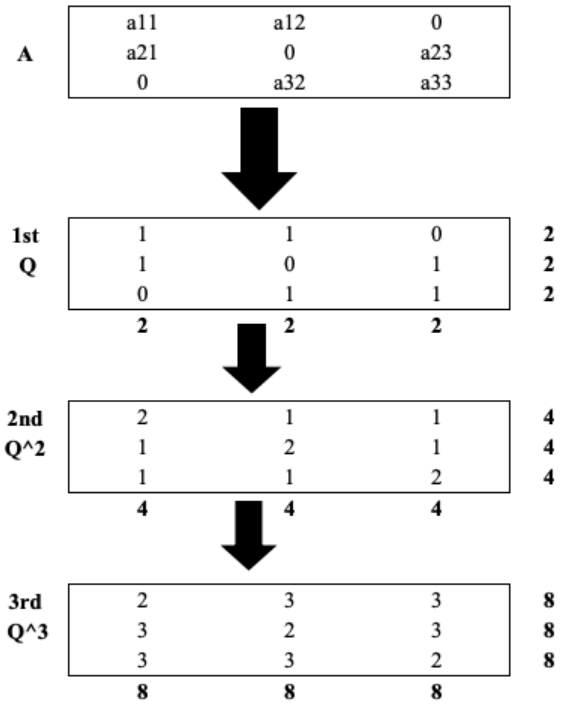


Figure A1: Converting from the Expended VIOT to the Expended QVIOT until third round of transaction.

Table A1: Rice and cattle and pigs transactions in Dang village.

Rank	Seller		Buyer		Rice	Rank	Seller ID	Buyer ID	HH status	Cattle and pigs
	HHID	HH status	HHID	HH status						
1	74	Rich	12	Poor	6	1	*13*	*13*	*Poor*	*4*
1	58	Middle	63	Rich	6	1	*1*	*1*	*Poor*	*4*
2	*1*	*Poor*	*1*	*Poor*	*4*	1	*36*	*36*	*Nearly poor*	*4*
2	*4*	*Poor*	*4*	*Poor*	*4*	1	*67*	*67*	*Rich*	*4*
2	*5*	*Poor*	*5*	*Poor*	*4*	1	*57*	*57*	*Middle*	*4*
2	*9*	*Poor*	*9*	*Poor*	*4*	1	*69*	*69*	*Rich*	*4*
2	*11*	*Poor*	*11*	*Poor*	*4*	1	*62*	*62*	*Rich*	*4*
2	*23*	*Poor*	*23*	*Poor*	*4*	1	*3*	*3*	*Poor*	*4*
2	*17*	*Poor*	*17*	*Poor*	*4*	1	*10*	*10*	*Poor*	*4*
2	*35*	*Nearly Poor*	*35*	*Nearly Poor*	*4*	1	*30*	*30*	*Poor*	*4*

Source: Calculated by the author from the expanded QVIOT of Dang village in the third round. *Note:* The numbers in *italics* are household products produced for their own consumption.

Table A2: Cattle and pigs and rice transactions in Houey Nambak village.

Rank	Seller ID	Buyer ID	HH status	Cattle and pigs	Rank	Seller		Buyer		Rice
						HHID	HH status	HHID	HH status	
1	*46*	*46*	*Middle*	*9*	1	45	Middle	51	Middle	10
1	*26*	*26*	*Nearly poor*	*9*	2	Inflow		51	Middle	7
2	*39*	*39*	*Nearly poor*	*8*	3	53	Middle	41	Middle	6
2	*7*	*7*	*Nearly poor*	*8*	3	45	Middle	55	Middle	6
2	*18*	*18*	*Nearly poor*	*8*	3	68	Rich	40	Nearly poor	6
2	*13*	*13*	*Nearly poor*	*8*	3	29	Nearly poor	35	Nearly poor	6
2	*43*	*43*	*Middle*	*8*	3	67	Rich	46	Middle	6
2	*32*	*32*	*Nearly poor*	*8*	3	67	Rich	62	Middle	6
2	*19*	*19*	*Nearly poor*	*8*	3	66	Rich	2	Poor	6
2	*41*	*41*	*Middle*	*8*	3	15	Nearly poor	6	Poor	6

Source: Calculated by the author from the expanded QVIOT of Houey Nambak village in the third round. *Note:* The numbers in *italics* are household products produced for their own consumption.

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