SOCIAL CAPITAL, COLLECTIVE ACTIONS, AND EFFICIENCY IN RICE PRODUCTION; LINKING TOWARDS AN IMPROVED PARTICIPATORY IRRIGATION MANAGEMENT IN THE MAE LAO IRRIGATION PROJECT, CHIANGRAI PROVINCE, NORTHERN THAILAND.

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ABSTRACT

Water resource management, particularly in agricultural use, plays a critical role in Thailand's national target of increasing the productivity of the agricultural sector. As Thai farmers are greatly affected by the fast-changing climate, developing efficient irrigation management is critical. The Royal Irrigation Department (RID) oversees and manages all irrigation projects throughout the country. However, the operation and maintenance of these irrigation projects are found to be costly for the irrigation department to finance alone. Since Thailand's 8th national plan in 1997, public participation in the governance, operation, and management of irrigation projects has been highly promoted.

The country adopted Participatory Irrigation Management (PIM) as the primary framework for promoting public participation in irrigation projects. The adoption of PIM

implies shared responsibility for maintaining the irrigation project between the irrigation department and the farmers. However, in many cases, sharing responsibility for government projects with people’s organizations has not been a smooth sailing process. Enforcement of rules and regulation of collective maintenance work entails high monitoring costs and efforts, particularly for irrigation officers and group leaders. In addition, the non-exclusion nature of surface irrigation is characterized by high incentives for the defection of taking responsibility for collective irrigation management. Nonetheless, successful cases of PIM implementation are characterized by a high level of social capital, i.e., high perceived trust, shared vision, commitment, and coordination.

Given the initial premise, the study aims to 1) identify and assess the drivers of collective action and the role of social capital in the context of participatory irrigation management; 2) assess the effect of the current irrigation management on the efficiency of rice farming; 3) assess and evaluate the link between the social capital concept, collective action, and farmers' efficiency in production under participatory irrigation management; 4) provide policy recommendations in improving the PIM adoption in the Mae Lao irrigation project in Chiang Rai province, Northern Thailand.

Qualitative and quantitative data were collected using the focus group discussion and face-to-face interviews with the irrigation officers, farmers, group leaders, and water users in the Mae Lao irrigation project in Chiang Rai province, Northern Thailand. A total of 304 randomly selected farmers were interviewed across the Mae Lao irrigation project branches. The collected data were assessed and evaluated in terms of reliability and validity. The main analytical tools adopted in the study are the stochastic frontier analysis for the production efficiency estimation and the partial least-square structural equation modeling in assessing the interrelationship of the social capital, collective action in PIM, and farmers’ efficiency.

The hypothesized driving factors for collective action in participatory irrigation management show social capital concept has the largest magnitude of impact. The result implies that farmers with a higher social capital endowment in terms of high perceived trust, reciprocity, and overall relationship within group members and their networks show higher participation in PIM’s collective irrigation management. At the same time, similar effects are observed for the human capital and perceived risk factor, which show a positive indirect effect on the operation and maintenance of the irrigation infrastructure.

On the other hand, the overall median technical efficiency across the three branches of Mae Lao irrigation was 83.62 percent. This suggested a potential 16.38 percent increase in efficiency when factors contributing to farmers’ inefficiencies were addressed. Whereas the median efficiency by branches is lower than the overall median efficiency. Branch 1 to 3 has a median efficiency of 84.6, 83.5, and 83.2 percent, respectively. Regarding the influence of farmers’ participation in PIM activities – dispute resolution, group meetings, maintenance work, and policy adherence reveals that maintenance work has the largest magnitude of effect on farmers' farming efficiency. Consequently, farmers’ adherence to policies and regulations has the second largest magnitude of effect. This implies that maintenance work and policy adherence directly impact farmers’ rice production.

Overall, the findings emphasize the social capital’s role in facilitating a real participatory engagement in shared resource management. Furthermore, understanding the link between the social capital concept, collective action in PIM, and its impact on

farmers' efficiency provides a holistic approach for policy inputs for improved implementation of participatory irrigation management when enforcing rules is insufficient or ineffective.

Keywords: PIM, irrigation, social capital, efficiency, production

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"Just keep moving forward."

- *Meet the Robinsons*

The quote above has been my guiding principle since 2008 when I first watched the movie Meet the Robinsons. It reminds us to keep moving forward in every challenge, failure, and success. Just like completing my Ph.D. journey, I will be moving forward toward my journeys in life.

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Above all, to my family, who have been supportive and never doubted what I wanted to pursue in life. *Daghang salamat! Pinangga ug gehigugma ko kamo!*

Christopher Almoroto Llones

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure no.	Title	Page

CHAPTER 1. INTRODUCTION

1.1. Research background

Water scarcity is part of the global agenda and one of the priorities of the United Nations (U.N.) Sustainable Development Goals (SDG). The SDG envisioned 2030 a substantial increase in water-use efficiency and reduce the number of regions suffering from water scarcity (Frenken, 2012). However, despite the efforts to achieve water sufficiency for food and global demand, more regions will face water scarcity (Frenken, 2012).

Among the national sectors, agriculture relies heavily on water for production (FAO, 2017). Regions in Southeast Asia rely on agriculture for livelihood, and farms with better access to water and irrigation facilities significantly support national food security (Faysse et al., 2022; Mutert & Fairhurst, 2002). However, farms are facing water shortage which constrains agricultural production affecting the income and livelihood of water-scarce regions (Faysse et al., 2020). As a coping mechanism, farmers diversify income sources through off-farm and non-farm livelihood in managing challenges and risks (Cramb et al., 2016; Vial et al., 2020). The annual trend shows that the agricultural sector is growing less than other sectors across mainland Southeast Asia but continues to contribute significantly to overall economic development (Cramb et al., 2016).

Thailand's long-term development targets are mapped in its twenty-year (2017-2036) national strategic plan. According to the National Economic and Social Development (NESD, 2019), the national strategic plan is a framework the government follows to regulate development implementation and attain the country's future development target. Under the long-term plan, infrastructures and technological innovation are one of the main interests in its steps for global development (NESD, 2019).

However, the agricultural sector is facing the challenge of declining growth coupled with a high percentage of people with low incomes relying upon agriculture as the primary source of livelihood (Cramb et al., 2016; FAO, 2017). Hence, poverty reduction programs center on productivity, efficiency, and the development of the overall performance in the agricultural sector. Among all the crops the country produces, rice covers half of the cultivated area and has the highest economic value (Ngammuangtueng et al., 2019; Papademetriou & Dent, 2001).

Rice production security for domestic consumption and exportation is closely linked to the country's river and irrigation systems (Faysse et al., 2020; Gloede et al., 2015). Thailand financed irrigation projects to supplement water demand, especially during the dry season. All the supervision of irrigation projects is under the Royal Irrigation Department of Thailand (Kumnerdpet & Sinclair, 2011). Nevertheless, establishing irrigation projects involves enormous investment and costly operation and maintenance (Onimaru, 2014).

The irrigation infrastructure is seen as promising in agricultural development, but the projects face the challenge of the increasing cost of maintaining the operation and management (Cohen & Pearson, 1998; Kumnerdpet & Sinclair, 2010). To relieve the burden of huge irrigation maintenance costs, the idea of decentralization gave a more significant role to farmers in operation and maintenance (Kumnerdpet & Sinclair, 2010; Walker et al., 2015). Decentralization aims to reduce the burden of managing irrigation projects, and the RID supports the joint management of the local irrigation department and the water user group (Walker et al., 2015).

RID has adopted Participatory Irrigation Management (PIM) as a framework for shared management (Walker et al., 2015). A participatory approach in irrigation management is a framework that engages the public's participation in the decision-making process. This approach is in the hope of a sustainable adoption of technology or shared accountability and management of government projects to the community (Raza Ullah et al., 2021). In the context of the RID's plan, the water user group is encouraged to participate during planning, decision-making, and in operation and maintenance of the irrigation project (Kumnerdpet & Sinclair, 2011).

Nonetheless, in many cases, sharing responsibility for government projects with people's organizations has not been a smooth sailing process. In the case of collective irrigation management under the PIM principles, enforcement of rules and regulation of collective maintenance work entails high monitoring costs and efforts, particularly for irrigation officers and group leaders. The situation can be partly attributed to the nature of surface irrigation, where irrigation services are easily accessible or non-excludable. Also, the incentive for defection with the agreed responsibility of collective maintenance work is high. This implies that enforcing rules and regulations of joint irrigation management entails high monitoring costs.

Successful cases of PIM implementation also exhibit similar constraints as unsuccessful water user groups. However, several case studies found that successful groups demonstrate strong group cohesion and higher perceived social capital endowment (Kumnerdpet & Sinclair, 2011; Molle et al., 2002; J. Ricks, 2018; J. I. Ricks, 2015). Putnam (2000) considers social capital as the "norms of reciprocity and trustworthiness resulting from social networks." These social norms serve as a social control on what is considered socially desirable and acceptable behavior in the absence of sanctions and rewards to facilitate voluntary participation in collective actions (Knoke, 1988; Luo et al., 2016; Onyx et al., 2000). The potential of social capital in applying to joint resource management problems gives rise to its growing research in the literature.

Given the above notions, it warrants the potential application of social capital in increasing the participation of water users in collective irrigation management under the PIM principles of the Mae Lao Irrigation Project. Improving the joint management of irrigation infrastructure under the PIM principles is vital to food sufficiency in Thailand. The efficient rice production system of the country is not only limited to the biophysical and cost reduction but also to the ability of farmers to utilize all available resources. Rice production employs several forms of capital (e.g., financial, physical, natural, and human capital). However, social capital is the less explored form of capital in the rice production processes. The social capital manifests in relationships within the farming community that could support the rice production system. Woolcock (2000) emphasized that social capital is an under-appreciated factor of production. There is increasing work on the social capital facilitating the adoption of agricultural innovations and technologies in improving the sustainability, productivity, and efficiency of agricultural production (Aida, 2019; Choi & Chang, 2020; Cofré-Bravo et al., 2019; LYU & JI, 2020).

1.2. Problem statement and research gap

The adoption of participatory irrigation management in MLIP was characterized by challenges related to unsatisfactory operational management, the inadequacy of the canal structure and control system, the widening of unregistered areas for irrigation, lack of supervision and compliance with water distribution rules, and unauthorized nighttime operation in the head canal. The situation implies that enforcement of rules is deemed ineffective in increasing participation in joint irrigation management. Therefore, the problems require a different approach to increasing voluntary participation in collective actions under participatory irrigation management.

The gradual transfer of the responsibilities of managing the irrigation with the public without emphasis on learning the nature and capacities of water users would be a possible threat to successful irrigation project reform (ICID & FAO, 2004). Rather than attempting to solve the problem abruptly, UNDP prefers the approach to capacity development that involves empowering people and organizations (ICID & FAO, 2004). Cofré-Bravo et al. (2019) and Woolcock (1998) emphasize the importance of knowing the people who participate in organization and networking, from which this idea is closely linked to the social capital concept. Social capital, just like the other forms of capital (e.g., physical capital, natural capital, human capital, and financial capital), gained increasing recognition by economists as an essential asset for strengthening the community in dealing with collective action problems. (ICID & FAO, 2004).

Furthermore, the irrigated rice farms' reliance on the Mae Lao irrigation project underscores the significance of enhancing water users' engagement in collective irrigation management. Any interruptions in the delivery of irrigation services would undoubtedly impact the productivity and efficiency of rice production. Given the previous premise, addressing the root cause of the current problems in MLIP requires a deep understanding of developing the involved stakeholders, particularly the WUG, in terms of their capacity to assume responsibilities towards irrigation management. Hence, the study tackles the following areas:

1. Though the shared irrigation management scheme under PIM adoption in MLIP has been founded for several years, many inefficiencies in management persist. Poor understanding of the inter- and intra-relationships among actors often leads to approaches being proposed that do not resolve the underlying irrigation management challenges.
2. Also, rice farmers face the challenge of unreliable water supply, which could affect their productivity and efficiency and add risks to their livelihood source. Considering that rice production in Thailand is closely linked to irrigation, knowing how irrigation management affects production and efficiency could leverage farmers to handle risks and provide crucial decision-making.
3. The irrigation project in MLIP under a PIM faces low participant adherence to irrigation policies and procedures. Therefore, it should be crucial to evaluate the internal and external factors of the projects and arrive at appropriate approaches to establish efficient irrigation project management under a participatory management approach.

1.3. Research questions

The high cost of the operation and maintenance of irrigation projects prompts the irrigation department to adopt participatory irrigation management. The adopted approach requires a collaboration between the irrigation department and farmers in the joint operation and management of the Mae Lao irrigation project. However, the non-excludability nature of surface irrigation incentivizes the defectors not to contribute or take responsibility for joint irrigation management. Therefore, enforcing irrigation rules may not suffice and requires developing the voluntary participation of the water users. The following research question seeks to provide insights for policy inputs in developing higher participation in PIM activities.

1. What factors drive higher intention for collective action, particularly the role of social capital in participatory irrigation management?
2. How does the current participatory irrigation management affect rice farmers' production and efficiency?
3. What is the link between developing social capital, collective action, and efficiency in rice production under participatory irrigation management?

1.4. Objectives of the study

The study's general objective seeks to assess the link between the social capital concept, collective actions, and efficiency in rice production as a policy input for improved participatory irrigation management in the Mae Lao irrigation project. While the specific objective of the study is as follows:

1. To identify and assess the drivers of collective action and the role of social capital in the context of participatory irrigation management.
2. To assess the effect of the current irrigation management on the efficiency of rice farming.
3. To assess and evaluate the link between the social capital concept, collective action, and farmers' efficiency in production under participatory irrigation management.
4. Provide policy recommendations based on the insights derived from the study's results.

1.5. Research framework

Figure 1.1 depicts the general framework and the analytical processes guiding the conduct of the study. The general framework section of the research framework presents the study's general objective linking the social capital concept, collective action, and their impact on production efficiency, which is hypothesized to improve the overall performance of the participatory irrigation management in the Mae Lao irrigation project. Formulating the research problem and objectives of the study resulted from consultations and discussions with experts, farmer groups, irrigation officers, and water users.

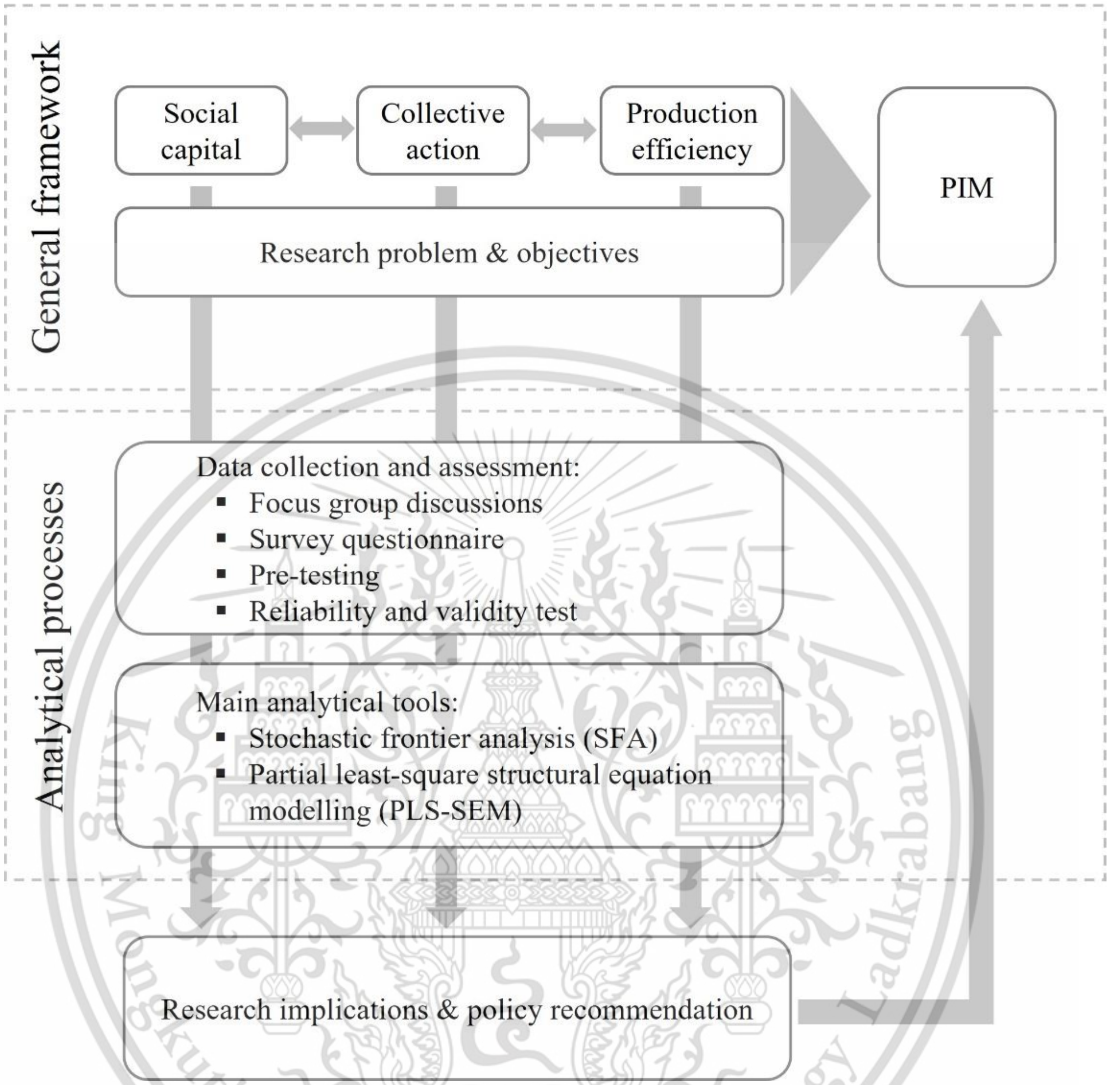


Figure 1.1. Research framework in linking the concepts of participatory irrigation management, social capital, and production efficiency.

The analytical processes employed in the study aim to answer the defined research problem and objectives presented in Sections 1.3 and 1.4, respectively. In the data collection, a series of focus group discussions and face-to-face interviews were conducted to gather qualitative and quantitative data. While the quality and validity of the data collection tools used in the study were assessed using the pre-testing of the survey questionnaire and the reliability and validity test.

In providing empirical evidence and results answering the hypotheses in the study, two main analytical tools were used – stochastic frontier analysis (SFA) and structural equation modeling (SEM). The SFA measures the level of productivity and efficiency of farmers targeting objectives 2 and 3. At the same time, the partial least-square structural equation modeling (PLS-SEM) enables the study to capture the indirect effects, direct effects, and the interrelationships of the social capital concept, collective actions, and PIM activities.

Insights from the empirical results provide the foundation for the policy input in providing recommendations for a better and improved PIM implementation. While no study is a panacea, the study aims to provide support and empirical evidence as inputs in the deliberation and formulation of better operation and management strategies in developing a better implementation of participatory irrigation management in the Mae Lao irrigation project.

1.6. Scope of the study

This study is limited to examining the drivers of collective action among MLIP actors, the impact of current irrigation management on the productivity and efficiency of rice farmers, and the assessment of the interrelationship of the social capital concept, collective action in PIM activities, and their impact to farmers efficiency in rice production. The study was conducted in Chiang Rai Province, Northern Thailand, wherein the MLIP's water user group is the primary focus case study. Selected representatives from the irrigation department handling the MLIP were also interviewed since the project is under participatory irrigation management.

1.7. Definition of research terms

Important research terms discussed in the study are defined and summarized in Table 1.1. These research terms are further discussed within this dissertation, while a reference to the literature is provided for further study of the research concept.

Table 1.1. List of important terms discussed.

Research terms	Definition	Source
Social capital	A form of capital that reflects *"the norms and networks that enable the people to act collectively."* The concept reflects *"the norms of reciprocity and trustworthiness resulting from the social networks."*	Woolcock (1998); Putnam (1994)
Collective action	Refers to civic engagement that reflects individuals working together in pursuit of shared interest.	
Participatory irrigation management	A framework that serves as the guiding principle between the irrigation department and the public for shared responsibility in the irrigation project.	Kumnerdpet & Sinclair (2011); Sinclair et al. (2013); Molle et al. (2002)

Technical efficiency	Farmers' ability to produce the possible maximum level of output given the specified level of inputs and existing technology. Also, it reflects farmers' capacity to use the least amount of inputs in producing a given output.	Farrell (1957); Schmidt & Knox Lovell (1979); Wang et al. (2020)
Partial least-square structural equation modeling (PLS-SEM)	*"A multivariate data analysis method for analyzing the complex relationship among constructs and indicators."*	Hair (2017); Jöreskog (1970); Ringle et al. (2023)

CHAPTER 2. REVIEW OF RELATED LITERATURE, CONCEPTUAL FRAMEWORK, AND HYPOTHESES

The study assesses the link between the social capital concept, collective actions, and the production efficiency of irrigated rice farms under participatory irrigation management. First, this chapter provides a background of the PIM implementation in Thailand. Second, the possible role of social capital in collective actions and their roles in developing better PIM implementation is explored. Afterward, the production efficiency measurement and the hypothesized structural link of the social capital, collective actions, and irrigation management are presented. The sections under this chapter are presented as follows:

2.1 Participatory irrigation management (PIM) in Thailand

2.2 Social capital, collective action and its role in PIM

2.3 Productivity and efficiency measurement

2.4 Interrelationships – PIM, social capital, and rice farming efficiency

2.1. Participatory irrigation management (PIM) in Thailand

Since establishing the Canal Department in 1902, and Royal Irrigation Department (RID) in 1923, Thailand has continuously invested in developing the country's irrigation. In its early phases, canal construction linking major rivers were first initiated in the central and northern region of the county. To increase the water diversion capacity of the irrigation infrastructure, the RID began constructing water weirs and dams in major rivers (Vudhivanich, 2008; Wongtragoon et al., 2010). The Royal Irrigation

Department oversees and manages the irrigation development in the county. The department has 17 main regional irrigation offices across the country, which provide technical support in water allocation and management, research, and development (Vudhivanich, 2008). The regional organizational structure consists of operation and maintenance (O&M) projects, provincial irrigation projects, and a water management division (Jewpanya et al., 2022; Vudhivanich, 2008).

Focusing on operation and management, the structure of the O&M project is divided into three main sections, the water management section, the engineering section, and the water master section. Planning, control, and budgeting for maintenance and repair are under the responsibility of the engineering section. While the water management section handles water allocation and delivery to the water master section. On the other hand, the water master section primarily deals with field operations such as planning and controlling the water distribution to different irrigation zones, data collection and reporting of the irrigated production area, crop yield, and organizing the water user groups along the irrigation canal.

However, providing irrigation services throughout the country also entails a high cost to the government. Therefore, in the eighth national development plan, the Thai government began to promote the participation of the local community in the governance, operation, and maintenance of irrigation projects (Kumnerdpet & Sinclair, 2011; J. I. Ricks, 2015). Thus, several reforms were introduced (e.g., laws and policies related to PIM reforms) that facilitate people's participation, mainly through the concept of participatory irrigation management (PIM) (Tan-kim-yong, 1983; Walker et al., 2015; Wongtragoon et al., 2010).

The principles behind the PIM encourage higher and better public participation, particularly among local people and communities, in the irrigation project's governance, operation, and maintenance (Jewpanya et al., 2022). This implies shared irrigation management between the irrigation department and the water users. The framework of this irrigation reform of the country is presented in Figure 2.1.

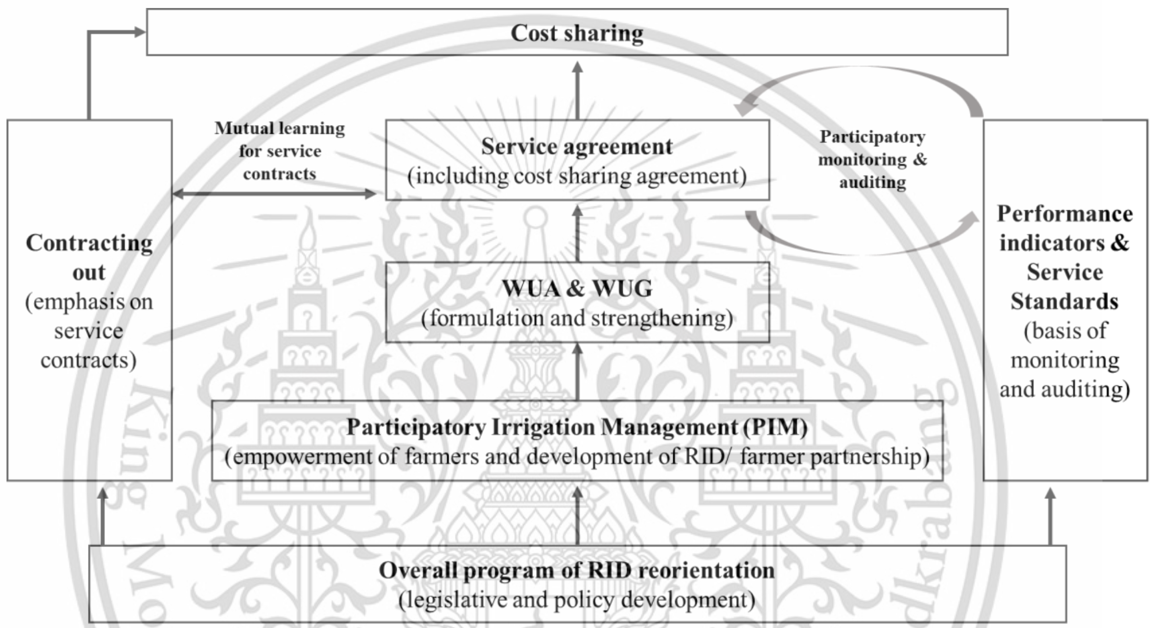


Figure 2.1. Irrigation reform framework in increasing farmers' decision-making role and developing partnerships between farmers and government as key factors for efficient and effective irrigation management. Figure adopted from Varawoot (2008).

Under participatory irrigation management, farmers at the sub-lateral canal, referred to as water users, are organized in groups as Water Users Group (WUG), and the federation of WUGs is organized as Integrated Water User Group (IWUG). In addition, Water User Associations are organized to unify WUGs and IWUGs (Vudhivanich, 2008). Costs related to operation and management at the sub-lateral canal level are transferred to the WUA. In contrast, for the lateral canal level, the associated costs are transferred to

IWUG, while the WUA and RID will share the overall cost of O&M at the main system level ((Vudhivanich, 2008).

However, the implementation of PIM emphasized that farmers (i.e., members of WUGs) are not expected to pay high irrigation service fees. However, cost sharing for O&M could be in the form of direct labor, hired labor, materials, or in-kind contributions (C. A. Llones et al., 2022; J. Ricks, 2018; Vudhivanich, 2008). Since adopting shared management under the PIM principles, there have been mixed outcomes regarding the success of implementing the PIM program(Aida, 2019; Reddy & Reddy, 2005; J. I. Ricks, 2015; Sinclair et al., 2013; Supriyasilp et al., 2021).

Joint irrigation management between farmers and the irrigation department is a collective action problem associated with high monitoring and enforcement costs (C. Llones et al., 2021; J. Ricks, 2018; J. I. Ricks, 2015). Given the non-excludability nature of surface irrigation, anyone along the irrigation canal can freely access it without restriction. For instance, violations of irrigation rules and regulations were noted during the group discussion, such as the illegal opening of watergate during nighttime. Hence, a strong incentive exists to free-ride without contributing to collective maintenance.

In addition, shared maintenance of the irrigation infrastructure between the irrigation department and farmers requires intensive information sharing. For example, water users are responsible for providing information on their production schedule and reporting any damages along the irrigation canal, while the irrigation department provides information on planned discharges, policy changes and discusses potential issues affecting the operation and management of the irrigation.

Several studies found that successful PIM adoption shows a higher presence of social capital (i.e., reflecting water users perceived trust, reciprocity, and social ties) that drives higher participation in collective actions (Azemzi & Erraoui, 2020; Kapoor, 2001; C. Llones et al., 2021; Onimaru, 2014). Given the need for the irrigation department to identify what drives the deliberate intention for higher participation in collective irrigation management. We argue that developing the social capital endowments of water users and strengthening its link to the irrigation department could have a larger influence on higher participation in PIM activities. The following section explores the role of the social capital concept in collective actions and its importance for the successful implementation of participatory irrigation management.

2.2. Social capital, collective action and its role in PIM

Publicly provided services tend to have a strong incentive to free ride and provide little to no incentives for the target stakeholders to contribute to maintaining these public goods (Cremades et al., 2015; Kim & Walker, 1984). Albeit a classic problem in all public goods, the political effort to remedy this problem has hardly succeeded. Similar cases have been observed in several irrigation projects, and the burden of maintaining these facilities requires a tremendous amount of investment from the government (J. I. Ricks, 2015). Hence, widely adopted by most irrigation projects across the globe is the public's participation in government projects, especially in operation and management. Public participation in the irrigation's operation, management, and decision-making is embodied under the principle of participatory irrigation management. This scheme aims to achieve sustainability through shared responsibility between the government and farmers (i.e., water users).

Typical for irrigation project management following the PIM principles is the election of a group leader responsible for coordinating collective activities such as water collection fees, canal repairs and maintenance, and enforcement of rules (Jewpanya et al., 2022; Onimaru, 2014; Walker et al., 2015). While the irrigation officer collects and organizes cropping calendar information from farmers as inputs for the irrigation department for water scheduling and planning. In addition, irrigation officers prepare irrigation maintenance reports and organize meetings with farmers for future water allocations and other important agendas. However, the group leader and irrigation officers cannot continually monitor possible irrigation rules and regulations violations. In addition, PIM activities require voluntary adherence from the water users, which makes PIM set up a collective action problem that requires high monitoring and enforcement costs (J. I. Ricks, 2015).

Sociologists often place collective action problems as the core of economic and political problems (Ostrom & Ahn, 2009). Consequently, the collective action paradigm is often used to frame social capital problems among social science researchers. However, one can ask where social capital fits in the economic and political issues, specifically in irrigation management and agricultural production. The concept of social capital began its popularity in the late 1980s and the 1990s. It was first famous among social scientists and later among economists (Pierre Bourdieu, 1986; Putnam, 2000; Woolcock, 1998). A basic understanding of capital is defined as a set of assets capable of generating future benefits. At the same time, other known capital takes the forms of physical capital (e.g., irrigation systems, schools, factories, and machinery), human capital (e.g., knowledge and skills), and financial capital (e.g., cash, credit).

In contrast, the social concept as another form of capital generates benefits through networks and linkages, which are likely to provide opportunities. In the case of MLIP, the irrigation department alone does not possess enough resources for a sustainable irrigation system. It requires sustainable development partnerships with the state, private sectors, and communities. In this notion, social relations could be treated as capital-providing benefits among actors.

According to Ostrom and Ahn (2009), the criticism of social capital research is often on the vague ideas of the concept and its measurement. The focus of this study is the farmers, who are organized as a water user group with a common interest in efficient irrigation management and operation through collective action and its attainment of the shared vision of providing better irrigation services among its members. To assess this view, the conceptual framework in Figure 2.2 shows the study's hypotheses that drive collective action and its influence toward better irrigation services.

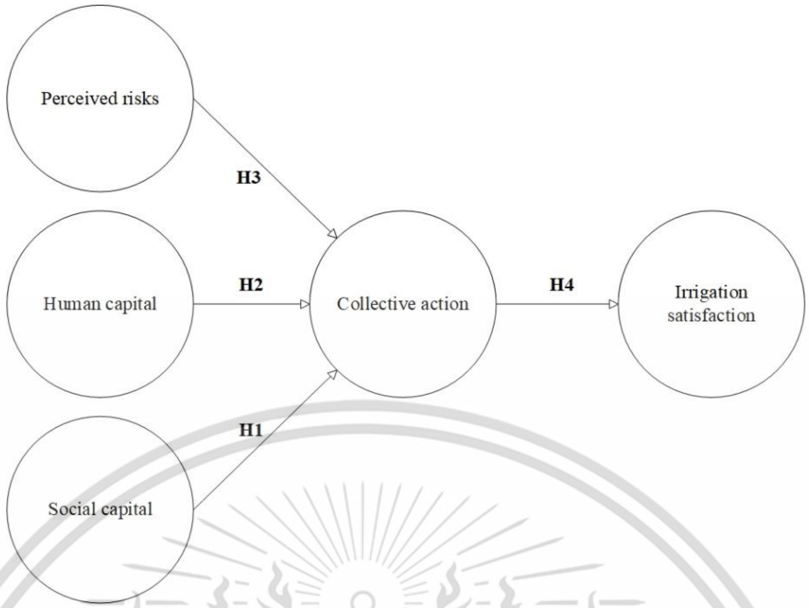


Figure 2.2. Hypothesized relationship of social capital and collective action in developing better irrigation services under participatory irrigation management.

In the H1 hypothesis, the study adopted the bonding and bridging distinction of the social capital concept (Cofré-Bravo et al., 2019; Nguyen-Trung et al., 2020; Patulny & Lind Haase Svendsen, 2007). Patulny (2007) noted that empirical research measures social capital in the *"one catch-all concept"* usually focused solely on bridging or bonding, but few attempts to include both simultaneously. The current study considers incorporating the social capital distinction to understand better the interrelationship dynamics between the WUG, the irrigation department, and the other involved institutions. Putnam et al. (1994) define bridging as *"outward-looking and encompassing people across diverse social cleavages."* These are relations formed by WUG within the structure of the MLIP's irrigation department, communities, or other organizations. Whereas bonding social capital "*is an inward-looking [network that] tends to reinforce* *exclusive identities and homogeneous groups*" (Putnam et al., 1994). The bonding describes the connection and relationship within the WUG.

The social capital concept as a primary driver of collective actions reflects the individual's (i.e., water users and irrigation department in the study's case) perceived trust and reciprocity through linkages and networks. Following Ostrom and Ahn (2009), the framework uses trust as a link with social capital and the achievement of collective action. The idea was to enhance the level of trust among the actors, which is hypothesized to enhance the likelihood of attaining intention towards participating in collective action.

For a successful implementation of MLIP, each member has their own perceived level of trustworthiness towards each member. The perceived trustworthiness could influence the decision of an individual whether to nominate someone for a position or expect to execute the responsibility the individual holds in the organization. In addition, the organization's informal and formal rules could also influence the actor's behavior. These concepts facilitate the formation of networks in the Mae Lao irrigation project, where each network's willingness to do partnerships and transactions is also considered in their perceived trust in their partner networks.

While perceived reciprocity reflects providing benefits for other actors without the expectation of receiving back the favor. Onyx and Bullen (2000) demonstrated that the presence of perceived trust and reciprocity increases people's attention toward the welfare and interest of other people. For the MLIP water user groups, developing farmers perceived trust and reciprocity among members drives collective action, especially since there is no monetary incentive to cooperate. Understanding the subdimension of social capital (i.e., bonding and bridging social capital) and how it links to collective action aids in understanding the concept embedded in irrigation management.

Moreover, perceived risk related to farming and human capital factors were also considered as drivers for collective action in Figure 2.2. The human capital concept reflects the water users' farming skills and the ability to take leadership roles. Higher human capital is hypothesized to be positively associated with higher intention to participate in collective PIM activities (i.e., H2 hypothesis). Likewise, perceived risks in farming are hypothesized to be positively associated with collective action. As farmers faced uncertainties in production outcomes (i.e., risky situations), non-participation in collective maintenance could further increase the potential uncertainties through disruption in the irrigation services.

Accordingly, the following section presents the conceptual background for estimating farmers' productivity and efficiency in rice farming. Next, we demonstrate the pathways linking the social capital concept, participatory irrigation management, and their impact on farmers' rice farming.

2.3. Productivity and efficiency measurement

As the water user group's production depends significantly on irrigation provided by the project, the condition of the irrigation management in MLIP could influence farmers' decision-making in the area. Hence, this section provides a background on the conventional method of measuring efficiency in production.

The theoretical explanation of the production function showing the possible output from a set of inputs given a fixed technology has been widely accepted (Cobb & Douglas, 1928). However, subjecting the theory to empirical testing, Farrel (1957) asserts that an actual efficiency measurement would be essential. Before the work of Farrell (1957), the measurement of average productivity was considered an adequate measurement of efficiency. However, Farrell expressed that measuring productivity as a measurement of efficiency was a *"patently unsatisfactory measure, as it ignores all inputs save."* Bridging the gap, the study follows Farrell's work that pioneered today's advancement in efficiency measurement.

Production efficiency can be decomposed into technical, allocative, or cost efficiency (T. J. Coelli et al., 2005). The former refers to the production of maximum output with the given set of inputs, while the former refers to producing a given output level at the least possible cost. If a farmer is both allocative and technically efficient, the farmer is said to be economically efficient (D. Aigner et al., 1977; Farrell, 1957; Førsund et al., 1980).

Estimating the water users' efficiency level in rice farming can be estimated using a parametric and non-parametric approach. In a non-parametric, the method is usually done through a linear programming method wherein the Data Envelopment Analysis is the most widely used. The main advantage of DEA is that no explicit functional form is imposed on the data and attributes all the deviation from the frontier to inefficiency. Whereas a parametric estimation, based on a frontier production function, can deal with stochastic noise. The approach also requires the underlying technology's explicit functional form and the inefficiency term's distributional assumption. In the recent developments of frontier estimation, researchers can assess and analyze from the frontier the technical, allocative, and economic inefficiency. Although Farrel (1957) pioneered the estimation of the frontier production function, the work of Aigner et al. (1977) developed a new approach to the estimation that addressed the shortcomings of the previous frontier estimation. In subsequent years, Schmidt & Knox Lovell (1979) decomposed the frontier function into technical and allocative efficiency.

The stochastic frontier function proposed by Aigner et al. (1977) restricts either output lying on or below the frontier. As the frontier assumed as the maximum production of output y_i by optimal x_i input use that any deviations from the frontier are due to statistical noise and inefficiency, see Figure 2.3. In the restriction of $y_i \leq f(x_i;\, \beta)$, Schmidt (1979) added a disturbance term ε_i to give the function with a statistical properties. Aigner et al. (1976) further decomposed errors ε_i into (1) accounting for random variation relating to the ability to use the best practice technology or u_i and (2) the measurement error or the statistical noise v_i. The decomposition of the error structure is given as $\varepsilon_i = v_i - u_i,\ i = 1, \dots, I.$ The disturbance term is assumed to be normally distributed with zero means and variance $N(0, \sigma^2)$. Using the Cobb-Douglas function, the stochastic frontier model is expressed in equation (1).

$$q_i = x_i'\beta + e^{\varepsilon_i} \qquad i = 1, \dots, I \qquad (1)$$

where q_i, x_i', β are the output of the i-th farm, a $K \times 1$vector of the logarithm of inputs, and a vector of unknown parameters, respectively. The essential features of equation (1) are illustrated graphically in Figure 2.3.

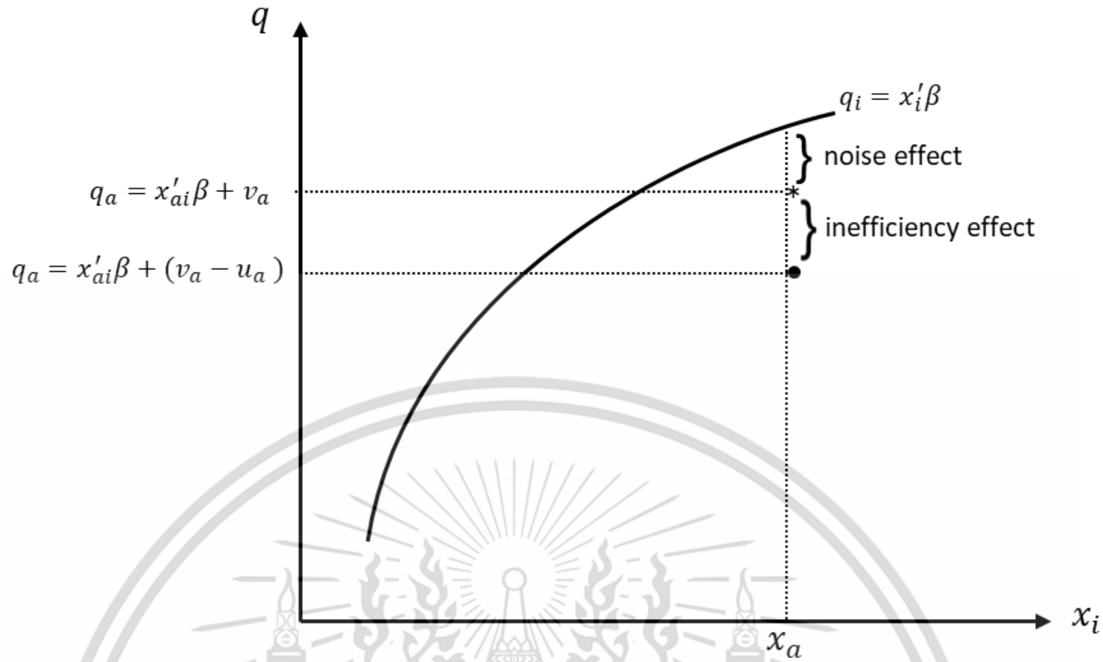


Figure 2.3. Illustration of the stochastic production frontier function. Figure adopted from Coelli et al. (2005).

The production frontier of the farm illustrated by the figure lies below the deterministic part of the frontier. At this level, the noise effect is negative, and concurrently the sum of the noise and inefficiency effects is negative such that $(v_i - u_i) < 0$. The production frontier could also lie above the deterministic frontier when the noise effect is positive and higher than the inefficiency effect. The observed outputs tend to lie below the frontier based on the previous assumptions of efficient production is the deterministic frontier. Using a stochastic frontier function proposed by D. Aigner et al. (1977), the estimation of the inefficiency effect derived from $y_i = f(x_i;\, \beta)\exp{(v - u)}$ into the expression as in equation (2).

$$TE = \frac{y_i}{exp(x_i'\beta + v_i)} = \frac{\exp{(x_i'\beta + v_i - u_i)}}{\exp{(x_i'\beta + v_i)}} = \exp{(-u_i)} \qquad (2)$$

The technical efficiency, $0 < TE < 1$, measures the output of the i-th farm using the same input vector. As can be observed from above, the estimation of the corresponding frontier function, as in (1), before the technical efficiency estimation. The stochastic frontier model of Aigner et al. (D. Aigner et al., 1977) was extended and developed by Schmidt and Knox Lovell (1979) into a stochastic cost frontier, as shown in equation (3).

$$c_i = \exp \mathrm{c}(q_i, p_i) + v_i + u_i \quad i = 1, \ldots, I \tag{3}$$

Although the current study only estimates farmers' technical efficiency, it is also important to present the other form of alternative efficiency measurement. The cost frontier is a function of q_i vector of output and p_i vector of input prices. In contrast with the production frontier, the latter has a positive error term, and the deterministic part is the $\mathrm{c}(q_i, p_i)$ in equation (3). Whereas the economic efficiency for an i-th farm is defined by the form,

$$EE_i = \frac{\exp\,(x_i\beta + v_i + u_i)}{\exp\,(x_i\beta + v_i)} = \exp\,(u_i) \tag{4}$$

wherein x_i is a vector of exogenous variables of both input prices and output. In equation (4), the statistical noise can be either positive or negative, implying its effect can increase or reduce the cost of production. In contrast, the error term of the cost frontier as the measurement for allocative inefficiency assumes a positive association with input usage.

Often existing studies on factors affecting farmers' efficiency include only sociodemographic and market-related factors. Therefore, we estimated the possible direct and indirect influence of the latent factors presented in Section 2.42.2. The following section presents the possible interrelationship of the latent factors in Figure 2.2 to the PIM principles and farmers' efficiency in rice production.

2.4. Interrelationships – PIM, social capital, and rice farming efficiency

RID's adoption of PIM seeks to contribute to farmers' economic development through secured and efficient irrigation for farm production. As previously demonstrated, high participation in collective irrigation management is critical to irrigated rice production. However, several studies examine the relationship between higher farm productivity and efficient irrigation management (Chaudhry, 2018; Hoffmann & Villamayor-Tomas, 2023; Song et al., 2019). There remains a scant study on understanding the interrelationship of the farming community's social capital endowment, the decision to participate in PIM, and their influence on the farmer's efficiency in farm production. Figure 2.4 presents an additional hypothesis derived from the previous framework in Figure 2.2 on the interrelationship of social capital, PIM, and efficiency in rice production.

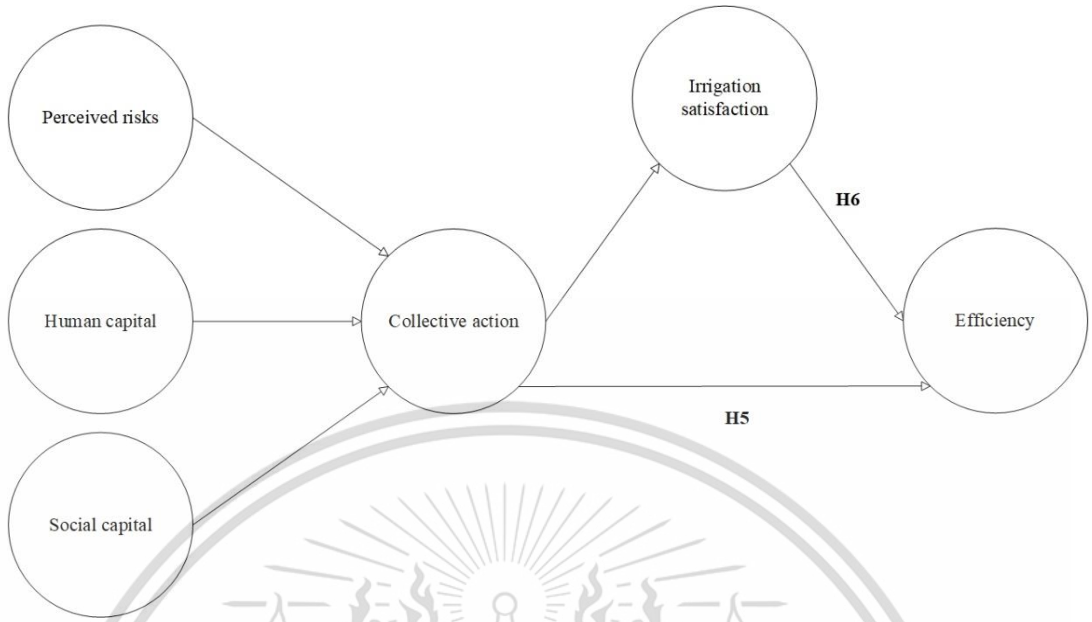


Figure 2.4. Additional hypotheses in assessing the influence of social capital and collective action on the production efficiency of rice farmers along the Mae Lao irrigation.

Farmers employ several forms of capital in production, which produces a stream of income or benefits. Conventionally, these capitals are in the form of financial capital (e.g., cash, credit for input purchasing), human capital (e.g., hired and family labor), natural capital (e.g., land, forest, natural vegetation), and physical capital (e.g., greenhouses, machinery, equipment). As illustrated in the preceding section, the optimal combination of these capitals or factors in production determines the level of productivity and efficiency of agricultural production. Previous studies investigating the factors affecting farmers' efficiency in rice production include factors such as education, farming years, household size, income source, gender, and market-related factors (e.g., Abebe, 2014; Khan et al., 2021; C. A. Llones et al., 2022; Onumah et al., 2018; Tiedemann & Latacz-Lohmann, 2013; Wang et al., 2020).

As demonstrated previously, social capital is highly observable, particularly within the farming community. Social capital, as one of the factors affecting farmers' production, is not often explored. Woolcock (1998) emphasized that social capital is an undervalued factor in production and productivity. Social capital as input in production is embedded within its ability to generate assets through social networking and facilitate access to information. Previous studies have demonstrated that social capital facilitates the adoption of agricultural technologies, sustainable practices, and innovations that enhance the productivity and efficiency of farmers (Chaudhry, 2018; Choi & Chang, 2020; Chuzu, 2002; Hayami, 2009; C. A. Llones et al., 2022; Sözbilir, 2018). For instance, Totin et al. (2014) found that lower participation in collective irrigation activities has an adverse effect on rice production in Benin. While farmer groups with a strong presence of social capital endowments show active participation in collective farming activities, wider networks, and better access to information and training (D'Annolfo et al., 2020; Pretty et al., 2020; J. I. Ricks, 2015). These opportunities have been highly associated with higher farm productivity and efficiency across studies (Abdul-Rahaman et al., 2021; Bojnec et al., 2011; Chaovanapoonphol et al., 2009; T. J. Coelli et al., 1996; C. A. Llones et al., 2022)

The social capital's ability to generate assets and access information provides arguments for why the concept is an undervalued factor that facilitates farm decision-making. Given this notion, we assessed the potential indirect influence of social capital in farm production and the direct impact of PIM activities represented in the collective actions, as shown in Figure 2.4.

CHAPTER 3. METHODOLOGY

This chapter presents the methodological and analytical processes applied in the study to assess the drivers of collective actions, understand the role of social capital, and measure the current level of production efficiency of irrigated rice farms under the current irrigation management. Towards the end of this chapter, the process of estimating the link between social capital, collective actions, and the farmers' efficiency in production under the current PIM implementation is presented. The sections under this chapter proceed as follows:

3.1 Study area

3.2 Data collection and assessment

3.3 Data analysis

3.1. Study area

The Mae Lao Irrigation Project (MILP) is one of the Royal Irrigation Department's largest irrigation projects in Chiang Rai province, Northern Thailand. The rainy season occurs from June to November, while the dry season is from March to May. The Mae Lao irrigation serves as a supplemental during the rainy season and allows rice production during the dry season. Access to irrigation services is the primary motivation for farmers to join the water user group organized by the irrigation department. Figure 3.1 illustrates the map of the Mae Lao irrigation project and the corresponding area coverage in total and by branches.

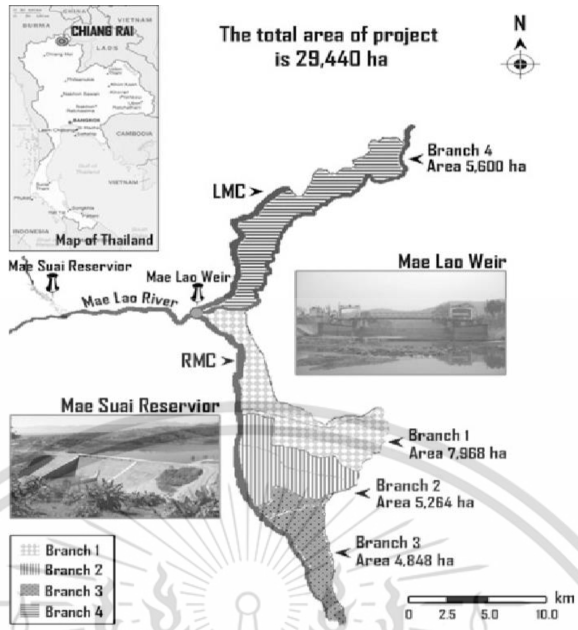


Figure 3.1. Map of the Mae Lao Irrigation Project (MLIP) by irrigation branches. The map is adopted from Wongtragoon et al. (2009).

The construction of MLIP was initiated in the 1950s and was completed in the 1960s. In 2001 and 2004, the project received substantial funds intended for its improvement under the Agricultural Sector Program Loan (ASPL) funded by Asian Development Bank (ADB) and the Japanese International Aid Corporation (JICA) (Palmer-Jones et al., 2012). The project is expected to provide supplemental irrigation in the wet season and enable rice cultivation during the dry season. However, the area receiving irrigation during the dry season is estimated to be approximately 80,000 rai, where irrigation supplies are barely adequate to make rotational irrigation necessary (Palmer-Jones et al., 2012). To this challenge, numerous trials on rationing systems have been attempted. In addition, adopting participatory irrigation management through the Water User Group (WUG) was required to play a crucial role in efficiently implementing and maintaining the MLIP (Wongtragoon et al., 2009). An actual photo of the irrigation infrastructure of the Mae Lao irrigation project is shown in Figure 3.2.

(a) (b)

Figure 3.2. Site visit in the Mae Lao irrigation project. Panel (a) shows the Mae Lao weir separating the right and left main canal. Panel (b) show the research team together, assisted by Dr. Unggoon Wongtragoon of the Faculty of Engineering, the Rajamangala University of Technology Lanna, and the water user group leader.

However, considering the vast area supplied by the Mae Lao irrigation, monitoring and enforcement of rules and regulations all the time in the area is nearly impossible for WUG leaders and irrigation officers. Therefore, ensuring the continued participation of farmers in joint operation and management activities requires high enforcement costs. Enforced participation in collective irrigation maintenance activities will not be sustainable and ideal in the long run operation. This implies the importance of developing a perceived sense of ownership and increased volunteerism among water users. Hence, the study posits that social capital and other latent factors are important drivers and must be developed for higher PIM activity participation.

3.2. Data collection and assessment

3.2.1. Survey questionnaire

The structure of the survey questionnaire used in data gathering is divided into four parts – geographical information and respondents' profile, production and marketing-related information, irrigation used and perceived risks, and organizational membership-related information of water users in the irrigation project.

The questionnaire was drafted in English and then translated into the local Thai language by a native Thai national expert. The Thai version was tested during the pre-test before the deployment of the final version for the face-to-face interview. Details of each part of the questionnaire are outlined in Table 3.1, while the questionnaire used in the data gathering is attached in Appendix B.

Table 3.1. Structure and corresponding information of the survey questionnaire.

Parts	Description
I. Geographical information and respondent's profile	The geographical information is data regarding the location of the respondents (e.g., province, districts, sub-district, and irrigation branch). In addition, the Respondent's profile includes information on civil status, age, gender, education, household information, and sources of income.

II.	Production and marketing-related information	The rice production information is divided into the following sections: *Section 1: Input utilization*. This section gathers information on input use, such as the quantity and costs of seeds, fertilizers, insecticides, herbicides, other chemicals, land use, water, and irrigation use. *Section 2: Labor utilization*. This section gathers information on labor use and the associated cost of land preparation, crop establishments, crop care, harvest and post-harvest activities, marketing, and administrative. *Section 3: Financial information related to production.* This section gathers information on farmers' sources of funds for their production. The information includes availing credits, linkage to financial intermediaries, farm insurance, the subsidy from the government, and other institutions. *Section 4: Marketing and other production-related information.* This section gathers information related to production but is not included in the previous sections, such as input sources, transportation, market outlet, training, sources of information in production, forms of knowledge sharing among farmers, and others.
III.	Irrigation use and perceived risks	This part gathers information on farmers' water use, irrigation use, water-saving alternatives, and management practices to minimize the risk during the dry season.

IV. Organizational membership, operation, and management	Part 4 of the questionnaire is divided into the following sections: *Section 1. Membership and organization.* This section gathers information such as the number of years as a member, position in the organization, reasons for joining, and questions related to their roles and responsibilities. *Section 2. Operation and Management.* This section gathers information on the management and operation of MLIP. In addition, this section includes awareness, perception, level of familiarity, and satisfaction with the organization's operation, policies, and activities. *Section 3. Social network and relationship.* This section gathers information on the social aspect of the members and their ways of social interactions. The information in this section includes farmers' frequency of social interaction among themselves, the community, the irrigation department, and the other institutions. The level of trust, perceptions, and reciprocity is also included.

3.2.2. Tests for reliability and consistency

The study used the Item-Objective Congruence (IOC) and Cronbach’s Alpha to assess the survey questionnaire's validity and reliability. The IOC is a process or procedure for testing the content validity of the items in the questionnaire during the development stage. The method was developed by Rovenelli and Hambleton (1976), which evaluates a test item against the objectives under the assumption that only one valid objective is measured by each item.

In the case of the study, each item can measure multiple objectives. To remedy this problem, the study adopted the IOC for multidimensional items developed by Turner & Carlson (2003), wherein the method is an extension of the former IOC. Similar to the former IOC, the expert evaluating the validity of each item will give a rating of 1 (clearly measuring), -1 (clearly not measuring), or 0 (content is unclear) across objectives (Turner & Carlson, 2003). An expert will rate the validity of an item against a set of objectives. The index of IOC for each item is shown in equation (5).

$$I'_{ik} = \frac{(N)\mu_k - (N-p)\mu_l}{2N-p} \tag{5}$$

where

I'_{ik} = index of item-objective congruence for item i on a set of objectives k

N = the number of objectives

p = the number of valid objectives

μ_k = the expert's mean rating on item i on valid objectives k

μ_l = the expert's mean rating on item i on invalid objectives l

A generally accepted value for the IOC index is 0.75 (Rovinelli & Hambleton, 1977; Turner & Carlson, 2003). Regarding internal consistency reliability, Cronbach's alpha is the most widely used. The alpha is the percent of the variance of the observed scale that could explain the hypothetical true scale composing all possible items. The alpha is a function of the test items and the average intercorrelation among the items, as shown in equation (6).

$$\alpha = \frac{N\bar{c}}{\bar{v} + (N-1)\bar{c}} \tag{6}$$

where

α = Cronbach's alpha

N= number of items

$\bar{c}$ = average inter-item covariance

$\bar{v}$= average variance

According to Garson (2013), an acceptable alpha could be at least 0.60 for exploratory research. While 0.70 for an adequate scale of confirmatory research and 0.80 for a good scale of confirmatory research. The summary results of the survey questionnaire's reliability are provided in Appendix C.

3.2.3. Focus group discussion (FGD)

A series of focus group discussions were conducted to understand the current situation of the Mae Lao irrigation project. In Figure 3.3, panel (a), the team organized a group discussion with the irrigation officer assigned to each Mae Lao irrigation project branch. The irrigation officers discussed information on the current practices related to the operation and maintenance activities under participatory irrigation management. This allows the research team to gather information on the issues, challenges, and plans for the irrigation project.

Consequently, as shown in Figure 3.3, panel (b), a group discussion with WUG leaders and members was organized to understand the current situation, challenges, issues, and prospects of the farmers or the water users. In addition, the focus group discussion provides insights into the perceived relationship of water users within the farming community, the perceived level of trust, and reciprocity among members. This information was also used in refining the questionnaire before the face-to-face interview with farmers.

(a) (b)

Figure 3.3. The research team conducted focus group discussions with representatives from the water user groups, farmer leaders, and irrigation officers. Panel (a) shows that the irrigation officer shares information regarding the current operation and maintenance practices adopted during the visit. Panel (c) research team briefing the farmers regarding the research to be conducted and their roles for possible collaboration.

3.2.4. Pre-testing and the face-to-face interview

The translated questionnaire was pre-tested during the site visit. In Figure 3.4, panel (a), selected farmers from each irrigation branch were invited for a face-to-face interview to pre-test the questionnaire. A total of 30 farmers were interviewed during the pre-test.

The conduct of the pre-testing enables the research team to identify questions that farmers find challenging to answer or unclear for them. These questions were revised based on the feedback of the farmers. In addition, additional questions were added based on the discussion and dialogues with farmers.

After several revisions, the final draft of the questionnaire was deployed during the entire face-to-face interview. Figure 3.3 panel (b) shows a Thai research enumerator conducting an onsite face-to-face interview with a farmer. Farmers' consent was asked before the interview, and 304 farmers were interviewed from October to November 2020. The collected information from the survey was subjected to data cleaning and processing before analyzing the data.

(a) (b)

Figure 3.4. Actual pre-testing and face-to-face interviews with water users, group leaders, and selected farmers in the Mae Lao irrigation project. Panel (a) shows the questionnaire pre-testing with selected farmers and water users. Panel (b) shows the face-to-face interview using the survey questionnaire across each irrigation branch.

3.3. Data analysis

3.3.1. Production and efficiency analysis

Figure 3.5 outlines the process for estimating the rice farmers' technical efficiency level. The first test is deciding which functional form of the production function will be appropriate such as the Cobb-Douglas and the Translog model specification. Second, the error term containing the (in)efficiency estimates may take the following distributions: half-normal, truncated normal distribution, and exponential. In the study, the decision on which functional form of the model and the inefficiency distribution will be based on the likelihood ratio test. The final empirical model used for interpretation will be based on the previous likelihood ratio tests. The subsequent section discusses in detail the process outlined in Figure 3.5.

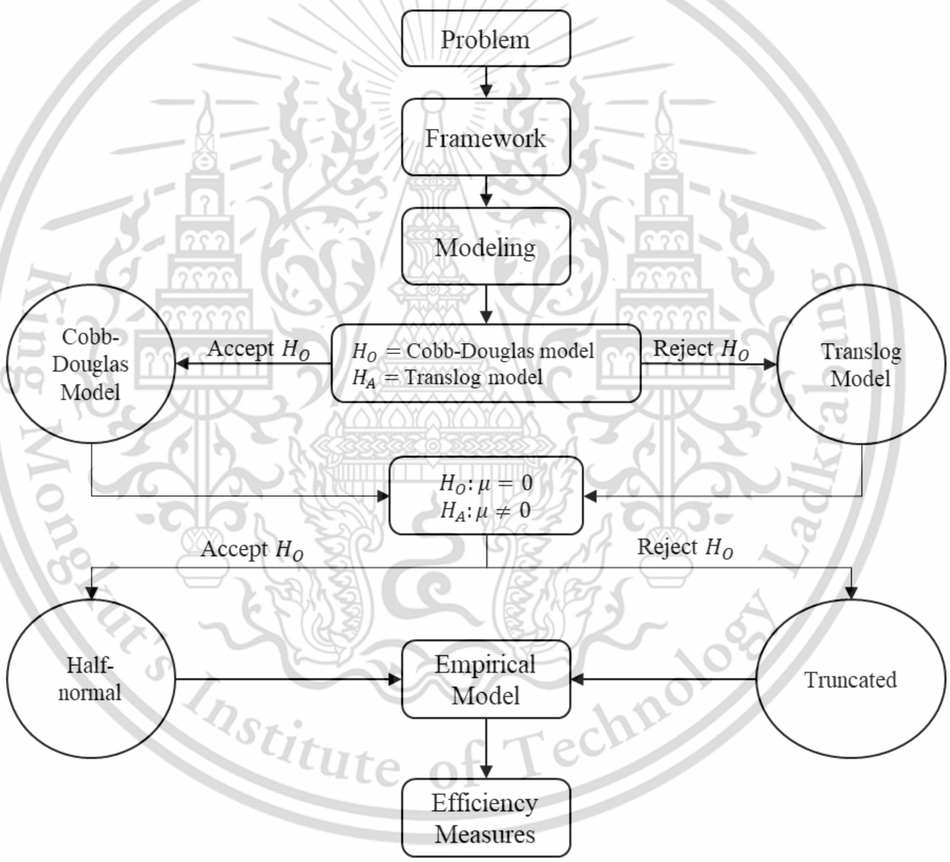


Figure 3.5. Analytical process in assessing the level of technical efficiency of rice farmers in the Mae Lao Irrigation Project (MLIP).

Functional Forms

The production function defined in (7) and (8) is the Cobb-Douglas and Translog production function specifications, respectively. Where y_i is the output, β_0 the intercept of the model, x_{ij} is the jth input of the ith farm, β_j are the parameters to be estimated and ε_i is the composite error term. As the frontier is assumed as the maximum production of output y_i by optimal x_i input use that any deviations from the frontier are due to statistical noise and inefficiency. In the restriction of $y_i \leq f(x_i;\, \beta)$, Schmidt & Knox Lovell (1979) added a disturbance term ε_i to give the function with a statistical properties which can be further decomposed into error accounting for random variation relating to the ability to use the best practice technology or u_i and the measurement error or the statistical noise v_i. The decomposition of the error structure is given as $\varepsilon_i = v_i - u_i,\ i = 1, \dots, I$.

On the other hand, the elasticity of substitution in a Cobb-Douglas production function specification for any input combination and output level is restricted to being equal to one. In contrast to a production function that takes a transcendental logarithmic form, the functional form does not restrict the elasticity of substitution equal to one.

$$lny_i = \beta_0 + \sum_{j=1}^{J} \beta_j lnx_{ij} + \varepsilon_i \qquad (7)$$

$$lny_i = \beta_0 + \sum_{j=1}^{J} \beta_j lnx_j + \frac{1}{2}\sum_{k=1}^{K}\sum_{j=1}^{J} \beta_{jk} lnx_j lnx_k + \varepsilon_i \qquad (8)$$

Given the specification defined in (7) and (8), the restrictions in (8) will be tested. If the test rejects the Translog model, then the Cobb-Douglas production function will be the appropriate production function form. The null hypothesis constructed against the alternative hypothesis is defined as follows:

$$H_O = \text{Cobb-Douglas production model is appropriate.} \\ H_A = \text{Translog production model is appropriate} \tag{9}$$

Different distributions of the inefficiency

The efficiency measurement using the frontier analysis is estimated relative to the stochastic production frontier. The Stochastic Frontier Analysis (SFA) controls the statistical noise's effect, controlling its impact on each efficiency score (Wheat et al., 2019). The SFA used in the study is estimated using the maximum likelihood method and estimate of the inefficiency from the composite error term $\varepsilon_i = v_i - u_i$ defined in (7) and (8).

The statistical noise, v_i, follows a symmetric normal distribution with zero mean and constant variance, $v_i \sim N(0, \sigma_v^2)$. Whereas the inefficiency component, u_i, usually follows a half-normal distribution or one-sided distribution. The estimated inefficiency scores can be sensitive to the choice of the distributional form (Meesters, 2014). Hence, the subsequent sections discuss the common assumption on the inefficiency component's distributional form.

The Half-Normal Distribution

The distributional form of the two error components assumed that statistical noise is normally distributed while the error component for inefficiency is half-normal. Functions (10) and (11) show the density function for v and u, respectively.

$$f(v) = \frac{1}{\sqrt{2\pi\sigma_v}} \exp\left(-\frac{v^2}{2\sigma_v^2}\right) \quad \text{(normal)} \tag{10}$$

$$f(u) = \frac{2}{\sqrt{2\pi\sigma_u}} \exp\left(-\frac{u^2}{2\sigma_u^2}\right), u \geq 0 \quad \text{(half} - \text{normal)} \tag{11}$$

Truncated Normal Distribution

Supposed the inefficiency term does not follow a half-normal distribution, the distribution assumes to follow a truncated normal distribution $u \sim N(\mu, \sigma_u^2)$. This distribution is a generalization of the half-normal wherein the mean or its mode is allowed to be non-zero. The density function of the truncated-normal distribution depends on two parameters σ_u and μ expressed in (12).

$$f(u) = \frac{1}{\sqrt{2\pi\sigma_u}\Phi(-\mu/\sigma_u)} . \exp\left\{-\frac{(u-\mu)^2}{2\sigma_u^2}\right\}, u \geq 0 \tag{12}$$

Equation (12) is a density function of normally distributed random variables with either a zero or a positive non-zero mean truncated at zero. Whereas the expected value of u_i and its variance is given by Equations (13) and (14).

$$E(u) = \mu + \sigma_u \left\{\frac{\phi(-\mu/\sigma_u)}{1 - \Phi(-\mu/\sigma_u)}\right\} \tag{13}$$

$$Var(u) = \sigma_u^2 \left\{1 - \frac{\phi(-\mu/\sigma_u)}{1 - \Phi(-\mu/\sigma_u)}\left[\frac{\mu}{\sigma} + \frac{\phi(-\mu/\sigma_u)}{1 - \Phi(-\mu/\sigma_u)}\right]\right\} \tag{14}$$

Given the specifications of the half-normal and truncated normal distribution for the inefficiency estimates, equation (15) defined the null hypothesis for the half-normal.

$$H_O: \mu = 0$$
$$H_A: \mu \neq 0 \quad (15)$$

Recall that if the normal distribution is truncated at $\mu = 0$, it is a half-normal distribution. Accepting the null hypothesis suggests that the half-normal is not the preferred representation of the distributional form for the inefficiency effects.

The hypotheses in (10) and (15) will be tested using the generalized likelihood ratio (L.R.) statistics. The process requires the estimation of the model defined as:

$$LR = -2\left[\frac{L(H_O)}{L(H_A)}\right] \quad (16)$$

Wherein the $L(H_O)$ and $L(H_A)$ are the values of the likelihood functions under the null and alternative hypotheses. The acceptance of the null hypothesis implies that the test follows a χ^2 the distribution having degrees of freedom equal to the number of restrictions of the model (T. J. Coelli et al., 1996).

Empirical model specifications

The empirical stochastic production function with Cobb-Douglas and Translog function specifications are defined in equations (17) and (18), respectively. Both the model specifications were estimated, while the final model used for interpretation is based on the generalized likelihood ratio test results.

$$lny_i = \beta_0 + \sum_{j=1}^{4} \beta_j lnx_{ji} + \sum_{m=1}^{3} \delta_m D_{mi} + V_i - U_i \quad (17)$$

$$lny_i = \beta_0 + \sum_{j=1}^{4} \beta_j lnx_j + \frac{1}{2}\sum_{k=1}^{4}\sum_{j=1}^{4} \beta_{jk} lnx_j lnx_k + \sum_{m=1}^{3} \delta_m D_{mi} + V_i - U_i \qquad (18)$$

The y_i denotes the rice production of the ith farm; x_{ji} is the production inputs (e.g., seed, fertilizer, labor) summarized in Table 3.2. Whereas the dummy variables, such as pesticides, perceived soil condition, and topography, are captured in D_{mi} which is considered as control variables in the model.

Table 3.2. Summary statistics of production inputs used in the stochastic production frontier model.

Variables	Mean (Percent)	SD
Production (kg)	740.91	160.57
Seed (kg)	17.42	4.88
Fertilizer (kg)	36.69	14.96
Family labor (hr)	77.13	56.80
Hired labor (hr)	9.69	7.81
Pesticide use (1=yes; 0=no)	(44%)	
Good soil (1=yes; 0=no)	(89%)	
Upland (1=yes; 0=no)	(75%)	

On the other hand, the technical efficiency estimation is specified in Equation (19). The Z_{ni} denotes the sociodemographic characteristics of farmers while C_{pi} captures the effects of collective action or PIM activities on farmers' technical efficiency. Details of the exogenous variables in the TE model in Equation (19) are summarized in Table 3.3.

$$\widehat{TE} = \theta_0 + \sum_{n=1}^{8} \theta_n Z_{ni} + \sum_{p=1}^{4} \beta_{pi} C_{pi} + \omega_i \qquad (19)$$

Table 3.3. Farmers' sociodemographic characteristics and the participatory irrigation management factors used in the efficiency model.

Variables	Mean	SD
Age (years)	57.88	9.77
Household size (head)	3.47	1.37
Primary (1=yes; 0=no)	0.66	0.48
Secondary or higher (1=yes; 0=no)	0.29	0.46
Farming experience (years)	30.91	14.34
Off-farm income (1=yes; 0=no)	0.19	0.39
Distance to market (km)	6.59	5.78
Distance to input market (km)	9.65	6.58
Collective actions [a]		
Maintenance work	4.97	1.54
Meeting	4.92	1.38
Dispute resolution	4.39	1.74
Policy adherence	4.99	1.49

[a] Likert scale 1 = never to 7 = always

3.3.2. Partial least square structural equation modeling

Structural equation modeling is a comprehensive statistical method that tests hypotheses about the relationships between observed and latent variables (Jöreskog, 1970). These latent variables are indirectly measured or evaluated using observed indicators. Although the latent variables are indirectly measured, their influence on the observable variables can be measured; thus, these are used as an indicator of the latent variables (Kaplan, 2001).

Instead of using several equations or regression models, SEM provides the ability to simultaneously define the direct and indirect relationship of a multidimensional construct like social capital, human capital, financial capital, and collective action concepts presented in Figure 2.2 and Figure 2.4.

Applying SEM begins with specifying the measurement component of the model. The measurement model defines how the theoretical variables are operationalized and how well the predictor variables capture the fundamental nature of the latent factor. The latent variables are constructed by linking to observable variables through the measurement equation for the endogenous and exogenous variables. These equations are defined in equations (20) – (22).

$$y = \Lambda_y \eta + \varepsilon \tag{20}$$

$$x = \Lambda_x \xi + \delta \tag{21}$$

$$\eta = \mathrm{B}\eta + \Gamma\xi + \zeta \tag{22}$$

Where:

y and x are vectors of endogenous and exogenous observed variables or indicators of the latent factors, respectively.

Λ_y and Λ_x are matrices of factor loadings.

ε and δ are vectors of measurement error of y and x

η a vector of endogenous latent variables

ξ a vector of exogenous latent variables

B a matrix of regression coefficients relating to the latent endogenous variables

Γ a matrix of regression coefficient relating endogenous variables to exogenous variables

ζ vector of disturbance terms

In operationalizing the latent variables of social capital, human capital, perceived risk, collective irrigation management, and perceived irrigation performance, the study used a 7-point Likert scale. The final set of indicator items used in measuring the latent factor specified in Figure 3.6 is summarized and discussed in Section 4.2.1. Whereas results of the hypothesized paths presented in Table 3.4 are discussed in Sections 4.2.4 and 4.3.1.

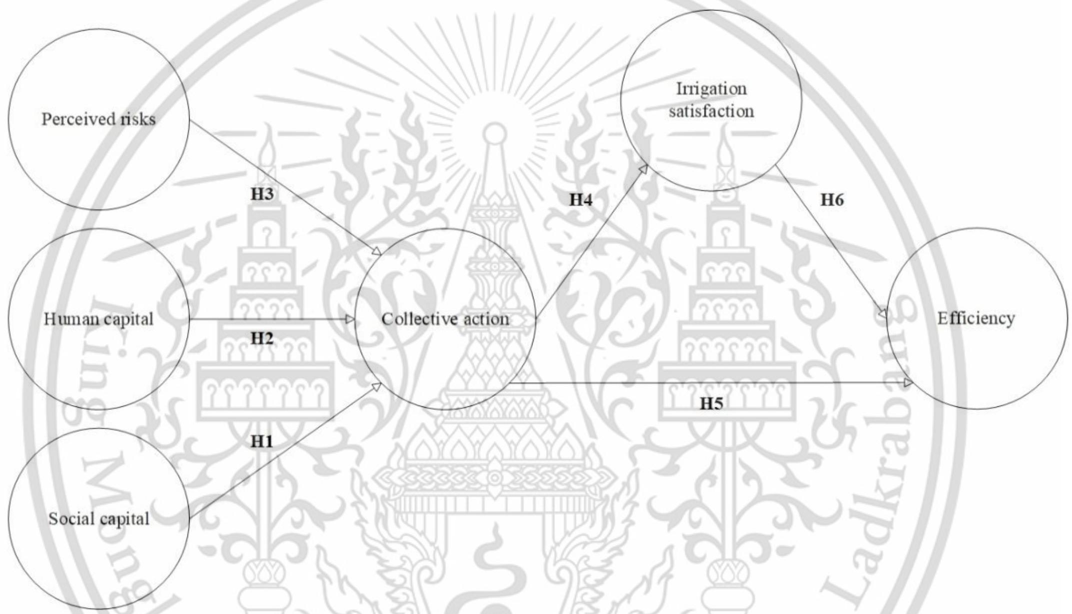


Figure 3.6. Empirical structural equation model of the hypothesized relationship of the latent factors. The hypothesized path reflects the interrelationship of the social capital, drivers of collective actions, and its influence on irrigation performance and farmers' level of technical efficiency.

Table 3.4. Summary of the expected relationship of the hypothesized structural path.

Hypotheses	Paths	Expected relationship
H1	Social capital → Collective action	Positive
H2	Human capital → Collective action	Positive
H3	Perceived risks → Collective action	Negative
H4	Collective action → Irrigation satisfaction	Positive
H5	Collective action → Efficiency	Positive
H6	Irrigation satisfaction → Efficiency	Positive

CHAPTER 4. RESULTS

This chapter presents the main findings of the study's analysis on assessing the interrelationships of the social capital concept, collective actions, production efficiency, and PIM implementation. First, the assessment of the current production performance of the water users is presented. Afterward, the role of social capital as a driver of collective action and its interrelationship with the PIM implementation and farmers' farm production are provided. The sections under this chapter proceed as follows:

4.1 Production efficiency under participatory irrigation management

4.2 Social capital as drivers for collective action

4.3 Linking PIM, social capital, and production efficiency

4.1. Production efficiency under participatory irrigation management

4.1.1. Input-output productivity.

Farmers' productivity, as output per unit of input use, is illustrated in Figure 4.1. Regarding the farming area, rice production in the Mae Lao irrigation areas is still operating at an increasing rate. While contrary to the usual U-shaped distribution of the input-output relationship, farmers are still operating within an increasing return to scale. This can be attributed to farmers operating at a small scale where increasing the production area still contributes a positive marginal return. For seed rate application, the output distribution follows the conventional inverted U-shaped. This implies that output increases as seed rate application increases. However, total production decreases when marginal productivity reaches negative returns or the total productivity is downward sloping.

Whereas farmers' rate of fertilizer use follows a U-shaped distribution which suggests that farmers need to be conscious of the required minimum fertilizer needed in production to avoid the stage of decreasing marginal productivity. A similar trend is observed for labor inputs; however, the marginal productivity is relatively inelastic for hired labor. This indicates that the magnitude of change in the output is lower than the unit increase in the use of hired labor.

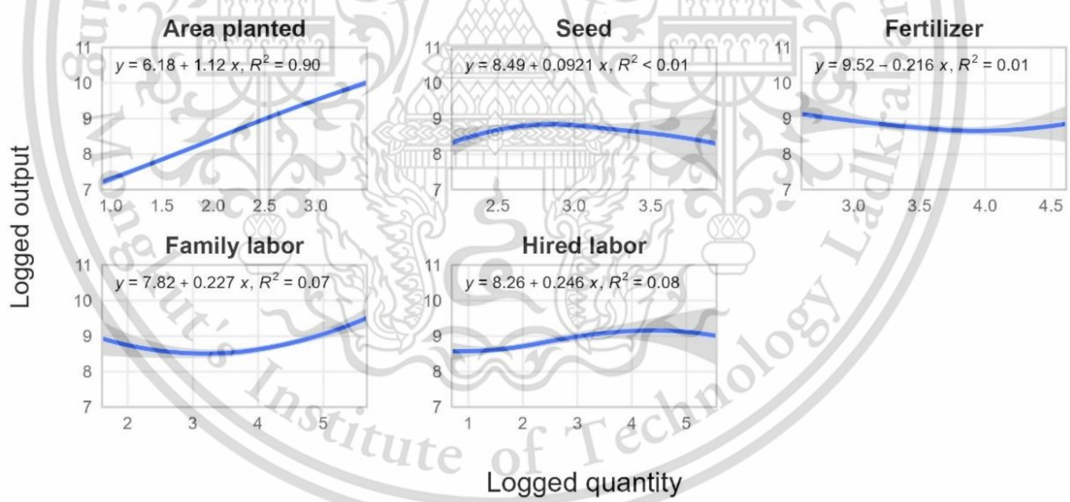


Figure 4.1. Production output distribution across input use.

Water users in the Mae Lao irrigation project are divided into branches. Group discussion reveals different experiences regarding irrigation services. For example, branch 1 is near the main canal and experiences fewer water interruptions than Branches

2 and 3. These differences may influence the production decision-making of farmers located in different irrigation branches. Figure 4.2 shows the output distribution against the marginal input usage, while Figure 4.3 illustrates the difference in input uses between each irrigation branch in Mae Lao.

Visual inspections of the distribution across branches show considerable differences in output-to-input use. However, looking at the slope of the input use across branches, there are differences in the input-to-output relationship. Branches 1 and 2 experience a negative association of seed to rice production, while Branch 3 is positive. Another observed difference is in fertilizer use. Branch 2 shows a positive input-output relation while the negative for the other branches. In addition, the output is less responsive or inelastic to changes in the family labor and hired labor use in Branch 3 compared to Branch 1 and 2.

Moreover, the test of difference of the input use across branches of MLIP reveals that the level of input use, like area and labor, are not statistically different. This implies that, on average, farmers across the Mae Lao irrigation follow a similar production protocol concerning the previously mentioned inputs. However, there is a significant difference in the seeds and fertilizer use across locations.

Disaggregating the input-output reveals a different association between the marginal output to the marginal input. Hence, further study, such as the conduct of experiments on the possible reason why there are observed changes in how the output responds to input across branch locations, is highly recommended. Unfortunately, this type of analysis is beyond the scope of the current study.

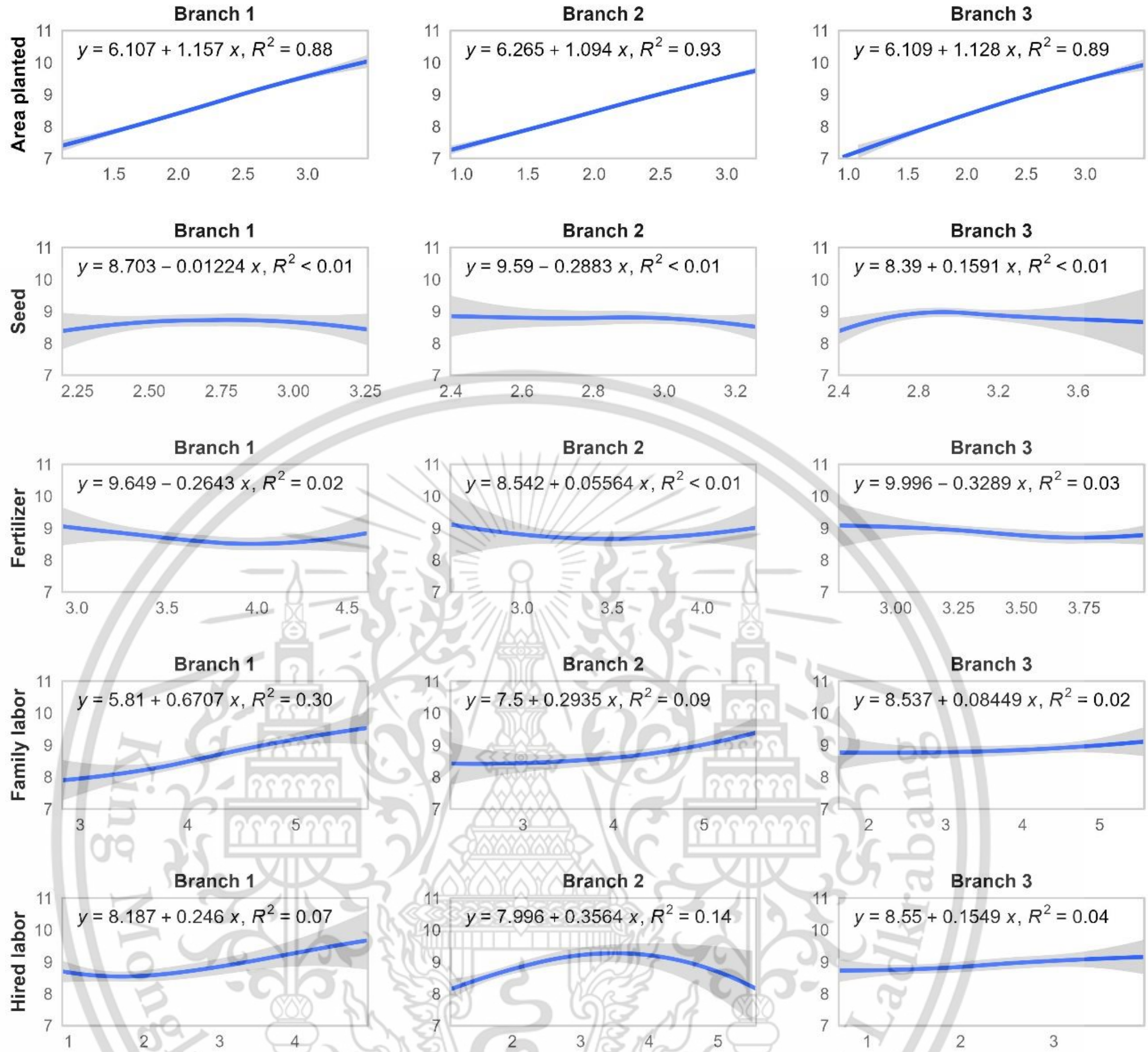


Figure 4.2. Output distribution across input usage by branches of the Mae Lao irrigation project.

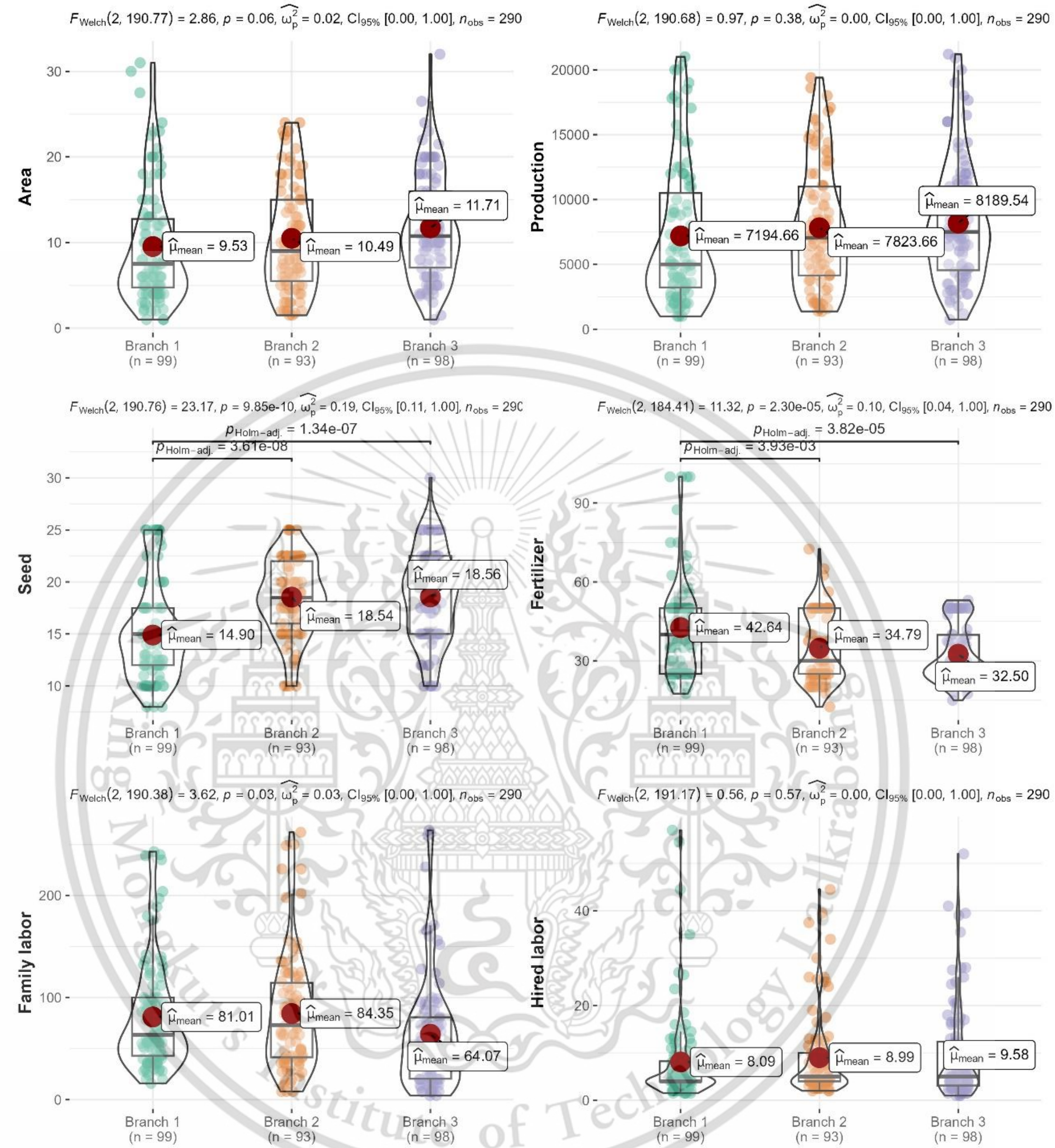


Figure 4.3. Test of difference of input use across Branches 1-3 of the Mae Lao irrigation project.

4.1.2. Estimating farmers' efficiency using the stochastic frontier analysis.

Parameter estimates for the two stochastic production frontier Translog and Cobb-Douglas models are summarized in Table 4.1. The variance ratio $\gamma = \sigma_U^2/(\sigma_U^2 + \sigma_V^2)$ is significant implying that presence of the technical inefficiency in production influences the production output of the sampled rice farmers. The Translog model accounts for 58.7 percent ($\gamma = 0.587$) while the Cobb-Douglas accounts larger variations of the output at 61.8 percent ($\gamma = 0.618$).

Production inputs are nonnegative, except for the interaction variables found to be significant. Regarding the returns to scale for the two models, farmers are operating under an increasing return to scale. This implies that, on average, farmers in irrigation projects experience a larger percentage of increase in input for every percent increase in the input use. Across inputs, seed input has the largest magnitude of influence on the output level, followed by fertilizer. For labor use, family labor contributes more variations in the output level than hired labor. This indicates the larger contribution of family labor than hired labor. Other studies found larger input elasticity for hired labor than family labor use (Ebers et al., 2017; Sherlund et al., 2002). However, the input elasticity of the two labor types is comparable when controlling for other factors, such as the availability of off-farm work. This can be attributed to farmers with off-farm work using hired labor to compensate for the lack of family labor due to engaging in other non-farm works (Ebers et al., 2017; Sherlund et al., 2002; Villano & Fleming, 2006). Also, results of hired and family labor interactions are positively associated with higher output productivity.

Conversely, farmers who use pesticides have a lower output than their counterparts. This may reflect the high reliance of rice farmers on pesticide use in Thailand. Nguyen et al. (2022) pointed out that the excessive use of these inputs could have adverse effects, such as lower production efficiency. However, study results also found that upland farmers were more productive than lowland farmers. At the same time, the productivity of upland farms against lowlands is mixed in the literature (e.g., H. V. Nguyen, 2005; Pilarova et al., 2018; Rigg et al., 2019).

Table 4.1. Parameter estimates of the Translog and Cobb-Douglas model using the stochastic frontier analysis.

	Translog Model		Cobb-Douglas Model	
	Estimate	Std. error	Estimate	Std. error
Intercept	0.347***	0.081	0.354***	0.070
ln Seed	0.467***	0.051	0.441***	0.039
ln Fertilizer	0.212***	0.049	0.227***	0.034
ln Family labor	0.151***	0.029	0.117***	0.018
ln Hired labor	0.049**	0.021	0.075***	0.017
0.5 * (ln Seed)²	-0.045	0.130		
0.5 * (ln Fertilizer)²	-0.051	0.125		
0.5 * (ln Family labor)²	0.047	0.034		
0.5 * (ln Hired labor)²	-0.047*	0.026		
ln Seed * ln Fertilizer	0.080	0.101		
ln Seed * ln Family labor	-0.070	0.059		
ln Seed * ln Hired labor	0.082**	0.038		
ln Fertilizer * ln Family labor	0.003	0.044		
ln Fertilizer * ln Hired labor	-0.034	0.040		
ln Family labor * ln Hired labor	0.007	0.022		
Dummy for Pesticide	-0.084***	0.030	-0.084***	0.030
Dummy for Good soil	0.037	0.051	0.041	0.050
Dummy for Upland	0.012	0.035	0.016	0.035
σ^2	0.103	0.020	0.111	0.020
γ	0.587	0.168	0.618	0.140
Log-likelihood value		-14.101		-19.853

4.1.3. Generalize likelihood-ratio test and model diagnostic tests.

To determine the statistically appropriate functional form of the stochastic production function (i.e., Translog vs. Cobb-Douglas) and the efficiency distribution, the generalized likelihood ratio was used to test the following null hypotheses presented in Table 4.2.

The null hypotheses for the stochastic production frontier were accepted, indicating that the Cobb-Douglas specification is a more appropriate functional form against the Translog mode. The second null hypothesis of no inefficiency detected in the model is rejected. This implies that the presence of inefficiency in production is found in the model. Whereas the half-normal distribution is favored against the truncated normal distribution.

Overall, the generalized likelihood-ratio test found that the Cobb-Douglas and half-normal distribution of the error term accounting for the inefficiencies is the better approach in estimating farmers' technical efficiency under the participatory irrigation management of the Mae Lao irrigation project.

Table 4.2. Generalized likelihood-ratio test of the null hypotheses.

Null hypothesis	Chi-sq critical value	df	Decision
Cobb-Douglas	11.5	10	Accept Null
No inefficiency effects	3.07	1	Reject Null
Half-normal	0.17	1	Accept Null

While the diagnostic test for the Cobb-Douglas stochastic production model satisfies the assumptions for the best linear unbiased estimates (Wooldridge, 2010). The plots presented in Figure 4.4 were generated using the performance package in R (Lüdecke et al., 2021).

The posterior predictive check for any discrepancies between the actual and simulated data. Results show that the model-predicted distribution derived in the Cobb-Douglas model resembles the actual data distribution. In addition, other diagnostics tests like linearity assumption, homogeneity of variance, possible influential observation, and normality of residuals are satisfied (Lüdecke et al., 2021).

On the other hand, the problem of multicollinearity in the adopted model is not a problem of the model used in estimating the technical efficiency. While the variance inflation factor is below the threshold of 5, implying that the correlation of the predictors is low and tolerable (Gujarati & Porter, 2009). The model diagnostic test results reveal that the required assumptions are met.

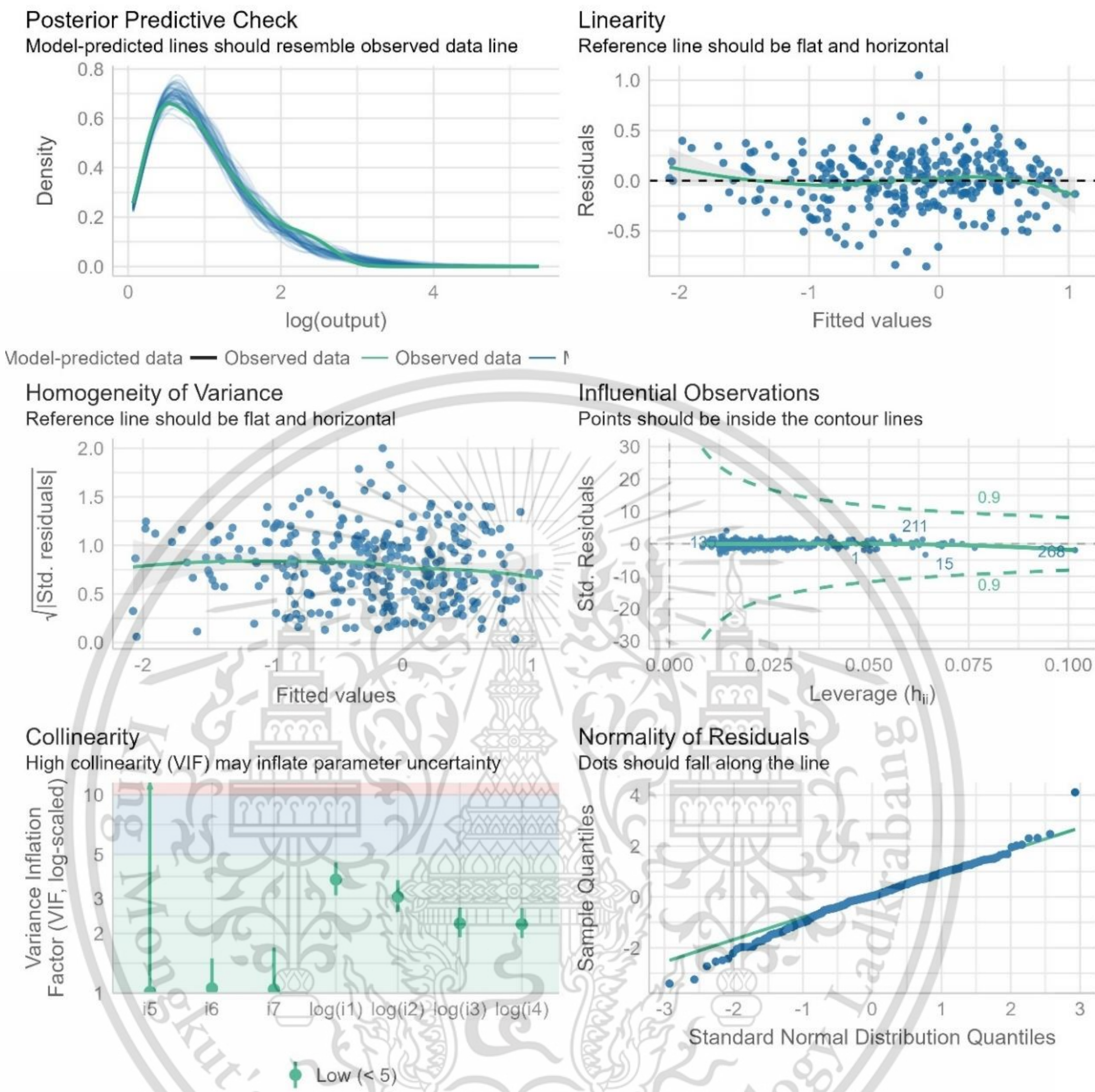


Figure 4.4. Model diagnostic tests of the stochastic production frontier.

4.1.4. Farmers' efficiency and participatory irrigation management effects.

Based on the generalized likelihood-ratio test results, the technical efficiency was derived using a Cobb-Douglas stochastic production function with a half-normal distribution. The empirical model was estimated using the R frontier package (T. Coelli & Henningsen, 2020).

The median technical efficiency across the three branches of Mae Lao irrigation was 83.62 percent. This suggested a potential 16.38 percent increase in efficiency when factors contributing to farmers' inefficiencies were addressed. Whereas the median efficiency by branches is lower than the overall median efficiency. Branch 1 to 3 has a median efficiency of 84.6, 83.5, and 83.2 percent, respectively. As shown in Figure 4.5, more farmers are efficient in Branch 1. At the same time, Branch has the least number of efficient farmers in Branch 3 relative to each irrigation branch in the Mae Lao irrigation project. The observed differences in the level of technical efficiencies across branches can be partly attributed to the distance of each branch to the main canal. Farmers situated near the main canal (e.g., Branch 1) experience less water disruption than farmers at the tail-end, such as in Branch 3.

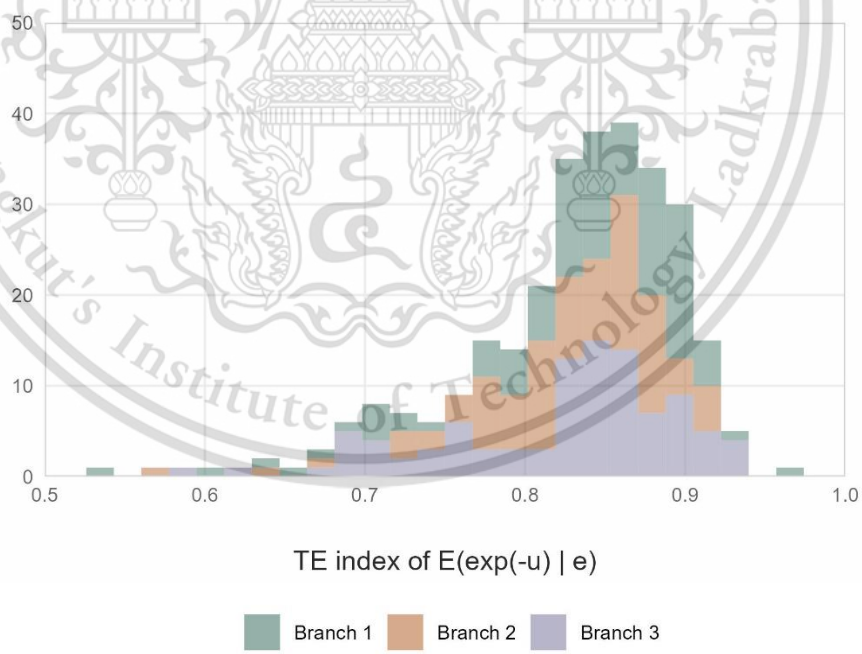


Figure 4.5. Technical efficiency distribution across branches of the Mae Lao irrigation project.

Regarding the possible influence of participatory irrigation management on the productivity and efficiency of farmers in rice production, Figure 4.6 presents the technical efficiency score distribution by the level of participation in each PIM activity. Farmers' participation level in PIM activities – dispute resolution, group meetings, maintenance work, and policy adherence- were derived from the Likert-scores (7-point scale) of how frequently they participate in the activities. Farmers' average ratings higher than the neutral scale (e.g., 4 on a 7-point scale) were considered to have a higher level of participation, likewise for the rating below the neutral scale.

Across activities, farmers with high participation in PIM activities have technical efficiency scores in the higher range. While the observed efficiency distribution in Figure 17 does not imply causality, it indicates a possible association between farmers with higher efficiency scores and higher involvement in participatory irrigation management. While a visual inspection in Figure 4.6 provides a quick assessment of the association of possible influence of the PIM, Table 4.3 provides the results of the simultaneous estimation of the technical efficiency and the possible effects of the exogenous variables, including the PIM activities.

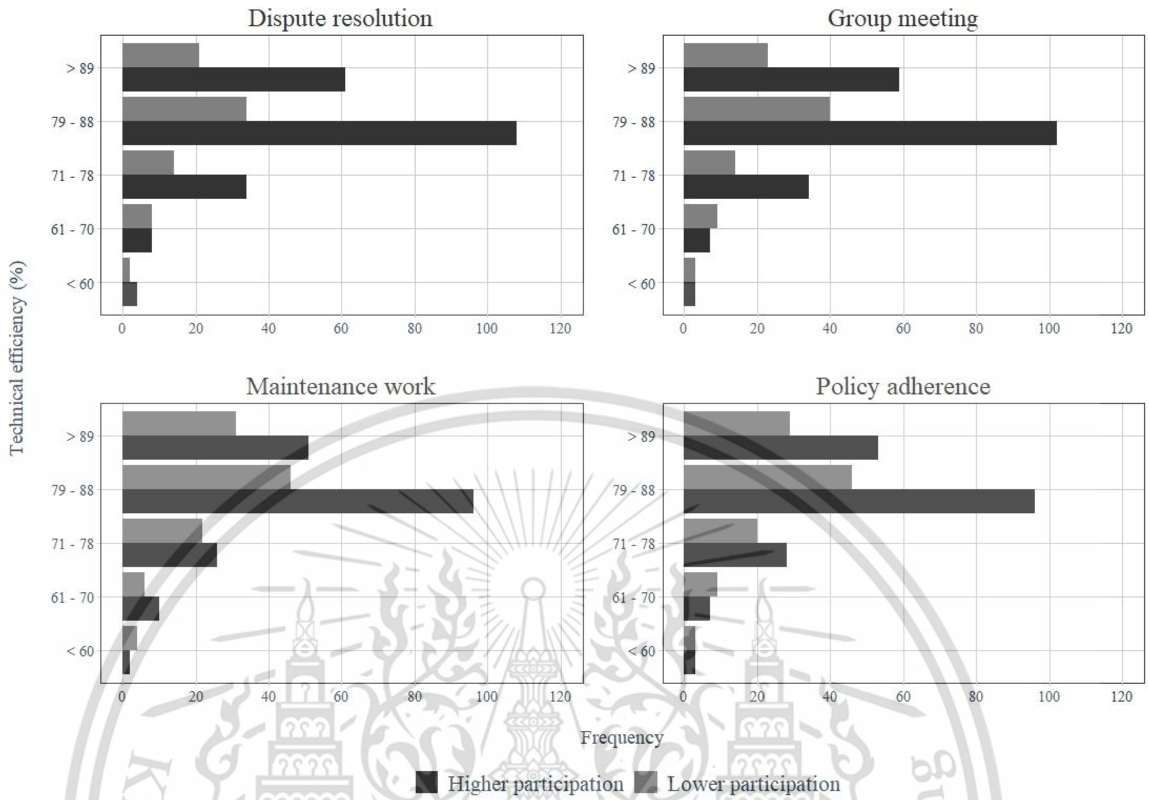


Figure 4.6. Technical efficiency and participatory irrigation management activities association.

Table 4.3 summarizes the relationship of PIM activities to the technical efficiency level of farmers. Due to the high correlation of the PIM activities, the activities are entered in the model one at a time while controlling for farmer attributes (e.g., household size, education, age, farming experience) and market-related variables (e.g., distance to nearest market and input source).

Among the PIM activities included in the model, maintenance work has the largest magnitude of effect on farmers' farming efficiency. At the same time, farmers' adherence to policies and regulations has the second largest magnitude of effect. The two PIM activities are twice as large as the group meeting and dispute resolutions. This implies that maintenance work and policy adherence directly impact farmers' rice production.

In surface irrigation, farmers share a secondary canal wherein under participatory irrigation management, they are responsible for cleaning and maintaining the canals along their farm areas. The poor condition of the canal due to negligence in maintenance work for the command irrigation canal will result in water disruption, affecting all farmers along the irrigation canal. Farmers performed maintenance tasks to benefit their farms and avoid disapproval from other farmers or water users. In addition, the established social norms in the farming community provide a social incentive to perform the required obligations.

Likewise, farmers' adherence to the rules and regulations of irrigation influenced farmers' production. For instance, farmers follow a rotational water allocation. In addition, cases of the illegal opening of the watergate during nighttime were noted in the study area, which could disrupt available water for other areas relying upon irrigation. However, overall adherence to irrigation policies and cooperation is functioning, which can be attributed to the high dependence on the Mae Lao irrigation as the main water source, especially during the dry season.

Moreover, participation in group meetings is positively associated with higher technical efficiency among water users. Group meetings in the Mae Lao irrigation are done at least once every season to discuss water allocation for the next cropping season. The agenda often includes planned water discharges to resolve potential conflicts or issues. Although dispute resolution is not statistically significant in the model, it is positively associated with higher technical efficiency. Overall, results show that participation in PIM activities will more likely increase the potential efficiency of rice farming.

Table 4.3. Estimated effects of participatory irrigation management activities on farmers' level of technical efficiency.

	Model 1	Model 2	Model 3	Model 4
Maintenance work	0.322**			
	(0.151)			
Group meeting		0.043***		
		(0.014)		
Dispute resolution			0.170	
			(0.109)	
Policy adherence				0.313**
				(0.151)
Famers characteristics control	control	control	control	control
Market-related variable control	control	control	control	control
Observation	294	294	294	294
Log-likelihood value	-10.627	-9.018	-12.745	-8.938

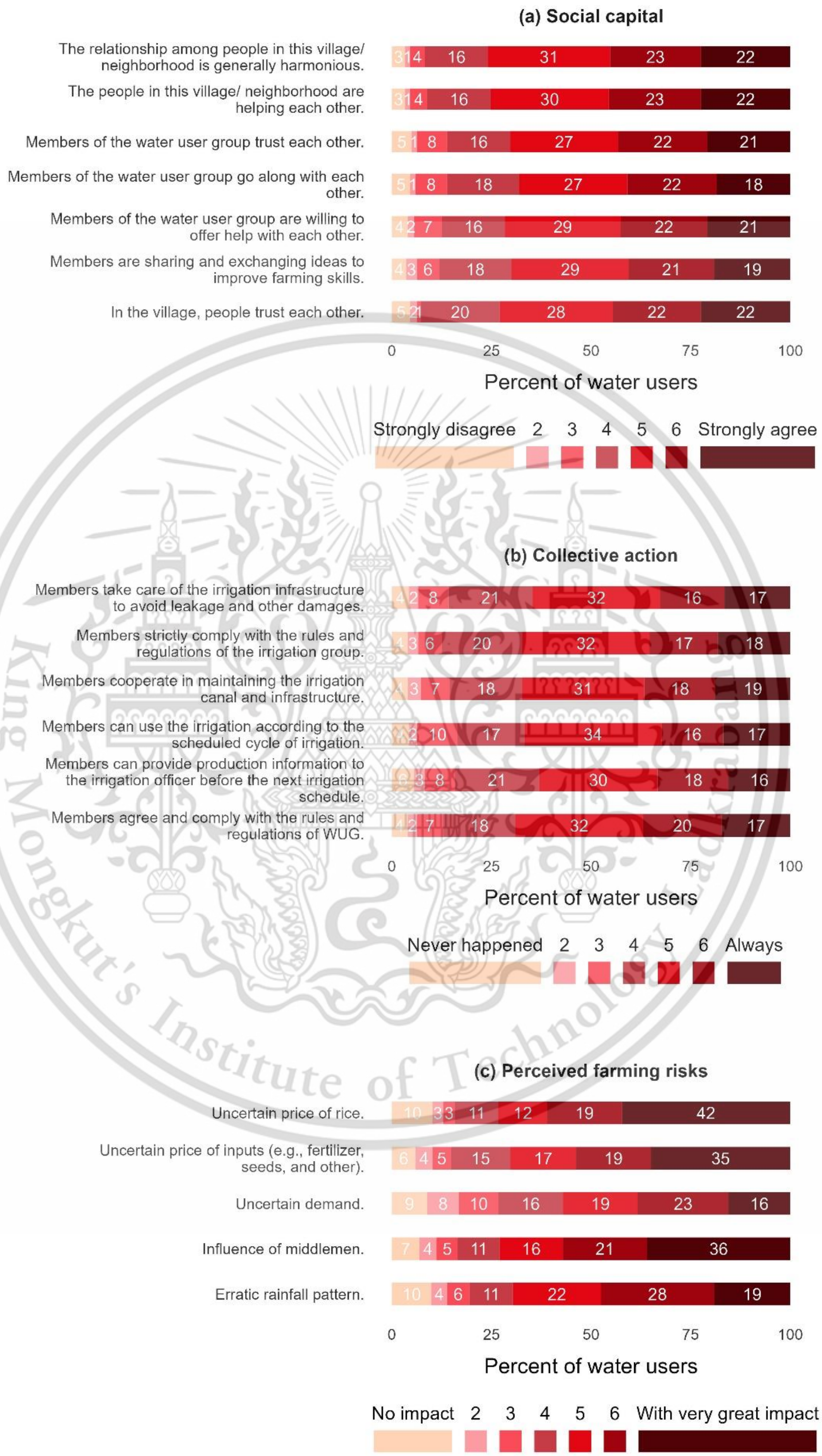
4.2. Social capital as drivers for collective action

4.2.1. Summary of the factor items.

The relative percent frequency of the farmers' responses to the question items used as indicators for the latent factors is summarized in Figure 4.7. In panel (a) are question items related to bonding and bridging social capital. For the items related to bridging social capital, a large proportion of the sampled farmers responded with agree to strongly agree that there is a relatively high presence of trust, reciprocity, and the overall relationship of the people living within the community is perceived to be harmonious. In contrast, 3-20 percent responded with disagree to disagree with the statements in panel (a) strongly.

A similar pattern can be observed with items related to the bonding social capital among the water users. Again, the perceived trust, reciprocity, and overall relationship among water users are perceived as high. Whereas items in panel (b) reflect the water users' willingness to participate in the collective irrigation operation and maintenance activities. The collective action activities often include the maintenance of irrigation canals and infrastructures, farm records, group meetings, and adherence to rules and regulations. Across collective activities, a large proportion of the sampled farmers (30-32 percent) responded with occasionally (5^{th} scale of the 7-point Likert scale), while only 16-19 percent considered participation as always.

The observed relatively large proportion of occasional participation reflects the findings in the previous study on the Mae Lao irrigation (e.g., Wongtragoon et al., 2010) and the focus group discussion results. For instance, water supply from the irrigation to farm areas follows a rotational schedule, however, several cases of illegally opening the canal gate were also noted. Hence, understanding the drivers for a higher intention to cooperate and participate in collective irrigation management will be crucial for policy interventions.


(a) Social capital
The relationship among people in this village/ neighborhood is generally harmonious.
3 1 4 16 31 23 22
The people in this village/ neighborhood are helping each other.
3 1 4 16 30 23 22
Members of the water user group trust each other.
5 1 8 16 27 22 21
Members of the water user group go along with each other.
5 1 8 18 27 22 18
Members of the water user group are willing to offer help with each other.
4 2 7 16 29 22 21
Members are sharing and exchanging ideas to improve farming skills.
4 3 6 18 29 21 19
In the village, people trust each other.
5 2 1 20 28 22 22
0 25 50 75 100
Percent of water users
Strongly disagree 2 3 4 5 6 Strongly agree
(b) Collective action
Members take care of the irrigation infrastructure to avoid leakage and other damages.
4 2 8 21 32 16 17
Members strictly comply with the rules and regulations of the irrigation group.
4 3 6 20 32 17 18
Members cooperate in maintaining the irrigation canal and infrastructure.
4 3 7 18 31 18 19
Members can use the irrigation according to the scheduled cycle of irrigation.
4 2 10 17 34 16 17
Members can provide production information to the irrigation officer before the next irrigation schedule.
6 3 8 21 30 18 16
Members agree and comply with the rules and regulations of WUG.
4 2 7 18 32 20 17
0 25 50 75 100
Percent of water users
Never happened 2 3 4 5 6 Always
(c) Perceived farming risks
Uncertain price of rice.
10 3 3 11 12 19 42
Uncertain price of inputs (e.g., fertilizer, seeds, and other).
6 4 5 15 17 19 35
Uncertain demand.
9 8 10 16 19 23 16
Influence of middlemen.
7 4 5 11 16 21 36
Erratic rainfall pattern.
10 4 6 11 22 28 19
0 25 50 75 100
Percent of water users
No impact 2 3 4 5 6 With very great impact

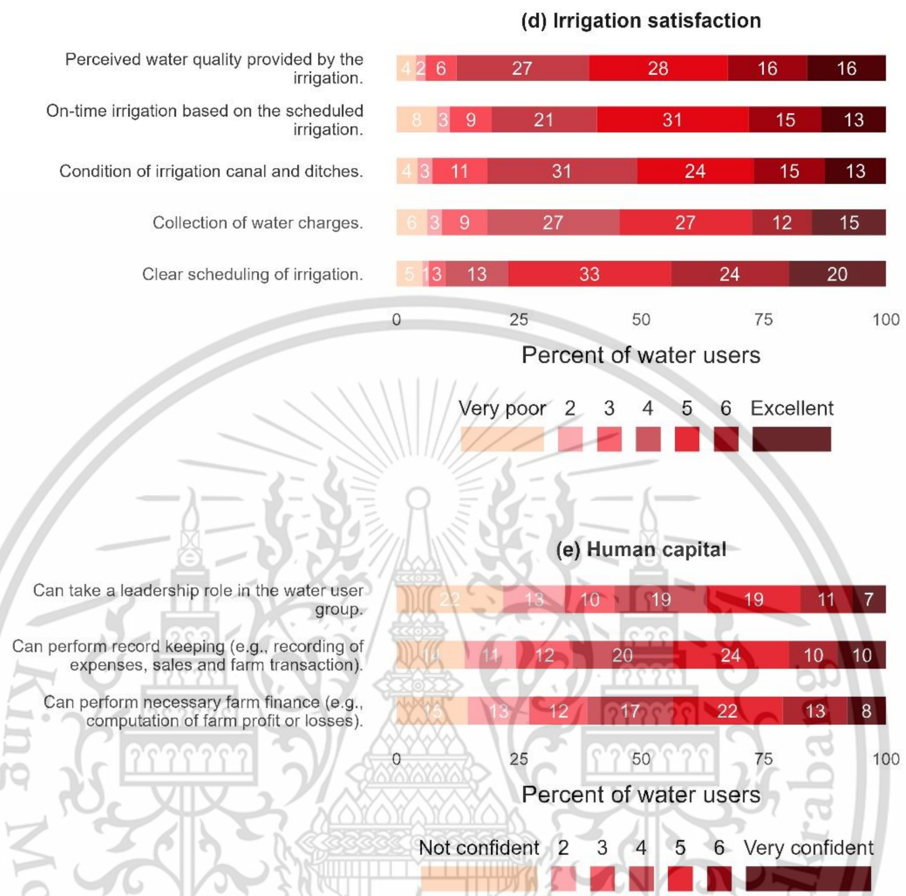


Figure 4.7. Summary of the farmers' responses to the question items used as indicators of the latent factors. The values correspond to the percent frequency of the 7-point Likert scale.

On the other hand, the top perceived risks farmers face are summarized in panel (c). The selling price of rice has the largest perceived impact on farm decision-making. While the impact of the price of rice is expected to have the greatest consideration, interestingly, the influence of middlemen precedes the topmost perceived risks in rice farming. This can be attributed to the strong bargaining power of middlemen against the rice farmers. As farmers lack available capital for all the needed farm inputs, they often depend on lenders and intermediaries for additional capital. While farmers receive support from the agricultural sector of the government, the convenience and immediate availability of funds from money lenders and intermediaries attract farmers to borrow. Whereas uncertainty of the demand for rice has the lowest perceived impact among sampled farmers. This can be attributed to the stable demand for rice, given that the population in the country is rice consumers.

Regarding farmers' satisfaction with the current irrigation operation and management, panel (d) demonstrates the percent frequency of the satisfaction level of the sampled water users. A relatively high proportion of farmers are neutral on whether the quality of irrigation services is poor or good. A small proportion of farmers (13-20 percent) considered the current irrigation O&M excellent.

Looking at farmers' capacity to take leadership roles, only 7 percent are confident, against 22 percent who perceived that they are not confident to lead the water user group. This can be attributed to the responsibilities associated with leading the group, such as organizing meetings and overseeing the overall tasks expected from members (e.g., production records and resolving any arising conflicts). In addition, even during the focus group discussion, members admitted that there were conflicts among members and violations of the set guidelines and rules of the water user associations. Hence, only a few are willing to take leadership roles.

4.2.2. Factor item’s reliability and validity

An exploratory factor analysis was conducted to identify the group of items suitable or highly associated with its intended latent factor. The items for each latent factor were extracted using the maximum likelihood with a varimax rotation. The criteria used in the selection include factor loadings higher than the recommended factor loadings at 0.30 and above (Williams et al., 2010; Zwick & Velicer, 1986). Figure 4.8 summarizes the selected factor items and their corresponding bootstrapped mean loadings with a 95 percent confidence interval. Across all the factor items, the factor loadings were above the recommended threshold (i.e., dashed line), and more than 50 percent of the variance of each item was explained by its intended latent factor.

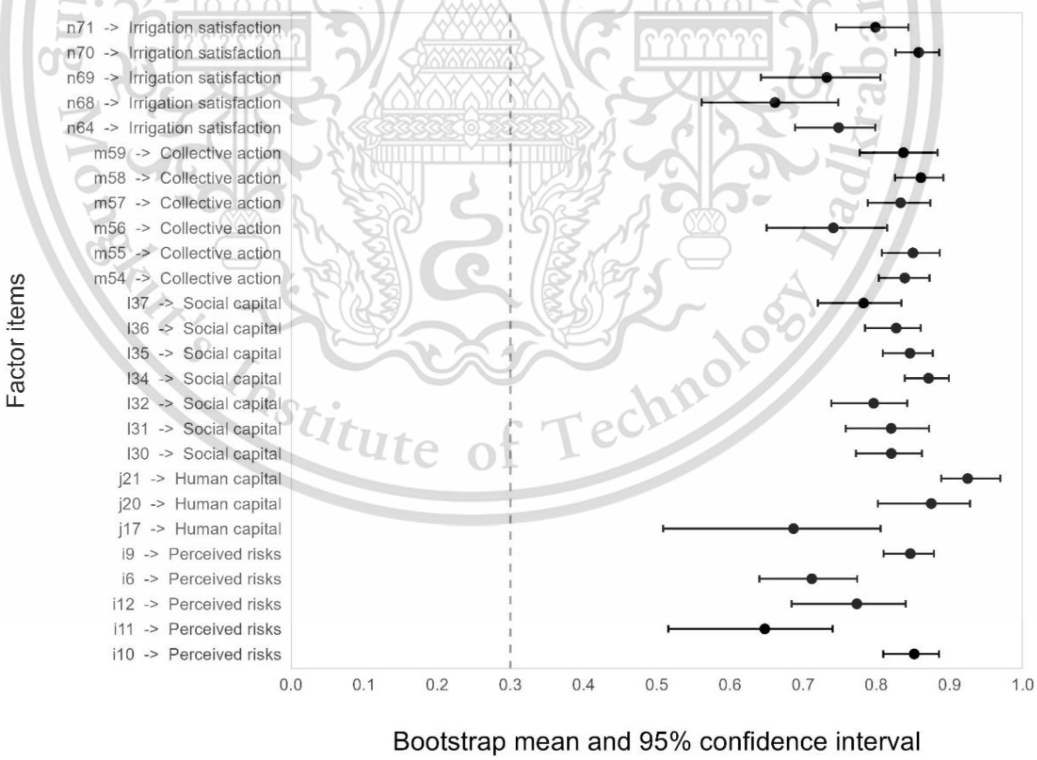


Figure 4.8. Bootstrap means with a 95 percent confidence interval. A 10,000 bootstrap iteration was used in estimating the factor loadings.

The factor reliability and validity test results of the five latent factors are shown in Figure 4.9. The alpha value, Rho A and Rho C, are the construct reliability indicators that assess the group of items' consistency to what they supposedly intend to measure. The construct reliability test results were above the threshold of 0.70, indicating that the items used in reflecting the latent factor are statistically reliable (Bentler, 1990; Bollen, 1989). At the same time, the convergent validity test is presented by the average variance extracted (AVE), which exceeds the minimum acceptable value of 0.50 (Hair, 2017). The convergent validity assesses how well the selected items are indicators for the expected constructs (Cheung & Rensvold, 2002; Hair, 2019; Hu & Bentler, 1999).

Figure 4.9. Factor reliability and validity. Alpha, rhoC, and rhoA should exceed 0.7, presented in the broken line.

4.2.3. Discriminant validity

A discriminant validity test assesses how distinct or unique the measured construct with the other construct. Two commonly used discriminant validity tests are the Fornell-Larcker criterion and the Heterotrait-Monotrait criterion (Fornell & Larcker, 1981; Hair, 2019; Hu & Bentler, 1999). Although both tests served the same purpose, the Fornell-Larcker criterion was the most widely used. In contrast, the Heterotrait-Monotrait addresses some limitations of the Fornell-Larcker criterion identified from simulation studies.

In Table 4.4 for the Fornell-Larcker criterion results, the italicized values in the diagonal area, the average variance extracted, and the off-diagonal values are the correlation of each factor. To establish the discriminant validity using the Fornell-Larcker criterion, the values in the diagonal must be higher than the off-diagonal values. For instance, the first construct reflecting the social capital concept with an AVE of 0.825 is higher than the constructs correlation shown in the second column.

Table 4.4. Discriminant validity using the Fornell-Larcker criterion.

	Social capital	Perceived risks	Human capital	Collective action	Irrigation satisfaction
Social capital	***0.825***				
Perceived risks	0.224	***0.775***			
Human capital	0.041	0.097	***0.847***		
Collective action	0.504	0.316	0.211	***0.829***	
Irrigation satisfaction	0.461	0.238	0.069	0.542	**0.765**

Fornell-Larcker criteria table reports the square root of AVE on the diagonal and constructs correlations on the lower triangle.

4.2.4. Structural model estimation using the PLS-SEM.

Results of the structural equation modeling using a partial least-square approach are summarized in Figure 4.10 and Table 4.5. Hypothesis H1 tests the effects of the social capital level on the farmers' intention to participate in the collective irrigation operation and maintenance. Results show that social capital ($\beta = 0.452, 95\%\ CI\ [0.357, 0.533]$) is positively associated with higher participation for collective action. Compared with other factors, such as perceived risks and human capital factors, social capital has the largest magnitude of effects in increasing participation in participatory irrigation management. This implies that the perceived trust, reciprocity, and the overall relationship reflected in the social capital concept are the main drivers for farmers to participate in PIM voluntarily.

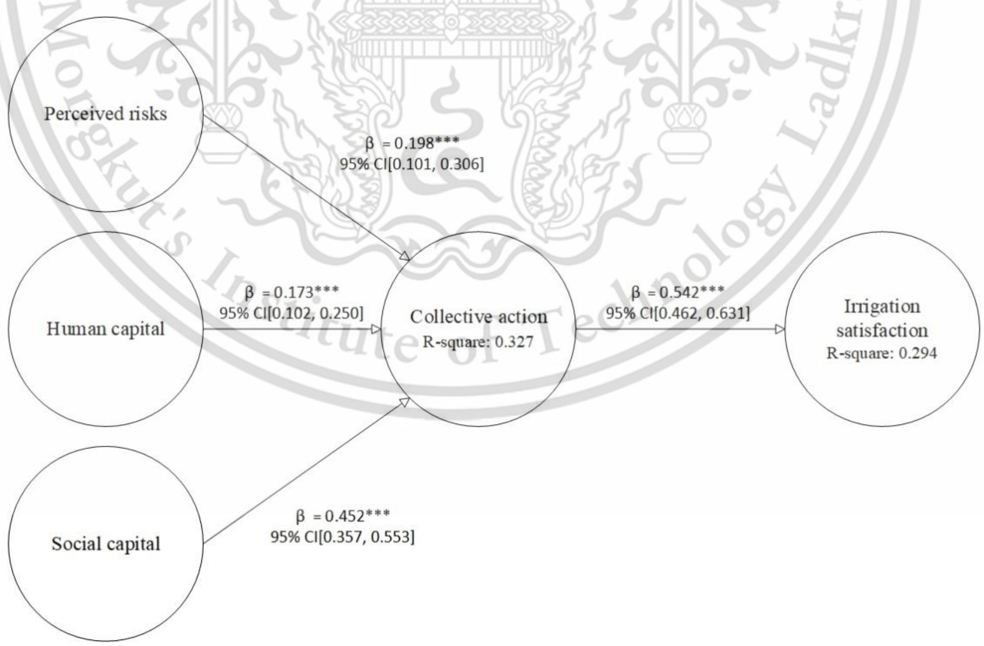


Figure 4.10. Results of the structural equation modeling using the PLS-SEM. The model tests the hypotheses presented in the conceptual framework in Figure 3.

The perceived farmers' skills reflected in the latent human capital ($\beta = 0.173$, $95\%\ CI[0.102, 0.250]$) factor indicates that skilled farmers or have the potential to take leadership roles are more likely to participate in collective actions. On the other hand, the study hypothesized perceived risks to be negatively associated with participation in collective actions. Results show that as the farmers faced high risks, the higher the intention to participate in collective action ($\beta = 0.198, 95\%\ CI[0.101, 0.306]$). The high dependence of farmers on the Mae Lao irrigation project for water supply influences farmers' intention to take responsibility as WUG members and adherence to rules. Any disruptions in the water supply due to inactive participation toward joint operation and management of irrigation increase the risks in rice farming and worsen the effect of drought during the dry season. Hence, higher perceived risks could push farmers to place higher values on participating in participatory irrigation management.

While participation in collective action explains almost 30 percent of the variations in farmers' level of satisfaction with the current irrigation operation and management, higher participation in collective action is positively associated with better irrigation services ($\beta = 0.542, 95\%\ CI\ [0.462, 0.631]$). While the observed relationship is as expected, the collective action latent factor is hypothesized to mediate the effects of perceived risk, human capital, and social capital toward irrigation satisfaction.

Figure 4.10 illustrates the direct effects of the drivers of collective action and irrigation satisfaction. Collective action latent factor also mediates the effect of the perceived risks, human capital, and social capital. The direct and indirect effects of social capital, human capital, and perceived risks are shown in Table 4.5.

Table 4.5. Bootstrapped estimates of the specified paths in the structural equation modeling.

Paths	Effects	Original estimate	Bootstrap means	Bootstrap SD	t-stat	95% CI
SC → CA	Direct	0.452	0.454	0.059	7.721	[0.356, 0.548]
SC → IS	Indirect	0.245	0.249	0.045	5.388	[0.179, 0.325]
PR → CA	Direct	0.198	0.199	0.063	3.156	[0.099, 0.303]
PR → IS	Indirect	0.107	0.109	0.036	2.94	[0.051, 0.171]
HC → CA	Direct	0.173	0.176	0.047	3.682	[0.098, 0.254]
HC → IS	Indirect	0.094	0.096	0.027	3.505	[0.053, 0.140]
CA → IS	Direct	0.542	0.547	0.053	10.228	[0.458, 0.634]

Note(s): The PLS-SEM estimation used 10,000 bootstrap subsamples estimating the effects of the specified paths in Figure 3. CI = Confidence interval; SC = Social capital; HC = Human capital; PR = Perceived risks; CA = Collective actions; IS = Irrigation satisfaction.

Social capital has a significant indirect effect on higher irrigation services satisfaction ($\beta = 0.245, 95\%\ CI[0.179, 0.325]$). This implies that farmers with higher social capital with high perceived trust, reciprocity, and overall relationship within group members and their networks are more satisfied with the current irrigation operation and management as mediated by the collective action factor. Similar effects are observed for the human capital and perceived risk factor, which show a positive indirect effect on perceived satisfaction. Regarding the total effects of the exogenous latent factors, the summation of the direct and indirect effects indicates the total effects of the endogenous latent factors.

An alternative structural model is estimated based on the previous model in Figure 4.10 to test the robustness of the observed results of the preceding hypotheses testing. Across the added path in the alternative model, only the social capital latent factor has a significant direct effect on perceived irrigation services satisfaction. At the same time, the direct effects of perceived risks and human capital have no apparent direct effects on the water users’ perceived satisfaction towards the MLIP irrigation services.

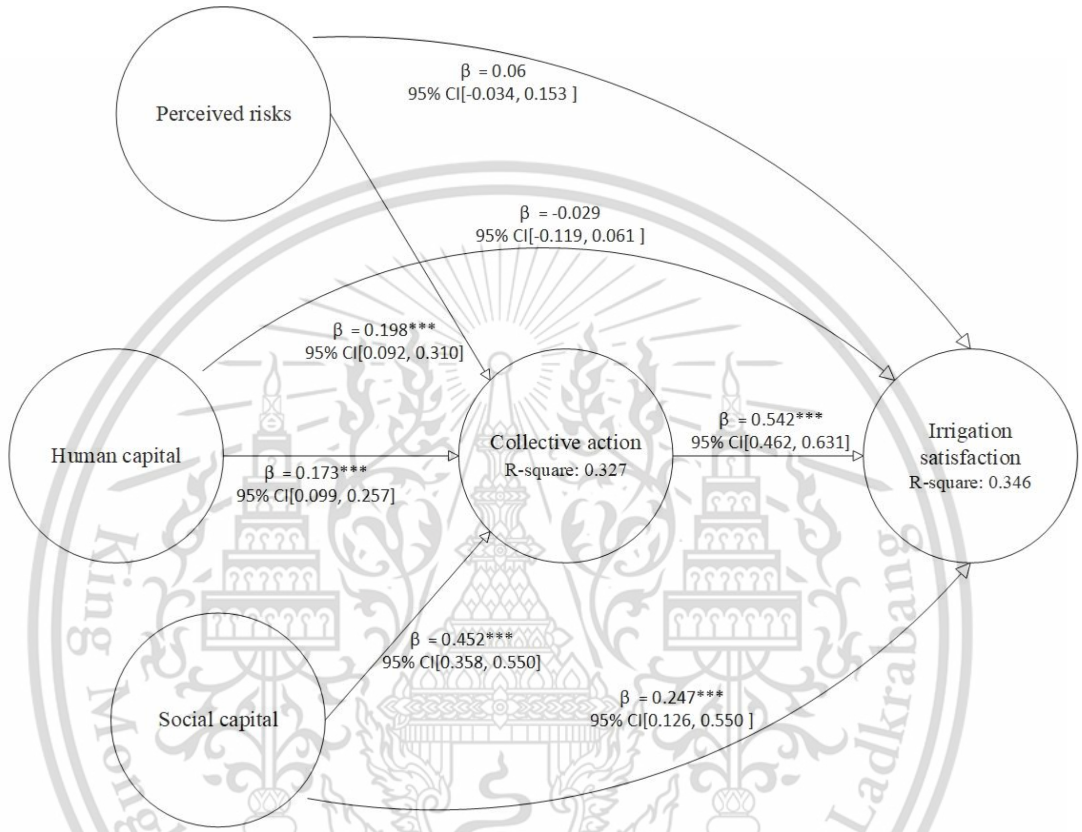


Figure 4.11. Alternative structural model in testing the hypotheses of the conceptual framework in Figure 3. The model adds the direct effects of the drivers of collective action.

Table 4.6. Bootstrapped estimates of the specified paths in the structural equation modeling.

Paths	Effects	Estimate	Bootstrap means	Bootstrap SD	t-stat	95% CI
SC → CA	Direct	0.453	0.453	0.060	7.605	[0.352, 0.553]
SC → IS	Total	0.431	0.428	0.061	7.013	[0.319, 0.524]
PR → CA	Direct	0.197	0.197	0.065	3.049	[0.092, 0.301]
PR → IS	Total	0.139	0.143	0.063	2.230	[0.043, 0.244]

HC → CA	Direct	0.173	0.176	0.050	3.451	[0.097, 0.256]
HC → IS	Indirect	0.041	0.043	0.060	0.676	[-0.066, 0.135]
CA → IS	Direct	0.404	0.408	0.063	6.417	[0.306, 0.514]

Note(s): The PLS-SEM estimation used 10,000 bootstrap subsamples estimating the effects of the specified paths in Figure 3. CI = Confidence interval; SC = Social capital; HC = Human capital; PR = Perceived risks; CA = Collective actions; IS = Irrigation satisfaction.

The consistency of social capital in terms of its direct and indirect effects indicates the concept's important role in participatory irrigation management. As surface irrigation is prone to deflection, developing the water users' trust, reciprocity, and overall relations to its community and network will be a critical driver for successfully implementing participatory irrigation management in the Mae Lao irrigation project. Furthermore, social capital has the largest effect size compared with other drivers of collective actions included in the models. This implies that a large proportion of the variations in the level of farmers' intention to participate in collective action can be accrued to the social capital the group has developed.

4.3. Linking PIM, social capital, and production efficiency

4.3.1. Structural model with farming efficiency using the PLS-SEM

A structural model derived from the previous model presented in Figure 4.10 is estimated with the addition of the farmers' technical efficiency. The factors' reliability and validity are the same as previously presented results since the same indicators were used for the factors in Figure 4.12. This section assessed the direct effects of collective actions and perceived irrigation satisfaction. In addition, the direct and indirect effects of the perceived risks and human capital toward technical efficiency were assessed in the alternative model in Figure 4.13.

Hypothesis H5 in Figure 2.4 examines the possible influence of collective action on the technical efficiency of rice farmers in the Mae Lao irrigation project. The result of the structural model shows a significant and positive association ($\beta = 0.116, 95\% \, CI[0.014, 0.237]$) of the collective action towards higher efficiency. In regards to the previous section, which investigate the impact of participation in PIM activities, results show a consistent conclusion on the effect of collective irrigation management and how it affects the efficiency of farmers. The difference with the previous model presented in Table 4.3, the PLS-SEM allows the simultaneous estimation of the interrelationships of the latent factors with their corresponding indicators.

While hypothesis 6 assessed the influence of perceived irrigation satisfaction on farmers' efficiency. Higher perceived satisfaction towards the current irrigation operation and management is positively associated with higher technical efficiency. At the same time, the test found enough statistical evidence for the effect's significance in the study area. Although the study did not find enough statistical evidence for the significance of irrigation satisfaction, the effect of collective action as mediated by the perceived irrigation satisfaction was significant. It implies that irrigation satisfaction may not have a significant direct impact. However, it serves as a mediator of the impact of collective action on the level of technical efficiency of rice farmers.

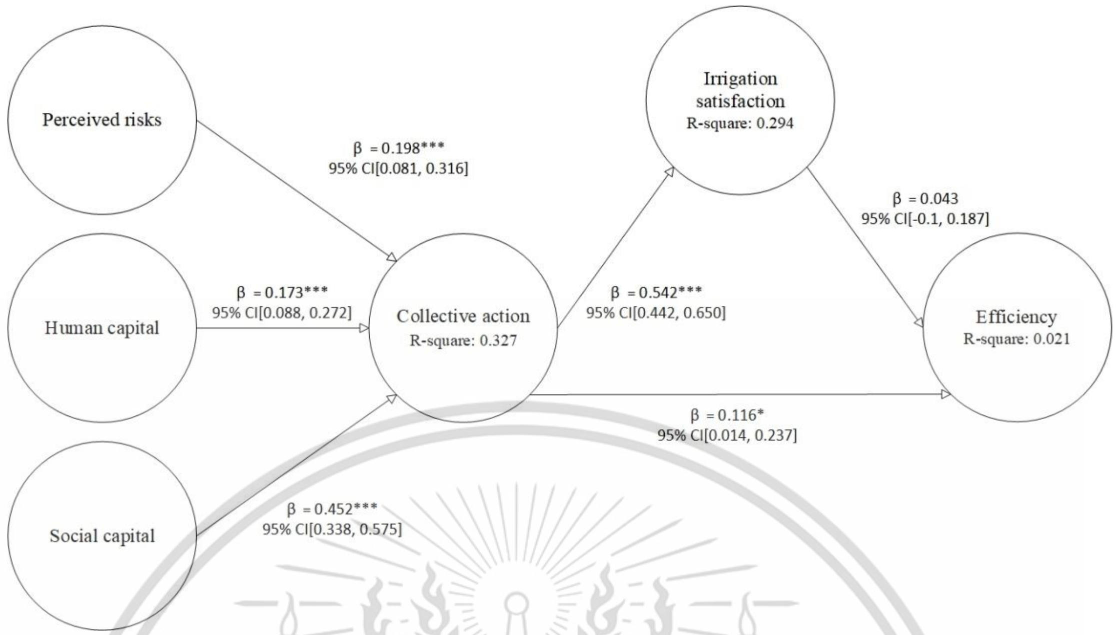


Figure 4.12. Estimates of the structural equation modeling using the PLS-SEM. The model tests the hypotheses presented in the conceptual framework in Figure 2.4.

Table 4.7. Bootstrapped estimates of the specified paths.

Paths	Effects	Original estimate	Bootstrap means	Bootstrap SD	t-stat	95% CI
SC → CA	Direct	0.452	0.452	0.058	7.728	[0.351, 0.546]
SC → IS	Indirect	0.245	0.248	0.045	5.443	[0.178, 0.325]
SC → Efficiency	Indirect	0.063	0.064	0.029	2.201	[0.018, 0.110]
PS → CA	Direct	0.198	0.201	0.061	3.234	[0.099, 0.303]
PS → IS	Indirect	0.107	0.110	0.035	3.037	[0.054, 0.171]
PS → Efficiency	Indirect	0.028	0.029	0.016	1.711	[0.007, 0.057]
HC → CA	Direct	0.173	0.174	0.048	3.567	[0.095, 0.251]
HC → IS	Indirect	0.094	0.095	0.027	3.455	[0.054, 0.141]
HC → Efficiency	Indirect	0.024	0.024	0.013	1.914	[0.006, 0.047]
CA → IS	Direct	0.542	0.546	0.053	10.243	[0.461, 0.629]
CA → Efficiency	Direct	0.139	0.141	0.060	2.326	[0.042, 0.237]
IS → Efficiency	Direct	0.043	0.045	0.069	0.619	[-0.072, 0.163]

In the alternative model in Figure 4.13, the direct effects of perceived risks and human capital are added to the structural model. The perceived risks do not directly impact the efficiency level ($\beta = 0.003, 95\%\ CI[-0.118, 0.125]$), but the influence of the perceived risk is found to be indirectly affecting farmers' efficiency. On the other hand, farming knowledge, skills, and the ability to take leadership roles as embedded in the human capital latent factors in the model have a significant and positive effect ($\beta = 0.174, 95\%\ CI[0.046, 0.285]$) towards farmers efficiency.

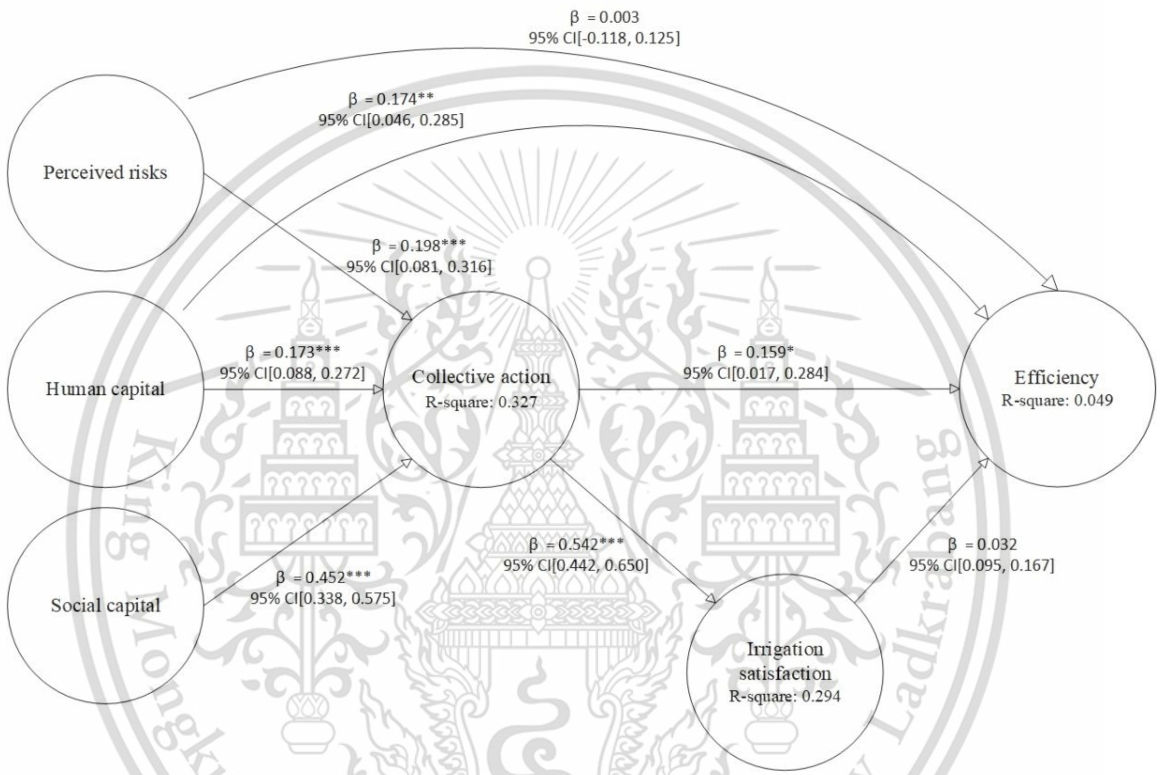


Figure 4.13. Alternative structural model in testing the hypotheses of the conceptual framework in Figure 5. The model adds the direct and indirect effects of perceived risks and human capital.

CHAPTER 5. DISCUSSION

This chapter discusses the study's findings on social capital as a driver for collective action under the current participatory irrigation management in the Mae Lao irrigation in Northern Thailand. Also, the interrelationship of the social capital concept, the collective irrigation management, and their impact on farmers' production are discussed. The sections under this chapter proceed as follows:

5.1 Social capital and drivers of collective action under PIM

5.2 Social capital and PIM: enhancing farmers' efficiency.

5.1. Social capital and drivers of collective action under PIM

The increasing application of the social capital concept lies within several unsuccessful cases and the limitations of standard approaches when dealing with economic development and political and societal issues (Ostrom & Ahn, 2009). Like the earlier established forms of capital (e.g., physical, financial, and human capital), social capital involves creating assets that generate future benefits (Choi & Chang, 2020; Ostrom & Ahn, 2009; Woolcock, 1998). These streams of benefits include access to information, trust, cooperation and collective actions, social support, and networks.

These associated traits of social capital, such as perceived trust and reciprocity built among water users, are vital to sustaining continued cooperation and participation in collective action in the Mae Lao irrigation project (MLIP). In addition, these traits facilitate a more cohesive water user group, driving for a higher participation in collective irrigation management under PIM. As the study shows, we found empirical evidence supporting how developing the social capital endowment of the water user groups increases the probability of participation in collective irrigation management (i.e., hypothesis H1).

Participation in collective irrigation management activities reveals substantial work that needs to be done to develop farmers' participation further. The focus group discussion reveals that active public participation occurs mainly with activities related to ditch-level decision-making due to the need for voluntary contribution or permission from the private landowner (i.e., farmers along the ditch canal). Despite adopting participatory irrigation management, farmers often perceived the irrigation department as passive in involving the public in major irrigation decision-making. For instance, irrigation departments often merely inform local residents of any anticipated projects and not being involved during the initial planning process. This partly contributed to the observed rate of participation in collective irrigation management. As revealed in Section 4.2.1, there was 30-32 percent of farmers whose participation in collective irrigation management activities was perceived as occasional, and only 16-19 percent with the response as always. Although social capital has a large magnitude of impact in increasing collective action in the study area, there is a considerable percentage of farmers with lower perceived trust, reciprocity, and overall relationship with other members, the farming community, irrigation officers, and other networks.

Notwithstanding the efforts to increase the roles and participation of the public in the governance and decision process, and as surface irrigation is prone to defection, the decision to participate in collective maintenance (e.g., weeding, clearing silted canals, submission of farm records) will be voluntary. Thus, the irrigation department needs to develop the capacity to facilitate the development of increased volunteerism of water users toward collective irrigation management. While providing training, coaching, and information drive on the benefits of participatory irrigation management in the area helps. However, this may not be the most sustainable approach in the long run. The irrigation department organized the water user group in the early phase, however the continued functioning of the group (e.g., collective irrigation management) is more likely to be sustained by the level of social relationship established by the members as well as with their partners (e.g., irrigation department, extension service providers, other water user groups).

Often the roles of social capital in collective action problems, such as in the application of participatory irrigation management are underappreciated and undervalued. Unsuccessful cases of PIM implementation in Thailand and similar cases in other countries often associate the failure to non-allocated budgets and uncooperative public irrigation officials (Azemzi & Erraoui, 2020; e.g., Bardhan, 2000; Molle et al., 2002). While studies that found successful PIM implementations associate success with a high presence of social capital and participation towards collective actions (e.g., Hopkins, 2011; C. Llones et al., 2021; Patulny & Lind Haase Svendsen, 2007). As pointed out by Hopkins, social capital endowments can shift from individualistic to group-level participation in collective action. For successful PIM implementations, social capital has compensated for the constraints and difficulties in establishing higher participation in collective irrigation management between the state and farmers or the water users.

Aside from the role of social capital for higher collective actions, perceived risks in farming and human capital are positively associated with higher collective action or higher participation in PIM activities. For example, since 2004, after several years of implementing the PIM principles, farmers gradually developed a sense of ownership in the command irrigation area. Developing a sense of ownership increases farmers' initiative for irrigation maintenance and water-saving efforts. For example, farmers negotiate with water officers to build a water gate to store water in the drainage channel. According to farmers, without their initiative to build the watergate by themselves, the water will flow wastefully into the river.

The mentioned case scenario from one of the farmers in the Mae Lao irrigation areas reflects their past experiences of risks such as drought during the dry season. This influences farmers to give importance to voluntarily participating in collective irrigation management of irrigation canals and developing initiatives to save water. Moreover, despite not having prior experience building watergate to control the water flow along the irrigation canal, tacit experience and learning from their network allows them to acquire new skills that further develop their human capital.

While the focus of most irrigation development pertains to the infrastructure and physical components, recent developments in irrigation recognized the importance of participation of the public sectors in common resource management problems. In the country's 8th national development plan, the Thai government emphasized increasing the roles of the local community in governance, operation, and management of irrigation projects. However, the initial primary goal in adopting the PIM was to reduce the burden of high maintenance costs by transferring some responsibility to the water users or farmers. However, the benefits of involving the public (e.g., farmers along the irrigation canal) are far more than the reduction in the cost of maintaining the operation and management of the Mae Lao irrigation project. The irrigation department recognized the

PIM's potential as a communicative forum for stakeholders (Kapoor, 2001), identifying and finding the solution to problems more efficiently (Mitchell, 2013) and incorporating local knowledge in the decision-making process (Tyler, 2006).

5.2. Social capital and PIM: enhancing farmers' efficiency.

Typical in analyzing the rice production system is assessing farmers' employment of different forms of capital such as financial capital (e.g., cash, credit), physical capital (e.g., land, equipment, and machinery), human capital (e.g., family and hired labor, education), and natural capital (e.g., rivers, forest). Social capital, an abstract concept, poses a challenge in linking to agricultural production and farmers' level of technical efficiency. To navigate this challenge, the study uses structural equation modeling to reflect the social capital concept and assess its association with farmers' level of technical efficiency. The method allows us to measure and assess the direct and indirect influence of social capital and PIM latent factors toward enhancing farm productivity and efficiency.

According to Putnam (2000), the presence of social capital is highly observable in the case of farming communities—the social capital concept manifest within the farming community and farmers' network. Woolcock (1998) emphasized the underappreciation of the social capital concept in agricultural production and productivity. Several studies have demonstrated how social capital facilitates the adoption of any agricultural technologies, sustainable practices, and innovations that enhance the productivity and efficiency of farmers (Chaudhry, 2018; Choi & Chang, 2020; Chuzu, 2002; Hayami, 2009; C. A. Llones et al., 2022; Sözbilir, 2018).

As rice production relies heavily on water availability, reliable irrigation is critical to the overall performance of rice production. For instance, Totin et al. (2014) found that lower participation in collective irrigation activities has an adverse effect on rice production in Benin. While farmer groups with a strong presence of social capital endowments show active participation in collective farming activities, wider networks, and better access to information and training (D'Annolfo et al., 2020; Pretty et al., 2020; J. I. Ricks, 2015). These opportunities have been highly associated with higher farm productivity and efficiency across studies (Abdul-Rahaman et al., 2021; Bojnec et al., 2011; Chaovanapoonphol et al., 2009; T. J. Coelli et al., 1996; C. A. Llones et al., 2022).

In the structural model presented in Figure 4.12, we tested how the social capital concept, perceived risks, and human capital as mediated by participatory irrigation management through the collective action factor influence farmers' level of technical efficiency. Social capital significantly and indirectly affects farmers' efficiency through higher participation in collective action. As demonstrated in the previous section, the higher presence of social capital is associated with a higher intention for collective action. At the same time, participation in collective action under the PIM activities directly impacts farmers' technical efficiency.

In the case of the Mae Lao water users, the participation in PIM activities such as maintenance work, group meetings, dispute resolution, and policy adherence show a positive and significant association with higher production efficiency. In surface irrigation, particularly under a participatory irrigation management concept, inactive participation in the collective maintenance works affects not only a farmers' farm but the adjacent farms as well. Group discussion reveals that farmers participate in the maintenance work to avoid disapproval from other members. Disapproval from the other group member puts pressure on members to act with socially desirable traits or follow social norms.

Moreover, farmers who actively participate in group meetings are associated with higher efficiency. Farmers' group meetings have been considered social gatherings among the farming community for knowledge-sharing and networking. As a result, farmers gain access to information such as best practices in farming and information on updated innovations and technology. In addition, networking improves access to information, training, and asset-generating opportunities. This implies that farmers are not only limited to their own resources but enable to use resources from their networks to improve welfare.

Aside from social capital, the human capital reflecting farmers' skills and attributes (e.g., knowledge in farming and agricultural practice) was assessed in terms of the concept's direct and indirect impact on farmers' technical efficiency. Studies assessing factors affecting technical efficiency only estimate the direct impact of farmers' human capital (e.g., Alam et al., 2019; Chaovanapoonphol et al., 2009; Mishra et al., 2019; Tiedemann & Latacz-Lohmann, 2013; Wang et al., 2020). Similarly, we found a positive association between efficiency and the human capital factor. Whereas the least estimated indirect effect of human capital significantly impacts farmers' technical efficiency.

CHAPTER 6. CONCLUSION, IMPLICATION, AND RECOMMENDATION

The conduct of study aims to identify and assess the drivers of collective action and the role of social capital under PIM; assess the effect of the current irrigation management on efficiency; investigate the link between the social capital concept, collective actions, and farmers' efficiency in production under the participatory irrigation management. The study results provide insights into the critical role of developing the social capital endowments of water user groups for higher participation in collective irrigation management. Moreover, investigating the interrelationship of the social capital, irrigation management under PIM, and their impact on farmers' production assist in informed decision-making and policy-making. Therefore, this study provides the concluding remarks, implications, and recommendations. The sections under this chapter proceed as follows:

6.1 Conclusion

6.2 Implications and recommendations

6.2.1 Irrigation department and PIM implementation

6.2.2 Water users and the participatory irrigation management

6.2.3 Future studies

6.1. Conclusion

Thailand's agricultural production is closely linked to the country's irrigation system, especially rice production. Irrigation projects are under the supervision of the Royal Irrigation Department, which served as a supplementary during the wet season and allowed production during the dry season. This led the country to adopt joint irrigation management with the farmers as water users. Furthermore, in the eighth national plan, the government emphasized increasing public participation in the operation and maintenance of irrigation projects under the principles of participatory irrigation management.

Across irrigation projects in the country, there have been cases of successful and unsuccessful implementation of participatory irrigation management. Previous studies found unsuccessful PIM adoption characterized by uncooperative irrigation officers, bureaucratic exercise, and fragmented water user groups. In contrast, successful PIM demonstrates high social capital, i.e., high perceived trust, shared vision, commitment, and coordination. Even with the absence of cooperative irrigation officials, a high level of trust, social ties, and cooperation among water user groups has been able to overcome or compensate the adversaries in performing the collective maintenance work.

Despite the RID's reform of the PIM guidelines in 2004, continuous defection among water users is observed. This implies that enforcing irrigation rules is not enough to sustain participatory irrigation management. It requires developing the water users' commitment, sense of volunteerism, and perceived trust to perform shared responsibility in the irrigation operation and maintenance. In the study, we test the potential role of the social capital concept in facilitating higher participation in collective irrigation activities under the participatory irrigation context. Furthermore, we compare the magnitude of the impact of social capital with potential drivers of collective action, such as human capital and perceived risks faced by farmers.

Between drivers of collective action, social capital has the largest influence on farmers in the collective maintenance work. Under social capital, developing higher perceived trust, reciprocity, shared vision, and networking among water users and irrigation officers are associated with a higher perceived intention to participate in collective action. In a group discussion, farmers revealed that increased interactions and allowing farmers to participate more in irrigation planning have contributed to increased confidence and perceived trust with irrigation officials and WUG members. In addition, increased roles and participation for farmers during the general meeting have contributed to the sense of ownership among WUG members. According to farmers, developing a sense of ownership regarding the command irrigation canal has given the farmers a perceived personal responsibility to maintain the irrigation canal in good condition. It also facilitates farmers to be innovative and initiative in water-saving. For example, farmers have the initiative to construct a storage system for excess water by creating a watergate along the ditch canal to prevent the water from flowing freely through the river. The set irrigation rules did not enforce this behavior but resulted from doing what is perceived as right in contributing to the management of the shared resource. Adhering to the social norm or the voluntary act of the farmers is rewarded by receiving praise from the farming community. This is an example of the importance of creating an environment facilitating higher perceived reciprocity or giving attention to others' welfare without expecting an immediate return of the favor.

On the other hand, farmers' confidence in their skills and perceived willingness to take leadership roles under the human capital are positively associated with higher participation in collective action. In contrast, we hypothesized that as farmers faced higher risks in farming, farmers' intention to assume responsibilities in collective maintenance work was lower. However, farmers with higher perceived risks in farming are associated with a higher intention to take responsibility for collective irrigation management. Furthermore, farmers reveal during a focus group discussion that disruption in the water supply due to deflecting responsibilities in maintaining the irrigation canal in good condition will further increase farmers' risk in farming, especially during the dry season.

As rice production heavily relies on irrigation, we investigated the potential influence of participatory irrigation management on the farmers' level of technical efficiency. Using the stochastic frontier analysis, we found the overall efficiency level in the Mae Lao irrigation at 83.62 percent, which implies a potential 16.38 percent increase in efficiency if factors contributing to the inefficiencies are addressed. However, across irrigation branches, the level of efficiency is 84.6, 83.5, and 83.2 percent for branches 1 to 3, respectively. Notably, farmers located in branch 1 experienced less water disruption than in branches 2 and 3. This partly gives insight into how water security is associated with efficiency in rice production.

Moreover, the level of farmers' efficiency is significantly associated with participation in the PIM activities such as dispute resolution, group meetings, maintenance work, and policy adherence. Among PIM activities, participation in maintenance work shows the largest impact on farmers' efficiency. Consequently, adherence to irrigation rules and regulations has the second magnitude of impact that explains the variation in the observed efficiency of farmers. While the observed results confirm the hypothesis, they provide empirical evidence of how participatory irrigation management affects farmers' productivity and efficiency in rice farming. Also, it shows how irrigation infrastructure could support the country's agricultural sector by securing water supply and improving farmers' productivity.

In the last part of the dissertation, we further test the link between social capital, collective action in participatory irrigation management, and farmers' efficiency altogether. We emphasized the importance of social capital in production as an input. While existing studies on rice productivity and efficiency mainly evaluated the factors related to sociodemographics, financial resources, human capital, physical capital, and natural capital. We used the partial-least square structural equation modeling to estimate the indirect effect of social capital on farmers' efficiency levels. The consistency of the social capital in its direct and indirect effects implies its importance in the successful implementation of participatory irrigation management. As surface irrigation is prone to deflection, developing the water users' trust, reciprocity, and overall relations to its community and network will be a critical driver for successfully implementing participatory irrigation management in the Mae Lao irrigation project.

6.2. Implications and recommendations

6.2.1. Irrigation department and PIM implementation

a) Character development and capacity building

During the start of the nationwide construction of the irrigation infrastructures, the immediate needs are planning and engineering personnel. However, in later years, the irrigation infrastructure's operation and maintenance became the irrigation department's focus. Moreover, the adoption of participatory irrigation management in 2004 for joint irrigation management between the irrigation department and farmers gave rise to the need for different specializations in dealing with and facilitating public participation.

The delivery of irrigation services to the public requires dealing with different behaviors. Thus training to capacitate irrigation officers in the following aspects will be an asset for a successful PIM implementation. The first is to develop effective communication with farmers. Effective communication with farmers involves an irrigation department being empathetic and compassionate. In the current practices, during general meetings irrigation department mainly delivers and informs future irrigation activities to farmers while farmers have little input. Therefore, the future meeting should aim at listening to farmers rather than merely presenting the RIO plans. Although this approach could be time-consuming, in the long run, this will build trust and develop the current poor relationship between irrigation officers and water users (i.e., farmers). Furthermore, given that the operation and management of irrigation projects follow the PIM principles, developing compassionate and empathetic communication among officers will be a stepping stone toward a compelling exploration of local problems and a better understanding of the farming community’s situation.

For a start, the RID or, ideally, a third party may conduct a workshop on leveling expectations for stakeholders involved in participatory irrigation management. Under leveling of expectations, each stakeholder (e.g., RID, irrigation officers, water users) will provide their expectations from each group. Listing expectations can be used as a starting point for policy reform, management strategies, and future actions directed to the stakeholders' expected outcomes in implementing successful participatory irrigation management.

b) PIM evaluation system reform

For years, the success of PIM implementation was represented by the number of water user groups organized in an irrigation area. However, the number of organized groups is a misleading indicator for successful participatory irrigation management; even some groups exist only on paper.

When the behavioral aspects of the target receiver of an intervention or policy reform are involved, a qualitative approach will provide more significant insights. The RID headquarters developed the current practices of gathering information that uses structured questioning. However, using structured interviews will be too formal when gathering information from farmers and could limit the opportunity for farmers to provide important information from their own perspectives. Open questions facilitate a deeper understanding of the topic and the issues. In addition, it allows the RID to understand the reasons behind the opinions shared by farmers.

A SWOT or TOWS analysis can be a starting qualitative method to supplement the close-ended questions practiced by the RID. For example, assessing the internal strengths and weaknesses of the current operation and management of the PIM will be a great starting point to start a discussion in finding solutions and facilitating collective or mutual learning among stakeholders involved in the PIM implementations.

6.2.2. Water users and the participatory irrigation management

Farmers' perceived sense of ownership can be initiated by increasing their engagement in the planning process. The ability of farmers to share ideas in the planning process helps instill a sense of control and ownership. However, in the current situation, farmers lack confidence and hesitate to express their opinions. Hence, building farmers' confidence and capacity to communicate what they intend to convey to the irrigation department must be developed. Developing farmers' communication skills that will lead to better negotiation skills is one of the skills that are undervalued and undertrained by most farm interventions.

Building trust among involved stakeholders in the PIM implementation creates a friendly environment for sharing. Regarding the previous recommendation, increasing group discussions would be a good start to create a comfortable environment for sharing opinions and ideas.

Moreover, in a successful PIM implementation, the shared management of the irrigation between the irrigation management and the water users (i.e., farmers) requires the latter to build a sense of ownership. Building a perceived sense of ownership among farmers increases their participation in maintenance work and collective irrigation activities.

6.2.3. Future studies

The current study focuses on the interrelationship of developing social capital and its role in higher intention for collective maintenance activities among water user groups. However, less attention is covered to the formal and informal institutions shaping the interaction between the state actors and service recipients. This implies that the behavior to participate in collective irrigation management also depends on or is shaped by the policy framework and the bureaucratic rules governing how irrigation officials interact with farmers.

In the current condition, irrigation officials have no incentives to invest resources (i.e., time and effort) in a policy developing the participatory irrigation management vis-á-vis working closely with farmers. For instance, the remunerations of irrigation officials do not depend directly on working closely with farmers. Although the study finds that developing perceived trust between irrigation officers and farmers facilitates voluntary participation in collective maintenance, social capital requires ample time and constant interaction to be established.

In a group discussion, farmers always worry about when new irrigation officers will be assigned to the area. Farmers are hoping that the new irrigation officer assigned in the area to be supportive, pay attention to farmers, and be interested in participatory irrigation management. Therefore, there is a need for a study focusing on developing a legal framework for reforming the incentive structure of irrigation officials that encourages working closely with farmers to some degree. An incentive tied to working closely with farmers to some degree protects the current progress of PIM implementation in an irrigation project when changes of irrigation officials assigned happen. Complementing efforts of developing the social capital and overall relationship between farmers and irrigation officers with policy reform on incentivizing working closely with farmers provide better PIM implementation outcomes.

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APPENDICES

A. R codes in data analysis and visualization

The R codes used in the data analysis and visualization are available in the GitHub repository. The repository can be accessed using the permalink: https://github.com/chris-allones/data-analysis-shared-code/blob/2d324315da6af26e231df35355b4f593815c24f8/mlip-data-analysis-code/data-analysis-viz.R

B. Survey questionnaire

Part 1

ID: ______________________

Research title: "Collective action, efficiency in production, and identifying alternative strategies to operation and management of the Mae Lao Irrigation Project in Chiang Rai, Northern Thailand."

Greetings!

This study seeks to understand the formation of collective action, evaluate production efficiency, and explore alternative strategies for the Mae Lao Irrigation Project's operation and management. The information obtained from this survey will be kept confidential and will only be used for research purposes.

Part 1

Section 1: Socio-demographic profile of respondents.

Section 2: Production information and land profile.

Section 3: Cost and return of rice production.

Enumerator
Name.. Las name...
Date of interview:
....

Section 1: Socio-demographic profile of respondents

A. Respondent's profile

1. Full name ______________________________ Contact no: ______________

2. Sex ☐ male ☐ female

3. Age: ________

4. Marital status ☐ Single ☐ Married ☐ Widow/er ☐ Divorced

5. Household member (including you): _______

6. Educational level ☐ No formal education ☐ Primary education ☐ High school ☐ Junior high school ☐ Senior high school ☐ Diploma or equivalent ☐ College ☐ Post-graduate

7. Years in farming: _________years

8. Household income ☐ Farm (approx.) _______ baht/ production season (beginning month: _________ ending month: ___________) ☐ Off-farm _________ baht/ month ☐ Non-farm _______ baht/month

9. Membership in water user group ☐ Member ☐Director ☐ Chairman ☐Group leader ☐ other (specify): ___________________

10. Tenure in water user group: _______ years _______ months; Name of water user group: ______________________________

B. Geographical information

11. Farm location: ☐ Branch 1 ☐ Branch 2 ☐ Branch 3 ☐ Branch 4

12. Irrigation department: ______________ District: ______________

13. Irrigation canal of the farm: ______________________________

Section 2: Production information and land profile

C. Land profile

14. Land ownership for rice ☐ Owner ☐ Renting: ______ baht/rai ☐ Tenants ☐ Other (specify) __________

15. Topography ☐ Low ☐ Medium ☐ High

16. Soil type ☐ Sandy ☐ Clayey ☐ Loamy ☐ Silty ☐ Other (specify) __________

17. Perceived soil quality ☐ Low ☐ Medium ☐ High

18. Irrigation ☐ Irrigated ☐ Partially irrigated ☐ Rainfed

19. ปีที่ผ่านมา ท่านทำนาปรัง หรือไม่ ☐ ทำ ☐ ไม่ได้ทำ เพราะ:

____

D. Rice farming profile

	Dry season	Wet season
20. Farming area (rai)		
21. Seed variety: traditional, modern, hybrid		
22. Name of rice variety		
23. Source of rice seeds*		
24. Planting method (1=Na Yod, 2=Na Wan, 3=Na Dam)		
25. Production (tons)		
26. average yield (kilo per rai)		

Note: * 1 own harvest, two other farmers/farmer's group, 3 seed grower/ Agri-store 4 received from the government, 5 other (specify)

Section 3: Cost and return of rice production

E. Material and input costs

Material and inputs	Unit (e.g., kilo)	Dry season			Wet season		
		Quantity	Price/ unit	Total cost	Quantity	Price/ unit	Total cost
27. Seeds							
28. Fertilizer (N-P-K)							
chemical fertilizer formula: ____________							
chemical fertilizer formula: ____________							
organic fertilizer (Manure)							
29. Pesticides							
Specify: __________________________							
30. Herbicides							
Specify: __________________________							
31. Fuel cost							
32. Irrigation							
Water charges							
Water management fee/water user group							
33. Other expenses							
Land rental							
Land tax							

F. Labor utilization

Activities		Dry season						Wet season					
		Family labor			Hired Labor			Family labor			Hired Labor		
		No of person	No of days	Working hours/day	No of person	No of days	Daily wage	No of person	No of days	Working hours/day	No of person	No of days	Daily wage
34. Land Preparation	Seedbed preparation												
	Plowing												
	Harrowing												
35. Crop care & establishment	Sowing												
	Fertilizer application												
	Weeding												
	Pest and disease control												
36. Harvest and post-harvest	Harvesting												
	Threshing												
	Transportation												
	Drying												

G. Do you use the following equipment in your rice farming?

Equipment	If yes, place a checkmark (✓)	Cost (baht/season)	
		Dry season	Wet season
37. Tractor			
38. Tiller			

39. Harvester			
40. Pump			
41. Rice milling machine			
42. Drone			
43. Other (specify): ________________			

H. Do you own the following equipment or machine?

Items	Quantity	Acquisition cost (Baht)	Estimated life span (years)	Dry season		Wet season	
				No days of usage/season	(%) used in farming	No days of usage/season	(%) used in farming
44. Tractor							
45. Tiller							
46. Harvester							
47. water pump							
48. rice sowing machine							
49. sprayer							
50. other (specify)............................							

I. Marketing and other production-related information

51. Does a local government or any government agricultural technician visit your farm for the last 2 years? ☐ Yes ☐ No
52. What is your main source(s) of financing in your rice farming? ☐ Own ☐ Borrowed ☐ Both ☐ other (specify) ________________

    If borrowed, *amount borrowed* ____________baht; interest ....baht/ year; lender: ____________________
53. How stable is your source of income in supporting your needs?

☐very unstable ☐ unstable ☐ somewhat unstable ☐ neither ☐ somewhat stable ☐ stable ☐ very stable

54. What is the estimated average distance from the farm to the market where major farm inputs are sourced ___________km

55. What is the estimated average distance from the farm to the market where the product is sold ___________km

56. Utilization of harvests ☐ Consumption ....percentage (or tons/kilograms)

☐ Planting .... percentage (or tons/kilograms)

☐ Sale .... percentage (or tons/kilograms)

57. Where do you usually sell your rice produce? ☐ the company through a contract ☐ middlemen ☐ local market ☐ rice mill ☐ other (specify)

58. Average rice sold during dry season ....baht/kg; rainy season ....baht/kg

59. What was the lowest price received (baht/ kilo) dry season................................baht/ kg; rainy season................................baht/kilo

60. What was the highest price received (baht/ kilo) dry season................................baht/ kg; rainy season................................baht/kilo

ID: ____________________

Part 2

Research title: "Collective action, efficiency in production, and identifying alternative strategies to operation and management of the Mae Lao Irrigation Project in Chiang Rai, Northern Thailand."

Greetings!

This study seeks to understand the formation of collective action, evaluate production efficiency, and explore alternative strategies for the Mae Lao Irrigation Project's operation and management. The information obtained from this survey will be kept confidential and will only be used for research purposes.

Part 2

Section 4: Risk assessment, confidence, and access to services related to rice farming.

Section 5: Social relations, roles, and the management and operation of the irrigation project.

Section 6: Other information on water usage, irrigation management, and operation.

Enumerator

Name.. Las

name..

Date of interview:

....

A. Farmer's information (required)

Full name: ______________________________ Contact no: ____________

Section 4: Risk assessment, confidence, and access to services related to rice farming

I. How would you assess the impact of the following risks in your farming activities? *1= no impact* → *7= with very great impact*

ความเสี่ยงด้าน	1	2	3	4	5	6	7
43. Drought	☐	☐	☐	☐	☐	☐	☐
44. Flooding	☐	☐	☐	☐	☐	☐	☐
45. Unpredictable/ changing weather	☐	☐	☐	☐	☐	☐	☐
46. Insect and pest infestation	☐	☐	☐	☐	☐	☐	☐
47. Rising temperature	☐	☐	☐	☐	☐	☐	☐
48. Erratic rainfall pattern	☐	☐	☐	☐	☐	☐	☐
49. Lack of market access	☐	☐	☐	☐	☐	☐	☐
50. Lack of financial access	☐	☐	☐	☐	☐	☐	☐
51. Uncertain price of rice	☐	☐	☐	☐	☐	☐	☐
52. Uncertain price of inputs (e.g., fertilizer, seeds, and other)	☐	☐	☐	☐	☐	☐	☐
53. Uncertain demand	☐	☐	☐	☐	☐	☐	☐
54. Influence of middlemen	☐	☐	☐	☐	☐	☐	☐

J. Please rate how confident you are in performing the following activities. *1= not confident* → *7= very confident*

หัวข้อ	1	2	3	4	5	6	7
55. Managing finances in the farm operation.	☐	☐	☐	☐	☐	☐	☐
56. Handling of risks in production such as drought, typhoon, pest and disease infestation, and others.	☐	☐	☐	☐	☐	☐	☐
57. Can identify the pest and disease in rice and the appropriate control or solution.	☐	☐	☐	☐	☐	☐	☐

J. Please rate how confident you are in performing the following activities. *1= not confident → 7= very confident*

หัวข้อ	1	2	3	4	5	6	7
58. Know how to control or use the right chemical application to address pest and diseases.	☐	☐	☐	☐	☐	☐	☐
59. Can take a leadership role in the water user group.	☐	☐	☐	☐	☐	☐	☐
60. Knows the policy and operation of the irrigation project.	☐	☐	☐	☐	☐	☐	☐
61. Can be able to work with the other farmers/people.	☐	☐	☐	☐	☐	☐	☐
62. Can perform record keeping (e.g., recording of expenses, sales and farm transaction)	☐	☐	☐	☐	☐	☐	☐
63. Can perform necessary farm finance (e.g., computation of farm profit or losses)	☐	☐	☐	☐	☐	☐	☐

K. Please rate your level of access to the following services. *1= no access → 7= with very high access*

บริการ	1	2	3	4	5	6	7
64. Credit/ loan	☐	☐	☐	☐	☐	☐	☐
65. Savings	☐	☐	☐	☐	☐	☐	☐
66. Farm input assistance	☐	☐	☐	☐	☐	☐	☐
67. Basic health services	☐	☐	☐	☐	☐	☐	☐
68. Training related to irrigation (e.g., water use, management services)	☐	☐	☐	☐	☐	☐	☐
69. Training related to production (e.g., GAP certification)	☐	☐	☐	☐	☐	☐	☐
70. Training related to marketing	☐	☐	☐	☐	☐	☐	☐
71. Training related to farm finance	☐	☐	☐	☐	☐	☐	☐

Section 5: Social relations, roles and the management and operation of the irrigation project

L. Please rate how much you agree with the following statements. *1= strongly disagree ⟶ 7= strongly agree*

ประเด็น		1	2	3	4	5	6	7
72.	In the village, people generally trust each other.	☐	☐	☐	☐	☐	☐	☐
73.	The relationship among people in this village/ neighborhood is generally harmonious.	☐	☐	☐	☐	☐	☐	☐
74.	The people in this village/ neighborhood are helping each other.	☐	☐	☐	☐	☐	☐	☐
75.	Everyone in the community has equal access to the irrigation system.	☐	☐	☐	☐	☐	☐	☐
76.	Members of the water user group go along with each other.	☐	☐	☐	☐	☐	☐	☐
77.	Members of the water user group trust each other.	☐	☐	☐	☐	☐	☐	☐
78.	Members of the water user group are willing to offer help with each other.	☐	☐	☐	☐	☐	☐	☐
79.	Members are sharing and exchanging ideas to improve farming skills.	☐	☐	☐	☐	☐	☐	☐
80.	Members are encouraged to share and learn from each other's experiences.	☐	☐	☐	☐	☐	☐	☐
81.	Members often exchange and combine ideas to find solutions to problems.	☐	☐	☐	☐	☐	☐	☐
82.	Members are aware of the policies and activities of the group.	☐	☐	☐	☐	☐	☐	☐
83.	Members and not only the officers have the opportunity to participate in decision-making.	☐	☐	☐	☐	☐	☐	☐
84.	In the operation of the irrigation system, water is delivered on-time as scheduled.	☐	☐	☐	☐	☐	☐	☐
85.	There is enough water for irrigation during the wet season.	☐	☐	☐	☐	☐	☐	☐
86.	There is enough water for irrigation during the dry season.	☐	☐	☐	☐	☐	☐	☐
87.	If irrigation payments are made, it will ensure that the water is delivered on-time.	☐	☐	☐	☐	☐	☐	☐

L. Please rate how much you agree with the following statements. *1= strongly disagree ⟶ 7= strongly agree*

ประเด็น		1	2	3	4	5	6	7
88.	Farmers will not receive irrigation water if they do not pay the irrigation charges.	☐	☐	☐	☐	☐	☐	☐
89.	There are cases of bribery to get the water first.	☐	☐	☐	☐	☐	☐	☐
90.	There is a mechanism in place to punish the rule breaker.	☐	☐	☐	☐	☐	☐	☐
91.	There is a mechanism in place to monitor irrigation use and compliance.	☐	☐	☐	☐	☐	☐	☐

M. Please rate the frequency of occurrence on the following event. *1= never happened ⟶ 7= always*

ประเด็น		1	2	3	4	5	6	7
92.	Members communicate or interact with each other.	☐	☐	☐	☐	☐	☐	☐
93.	Members communicate or interact with the WUG officer.	☐	☐	☐	☐	☐	☐	☐
94.	Members communicate or interact with the irrigation officer/ staff.	☐	☐	☐	☐	☐	☐	☐
95.	WUG communicated or interact with local government officials.	☐	☐	☐	☐	☐	☐	☐
96.	Members agree and comply with the rules and regulations of WUG.	☐	☐	☐	☐	☐	☐	☐
97.	Members cooperate in maintaining the irrigation canal and infrastructure.	☐	☐	☐	☐	☐	☐	☐
98.	Members can provide production information to the irrigation officer before the next irrigation schedule.	☐	☐	☐	☐	☐	☐	☐
99.	Members can use the irrigation according to the scheduled cycle of irrigation.	☐	☐	☐	☐	☐	☐	☐
100.	Members take care of the irrigation infrastructure to avoid leakage and other damages.	☐	☐	☐	☐	☐	☐	☐
101.	Members strictly comply with the rules and regulations of the irrigation group.	☐	☐	☐	☐	☐	☐	☐
102.	Members received training about farm production.	☐	☐	☐	☐	☐	☐	☐

M. Please rate the frequency of occurrence on the following event. *1= never happened ⟶ 7= always*

ประเด็น	1	2	3	4	5	6	7
103. If there is a problem with irrigation, members will work together to find solutions.	☐	☐	☐	☐	☐	☐	☐
104. There are tensions in irrigation management.	☐	☐	☐	☐	☐	☐	☐
105. Some members violate the rules and regulations in the opening-closing of the irrigation gate.	☐	☐	☐	☐	☐	☐	☐

N. How much would you rate the irrigation project on the following activities? *1= very poor ⟶ 7= excellent*

ประเด็น	1	2	3	4	5	6	7
106. Clear scheduling of irrigation.	☐	☐	☐	☐	☐	☐	☐
107. Participation of farmers in water management and maintenance.	☐	☐	☐	☐	☐	☐	☐
108. Adequacy of water supply during the wet season.	☐	☐	☐	☐	☐	☐	☐
109. Adequacy of water supply during the dry season.	☐	☐	☐	☐	☐	☐	☐
110. On-time irrigation based on the scheduled irrigation.	☐	☐	☐	☐	☐	☐	☐
111. Collection of water charges.	☐	☐	☐	☐	☐	☐	☐
112. Perceived water quality provided by the irrigation.	☐	☐	☐	☐	☐	☐	☐
113. Condition of irrigation canal and ditches.	☐	☐	☐	☐	☐	☐	☐
114. Overall condition of the irrigation infrastructure	☐	☐	☐	☐	☐	☐	☐
115. Handling of rule-breaking activities such as illegal operation.	☐	☐	☐	☐	☐	☐	☐
116. Handling of complaints regarding irrigation problems.	☐	☐	☐	☐	☐	☐	☐
117. Managing disputes among members in the irrigation projects.	☐	☐	☐	☐	☐	☐	☐

N. How much would you rate the irrigation project on the following activities? *1= very poor ⟶ 7= excellent*

ประเด็น	1	2	3	4	5	6	7
118. Consistency in irrigation monitoring and control.	☐	☐	☐	☐	☐	☐	☐
119. Overall compliance with policy/ rules being implemented.	☐	☐	☐	☐	☐	☐	☐

Section 6: Other information on water usage, irrigation management, and operation

120. What is your perception of water availability in your rice farming?

- Dry season ☐ Insufficient ☐ Sufficient ☐ Excessive
- Wet season ☐ Insufficient ☐ Sufficient ☐ Excessive

121. How many times do you receive irrigation (number of turnouts of the irrigation gate)? ____________________

122. How much is the irrigation fee do you usually pay? __________________ baht/ season

123. How is the amount of the irrigation fee determined?

☐ volume of water received ☐ based on crops ☐ farm size irrigated ☐ Do not know ☐ Other (specify) __________________

124. Would you consider the current irrigation fee is enough for the operation and maintenance? ☐ Yes ☐ No

125. Would you support an increase in the irrigation fee? ☐ Yes ☐ No

126. Do you practice any water-conservation/ water-saving management (e.g., drought-tolerant variety, wetting, and drying) in your rice field? ☐ Yes

☐ No

- If yes, what are those water-conservation/ practices you are adopting?

....

....

127. Important issues you encounter or any suggestions related to irrigation:

ก. Irrigation system

....

ข. Water distribution

....

ค. Performance of the irrigation officers

....

ง. Farmer side

....

Thank you for your cooperation and participation!

C. **IOC evaluation of the survey questionnaire**

No.	ITEMS	Objective 1			Objective 2			Objective 3			OIC	Remark
		E1	E2	E3	E1	E2	E3	E1	E2	E3		
1	Years in farming	1	1	1	1	1	1	1	1	1	1.00	Acceptable
2	Sources of income	1	0	-1	1	1	1	1	1	1	0.67	Acceptable
3	Land ownership	1	1	1	1	1	1	0	1	1	0.89	Acceptable
4	Land topography	1	1	1	1	1	1	0	1	1	0.89	Acceptable
5	Soil type and quality	0	0	0	1	1	1	1	1	1	0.67	Acceptable
6	Distance of farm to irrigation	1	1	1	1	1	1	1	1	1	1.00	Acceptable
7	Production area	1	1	1	1	1	1	1	1	1	1.00	Acceptable
8	Source of seeds	0	0	0	1	1	1	1	1	1	0.67	Acceptable
9	Variety of seeds	0	0	0	1	1	1	1	1	1	0.67	Acceptable
10	Volume of production	0	0	0	1	1	1	1	1	1	0.67	Acceptable
11	Quantity and cost of fertilizer	0	0	0	1	1	1	1	1	1	0.67	Acceptable
12	Quantity and cost of insecticide	0	0	0	1	1	1	1	1	1	0.67	Acceptable
13	Quantity and cost of herbicide	0	0	0	1	1	1	1	1	1	0.67	Acceptable
14	Irrigation charges	1	1	1	1	1	1	1	1	1	1.00	Acceptable
15	Transportation cost	1	0	1	1	1	1	1	1	1	0.89	Acceptable
16	Administrative cost	1	1	1	1	1	1	1	1	1	1.00	Acceptable
17	Labor costs	1	1	0	1	1	1	1	1	1	0.89	Acceptable
18	Materials and equipment costs	1	1	1	1	1	1	1	1	1	1.00	Acceptable
19	Does a local government or any agricultural technician visit your farm?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
20	What are your main sources of financing in rice farming?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
21	Have you recently availed of a loan?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
22	What is the amount of the loan?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
23	What are the main sources of your	1	1	1	1	1	1	1	1	1	1.00	Acceptable

	loan?											
24	What is the estimated distance from the farm to the market where major inputs are sourced?	0	0	1	1	1	1	1	1	1	0.78	Acceptable
25	What is the estimated distance from the farm to the market where the product is sold?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
26	Where do you usually sell your harvested rice?	0	1	1	1	1	1	1	1	1	0.89	Acceptable
27	What was the lowest price received?	1	0	1	1	1	1	1	1	1	0.89	Acceptable
28	What was the highest price received?	1	0	1	1	1	1	1	1	1	0.89	Acceptable
How would you assess the impact of the following risks in your rice farming?												
29	Drought	1	1	1	1	1	1	1	1	1	1.00	Acceptable
30	Flood	1	1	1	1	1	1	1	1	1	1.00	Acceptable
31	Changing or unpredictable weather	1	1	1	1	1	1	1	1	1	1.00	Acceptable
32	Insect and pest infestation	1	1	1	1	1	1	1	1	1	1.00	Acceptable
33	Rising temperature	1	1	1	1	1	1	1	1	1	1.00	Acceptable
34	Erratic rainfall pattern	1	1	1	1	1	1	1	1	1	1.00	Acceptable
35	Lack of access to market	1	1	1	1	1	1	1	1	1	1.00	Acceptable
36	Lack of access to finance	1	1	1	1	1	1	1	1	1	1.00	Acceptable
37	Uncertain price for rice	1	1	1	1	1	1	1	1	1	1.00	Acceptable
38	Uncertain price for inputs	1	1	1	1	1	1	1	1	1	1.00	Acceptable
39	Uncertain demand	1	1	1	1	1	1	1	1	1	1.00	Acceptable
40	Influence of middleman	1	1	1	1	1	1	1	1	1	1.00	Acceptable
Please rate how confident are you in performing the following items.												
41	Managing finances in the farm operation.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
42	Handling of risks in production such as drought, typhoon, pest and disease infestation, and others.	1	1	1	1	1	1	1	1	1	1.00	Acceptable

43	Can identify the pest and disease in rice and the appropriate control or solution.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
44	Know how to control or the right chemical application to pest and disease.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
45	I can take a leadership role in the water user group.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
46	Familiar with the policy and operation of the irrigation project.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
47	Can be able to work with other people.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
48	Can perform record keeping (e.g. Recording of expenses, sales, and farm transactions)	1	1	1	1	1	1	1	1	1	1.00	Acceptable
49	Can perform basic farm finance (e.g., computation farm profits or losses)	1	1	1	1	1	1	1	1	1	1.00	Acceptable
50	Please rate how much is your level of access to the following services	1	1	1	1	1	1	1	1	1	1.00	Acceptable
51	Credit/ loans	1	1	1	1	1	1	1	1	1	1.00	Acceptable
52	Savings	1	1	1	1	1	1	1	1	1	1.00	Acceptable
53	Farm input assistance	1	1	1	1	1	1	1	1	1	1.00	Acceptable
54	Health services	1	1	1	1	1	1	1	1	1	1.00	Acceptable
55	Training related to irrigation	1	1	1	1	1	1	1	1	1	1.00	Acceptable
56	Training related to production	1	1	1	1	1	1	1	1	1	1.00	Acceptable
57	Training related to farm finance	1	1	1	1	1	1	1	1	1	1.00	Acceptable
Please rate how much you agree on the following statements.												
58	In this village, people generally trust each other.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
59	The relationship among people in this village/ neighborhood is generally harmonious.	1	1	1	1	1	1	1	1	1	1.00	Acceptable

60	The people in this village/ neighborhood are helping each other.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
61	Everyone in the community has equal access to the irrigation system.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
62	For the water user group, members go along with each other.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
63	Water user group members generally trust each other.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
64	Water user group members are willing to offer help with each other.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
65	The members are aware of the policies and activities of the group.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
66	The embers and not only officers have the opportunity to participate in decision-making.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
67	In the operation of the irrigation system, water is delivered on-time as scheduled.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
68	There is enough water for irrigation during the wet season.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
69	There is enough water for irrigation during the dry season.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
70	My payment for irrigation ensures I received on-time water delivery.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
71	Farmers will not receive irrigation water if they do not pay the irrigation charges.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
72	There are cases of bribery to get the water first.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
73	There is a mechanism in place to punish the rule breaker.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
74	There is a mechanism in place to monitor irrigation use and compliance.	1	1	1	1	1	1	1	1	1	1.00	Acceptable

Please rate the frequency of occurrence on the following items.												
76	Members communicate or interact with each other.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
77	Members communicate or interact with water user group officers?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
78	Members communicate or interact with irrigation officers?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
79	The water user group communicate or interact with local government officials?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
80	Attend the water user group's meeting?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
81	Have you participated in the voting or selection of officers?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
82	The members received training on-farm production?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
83	The members received training on irrigation related.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
84	If there was an irrigation problem, members will cooperate to try solving the problem?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
85	There are tensions over irrigation water.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
86	Some members violate the schedule by doing illegal operation of the irrigation gate.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
How much would you rate the irrigation project in the following areas?												
87	Scheduling of water irrigation.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
88	Collection of water charges.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
89	Perceived water quality provided by the irrigation	1	1	1	1	1	1	1	1	1	1.00	Acceptable
90	Perceived adequacy of water supply during the wet season.	1	1	1	1	1	1	1	1	1	1.00	Acceptable

91	Perceived adequacy of water supply during the dry season.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
92	Perceived condition of the irrigation canal	1	1	1	1	1	1	1	1	1	1.00	Acceptable
93	Perceived condition of the overall irrigation infrastructure.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
94	Handling of rule-breaking activities such as illegal operation.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
95	Handling of complaints regarding irrigation problems.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
96	Managing disputes among members in the irrigation project.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
97	Overall irrigation monitoring and control	1	1	1	1	1	1	1	1	1	1.00	Acceptable
98	Overall policy/ rules implementation.	1	1	1	1	1	1	1	1	1	1.00	Acceptable
99	How is the irrigation fee determined?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
100	How much is the irrigation fee for your rice farm?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
101	How many times do you receive irrigation (number of turn-out of the irrigation gate?)	1	1	1	1	1	1	1	1	1	1.00	Acceptable
102	Would you consider the current irrigation collection enough for the operation and maintenance?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
103	Would you support an increase in the irrigation fee?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
104	What is your perception of the water adequacy in your rice farm?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
105	Do you practice water conservation?	1	1	1	1	1	1	1	1	1	1.00	Acceptable
106	What water conservation practices are you adopting?	1	1	1	1	1	1	1	1	1	1.00	Acceptable

D. Journal and conference publications

Only the front page of the attached published articles is provided in this section due to copyrights from the journal publisher. However, a link to access the full article is provided.

D.1 Bonding and bridging social capital towards collective action in participatory irrigation management. Evidence in Chiang Rai Province, Northern Thailand.

Journal: International Journal of Social Economics

Quartile rank: Q2 SJR and Q2 Web of Science

D.2 Production efficiency and the role of collective actions among irrigated rice farms in Northern Thailand.

Journal: International Journal of Agricultural Sustainability

Quartile rank: Q1 SJR and Q1 Web of Science

D.3 Influence of perceived risks in farmer's decision towards sustainable farm practices. Evidence from Northern Thailand.

Journal: International Journal of Agricultural Technology

Quartile rank: Q4 SJR

D.4 Social capital and production risks: examining association using the case of irrigated rice farms in Northern Thailand.

Proceeding: Innovation for Resilient Agriculture

D.5 The role of engagement among farmers in developing farming knowledge: evidence from northern Thailand.

Proceeding: International conference on agriculture, natural resource, and rural development.

D.6 Production risk and efficiency: examining the influence of perceived environmental and market risks among rice farmers in Chiang Rai province, Northern Thailand.

Journal: International Journal of Agricultural Technology

Quartile rank: Q4 SJR

D.1. Bonding and bridging social capital towards collective action in participatory irrigation management. Evidence in Chiang Rai Province, Northern Thailand. Access link: https://doi.org/10.1108/IJSE-05-2021-0273

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Bonding and bridging social capital towards collective action in participatory irrigation management. Evidence in Chiang Rai Province, Northern Thailand

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Abstract

Purpose – The purpose of this paper is to examine the effect of social capital with bonding and bridging distinction in promoting higher participation in collective action in participatory irrigation management.

Design/methodology/approach – A sample of 304 farmers was surveyed using a structured questionnaire. A focus group discussion was also carried out with randomly selected water users, leaders and irrigation officers. A confirmatory factor analysis and structural equation modelling were used to test the hypothesised relationship of bonding and bridging social capital towards collective action.

Findings – The findings show that social capital has a significant direct effect on collective action and an indirect effect on joint irrigation management's perceived performance through collective action (mediator). It implies the need to complement the participatory irrigation management programme with an understanding of the social aspects for a higher farmer's participation over the shared resource.

Originality/value – The paper emphasises social capital's role in facilitating a real participatory engagement in shared resource management. Also, it is the first scholarly work linking social capital with bonding and bridging distinction towards collective action in a joint resource management context.

Keywords Social capital, Collective action, Irrigation management, PIM

Paper type Research paper

1. Introduction

Despite the efforts to achieve water sufficiency for food and global demand, an increasing number of regions will face water scarcity (FAO, 2017). Among sectors, agriculture relies heavily on water for production (Faysse *et al.*, 2020; Gödecke and Waibel, 2011). Most regions in Southeast Asia rely on agriculture for livelihood (Mutert and Fairhurst, 2002). Farms with better access to water and irrigation facilities play a significant role in supporting national food security (Cramb *et al.*, 2015). Although Thailand's long-term development targets are mapped in its 20-year (2017–2036) national strategic plan, a framework is being followed regulating development targets. The country's agricultural sector occupies a large share of its total output, wherein agricultural production is closely linked to its river and irrigation systems. Irrigation projects are under the Royal Irrigation Department (RID) and run in a top-

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D.2. Production efficiency and the role of collective actions among irrigated rice farms in Northern Thailand.

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Production efficiency and the role of collective actions among irrigated rice farms in Northern Thailand.

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ABSTRACT

The idea of shared irrigation management is expected to result in a better production outcome for farmers. However, there is little evidence of whether collective action participation leads to a higher level of production efficiency. Using cross-sectional survey data from irrigated rice farms in Northern Thailand, we found that a higher level of production efficiency is associated with higher participation in collective action. At the same time, engagement in collaborative works such as irrigation maintenance, group meetings, conflict resolution, and policy adherence has a marginal effect on farmers' efficiency. Our findings suggest that complementing existing efforts in addressing irrigation issues with efforts to mobilize collective actions among farmers leads to an improved on-farm outcome.

KEYWORDS
Efficiency; collective action; irrigation; rice farming

1. Introduction

Thailand's agricultural sector has been designated a priority in the country's 20-year (2017-2036) national strategic plan. The policy aims to maintain Thailand's status as one of the world's leading rice exporters. Studies on the country's rice production efficiency found that efficiency ranges from 63% to 80% (Chaovanapoonphol et al., 2009; Ebers et al., 2017; Rahman et al., 2009), this indicates a 20% to 40% potential development of rice production if inefficiencies are addressed. At the same time, the small-scale farmers are mostly the ones experiencing resource constraints and exhibit lower efficiency in production (Brown et al., 2018; Ebers et al., 2017).

The productivity in rice production has been linked to the development of irrigation systems in the country. Irrigation projects are under the Royal Irrigation Department (RID), and most are under participatory irrigation management (PIM), which is a scheme for shared irrigation management with farmers (Walker et al., 2015). The PIM is based on the principle of better irrigation management wherein farmers participate in decision-making and collective irrigation maintenance (Molle et al., 2002). Farmers are organised into water user groups (WUG) to manage local irrigation infrastructure, collect water charges, and coordinate collective works in the irrigation system.

Particularly in our study area in Northern Thailand, in a focus group discussion, farmers have associated on-farm performance with irrigation systems management and maintenance. Since rice production is heavily reliant on water, reliable irrigation plays a vital role in the overall on-farm performance of rice farmers. For example, Bandyopadhyay et al. (2010) found that higher farm productivity is associated with improved irrigation maintenance among farmers in the Philippines. At the same time, Totin et al. (2014) found that lower participation in irrigation maintenance affects rice production among rice farmers in Benin. In addition, field reports and published literature show that collective resource management has a significant impact on boosting the

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D.3. Influence of perceived risks in farmer's decision towards sustainable farm practices. Evidence from Northern Thailand.
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Influence of perceived risks in farmer's decision towards sustainable farm practices, Evidence from Northern Thailand

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Llones, C. and Suwanmaneepong, S. (2021). Influence of perceived risks in farmer's decision towards sustainable farm practices. International Journal of Agricultural Technology 17(6):2143-2154.

Abstract Under the sustainable development goals, nations worldwide are enjoined to take immediate action through sustainable adaptations to mitigate climate variability and change. At the same time, agriculture is both a victim and a contributor to climate change. The situation prompted Thailand's agriculture to explore sustainable practices for food security and deliver environmental services. Using a binary logit model, the potential effects of farmers' perceived risks on adopting sustainable farming practices were investigated. The study revealed that farmers are somewhat hesitant to radically shift from their usual practices due to associated costs and the perceived potential risks. In addition, the study found that factors affecting adoption were site-specific. Hence, government actions should be flexible and tailored to a local level while still aligning with the national policy goals. For this, inter-agency coordination at the local, provincial and central levels is needed for agricultural support and enable farmers to make necessary changes to successfully adapt to emerging risks.

Keywords: Risk, Sustainable farming, Adoption

Introduction

Southeast Asian member states have been considered vulnerable to climate variability and change (Amnuaylojaroen *et al*., 2021; Ramsden *et al*., 2017). While a substantial portion of the population of its member states, such as in the agricultural sector, is reliant on nature for livelihood (Lee, 2021). These countries are already fighting poverty, and climate change-related issues constitute an additional burden. The adverse consequences warranted a global action which is one of the priorities under the Sustainable Development Goals (SDG) (UNDP, 2016). The SDG 13 calls on countries to take immediate action to combat climate change through sustainable adaptation and mitigation plans (Appiah, 2019; UNDP, 2016).

Particularly in Thailand, the agricultural sector takes a vital role in the country's economic system. For instance, the sector provides livelihood to more than thirty percent of the country's workforce (Rayfuse and Weisfelt, 2012). On

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D.4. Social capital and production risks: examining association using the case of irrigated rice farms in Northern Thailand.

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Social capital and production risk: examining association using the case of irrigated rice farms in Northern Thailand.

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Llones, C., Suwanmaneepong, S. and Mankeb, P. (2022). Social capital and production risk: examining the association in the case of irrigated rice farmers in Northern Thailand. International Journal of Agricultural Technology

Abstract Although different forms of interventions such as economic incentives have been widely implemented to help farmers manage production risks. Farmers continually face high variability in production and declining productivity. While less attention is given to the social capital aspect related to production risk management, this study aims to contribute to the literature by examining the association of social capital with farmers' production risk. We estimate the output variability as an approximation of the farmer's production risk using a stochastic frontier production function with risk specification. Higher perceived interpersonal trust and network relationships among farmers are negatively associated with variability in production. The study provides evidence on the importance of developing and strengthening the social capital of farming communities in supporting farmers' risk management. Especially among farmers with less access to information, the farmer's network facilitates knowledge sharing on farming innovations and improved practices.

Keywords: stochastic frontier, social capital, risk, production, rice

Introduction

Thailand recognized the importance of agriculture in achieving several SDG goals (e.g., no poverty, zero hunger, economic growth, and responsible production). For Thailand, the Sufficiency Economy Philosophy (SEP) has been the primary framework in the country's policy formulation through the National Economic and Social Development Plan (NESDP), which also aligns with achieving the SDG goals. The SEP considers four major impacts of any policies and programs: material, cultural, environmental, and social (Jeenaboonrueang, 2019).

This study focuses on the social aspects using the social capital concept and its link to production risk. Following the study of Yang et al. (2020), we used the two subdimensions of social capital on the perceived interpersonal trust and network relationship. The network relationship refers to farmers' connected actors with whom they often interact in seeking information and

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D.5. The role of engagement among farmers in developing farming knowledge: evidence from northern Thailand.

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The role of engagement among farmers in developing farming knowledge: evidence from northern Thailand

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Abstract. Several studies found science-based knowledge has only able to reach a small fraction of their desired recipient. To compensate for the lack of formal sources, farmers often relied on informal sources of knowledge within their farming community. This study investigates the role of farmer's social engagement in developing farming knowledge and farmer's decision-making. A structural equation modelling was used to test the hypothesised moderating role of social engagement among farmers on the effects of service access, training, and knowledge-sharing on farming knowledge. The study used the case of rice farmers in Northern Thailand, wherein a focus group discussion and a series of survey interviews were conducted. Study results found that social interactions among farming communities significantly moderated the effects of training and knowledge-sharing. The findings support the critical role of social engagement among farmers in increasing information flow and experiential knowledge exchange in developing farming knowledge. Furthermore, social interactions promote farming innovation and management practices through advice-seeking with other farmers. Hence, in supporting farming sustainability, extension support should also focus on network building among actors within the farming community and understand how farmers exchange experiential knowledge to compensate for the lack of formal sources of knowledge.

1. Introduction

Innovation in agriculture is essential in driving Thailand towards a sufficiency economy. The philosophy under the sufficiency economy served as the central policy towards sustainable agricultural development of the country [1]. This drives the introduction of new farming technologies and improved practices such as precision farming, bio-pesticides, organic fertiliser, and crop diversification. Access to these innovations can equip farmers with the necessary knowledge and skills to attain the country's agricultural development goal. However, science-based information from research investment reached only a small fraction of their intended recipients and achieved less than the expected impact [2,3]. In addition, the adoption rate of farming technologies and improved farming practice is lower than the targeted threshold.

Nonetheless, several studies considered that farmer's social network holds an essential role in diffusing knowledge and boosting adoption rate of improved agricultural technology within farming communities [4,5]. The flow of information within and across farmer's social networks increases the potential adaptive capacity of farming communities [4,6]. For example, the study found that farmers exchange experiential knowledge among themselves during group meetings and assemblies to discuss farming-related issues. Furthermore, typical daily interaction and even friendly visits to each farm as a form of informal peer to peer advice facilitate information flows. In addition, Isaac et al. [3] found that

1

D.6. Production risk and efficiency: examining the influence of perceived environmental and market risks among rice farmers in Chiang Rai province, Northern Thailand.

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Production risk and efficiency: examining the influence of perceived environmental and market risks among rice farmers in Chiang Rai province, Northern Thailand.

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Abstract

Thailand continued to be a net rice exporter however, annual production is declining. Like in other countries, Thailand is vulnerable to climatic changes as well as environmental and market risks. Empirical research revealed that production risks and inefficiencies lead to variation in production. However, most studies focused on investigating either the risk or inefficiency in farming, while few studies consider both factors. Using the case of rice farmers in Chiang Rai province, Northern Thailand, this study employs a stochastic production frontier model with risks specification. The analysis investigates both the production risks and technical inefficiency to explain the total variability in production. Study results show the availability of family and hired labour are risk decreasing while inefficiencies in applying seeds and fertilizer may increase production variability. While farmers who avail credit face higher risk since credit amount is not intended solely for production purposes. As expected, farmers with higher perceived environmental and market risks show higher production risks. Diversifying sources of income would be advantageous in light of the global climate change experience and its effects on agricultural livelihood. Given that both agriculture and rising food production contribute to greenhouse gas emissions, a comprehensive strategy for reaching the sustainable development goals requires a thorough understanding of the environmental, social, and economic effects of policy interventions.

Keywords – rice, farming, production risk, efficiency, stochastic frontier

Introduction

Since the establishment of the sustainable development goals (SDG), Thailand has aligned its National Economic Development Plan (NEDP) through the principles of Sufficiency Economy Philosophy (SEP) to achieve the SDGs. The SEP aims to provide a holistic approach to developing the country's agricultural management system to promote food security and sustainability, aligning to SDG1 ending poverty and SDG2 zero hunger (Kuwornu, 2017). However, agriculture is one of the many sectors that is highly affected by climate change, and in response, the SDG13 focuses on "combating climate change and its impacts" (Bruce M et al., 2018). To add, the occurrence of the Covid-19 pandemic has disrupted the global trade and supply chains affecting the progress of the SDG 2030 agenda (UN, 2022). The current global state added challenges to farmers' long-existing constraints and the increasing variability in production. In a resource-constraint country like Thailand, the increasing occurrence of floods, drought, rising temperatures, and unpredictable weather conditions coupled with restrictions brought by the pandemic further increase output variation. For instance, in a meta-analysis summarizing agricultural-related studies, the analysis shows that 70 percent of the studies included projected a 10-50 percent decline in crop yield by 2030, partly due to climate change impacts (Challinor et al., 2014).

On the other hand, studies that show how technical efficiency influences input choices

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VITA

Christopher Almoroto Llones was born in the eastern Visayas, Philippines. He earned his bachelor's degree in economics from the Visayas State University in 2016. After finishing his bachelor's degree, he worked as a science research assistant in an international research project funded by the Australian Center for International Agricultural Research (ACIAR) for two years in collaboration with the University of Queensland, the University of The Philippines, and Land Care. After the end of the project, he was hired as a lecturer in the Department of Business and Management at the Visayas State University, teaching subjects in Managerial Economics, Microeconomics, Principles of Accounting, Econometrics, and Research Methodology. In 2019, he received a scholarship to pursue a doctoral degree in the School of Agricultural Technology at the King Mongkut's Institute of Technology Ladkrabang (KMITL). His current research is in agricultural economics and development. While taking his Ph.D. program, he was also invited as a resource person for the training workshop on structural equation modelling and data visualization using R programming. In addition, he is also actively involved in data analysis consultancy for master's and doctoral students in the Philippines. In 2022, he was invited to be one of the pools of experts for the Visayas Scio-Economic Research and Data Analytics Center (ViSERDAC) based in Eastern Visayas, Philippines.