博士論文

論文題目　　Irrigation, Community, and Poverty

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Acknowledgements

First and foremost, I would like to express my deepest gratitude to my main advisor, Yasuyuki Sawada, for his invaluable academic guidance. I began studying development economics in his undergraduate seminar, and he has supported me ever since. I have learned a great many things from him, especially through taking part in joint research projects. Without his kindness, guidance, and support, I could not have completed this Ph.D. program.

I am also very grateful to the members of my dissertation committee, Professors Hidehiko Ichimura, Hitoshi Matsushima, Alistair Munro, and Yasuyuki Todo. I would like to thank Professors Hidehiko Ichimura and Hitoshi Matsushima for their many valuable suggestions and comments, which strengthened both my doctoral dissertation and Master's thesis. I am also grateful to Professors Alistair Munro and Yasuyuki Todo for agreeing to be external members of my dissertation committee and giving me many constructive suggestions and comments.

My sincere thanks go to Sonali Senaratna Sellamuttu, Ryuji Kasahara, and Deeptha Wijerathna, who were my research collaborators on Chapter 3 of the dissertation. Thanks to their collaborative efforts, our paper was published in the *Journal of Development Studies*. I appreciate their willingness to allow it to be a part of my dissertation.

Each chapter of this dissertation is based on a research project conducted at the JICA Research Institute. I am very grateful to everyone at the Institute for their understanding and administrative support. I would also like to acknowledge the support I received through the Grant-in-Aid for JSPS Fellows (12J10183).

Last but not least, I would like to express my deepest appreciation to my family for their understanding and support during my studies.

Chapter 1:

Introduction

It is estimated that the world population will reach 9.1 billion by 2050. In contrast to this rapid population growth, agricultural land has been expanding at a much slower rate, which can result in serious food shortages. However, the Malthusian trap has been avoided because of agricultural productivity growth. In this productivity growth, irrigation has played an important role because improving irrigation access not only enhances land productivity directly, but also is a necessary condition for the Green Revolution (e.g., Hayami and Godo 2005).

Effective irrigation management has been a traditional issue in economics. In the lead article of the first volume of the *American Economic Review*, Coman (1911) points out the difficulty of irrigation management as an "unsettled problem." This problem results from common property natures of irrigation: non-renewability and open access. After 100 years, Ostrom (2011) and Stavins (2011) revisited this issue and argued that the problem is becoming more and more important today. Frequent droughts due to climate change have resulted in water scarcity whereas demand for water in both the agricultural and non-agricultural sectors is rising (World Bank 2007). Recently, both academic and practical fields have reached the consensus that community-based irrigation management, rather than state governance systems, leads to better performance (e.g., Ostrom 1990; Aoki and Hayami 2001). However, the effectiveness of community-based irrigation management is unclear when there is heterogeneity among resource users.

Enhancing agricultural productivity is also important for poverty alleviation. Since agriculture is the primary sector in most developing countries and most of the poor depend on agriculture for their livelihood, agricultural growth is key to alleviating poverty (World Bank 2007). Further, it is also desirable in terms of food security for small-scale farmers (Mukherji et al. 2009). For these reasons, investment in irrigation is still necessary.

In contrast to this growing demand, rigorous quantitative evaluation of irrigation projects is very limited.

An obstacle to evaluating the impact of infrastructure on poverty alleviation is the endogeneity of their placement. Randomized control trial (RCT) brought a "revolution" in the evaluation of development projects and succeeded in linking the academic and practical field of international development. RCT is indeed a powerful tool to evaluate development projects especially for micro-level interventions such as microcredit and conditional cash transfer programs (e.g., Banerjee and Duflo 2011; Karlan and Appel 2011). However, certain projects are not suitable for RCT because randomly assigning treatment and control groups is technically difficult. In spite of this difficulty, evaluating these projects is necessary in terms of assessing aid efficiency.

Even though irrigation access enhances the farmers' income and reduces chronic poverty, it is still important for them to cope with idiosyncratic risks. Risks such as weather, crop disease, and price fluctuation, are inevitable in agriculture. Since formal institutions that relieve the poor from these shocks are weak in developing countries, informal consumption smoothing within a community is an important issue to mitigate transient poverty (e.g., Townsend 1994; Morduch 1995; World Bank 2013). Since the poor are more vulnerable to risks, how to relieve these people is an important policy issue. Thus, investigating the structure of risk sharing networks is important not only for academic purposes but also for designing an effective policy intervention.

This dissertation investigates the nexus among irrigation, community, and poverty by employing modern methods in economics. Each chapter of this dissertation uses the data on an irrigation project in southern Sri Lanka, which was collected as a research project of the Japan International Cooperation Agency (JICA)[1]. The study site is located in a semi-arid area where slash and burn farming had been a dominant form of agriculture. The

[1] See JBIC Institute (2007) for detail.

government started irrigation construction in 1995 using Japanese ODA loans, which has enabled farmers to cultivate more lucrative crops such as paddy, sugarcane, and banana. In order to assess the impact of this project, JICA conducted 8 household surveys as well as an economic experimental session. Since the irrigation canal was constructed from the upstream and gradually extended to the downstream, there are time lags in irrigation access among each area. Combined with a unique feature of the study site wherein they employed a lottery to allocate irrigated plots, this situation provided us exogenous variations to assess the impact of this ODA project.

Chapter 2 analyzes the water allocation problem between the farmers of upstream and downstream in irrigation canals, which has traditionally been an important issue in agricultural and environmental economics. Though it is known that community-based management leads to better performance in irrigation management, its effectiveness is not clear among heterogeneous players in terms of access to resources. By combining an artefactual field experiment and an actual water allocation problem, this chapter finds that the social capital between upstream and downstream farmers prevents over-extraction of irrigation water, especially for upstream farmers.

Although social capital has been considered as a key instrument for common pool resource management, few studies focus on its effect directly because of the difficulty in measuring social capital. However, recent developments in experimental methods have enabled us to quantify the degree of social capital (Camerer and Fehr, 2004; Levitt and List 2007; Cardenas and Carpenter, 2008). Since the incentive structure of irrigation water allocation for upstream farmers closely resembles that of the dictator and trust games, which are standard experiments to measure social capital, the findings of this chapter also support the validity of experimentally measured social capital.

Chapter 3 analyzes the impact of irrigation access on poverty alleviation[2]. Using

[2] This chapter is based on a joint research with Sonali Senaratna Sellamuttu, Ryuji Kasahara, Yasuyuki Sawada, and Deeptha Wijerathna.

the natural experimental situation in the study site, this chapter overcomes the difficulty of evaluating infrastructure development and clearly identifies the impact of irrigation on poverty alleviation. By combining the livelihood approach in sociology with a micro-econometric approach, this chapter analyzes the impact of irrigation access on income through the changes in livelihood choice.

Livelihood approach considers that people's livelihood strategies are determined by a combination of different types of capital (assets): human, physical, natural, social, and economic (Ellis 2000). However, how to combine these capital types is greatly influenced by institutions and cultures. Chapter 3 focuses on how improved irrigation access affects livelihood strategies and consequently leads to income growth. By employing the livelihood approach, this chapter shows the mechanism of how irrigation affects poverty reduction, which has been treated as a "black box" in previous studies.

Chapter 4 analyzes risk sharing among households, which is one of the most important issues to mitigate transitory poverty through informal insurance mechanisms. The existing studies focus on either spatial or social networks as a cluster of risk sharing, and few studies compare the effects of these networks. Using a spatial econometric approach, this study quantifies the diffusion of income shocks in spatial and social networks and compares the effectiveness of each network. The results show that the shocks are diffused better in spatial networks than social networks especially for smoothing food consumption.

Spatial econometrics focuses on spatial effects resulting from spatial dependence and spatial heterogeneity (e.g., Anselin 1988; LeSage and Pace 2009). Recently, researches have been shifting to panel data analysis, and estimation methods have also been developed (e.g., Elhorst 2003, 2010; Kapoor et al. 2007; Anselin et al. 2008). By employing these models, Chapter 4 analyzes spatial and social network effects in risk-sharing arrangements.

Though the topic of each chapter is rather traditional, this dissertation aims to shed new light on these classical themes by employing modern experimental and econometric approaches.

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Chapter 2:

Social Capital as an Instrument for Common Pool Resource Management: A Case Study of Irrigation Management in Sri Lanka[†]

ABSTRACT. This paper investigates the effect of social capital between irrigation canal upstream and downstream farmers on their water allocation problem. The water allocation problem between upstream and downstream is a serious problem in irrigation management. Using a combination of unique natural and artefactual field experiment data and general household survey data, this study finds that farmers with higher social capital, especially trust toward their downstream farmers, optimize their water demand, showing consideration for their downstream farmers. Since the incentive structure of irrigation water allocation for upstream farmers closely resembles that of the dictator and trust games, this finding also supports the validity of experimentally measured social capital. Additionally, this study deals with the simultaneity bias between satisfaction level and experimentally measured social capital and finds that the OLS estimators are downward biased, which is consistent with the hypothesis that scarcity of resources enhances social capital.

Keywords: Social capital; irrigation; artefactual field experiment; upstream and downstream; external validity

[†]This research was conducted as part of the research project "Impact Assessment of Infrastructure Projects on Poverty Reduction" at JICA Research Institute (JICA-RI). I am especially grateful to Yasuyuki Sawada, Hidehiko Ichimura, and Hitoshi Matsushima for their valuable suggestions on a draft of this paper. I also wish to thank two anonymous reviewers of JICA-RI and Keitaro Aoyagi, Jun Goto, Kei Kajisa, Yoko Kijima, Nobuyoshi Kikuchi, Ilan Noy, Masaki Nakabayashi, Petr Matous, Alistair Munro, Keijiro Otsuka , Tatsuyoshi Saijo, Yasuyuki Todo, Junichi Yamasaki, and participants at the 2011 JEA Spring Meeting, the IEA 16th World Congress, the 7th ASAE International Conference, the 6th Annual Meeting of ABEF, the 2013 Asia-Pacific Meeting of the ESA, TEA 2013, and seminars at the University of Tokyo and Osaka University, for their constructive comments. The usual disclaimers apply.

1. Introduction

Common pool resources (CPRs) are characterized by non-excludability and rivalness of consumption. These characteristics lead rational players to use these resources beyond the socially optimal level, and ultimately, they will be exhausted. This is the well-known story of the "tragedy of the commons" (Hardin, 1968). However, many empirical studies have shown that this tragedy does not occur even in developing countries where formal institutions are weak (e.g., Ostrom, 1990; Aoki and Hayami, 2001). The key instrument for the success of CPR management is social capital (Bowles and Gintis, 2002; Hayami, 2009). In the theoretical background, cooperation in CPR management is often explained using simple repeated game where social capital is not included explicitly (e.g., Baland and Platteau, 2000). One interesting exception is Aoki (2001), who shows that players will cooperate in irrigation management even in situations where they can shirk this responsibility, for fear of being excluded from social exchange, i.e., losing social capital.

However, Bardhan and Dayton–Johnson (2002) survey various empirical studies and conclude that irrigation management is difficult when there is heterogeneity among players in terms of income or wealth, exit options, and ethnic or social characteristics and importantly, when asymmetry between head-enders and tail-enders (or, upstream and downstream farmers) exists. Among these, the last point presents a specific problem in irrigation management. Head-enders and tail-enders differ in terms of their access to irrigation water: if head-enders use too much water, tail-enders are deprived of their share. This type of heterogeneity can violate both equity and efficiency and leads to irrigation management failure (e.g., Chakravorty and Roumasset, 1991; Ferguson, 1992; Ray and Williams, 2002).

Many empirical studies have focused on this theme, but the results are ambiguous. Based on observational data, several studies find that the difference in water availability between upstream and downstream farmers leads to irrigation management failure (Wade, 1988; Tang, 1992; Fujiie *et al*., 2005). Ostrom and Gardner (1993) show that cooperation in irrigation maintenance between head-enders and tail-enders can be achieved, although they also mention that modern irrigation systems may impede this cooperation. Meinzen–Dick *et al*. (2002) find that while the head or tail location of minor canals does not affect the formation of organizations or canal maintenance, it does affect collective lobbying for additional water demands. Recently, Nakano and Otsuka (2011) find that the distance from the main channel has an inverted U-shaped relationship with the contribution to channel cleaning. However, these survey-based analyses have not been able to directly identify the effect(s) of social capital due to the inherent difficulties in measuring social capital. In addition, most of these studies do not focus directly on the water allocation problem; rather, they address irrigation maintenance.

In addition to these analyses, there is a growing literature on CPR experiments (Ostrom, 2006; Cardenas, 2011), and several studies have focused on the water allocation problem between upstream and downstream farmers. Among these, one of the most relevant experiments for this study is the irrigation game introduced by Cardenas *et al*. (2013), which combines the voluntary cooperation game with resource extraction in a unidirectional order. Without any treatment, upstream players extract significantly more water than downstream players in this game (Cardenas *et al.*, 2013; Janssen *et al.*, 2011). However, they also find that this unfair allocation diminishes after an extraction rule is enforced. On the other hand, Cardenas *et al*. (2010) and Holt *et al*. (2012) show that communication among players leads to better cooperation and more efficient water allocation. In addition, several studies analyze this problem using standard economic experiments. Jack (2009) analyzes the effect of enforcement treatment, by using the trust game to analyze transactions in watershed management. Using the ultimatum game, D'Exelle *et al*. (2012) find a strong preference for equal resource allocation between upstream and downstream users, especially when the resource is abundant. However, these studies analyze the said behavior in experimental (field) laboratories, and comparison with actual CPR management remains an important issue to be addressed.

This study aims to overcome the limitations in survey-based and experimental analyses by showing the link between actual irrigation water allocation and experimentally measured social capital. There are various definitions of social capital (e.g., Durlauf and Fafchamps, 2005). Based on Hayami (2009), this paper defines social capital as informal social relationships, based on norms and trust, which induce cooperation among members. This study focuses especially on altruism and trust within the CPR user group. Recent developments in experimental methods have enabled us to measure social capital quantitatively (Camerer and Fehr, 2004; Levitt and List 2007; Cardenas and Carpenter, 2008). Furthermore, social capital measured by these experimental methods can predict actual economic outcomes (e.g., Karlan, 2005; Barr and Serneels, 2008; Carter and Castillo, 2011 Carpenter and Seki, 2011). Among these, several studies find a positive correlation between experimentally measured social capital and cooperation in CPR management (Bouma *et al*., 2008; Fehr and Leibbrandt, 2011). However, these studies do not address the heterogeneity in accessibility to resources.

The main contribution of this paper is to estimate the effect of social capital between upstream and downstream farmers on the irrigation water allocation problem. This paper uses a unique dataset of an irrigation project in southern Sri Lanka, which was collected by the Japan International Cooperation Agency (JICA). It contains artefactual field experiment data from a dictator game and a trust game as well as household survey data. In addition, the study site has a unique natural experimental setting, in which the distribution of irrigated plots was exogenously determined. Making use of these advantages, this paper can estimate the effect of social capital on irrigation water allocation in an ideal setting.

Another contribution of this paper is to show the validity of experimentally measured social capital. As Roe and Just (2009) mention, external validity is one of the most important issues in economic experiments. This paper tests the validity of the dictator game and the trust game, which are the most standard experiments in experimental economics, by demonstrating links between the results of these experiments and actual economic transactions. The incentive structure of irrigation water allocation for upstream farmers closely resembles the incentive structures in the dictator and trust games. In reality, it is difficult to charge water extraction fees according to the usage amount (Schoengold and Zilberman, 2006). Thus, rational farmers in the upstream area would extract as much water as they want, leaving too little for the downstream farmers. In the dictator and trust games, the proposer is endowed with a certain amount of money, and he/she decides how much money should be sent to the partner. The optimal strategy for the proposer in these games is to send nothing and keep all the money for himself. In the trust game, receivers have the option to send money back to the proposer, which is the equivalent of downstream farmers cooperating in irrigation canal management (Ostrom and Gardner, 1993; Jack, 2009) or some other similar forms of social exchange (Aoki, 2001). By comparing the "natural" dictator or trust games to artefactual field experiment results, this paper thus shows the validity of these games in a conclusive way.

This paper is organized as follows. Section 2 describes the study site and its natural experimental situation as well as the artefactual field experiment data. Section 3 describes the empirical strategy this paper employs. Section 4 presents the descriptive statistics and the main empirical results. The final section summarizes the study and offers concluding remarks.

2. The Setting of the Natural and Field Experiments

2.1. The study site and the natural experiment

This paper uses a dataset from an irrigation project in Sri Lanka, which was originally compiled by JICA.[3] The study site is the Walawe Left Bank (WLB) located in the southern part of Sri Lanka. The government of Sri Lanka constructed the Uda Walawe reservoir during 1963–1967. This reservoir is located on the boundary between the wet and dry zones

[3] See JBIC Institute (2007) for details.

of Sri Lanka, and the rainfall pattern in this area is influenced by the monsoon winds. There are two main canals in this basin: the Right Bank Main Canal (RBMC) and the Left Bank Main Canal (LBMC). Construction of the RBMC was completed with financial assistance from the Asian Development Bank (ADB) under the Walawe Development Project (1969–1977) and the Walawe Irrigation Improvement Project (1986–1994). Construction of the LBMC, which is the focus of this paper, was launched in 1995 with Japanese ODA loans. By the end of 2008, almost every household had acquired access to irrigation facilities.

JICA (formerly the Japan Bank for International Cooperation or JBIC) initiated a household survey in 2001 to assess the impact of the irrigation system. They had conducted eight household surveys by May 2009 and also conducted one field experimental session in March 2009. This study uses the household data from the last survey combined with the artefactual field experiment data.

The study site is divided into five blocks, according to their accessibility to irrigation: Sevanagala Irrigated, Sevanagala Rainfed,[4] Kiriibbanwewa, Sooriyawewa, and Extension Area. In each block, there are a number of distribution canals (D-canals) that draw water from the main canal in order to distribute it to each area of farmland. Figure 1 shows the sampling structure of the original dataset and the relationship between each block and the D-canals. The water supply is controlled at each D-canal by the authorities. Thus, collective action to manage irrigation water is conducted at the D-canal level.

The study site possesses unique natural experimental characteristics that are ideal for this research. Regarding the irrigated land, lottery-based allocation was employed for new settlers. Re-settlers (i.e., those who were at the study site before the construction of the irrigation system) were allowed to select land from their former cultivation area.[5] However,

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[4] There is no irrigation access in the Sevanagala Rainfed area because of topographic constraints. This study excludes people living in this area.

[5] Approximately half the households indicated that they would like to claim a preference for plot-level land (Aoyagi *et al*., 2012). Lottery-based allocation was employed for 30 per

re-settlers too were not given the opportunity to choose which D-canals they would like to be assigned to. Thus, land allocation was exogenously determined, i.e., independent from observable and unobservable household characteristics, at the D-canal level.[6] In addition, property rights to the irrigated plots were not given to the farmers until April 2009, and therefore, farmers could neither sell nor collateralize their irrigated plots until that time.

As Bardhan and Dayton–Johnson (2002) mention, locational advantages and disadvantages, such as the head-end or the tail-end of the canal, will be reflected in land values if land markets work well. Thus, it is difficult to clearly identify the effect of heterogeneity arising from head and tail asymmetry. However, the study site is free from this problem, because the distribution of the irrigated plots was exogenously determined. Figures 2 and 3 show the cumulative distribution functions (CDFs) of income and total irrigated plot size in 2009 by canal section. Though the difference in total plot size between the head and middle sections is marginally significant by the combined Kolmogorov-Smirnov test (P-value = 0.063), there are no systematic differences in other pairs for both variables. These results confirm that the data are free from systematic differences in income or plot size between the head-end and the tail-end. Therefore, this study can address head and tail asymmetry with "cleaner" data compared to previous studies.

Another important feature is that all of the respondents are Sinhala speakers and belong to the same religious group. Although ethnic conflict between the Sinhalese and the Tamils had been a serious problem in Sri Lanka, it is not necessary to consider how this problem may confound this study, as the dataset is free from ethnic and social heterogeneity.

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cent of the farmers.

[6] Aoyagi *et al*. (2012) find supportive evidence that households were exogenously allocated to canal communities and within each distribution, regardless of their observed characteristics.

2.2. Artefactual field experiments

The experiments included the dictator game, the trust game, and the risk game (Forsythe *et al.*; 1994; Berg *et al.*, 1995; Schechter, 2007). The sample consisted of 268 farmers randomly selected from the survey area. Figure 1 shows the sampling structure by each block and D-canal level. The total sample size was 268 households, which were randomly selected. Of the 268 samples, 188 were part of the previous household surveys. Although the originally invited participants were either household heads or household members, seven households could not send their representatives to the experiment and instead sent a son or a daughter who lived separately in another city. Because these agent players are irrelevant from the perspective of actual irrigation management, these observations were excluded from this study.

The experiments exploited the strategy method. In the dictator and trust games, each player was given Rs. 500, which was equivalent to one day's wages for a typical farmer in the study area. Then, using an answer sheet, they were asked to fill in the amount $x \in \{0, 50, 100, 150, 200, 250, 300, 350, 400, 450, 500\}$ to send to four types of partners: three non-anonymous players in the same D-canal, an anonymous player in the same D-canal, an anonymous player in the same block, and an anonymous player in a different block.

In the dictator game, players decided how much money to send to their partners, and the partners received the same amount sent by the player. In the trust game, when all the participants had finished their decision-making as senders, they were paired with one of the partners for the actual transaction. However, they could not identify their partners. The transferred amount was based on their strategy as senders and their partners received thrice the amount. All participants, when they were receivers, knew only of the tripled amount they had received from their partner and decided how much money to send back to their four potential partners. Note that all the participants were paired with only one of the potential partners. In other words, they decided on the amount they wished to send back to four types of partners, as though the amount they had received had been from each of them.[7] In both games, the players would not send any money in a Nash equilibrium, and thus, deviation from the equilibrium is interpreted as altruism in the dictator game and trust in the trust game (e.g., Camerer and Fehr, 2004; Levitt and List, 2007). Note that the incentive structures in these games are similar to those faced by a head-ender in an actual irrigation water allocation problem.

In addition to these games, a dice game based on Schechter (2007) was conducted in order to measure their risk attitude. A player was given Rs. 500 as an initial endowment and could choose how much of this money they wanted to invest. The player then rolled a die with different colors on each of the six faces to determine the investor's payoffs, such that $\{0, 0.5x, x, 1.5x, 2x, 2.5x\}$, where x is the invested amount.

3. Empirical Strategy

Using the experimentally measured social capital variable, this paper aims to estimate its effect on the irrigation water allocation problem. As noted earlier, it is difficult to charge an irrigation water usage fee based on the amount of an individual's water usage. In such a case, farmers demand more water as long as its marginal productivity is positive, which results in water shortage in the tail-end area. In contrast to such a model, according to utility functions with altruism or trust head-enders who care for others tend to demand less irrigation water, because there is a utility gain from leaving water for the tail-enders (e.g., Hayami, 2009; Velez *et al.*, 2009).[8] If the head-end farmers' motives are based on altruism, they achieve higher utility by leaving more water for tail-enders as long as the marginal

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[7] Because of this feature, the amount sent back might not capture the actual degree of trustworthiness. For this reason, this study does not investigate the effect of receivers' behaviors in the trust game.

[8] Velez *et al.* (2009) also show that a simple self-interested utility function cannot explain the motivation for CPR management adequately.

utility gain from the improvement of tail-enders' payoffs is higher than the marginal loss of utility from giving up part of their own extraction. If their motive is based on trust, expecting a positive return from tail-enders, such as cooperation in irrigation management or other forms of social exchange, they have an incentive to leave more water in the canal as long as the expected marginal return is larger than the marginal loss of utility. Thus, a higher level of altruism or trust leads to a lower demand for irrigation water compared to the model based purely on self-interest.

Traditionally, the measurement of water allocation at the individual level has posed a hurdle. As Schoengold and Zilberman (2006) mention, it is hard to measure individual water usage directly. Thus, this study uses respondents' subjective answers to the question asking "In the Maha (the rainy season that extends from October–March) 2008-2009 season, could you get water as much as you wanted when you needed it?" If they responded in the negative, they were asked "How much water (in %) did you get compared to the amount you wanted during the Maha 2008-2009 season?" Thus, the former answer is a binary variable that indicates whether the respondents were satisfied, and the latter, a continuous variable, that shows the percentage of water they used compared to the amount they wanted.[9]

This study focuses on farmers who cultivated paddy fields (rice) in the irrigated land for the following two reasons. First, paddy-grown rice is the major crop in this area and is cultivated by 78% of the sample households. Second, paddies require much more water during the growing season compared to other crops. The water allocation problem is thus most serious for paddy cultivation.

Regarding land holdings, some farmers had more than one irrigated plot. Although the dataset contains water satisfaction levels for each plot, it is impossible to identify what crop

[9] The percentage satisfaction variable is noted as 100 if respondents answered that they were satisfied with water received. As shown in the following results, this upward censoring does not affect the qualitative results of this paper.

they were cultivating at each plot. This study primarily focuses on the main plot, which is defined as the largest irrigated plot possessed by each household, because the respondents tended to cultivate paddy in larger plots. In addition to these variables, the averages of satisfaction for each plot weighted by plot size were used as alternative measures. These alternative measures were calculated as $\Sigma_p size_{ip} \times satisfaction_{ip}/\Sigma_p size_{ip}$, where $size_{ip}$ is the size of household i's irrigated plot p, and $satisfaction_{ip}$ represents the satisfaction variables for plot p. Note that this average satisfaction level might include the satisfaction level of plots with other crops for which irrigation water allocation is less crucial.

It is natural to assume that satisfaction with water usage is determined by the difference between demand and supply: if demand for irrigation water exceeds the level of supply, a farmer will not be satisfied. Thus, if the water supply level is controlled, farmers with a larger water demand would tend to be less satisfied with their water usage. In order to control for the water supply level, D-canal fixed effects are included. These fixed effects capture all the differences within the CPR user group, including the water supply level.[10]

As noted above, head-enders and tail-enders face different water usage incentive structures. Head-enders with higher social capital will decide how much water to use while considering tail-enders. In contrast, tail-enders do not need to consider head-enders, because they are the last people to extract water. Therefore, although social capital is expected to have a significantly positive effect on satisfaction for head-enders, its effect for tail-enders is unclear. This structure closely resembles that of the dictator and trust games, where the first mover decides how much of a resource they will keep and how much they will release to their partner. In order to take this asymmetry into account, the game results distinguish whether the partner is at the head or the tail relative to the player.

Because the dataset contains game results for three non-anonymous partners per

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[10] Because irrigation management is conducted at the D-canal level, the extraction rules and punishments for violators may differ among D-canal areas. There is no data on these rules, but the D-canal fixed effects also control for these systematic differences.

player in the dictator and trust games, the respective data are stacked for each observation.[11] In each observation, players can identify whether their partner is located in a head/tail area relative to themselves. Because samples were selected randomly from each D-canal, the cross terms of the game results and whether the partner is in the head/tail area capture the mean level of altruism and trust toward the head-enders/tail-enders. The specification is as follows:

$$Satisfaction_i = \alpha + \beta_1 SC_{ij} + \beta_2 vs\_tail_{ij} \times SC_{ij} + \beta_3 vs\_head_{ij} \times SC_{ij} + \gamma X_i + DC_i + \varepsilon_{ij} \quad (1)$$

where SC_{ij} is the amount sent from player i to partner j in the dictator or trust game, and vs_tail_{ij} and vs_head_{ij} are binary variables that take one if j is located in the tail- or head-end relative to i, i.e., $vs\_tail_{ij} = 1$ if $(i, j) \in \{(head, middle), (head, tail), (middle, tail)\}$, and $vs\_head_{ij} = 1$ if $(i, j) \in \{(tail, middle), (tail, head), (middle, head)\}$. X_i is a set of other control variables and DC_i is a set of binary variables corresponding to the D-canal to which i belongs. ε_{ij} is the measurement error of the subjective satisfaction variable. Note that observations within each player are not independent. Thus, standard errors need to be adjusted for correlation within individuals. The parameter of interest is β_2. If farmers optimize their water extraction level so as to care for their tail-enders, their demand should be lower, which means that they are more likely to be satisfied. Therefore, the testable hypothesis is whether β_2 is positive. Also, the games capture the incentive structure of the head-enders only. Thus, no predictions can be drawn for the sign of β_3, which captures altruism or trust toward the head-enders.

In using the trust game as a social capital variable, it is necessary to control for altruism and risk attitude. Cox (2004) shows that the behavior of the first mover in the trust

[11] Basically, the total sample size is three times the number of relevant participants. However, the actual sample size is slightly smaller than this, because the cases of relevant players with irrelevant partners are also excluded from this analysis.

game is confounded by altruism. For this reason, the results of the dictator game should be included. Regarding risk attitude, previous studies such as Schechter (2007) show that the first mover's behavior in the trust game confounds the level of trust with his/her own risk attitude, because the amount of money the second mover will return is uncertain for the first mover. In order to control for this effect, a risk attitude variable measured by the dice game is also included.

Another important control variable is the exit option. Previous studies show that irrigation management is difficult if users have access to income sources other than those related to irrigation (e.g., Bardhan, 2000; Fujiie *et al*., 2005; Kajisa *et al*., 2007; Nakano and Otsuka, 2011). In order to control for the effect of exit options, the size of unirrigated farmland is included. Some farmers had unirrigated farmland, namely rainfed or *chena* (slash and burn farming) plots in addition to their irrigated plot. Because unirrigated land size captures the effect of an exit option, a larger unirrigated land size may lead to less cooperative behavior, and thus, this variable is expected to have a negative effect on satisfaction. Because all their land was acquired before 2007, this variable is free from the possibility that the respondents added unirrigated land, because they were dissatisfied with irrigation water usage.

Equation (1) is estimated as a benchmark, but this specification may be too naïve, because it ignores reverse causality between social capital and satisfaction. Higher social capital is assumed to lead to better water allocation and higher satisfaction with water usage, because social capital decreases the demand for water. However, social capital itself also reflects the result of water allocation. In other words, not only does social capital affect satisfaction with water usage, but this satisfaction may also affect social capital.

In order to cope with this problem, it is necessary to find instruments that are highly correlated with the game results toward the partners in the same D-canal, but that are exogenous with respect to the satisfaction level. This study uses the dictator and trust games in a situation where the partner is not identified, except that he/she is in a different D-canal area. It is natural to assume that both cases share the player's inherent altruism or trust, and there is a positive correlation between them. In addition, because irrigation water is managed at the D-canal level, the water allocation problem does not occur across different D-canal areas. Therefore, the results of water allocation and their satisfaction with it do not affect their altruism or trust toward those who are in different D-canal areas. Because the participants in the experiment were randomly chosen from each D-canal area, whether the partner is a head-ender/tail-ender is also determined exogenously. Therefore, cross terms between these variables and altruism/trust toward a member of another D-canal also serve as valid instrumental variables (IVs).

4. Data Description and Empirical Results

4.1. Descriptive statistics

Table 1 shows the descriptive statistics used for the main empirical study. Panel A shows the household characteristics. The binary variable for satisfaction in the main plot shows that 67% of the sample answered that they were satisfied with their water usage; in other words, one-third of the respondents were not satisfied with the amount of water they used. This indicates that there is not enough irrigation water for everyone to have a sufficient amount, pointing to the need for coordinating water allocation. The weighted averages of the satisfaction variables are not substantially different from the satisfaction variables in the main plot.

Table 2 shows the average of satisfaction levels by canal section. Note that the sample size differs from that in table 1, because this table uses observations before stacking for artefactual experiment data. There is little difference between the satisfaction level of the main plot and the weighted averages for the binary and continuous cases. As for the binary satisfaction variables, the satisfaction level decreases from the head-end to the tail-end. Though the percentage satisfaction levels of the main plot slightly increase from the middle to the tail, there is a clear difference between the head and the middle, and the head and the tail.[12] The last column shows the *t*-value of the one-sided test, i.e., whether the mean of the head-enders' satisfaction levels is higher than the corresponding value for the tail-enders. All the results show significant differences, implying the possibility that downstream farmers face a locational disadvantage in water availability. Note that these results are unconditional on social capital or other household characteristics.

Panel B of table 1 shows the results of the artefactual field experiment. Interestingly, the amount sent decreases as the social distance between partners increases, which is consistent with previous studies (e.g., Hoffman *et al*., 1996; Etang *et al*., 2009; Leider *et al*., 2009) and ingroup favoritism in the literature of social psychology (e.g., Tajfel *et al*., 1971). Assuming additive separability, the differences between (a) and (b), (b) and (c), and (c) and (d) show the effect of whether the partner is identified, the effect of sharing the same D-canal, and the effect of living in the same block, respectively.

Panels A and B of table 3 show the correlation of the game results for different partners in the dictator and trust games, respectively. The amounts sent positively correlate with each other, which implies that all the sent amounts share the players' inherent altruism and trust.

Table 4 shows the determinants of the game results.[13] The dependent variables in column 1 and 2 are the results of the dictator game and the trust game, respectively. The specification in column 3 controls for the effect of altruism and risk attitude. Interestingly, the presence of the partner in the head- /tail-end area relative to the player does not show a significant effect in any of the specifications. As previous studies have pointed out, both altruism and risk attitude have significantly positive effects on the results of the trust game. This result confirms the necessity for controlling for these effects in specification (1) using the results of the trust game.

[12] The increase from the middle to the tail-end is statistically insignificant.

[13] Also see Aoyagi *et al.* (2012) for a detailed discussion.

4.2. Potential water conflict between head-enders and tail-enders

Though table 2 shows the existence of a locational disadvantage in irrigation water accessibility, these results are unconditional on household characteristics. Before investigating the effect of social capital on irrigation water allocation, it is necessary to show whether water conflict between head-enders and tail-enders still exists after controlling for household characteristics. In order to test the locational disadvantage of tail-enders conditional on household characteristics, model (1) is estimated without social capital variables.

Table 5 shows whether the location within each canal has an effect on satisfaction. The dependent variables are binary satisfaction in columns 1 and 2, and percentage satisfaction in columns 3 and 4. Note that the observations are not stacked, because the game results are not included in the regression. The coefficients on tail-end dummy are all negative and statistically significant at the 10% level in columns 1 and 2. Thus, tail-enders tend to be less satisfied with their water usage comparing to the base category (i.e., head-enders), and thus, there is a potential difference in water availability between the head and the tail. Note that these results are also unconditional on social capital variables, which is often the case with studies using observational data only. Thus, whether this significant effect of location within irrigation canals holds even after controlling for social capital is an important question.

4.3. Effect of altruism on satisfaction level

Table 6 shows the effect of altruism on satisfaction with water usage using the results of the dictator game. The first four columns show the results of the ordinary least squares (OLS) estimation of equation (1). The coefficient on the dictator game itself is insignificant in all specifications. Because the model controls for the case in which the partner is a head-ender/tail-ender relative to the player, altruism toward people in the same part of the canal does not affect satisfaction. Though the parameter of interest (altruism toward the tail-enders) is positive, none of the coefficients are significant. Altruism toward head-enders does not show a significant effect. Because tail-enders do not need to consider head-enders when they decide how much water to extract, this result is reasonable. Interestingly, once the social capital variables are controlled for, the coefficients on the middle and tail dummies are not significant. This indicates that tail-enders are not necessarily less satisfied with water usage, and therefore, the irrigation water is being allocated satisfactorily between the head-end and the tail-end. Thus, the negative sign on the location variable in the previous subsection reflects the bias from omitting the social capital variable. Unirrigated plot size affects satisfaction level negatively and significantly when the weighted average of each plot is considered as the dependent variable, indicating the negative effect of the exit option.

The fact that the percentage satisfaction variables are upward censored at 100 is of concern. In order to control this bias, the results of the Tobit estimation are shown in columns (5) and (6) in table 6. As expected, the sign of the coefficients on altruism toward tail-enders remains unchanged, though the absolute values of the coefficients become larger.

The last four columns show the results of the IV estimation of equation (1).[14] Note that the first-stage *F*-test rejects the null hypothesis, namely that the coefficients on excluded instruments are jointly zero at the 1% level for all endogenous variables and for all specifications. The effect of altruism toward tail-enders is positive in all cases and is significant when the dependent variables are continuous. This result is consistent with the main hypothesis that the farmers in upstream areas are considerate toward their downstream counterparts and optimize their water demand level accordingly. Intriguingly, the magnitude of coefficients on this variable is larger in the IV estimation than in the OLS estimation, indicating that the reversed effect of satisfaction level on altruism is negative. Although this

[14] Because IV Tobit estimations do not converge in all cases, they are not reported.

seems to be counterintuitive, it is consistent with previous studies suggesting that collective actions are likely to take place when resources are scarce (Fujiie *et al*., 2005; Hayami, 2009; Nakano and Otsuka, 2011). Because scarcity of resources requires coordination among players, it leads to social capital being enhanced. Further, consistent with previous results, unirrigated plot size, representing the exit option, negatively affects satisfaction level.

4.4. Effect of trust on satisfaction level

Table 7 shows the effect of trust on satisfaction level with water usage using the results of the trust game. Similar to the previous subsection, the first four columns show the results of the OLS estimation of equation (1). The effects of trust toward the tail-enders are all positive and significant when the dependent variables are continuous. This also confirms the consideration of the head-enders toward the tail-enders, evident in the optimization of their irrigation water demand. Risk attitude measured by the dice game has a negative effect on satisfaction level. This may imply that risk-averse farmers tend to demand more water in order to cope with expected environmental risk. Unirrigated plot size affects negatively, indicating the negative effect of the exit option. The locational disadvantage becomes insignificant like the dictator game case.

Columns (4) and (5) show the Tobit estimation results that control censoring bias in the continuous satisfaction variables. The basic qualitative results of the parameter of interest (trust toward the tail-enders) remain unchanged, though the magnitude of coefficients becomes larger. Thus, this result is also consistent with the hypothesis.

The last four columns of table 7 show the IV estimation results of equation (1), using the results of the trust game. The first-stage F-test strongly rejects the null hypothesis at the 1% level in all cases. As expected, trust toward the tail-enders has a positive and significant effect in all cases. Compared to the relatively ambiguous effect of altruism, trust toward the tail-enders has a much more robust positive effect on satisfaction. Similar to the dictator game case, coefficients in the case of the IVs are larger than those in the OLS case, indicating the negative effect of satisfaction level on trust. These results also confirm that the incentive of head-enders in irrigation water allocation can be explained adequately in terms of trust.

4.5. Robustness check

The results in the previous subsections, namely that altruism and trust toward the tail-enders positively affects the satisfaction level of head-enders, are consistent with the main hypothesis. However, there are several concerns worth noting. First, the validity of subjective assessment on the water usage level needs to be verified. The dependent variables used so far concern the subjective assessment of each farmer's water usage level. While the use of subjective measures is becoming more common in economics, it is still necessary to show the link between the satisfaction level variables and actual agricultural productivity. Another concern is the possibility of interpreting the results differently: people with higher social capital tend to be satisfied simply because they extract more water, and consequently, they enjoy higher productivity. If this is the case, the significantly positive coefficient on altruism and trust toward tail-enders is spurious, because productivity is omitted from the equation.

In order to cope with these concerns, equation (1) is reestimated by including the total amount of paddy produced during the same period. Tables 8 and 9 show the results of this estimation using the results of the dictator game and the trust game, respectively. The total amount of paddy produced positively correlates with the water usage of the head-enders and is significant, except for the cases where the dependent variable is the weighted average of binary satisfaction. This is because the weighted average variables are more likely to include the satisfaction level of non-paddy farmland. Thus, these results validate our use of the subjective measures of satisfaction level.

Even after controlling for productivity, the qualitative results of the parameter of interest are not much affected. This means that higher altruism of the head-enders and their trust toward their tail-enders have a positive effect even if their produced amounts are the same. Note that if the positive connection between satisfaction and social capital in the previous results resulted from the effect of higher income or higher productivity, this connection would have vanished once the productivity is controlled for. Thus, the results are more consistent with the original hypothesis that altruism and trust towards tail-enders leads to better water allocation.

Another possible concern is that the cropping pattern might be different among the canal sections, depending on their water accessibility (e.g., Ray and Williams, 2002). It is possible that head-end farmers with adequate water access might cultivate paddy and tail-end farmers with less water access might cultivate less water-intensive crops. If this is the case, the previous empirical results might be biased. Table 10 shows the cropping pattern calculated as the share of paddy-cultivated land in the total cultivated land size in the head, middle, tail areas. As shown in the table, there is little difference among canal sections. Thus, all the results are free from the bias arising from possible systematic differences in the cropping pattern.

5. Concluding Remarks

Social capital has long been considered a key instrument for CPR management, but there is little consensus on its effect on the water allocation problem between irrigation canal head-enders and tail-enders. As existing studies have analyzed observational or experimental data only, internal and external validity remains an important, and as yet, unaddressed issue. This study aimed to bridge this gap by combining artefactual field experiment data and household survey data. In addition, the natural experimental situation of the study site enabled us to overcome the potential difference in income or asset holdings between head-enders and tail-enders. Thus, this study clearly estimated the effect of social capital on farmers' satisfaction with irrigation water usage.

The most important finding is that social capital with respect to tail-enders, especially trust toward tail-enders, has a significantly positive effect on satisfaction with water usage. This is consistent with the hypothesis that head-enders optimize their water demand with due consideration for their tail-enders. Another important finding is that OLS estimators for these social capital variables are downward biased. This result confirmed the hypothesis that scarcity of resources induces social capital accumulation (Hayami, 2009).

The difference in the results between altruism and trust implies an important feature of irrigation management. In the case of altruism, a player's utility is higher just because his/her partner's payoff improves. In contrast, a player may trust his/her partner, in the sense that he/she expects a positive return from the partner. This reciprocal behavior of tail-enders can take the form of cooperation in irrigation management or other social exchanges. Thus, by leaving enough water for the tail-enders, head-enders anticipate better cooperation with tail-enders.

In addition to the main results, the significantly positive effect of the dictator and trust games supports the validity of using experimental data as a measure of social capital. By considering the irrigation water allocation problem for head-enders as a natural dictator game or trust game, the results showed a strong link between the artefactual field experiments and actual economic transactions.

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no irrigation in this block.

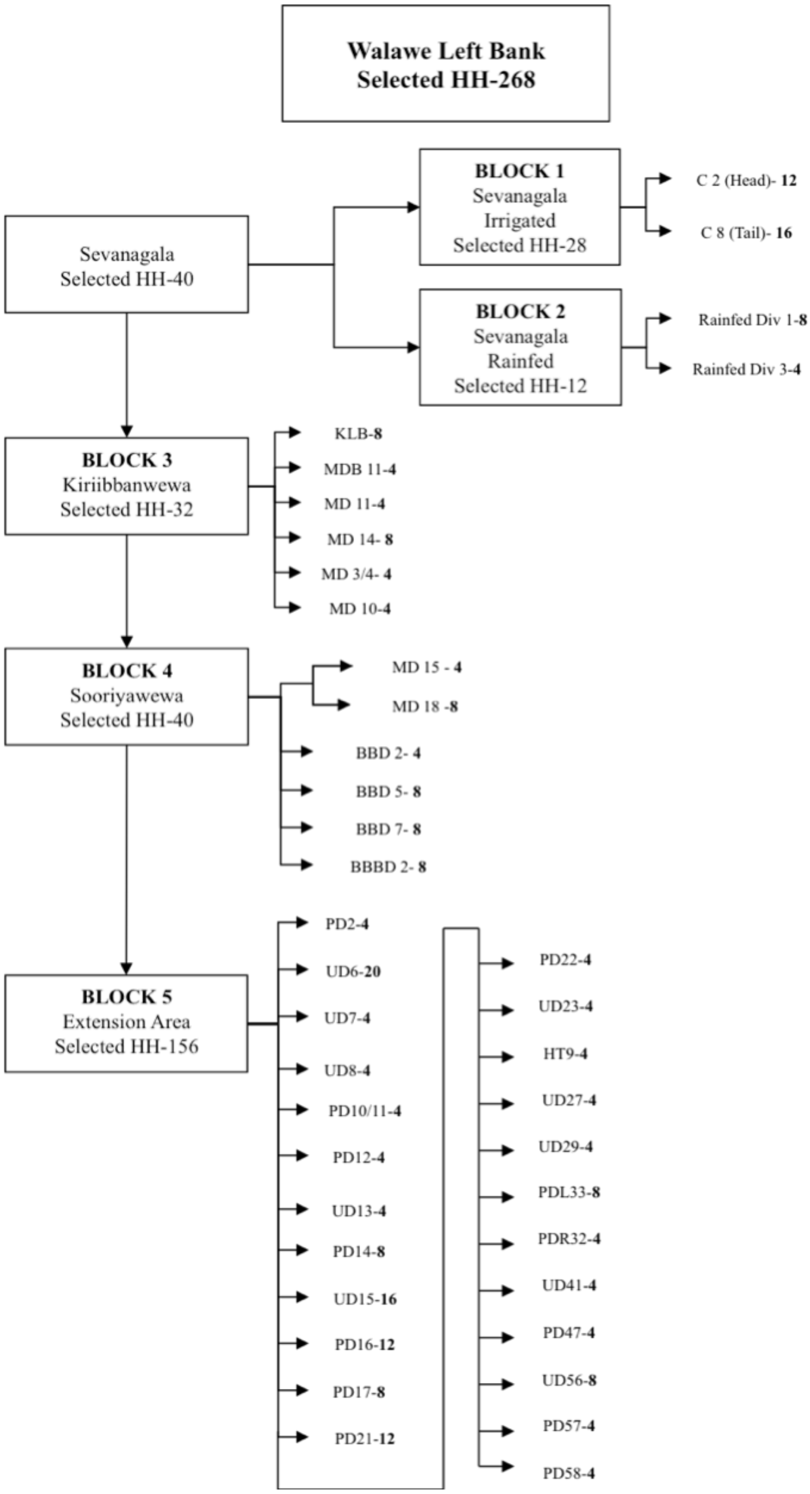

Figure 1. Sampling Structure

Note: The households in Sevanagala Rainfed are excluded from this study because there is no irrigation in this block.

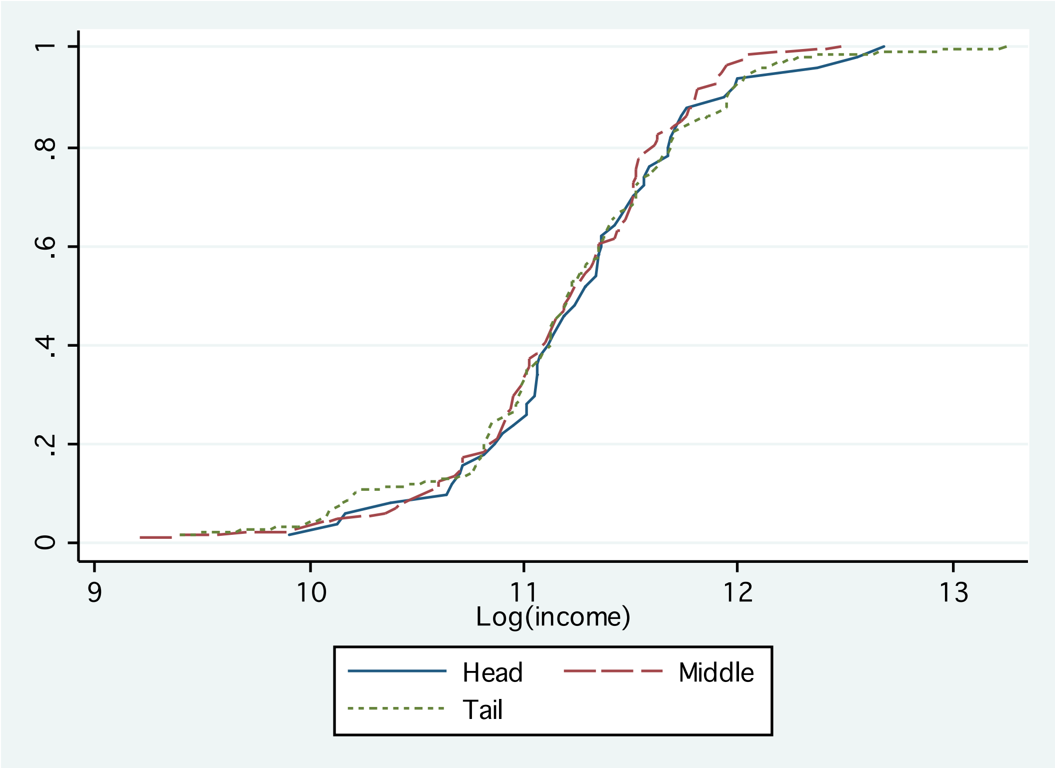

Figure 2. CDF of log(income)

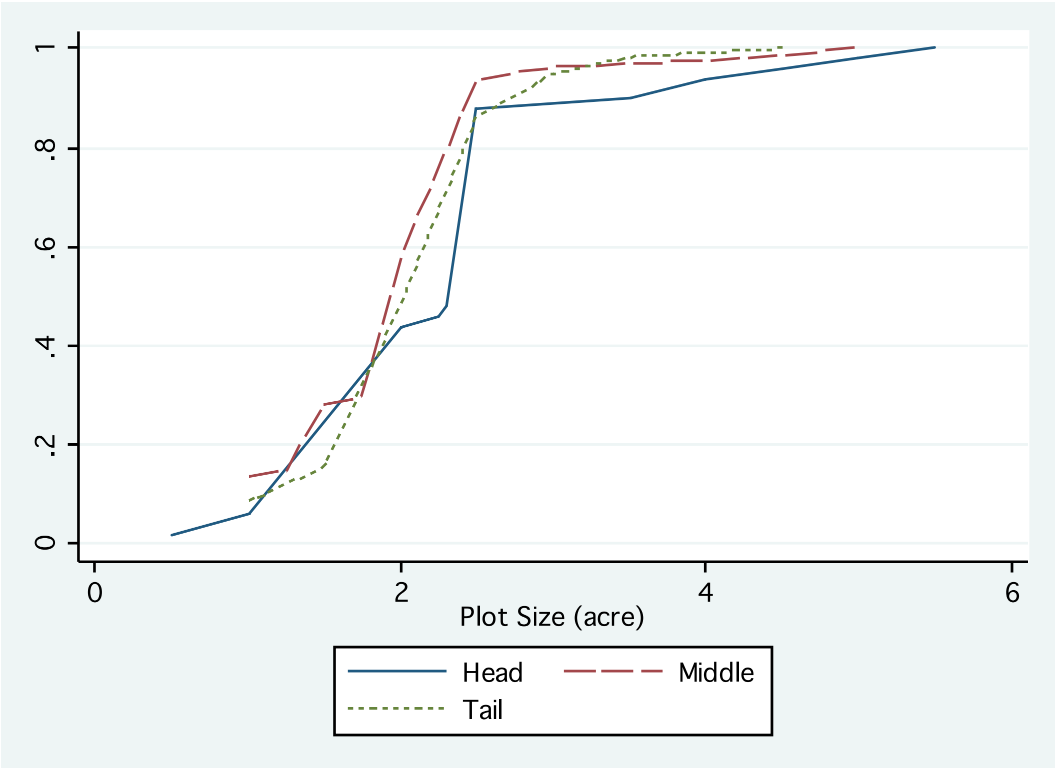

Figure 3. CDF of total irrigated plot size.

Table 1. Descriptive statistics

Variable	Obs.	Mean	Std. Dev.
Panel A: Household characteristics			
Satisfaction (binary): main plot	547	0.6709324	0.4703047
Satisfaction (%): main plot	547	89.08592	18.44917
Satisfaction (binary): weighted average	544	0.6737482	0.4575363
Satisfaction (%): weighted average	544	88.86633	18.02452
Location			
Head (base category)	552	0.2663043	0.4424262
Middle	552	0.4275362	0.4951699
Tail	552	0.3061594	0.4613148
Log (plot size)	552	0.6861963	0.2943527
Log (total plot size)	552	.7495168	0.3499816
Log (un-irrigated land size)	552	-4.346148	1.091339
Household heads participating in the experiment	552	0.7210145	0.4489072
Age of household head	549	52.49362	10.5643
Female household head	549	0.0928962	0.2905516
Education of household head	540	6.214815	3.24997
Log (total amount of paddy produced (kg))	552	7.79585	0.7774395
Panel B: Artefactual field experiment			
Vs tail	552	0.3115942	0.463565
Vs head	552	0.3097826	0.4628233
Dictator game			
(a) Same D-canal (non-anonymous)	552	160.6884	111.1068
(b) Same D-canal (anonymous)	552	137.1377	104.8175
(c) Different D-canal, same block (anonymous)	552	102.4457	98.66807
(d) Different block (anonymous)	552	80.07246	91.97172
Trust game			
(a) Same D-canal (non-anonymous)	552	211.5942	130.6885
(b) Same D-canal (anonymous)	552	160.0543	120.1307
(c) Different D-canal, same block (anonymous)	552	128.5326	126.0031
(d) Different block (anonymous)	552	109.5109	118.5788
Dice game	552	205.7971	119.4471

Note: For all variables in logarithmic form, 0.01 is added before taking the log.

Table 2. Satisfaction level of irrigation water usage by canal section

	Head	Middle	Tail	*t*-value (head vs tail)
Sample size	50	80	57	
(Mean) Satisfaction (binary)	0.76	0.6625	0.5964912	1.8094**
(Mean) Satisfaction (%)	92.3	87.4375	87.7193	1.4149*
Sample size	50	80	56	
(Mean) Satisfaction (binary, average)	0.76	0.6656944	0.5997166	1.8224**
(Mean) Satisfaction (%, average)	92.3	87.28611	87.20011	1.6404*

Note: One-sided *t*-test. ** and * indicate that $p < 0.05$ and $p < 0.1$, respectively.

Table 3. Correlation of the game results among social distances

Panel A: Dictator Game

	(a)	(b)	(c)	(d)
(a)	1			
(b)	0.4634	1		
(c)	0.4018	0.3748	1	
(d)	0.4926	0.5668	0.8039	1

Panel B: Trust Game

	(a)	(b)	(c)	(d)
(a)	1			
(b)	0.4905	1		
(c)	0.5367	0.5526	1	
(d)	0.5474	0.4867	0.7777	1

Note: (a), (b), (c), and (d) indicate same D-canal (non-anonymous), same D-canal (anonymous), different D-canal, same block (anonymous), and different block (anonymous), respectively.

Table 4. Determinants of the results of the dictator and trust games

VARIABLES	(1) Dictator Game	(2) Trust Game	(3) Trust Game
Vs head	8.870	11.22	2.011
	(13.25)	(16.29)	(13.16)
Vs tail	12.54	1.548	-8.519
	(13.06)	(14.13)	(11.62)
Dictator game			0.665***
			(0.0627)
Dice game			11.52*
			(6.104)
Household head	-28.02	-27.67	-7.886
	(19.08)	(20.85)	(14.94)
Age of household head	0.645	1.458	0.900
	(0.770)	(0.909)	(0.703)
Female household head	32.84	37.16	21.58
	(32.07)	(32.90)	(27.58)
Education of household head	2.659	-1.449	-2.909
	(2.262)	(2.646)	(1.883)
Constant	119.1***	157.0***	58.91
	(45.20)	(55.65)	(41.30)
Observations	540	540	540
R-squared	0.028	0.028	0.375

Note: Standard errors in parentheses are adjusted for correlations within individuals.

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 5. Potential water conflict between head-enders and tail-enders

VARIABLES	(1) OLS Main plot Binary	(2) OLS Average Binary	(3) OLS Main plot %	(4) OLS Average %
Middle	-0.106	-0.112	-2.777	-3.778
	(0.0873)	(0.0880)	(3.064)	(3.146)
Tail	-0.179*	-0.172*	-2.139	-2.977
	(0.102)	(0.102)	(3.409)	(3.554)
Log (plot size)	-0.143		-5.482	
	(0.111)		(4.356)	
Log (total plot size)		-0.0537		-3.471
		(0.0882)		(3.463)
Log (un-irrigated land size)	-0.0369	-0.0484*	-2.424	-3.014
	(0.0282)	(0.0258)	(1.903)	(1.855)
Household head	0.0338	0.0165	-1.152	-0.725
	(0.105)	(0.105)	(3.620)	(3.669)
Age of household head	0.000524	0.000540	0.00802	-0.00323
	(0.00451)	(0.00447)	(0.169)	(0.165)
Female household head	0.0957	0.0578	0.445	-0.986
	(0.136)	(0.144)	(5.569)	(5.832)
Education of household head	0.0163	0.0144	0.463	0.256
	(0.0124)	(0.0123)	(0.503)	(0.503)
Constant	-0.125	0.0154	51.04***	58.28***
	(0.296)	(0.302)	(13.95)	(14.21)
D-canal dummies	YES	YES	YES	YES
Observations	183	182	183	182
R-squared	0.399	0.373	0.417	0.385

Note: Robust standard errors in parentheses. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Table 6. Effect of altruism on satisfaction level of water usage

VARIABLES	(1) OLS Main plot Binary	(2) OLS Average Binary	(3) OLS Main plot %	(4) OLS Average %	(5) Tobit Main plot %	(6) Tobit Average %	(7) IV Main plot Binary	(8) IV Average Binary	(9) IV Main plot %	(10) IV Average %
Dictator game	-0.00278	-0.00386	0.503	0.664	1.188	1.168	-0.00254	0.0192	2.063	2.742
	(0.0288)	(0.0283)	(1.109)	(1.094)	(2.828)	(2.714)	(0.0566)	(0.0545)	(2.205)	(2.160)
Vs_tail × dictator game	0.00441	0.00667	1.180	1.086	2.210	1.823	0.0341	0.0367	2.008**	2.149**
	(0.0223)	(0.0225)	(0.750)	(0.782)	(1.954)	(1.984)	(0.0267)	(0.0264)	(1.013)	(1.036)
Vs_head × dictator game	-0.0267	-0.0291	-1.024	-0.954	-2.386	-2.385	-0.0501	-0.0389	-1.693	-1.585
	(0.0250)	(0.0247)	(0.888)	(0.880)	(2.359)	(2.209)	(0.0340)	(0.0325)	(1.374)	(1.392)
Middle	-0.0778	-0.0793	-0.807	-2.026	-5.227	-8.853	-0.0336	-0.0485	0.276	-0.854
	(0.0823)	(0.0835)	(2.882)	(3.036)	(8.717)	(8.669)	(0.0821)	(0.0822)	(2.919)	(3.002)
Tail	-0.139	-0.126	0.970	-0.143	-5.106	-7.930	-0.0624	-0.0664	3.294	2.477
	(0.100)	(0.0999)	(3.243)	(3.346)	(9.765)	(9.524)	(0.102)	(0.102)	(3.603)	(3.621)
Log (un-irrigated land size)	-0.0381	-0.0499**	-2.442	-3.024*	-4.359	-5.905**	-0.0394*	-0.0494**	-2.416	-2.974*
	(0.0252)	(0.0228)	(1.703)	(1.653)	(3.062)	(2.723)	(0.0238)	(0.0216)	(1.593)	(1.531)
Other controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
D-canal dummies	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
First stage *F*-stat										
Dictator game							16.46***	16.75***	16.46***	16.75***
Vs_tail × dictator game							40.65***	39.98***	40.65***	39.98***
Vs_head × dictator game							32.10***	32.80***	32.10***	32.80***
Observations	535	532	535	532	535	535	535	532	535	532
R-squared	0.397	0.367	0.411	0.376	0.126	0.116	0.392	0.360	0.401	0.358
Dictator game	-0.00278	-0.00386	0.503	0.664	1.188	1.168	-0.00254	0.0192	2.063	2.742

Note: Standard errors in parentheses are adjusted for correlations within individuals. *** p < 0.01, ** p < 0.05, * p <0.1
The results of the dictator game, trust game, and dice game are divided by 100 for scaling.
Endogenous variable: dictator game, vs_tail × dictator game, vs_head × dictator game.
Other controls include log(plot size) or log(total plot size), HH head dummy, age, female HH head dummy, education level, and constant.

Table 7. Effect of trust on satisfaction level of water usage

VARIABLES	(1) OLS Main plot Binary	(2) OLS Average Binary	(3) OLS Main plot %	(4) OLS Average %	(5) Tobit Main plot %	(6) Tobit Average %	(7) IV Main plot Binary	(8) IV Average Binary	(9) IV Main plot %	(10) IV Average %
Trust game	0.00844	0.00199	-0.0805	-0.340	0.768	0.0517	0.113	0.0965	1.379	0.749
	(0.0240)	(0.0244)	(0.997)	(1.059)	(2.284)	(2.292)	(0.101)	(0.104)	(3.594)	(3.705)
Vs_tail × trust game	0.0226	0.0212	1.257**	1.132*	3.368**	2.581*	0.0547**	0.0584**	2.358***	2.584***
	(0.0160)	(0.0161)	(0.562)	(0.601)	(1.492)	(1.553)	(0.0232)	(0.0233)	(0.833)	(0.861)
Vs_head × trust game	-0.00892	-0.00244	0.238	0.523	0.396	1.098	-0.0397	-0.0213	-0.800	-0.550
	(0.0181)	(0.0180)	(0.729)	(0.729)	(1.526)	(1.478)	(0.0308)	(0.0287)	(1.017)	(1.049)
Dictator game	-0.00498	-0.00246	1.069	1.374	1.085	1.362	-0.0912	-0.0519	1.819	3.037
	(0.0310)	(0.0306)	(1.134)	(1.152)	(2.920)	(2.766)	(0.117)	(0.116)	(4.325)	(4.290)
Dice game	-0.0442	-0.0429	-2.364**	-2.328**	-5.956**	-5.541**	-0.0518	-0.0596*	-3.046***	-3.203***
	(0.0306)	(0.0300)	(1.098)	(1.057)	(2.649)	(2.424)	(0.0330)	(0.0322)	(1.182)	(1.138)
Middle	-0.0375	-0.0524	0.149	-1.392	-2.698	-7.903	0.0333	0.0146	2.694	1.600
	(0.0875)	(0.0891)	(3.065)	(3.214)	(8.645)	(8.587)	(0.0939)	(0.0928)	(2.956)	(2.993)
Tail	-0.111	-0.121	0.414	-1.259	-5.326	-10.38	-0.00419	-0.0224	4.654	3.729
	(0.0941)	(0.0945)	(3.119)	(3.163)	(8.923)	(8.759)	(0.110)	(0.108)	(3.645)	(3.609)
Log (un-irrigated land size)	-0.0366	-0.0479**	-2.335	-2.910*	-4.379	-5.934**	-0.0422	-0.0516**	-2.320	-2.837*
	(0.0248)	(0.0228)	(1.669)	(1.639)	(2.826)	(2.596)	(0.0261)	(0.0246)	(1.555)	(1.511)
Other controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
D-canal dummies	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
First stage *F*-stat										
Trust game							28.84***	20.10***	28.84***	20.10***
Vs_tail × trust game							70.69***	68.94***	70.69***	68.94***
Vs_head × trust game							50.47***	54.30***	50.47***	54.30***
Dictator game							24.30***	31.27***	24.30***	31.27***
Observations	535	532	535	532	535	532	535	532	535	532
R-squared	0.406	0.375	0.425	0.390	0.132	0.121	0.357	0.327	0.404	0.359

Note: Standard errors in parentheses are adjusted for correlations within individuals. *** p < 0.01, ** p < 0.05, * p < 0.1
The results of the dictator game, trust game, and dice game are divided by 100 for scaling.
Endogenous variable: trust game, vs_tail × trust game, vs_head × trust game, dictator game.
Other controls include log(plot size) or log(total plot size), HH head dummy, age, female HH head dummy, education level, and constant.

Table 8. Effect of altruism on satisfaction level of water usage (considering the amount of paddy produced)

VARIABLES	(1) OLS Main plot Binary	(2) OLS Average Binary	(3) OLS Main plot %	(4) OLS Average %	(5) IV Main plot Binary	(6) IV Average Binary	(7) IV Main plot %	(8) IV Average %
Dictator game	-0.00515	-0.00595	0.388	0.561	-0.00438	0.0167	1.980	2.623
	(0.0290)	(0.0285)	(1.125)	(1.107)	(0.0554)	(0.0536)	(2.150)	(2.115)
Vs_tail × dictator game	-0.00116	0.00219	0.910	0.862	0.0285	0.0328	1.756*	1.955*
	(0.0221)	(0.0224)	(0.748)	(0.781)	(0.0265)	(0.0262)	(0.994)	(1.015)
Vs_head × dictator game	-0.0314	-0.0328	-1.254	-1.139	-0.0511	-0.0396	-1.738	-1.619
	(0.0254)	(0.0251)	(0.876)	(0.872)	(0.0336)	(0.0323)	(1.334)	(1.358)
Log (total amount of paddy produced)	0.0861*	0.0757	4.172**	3.775*	0.0839*	0.0685	3.821**	3.326*
	(0.0493)	(0.0503)	(1.882)	(1.945)	(0.0476)	(0.0485)	(1.799)	(1.869)
Middle	-0.0705	-0.0748	-0.454	-1.802	-0.0295	-0.0465	0.459	-0.759
	(0.0823)	(0.0836)	(2.872)	(3.043)	(0.0819)	(0.0822)	(2.910)	(2.999)
Tail	-0.157	-0.145	0.0966	-1.074	-0.0851	-0.0871	2.260	1.474
	(0.0984)	(0.0981)	(3.208)	(3.320)	(0.100)	(0.101)	(3.576)	(3.605)
Log (un-irrigated land size)	-0.0346	-0.0469**	-2.273	-2.875*	-0.0358	-0.0466**	-2.251	-2.836*
	(0.0249)	(0.0222)	(1.778)	(1.710)	(0.0235)	(0.0210)	(1.656)	(1.576)
Other controls	YES	YES	YES	YES	YES	YES	YES	YES
D-canal dummies	YES	YES	YES	YES	YES	YES	YES	YES
First stage *F*-stat								
Dictator game					15.84***	16.22***	15.84***	16.22***
Vs_tail × dictator game					39.80***	39.29***	39.80***	39.29***
Vs_head × dictator game					33.09***	33.50***	33.09***	33.50***
Observations	535	532	535	532	535	532	535	532
R-squared	0.409	0.377	0.429	0.391	0.405	0.370	0.419	0.373

Note: Standard errors in parentheses are adjusted for correlations within individuals. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The results of the dictator game, trust game, and dice game are divided by 100 for scaling.

Endogenous variable: dictator game, vs_tail × dictator game, vs_head × dictator game.

Other controls include log(plot size) or log(total plot size), HH head dummy, age, female HH head dummy, education level, and constant.

Table 9. Effect of trust on satisfaction level of water usage (considering the amount of paddy produced)

VARIABLES	(1) OLS Main plot Binary	(2) OLS Average Binary	(3) OLS Main plot %	(4) OLS Average %	(5) IV Main plot Binary	(6) IV Average Binary	(7) IV Main plot %	(8) IV Average %
Trust game	0.0103	0.00297	0.0103	-0.290	0.127	0.107	1.999	1.244
	(0.0245)	(0.0248)	(1.008)	(1.070)	(0.102)	(0.104)	(3.629)	(3.719)
Vs_tail × trust game	0.0193	0.0184	1.094*	0.992*	0.0523**	0.0570**	2.247***	2.515***
	(0.0159)	(0.0159)	(0.558)	(0.593)	(0.0241)	(0.0240)	(0.862)	(0.885)
Vs_head × trust game	-0.0130	-0.00583	0.0371	0.352	-0.0437	-0.0244	-0.979	-0.705
	(0.0187)	(0.0185)	(0.729)	(0.735)	(0.0316)	(0.0296)	(1.044)	(1.077)
Dictator game	-0.00992	-0.00614	0.827	1.189	-0.106	-0.0636	1.163	2.461
	(0.0310)	(0.0306)	(1.127)	(1.145)	(0.116)	(0.115)	(4.226)	(4.190)
Dice game	-0.0462	-0.0445	-2.461**	-2.407**	-0.0547	-0.0615*	-3.177***	-3.297***
	(0.0310)	(0.0304)	(1.103)	(1.058)	(0.0335)	(0.0326)	(1.188)	(1.139)
Log (total amount of paddy produced)	0.0877*	0.0768	4.286**	3.862*	0.0894*	0.0708	4.034**	3.482*
	(0.0492)	(0.0503)	(1.884)	(1.966)	(0.0489)	(0.0494)	(1.802)	(1.878)
Middle	-0.0267	-0.0451	0.673	-1.029	0.0455	0.0228	3.243	2.004
	(0.0866)	(0.0887)	(3.007)	(3.192)	(0.0937)	(0.0930)	(2.972)	(3.019)
Tail	-0.125	-0.137	-0.293	-2.049	-0.0188	-0.0357	3.995	3.073
	(0.0908)	(0.0916)	(3.019)	(3.071)	(0.107)	(0.106)	(3.596)	(3.567)
Log (un-irrigated land size)	-0.0331	-0.0449**	-2.165	-2.759	-0.0393	-0.0494**	-2.191	-2.729*
	(0.0244)	(0.0222)	(1.745)	(1.696)	(0.0254)	(0.0238)	(1.599)	(1.540)
Other controls	YES	YES	YES	YES	YES	YES	YES	YES
D-canal dummies	YES	YES	YES	YES	YES	YES	YES	YES
First stage *F*-stat								
Trust game					30.01***	30.86***	30.01***	30.86***
Vs_tail × trust game					70.00***	68.40***	70.00***	68.40***
Vs_head × trust game					50.16***	53.67***	50.16***	53.67***
Dictator game					25.08***	31.67***	25.08***	31.67***
Observations	535	532	535	532	535	532	535	532
R-squared	0.418	0.385	0.443	0.406	0.360	0.329	0.419	0.372

Note: Standard errors in parentheses are adjusted for correlations within individuals. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

The results of the dictator game, trust game, and dice game are divided by 100 for scaling.

Endogenous variable: trust game, vs_tail × trust game, vs_head × trust game, dictator game.

Other controls include log(plot size) or log(total plot size), HH head dummy, age, female HH head dummy, education level, and constant.

Table 10. Cropping pattern by canal section

	Head	Middle	Tail	*t*-value (head vs tail)
Sample size	50	81	58	
(Mean) Share of paddy cultivated land	0.728	0.721	0.765	-0.6332

Chapter 3:

How Access to Irrigation Influences Poverty and Livelihoods:

A Case Study from Sri Lanka

ABSTRACT. This study combines a livelihoods approach with a regression approach to quantify the effectiveness of irrigation infrastructure investment on improving people's livelihood strategies. Using a unique dataset based on households in southern Sri Lanka, and a natural experimental setting, we estimate from a two stage income regression model to show that irrigation access has a positive effect on income through livelihood choices. We also show through qualitative approaches that factors not linked to irrigation infrastructure may contribute to changes in livelihood portfolios. In addition, we highlight factors that result in certain households being unable to move out of poverty despite access to the improved irrigation infrastructure.

Keywords: irrigation, poverty, livelihoods

[†]This chapter is a joint work with Sonali Senaratna Sellamuttu, Ryuji Kasahara, Yasuyuki Sawada, and Deeptha Wijerathna. This is an Author's Accepted Manuscript of an article published in *Journal of Development Studies*, Volume 50, Issue 5, 2014, pp. 748-768, available online: http://www.tandfonline.com/10.1080/00220388.2013.841887. This paper forms part of a research project titled 'Impact Assessment of Infrastructure Projects on Poverty Reduction' conducted by the former Japan Bank for International Cooperation Institute, which was integrated into the Japan International Cooperation Agency Research Institute. We would like to thank Masahito Aoki and Taro Katsurai for their collaboration in the project design, survey implementation, and data processing. We also acknowledge the efforts of field survey supervisors Intizar Hussain, Fuard Marikar, and Sunil Thrikawala, and we thank the enumerators of the International Water Management Institute. We acknowledge the helpful comments and suggestions of Keitaro Aoyagi, Mark Giordano, Masahiro Shoji, and Mika Ueyama. Of course, we are responsible for any remaining errors.

1. Introduction

Because investment in irrigation infrastructure continues to be substantial, governments and donor agencies need to know whether such infrastructure helps alleviate the poverty of those who have access to irrigation in the context of achieving the Millennium Development Goals. Indeed, recent empirical studies have started to focus on the role of infrastructure in reducing poverty directly (Datt and Ravallion, 1998; Jacoby, 2000; Gibson and Rozelle, 2003; Jalan and Ravallion, 2003; Lokshin and Yemtsov, 2004, 2005; Jacoby and Minten, 2008). Although existing empirical studies try to uncover the important causal influences of infrastructure on poverty reduction, the structure of poverty reduction in this regard remains largely unaddressed. In this paper, we thus aim to bridge this gap in the existing quantitative studies by combining the canonical empirical framework of income regression and the livelihoods approach of Ellis (1998, 1999) and Ellis and Freeman (2004) to analyse household selection, or the 'portfolio' of livelihood activities that generate significant income.

The concept of poverty is complex because it is both multidimensional and dynamic in nature. Although conventional poverty measures focus on income and consumption expenditure (World Bank, 2001), an emerging body of research has argued that these measures only cover certain dimensions of poverty and lack the ability to indicate the actual meaning of poverty in the lives of those people who experience it (Brock, 1999; Narayan *et al.*, 2000; Fisher *et al.*, 2005). The sustainable livelihoods approach is one method that looks into different dimensions of poverty such as environmental, social, economic, and political ones, in order to provide a better understanding of the complex driving forces and processes behind it (Chambers and Conway, 1992; Davies, 1996; Carney, 1998; Scoones, 1998).

In this paper, we combine the canonical empirical framework of income regression with the sustainable livelihoods approach, with robustness checking through qualitative interviews. We show how access to irrigation influences poverty and livelihoods. More specifically, we first assess the impact of irrigation access on poverty alleviation by exploiting the natural experimental situation. Second, we estimate a multinomial logit model as a nonlinear difference-in-difference approach in order to show how a livelihood strategy changes according to the degree of irrigation access. In addition, we estimate a two stage income equation using the results of the livelihood choice and show the impact of irrigation access on income using a livelihood strategy. Finally, we investigate why the influences of irrigation investment may not be uniform across poor households, using the results of the in-depth interviews. For example, we address the reasons why certain households that have access to the improved irrigation infrastructure are still poor. This qualitative method enables us to address multiple dimensions of the impact of irrigation, which quantitative approaches usually overlook.

The present study makes two important contributions to the body of knowledge on livelihoods approaches. First, we apply the livelihoods approach in the context of irrigation infrastructure. We estimate the effect of irrigation access on livelihood strategy by employing a nonlinear difference-in-difference approach. To our knowledge, no previous empirical study of program evaluation has applied a livelihoods approach specifically to an irrigation infrastructure investment project. Second, we combine an income regression approach with an endogenously selected livelihood strategy. Although Jansen *et al*. (2006) developed factor and cluster analysis to group households based on the use of their main livelihoods assets (capitals), our approach carefully integrates the canonical income regression approach with the livelihoods approach.

Our approach is closely related to the one developed by Hansen *et al.* (2011) and White (2011) which discusses that it is beneficial for policy makers to understand the selection mechanism as a possible causal mediation effect, especially in impact evaluation of infrastructure interventions. This means that estimating the direct impact of irrigation access on income is less informative, because the causal mechanism is ignored as a black box. Our empirical strategy is to break down the causal effects of irrigation access on income by employing the livelihood approach. This approach enables us to avoid self-selection bias between irrigation access and income, and to extract the pure causal mediation effect on endogenous livelihood choice. Our approach is effective because irrigation access does not directly lead to poverty reduction. Rather, it involves the changes in livelihood choices from low productive ones to more productive ones such as cultivation of paddy or other commercial crops, which results in an increase in household income and poverty alleviation (e.g., Huang *et al*. 2006). Thus, it is important and informative to show the causal effect of irrigation access on income through the changes in livelihood choice. Note that our research design is different from a simple mixed method combing qualitative and quantitative approaches; instead, our design of combining a livelihood approach and impact evaluation of infrastructure interventions is necessary in order to comprehend the endogeneity of livelihood choice, or the causal mediation effect, rigorously. In addition, we believe that this approach validates the robustness of the estimated impact of irrigation access. We define the following causal links between pre-irrigation characteristics, livelihood strategy, and income and poverty: irrigation access enables farmers to cultivate paddy or other crops, which require large amounts of water even during dry seasons, which in turn results in poverty reduction.[15]

The remainder of this paper is organised as follows. Section 2 explains the study site and its natural experimental setting. Sections 3 and 4 explore how irrigation access influences poverty alleviation and primary livelihood activity and income, respectively. Section 5 discusses the qualitative aspect to irrigation infrastructure development and supports the quantitative findings. The final section presents our overall conclusions.

2. Research Design

2.1 Study site

The present study focuses on the Walawe left bank irrigation system in the southern dry zone of Sri Lanka. This irrigation system is a part of the Uda Walawe irrigation and resettlement project, implemented to develop a land area of 32,000 ha in the dry zone of

[15] In other words, our position is that it would be difficult to presume that irrigation access directly leads to higher income for individuals without changing their livelihood choices.

southern Sri Lanka for irrigated agriculture (Figure 1). The left bank area was divided into five divisions or blocks known as Sevanagala block located upstream of the Left Bank Main Canal (LBMC); Kiriibbanwewa block, located in the middle of the LBMC; Sooriyawewa block, located downstream of the LBMC; and the Mayurapura and Tissapura blocks which were implemented in different phases as a result of financial constraints. By 1997, irrigation water was only present up to the middle of the Sooriyawewa block (Hussain *et al.*, 2007; Molle and Renwick, 2005).

The upgrading and extension of the Walawe left bank irrigation system was funded by the Japan Bank for International Cooperation in 1997.

2.2 Method and Sample

We drew upon the relevant aspects of the reviewed empirical studies in order to adopt a livelihoods approach that combines both qualitative and quantitative methods, since previous studies have clearly illustrated the value of using mixed methods (Carvalho, and White, 1997).

Data for this analysis was gathered from a series of surveys that we have carried out in this area from the year 2000. An initial evaluation study was commissioned between 2000 and 2002 to assess the impact of irrigation infrastructure on poverty reduction (Hussain *et al.*, 2002; Sawada *et al.,* 2010). In 2005, a section of the project coverage area; i.e. Mayurapura block, that was not irrigated at the time of the first evaluation, was finally serviced, and a follow-up evaluation was then carried out between 2007 and 2008. By 2009, eight household surveys were conducted in this project. During the first five rounds of surveys, the Walawe left bank system was divisible into two areas: the first had adequate access to irrigation and the second was a rain-fed area with provisions for irrigation in the near future. When the sixth and seventh rounds of data were collected, the formerly rain-fed areas had been transformed into irrigated areas. Households who obtained plots in the north (head end) were able to have earlier access to irrigation than were households in the south (tail end). This situation provided us with important variations in access to irrigation infrastructure in order to evaluate the impact of irrigation infrastructure. Moreover, the type of farming in the study area varies from irrigated to rain-fed and *chena* (slash and burn) cultivation and the project area show considerable variability in terms of cropping patterns. Hence, these data are suitable for evaluating the role of infrastructure in improving livelihoods. For the livelihoods study, we utilised some of the data gathered during the first seven surveys (Appendix A) in addition to information obtained through a set of in-depth interviews in order to determine how the improved irrigation infrastructure had influenced the livelihood dynamics and poverty levels in the described study site.

For the quantitative analysis, panel data were used comprising seven household surveys (covering six cropping seasons), with five surveys conducted from October 2000 to September 2002 (Hussain *et al*., 2002), and two surveys from October 2006 to September 2007[16]. The household sample consisted of 193 households, which was a sub-sample of 22 per cent of the original 858 household sample used by Hussain *et al*. (2002). This included 92 households from the irrigated and rain-fed blocks of Sevanagala, Kiriibbanwewa, and Sooriyawewa, and 101 households from the extension area of the irrigation project, comprising the Mayurapura and Tissapura blocks on the left bank. Prior to the inception of the irrigation scheme, this area was primarily rain-fed or under *chena* cultivation. Mayurapura, our treatment group, was comprised of 85 sample households and had access to improved irrigation from 2005. In contrast, Tissapura, which was comprised of 16 sample households, did not have access to the improved irrigation infrastructure in 2007 and therefore acted as a control group. Sevanagala (the irrigated area), Kiriibbanwewa, and Sooriyawewa, where irrigation was available for all six seasons, also acted as other control groups. Table 1 summarizes the sample size and irrigation accessibility at each time period. Note that the Sevanagala rain-fed block was excluded from the study because irrigation canals did not reach this area owing to topographical constraints. Thus, the total sample size is 184.

[16] There were some inconsistencies in the survey method between the latest survey in 2009 and those of the previous ones. Thus, this study uses the first seven surveys.

For the qualitative case studies, we utilised a poverty mobility score in identifying our purposive sample of households to conduct in-depth interviews. Based on the categories of poverty measures described in Section 3.3, a simple poverty mobility score was assigned to each household for the period under investigation. We adopted a method similar to one used in some earlier empirical studies (Hettige and Mayer, 2003; Fuenfgeld *et al.,* 2004; Lawson *et al.,* 2007). We used this poverty mobility score to identify the households that represented outliers. This included households in the following mobility categories: those that had remained 'very poor' or 'better off' or had moved from 'very poor' to 'better off' between 2002 and 2007 (that is, after the irrigation infrastructure had been improved). Our purpose sample included households in the extension area that had access to improved irrigation infrastructure from 2007 (i.e., in Mayurapura, our treatment group) and households that did not have access to improved irrigation in 2007 (i.e., in Tissapura, our control group 2), as well as those in areas that had undergone earlier development (that is, Sevanagala, Sooriyawewa, and Kiriibbanwewa). The locations of the sample households in the study site are shown in Figure 1.

A semi-structured open ended questionnaire was used for the in-depth interviews, which covered some of the key livelihood 'capitals' described in the frameworks proposed by DFID (2001) and by Hettige and Mayer (2003).

2.3 Extension of the irrigation system

Table 2 shows the land ownership and irrigation accessibility by year. The left hand column shows whether the household owns the irrigated land and the right hand column includes rented land. Although half of households had no irrigation access in 2001, 90 per cent had irrigation access by 2007. Even though irrigation access deteriorated slightly from 2001 to 2002, overall long run accessibility improved. This deterioration may reflect a temporal stop in the water supply because of the construction of irrigation canals. Furthermore, although some households moved from irrigation access to no access, excluding them has little effect on our results.

2.4 Natural experimental setting

Although the entire Walawe left bank area is agro-climatically and geographically similar, only half of households had access to irrigation in 2001. Yet, by the end of 2007, almost all households had gained irrigation access. During the construction program, the government provided farmers with 0.2 ha of land for residence as well as 1.0 ha of irrigated paddy fields or 0.8 ha of other field crops[17]. However, according to settlers' subjective assessments following this land allocation, approximately half of households could claim a preference for plot-level land (Aoyagi *et al*., 2010). Intriguingly, the government used lotteries to distribute land for 30 per cent of farmers, and thus, these households received plots for certain crops regardless of their preferences. Consequently, 35 per cent of households did not obtain their preferred lands (Aoyagi *et al*. 2010). Therefore, some community and household characteristics were exogenously given in this setting. In fact, the econometric analysis by Aoyagi *et al*. (2010) finds supportive evidence that households were exogenously allocated to canal communities and within each distribution regardless of their observed characteristics. We thus conclude that sample selection errors are not serious with these data.[18] Therefore, by using this natural experimental situation, a simple comparison of the outcomes between the irrigated and non-irrigated groups shows the unconditional impact of irrigation access on poverty alleviation.

We utilize this situation to show the connection between irrigation access and livelihood choice as a causal mediation effect in the impact evaluation of irrigation infrastructure intervention following the spirit of Hansen *et al.* (2011) and White (2011). By combining the livelihood "choice" approach and clean quantitative impact evaluation method, we extracted selection bias arising from endogeneous livelihood choice and

[17] For the purpose of the livelihoods analysis, we consider this category to include sugarcane, banana, chilli, onion, and other crops.

[18] Appendix B tests the exogeneity of irrigation access by showing the results of the conditional independence test.

evaluated the impact of irrigation access rigorously.

3. Poverty Dynamics

3.1 Average consumption by irrigation status

Table 3 shows the average monthly consumption level per adult including self-production. We can see that the consumption level of households that have irrigated land is higher compared with those that do not have irrigated land, except for food consumption in 2002. In particular, the consumption level of those who have irrigation access is higher than that of those without irrigation, and the difference is statistically significant in 2001 and 2002.

3.2 Poverty and irrigation

Table 4 shows the statistical poverty measure using the Foster-Greer-Thorbecke (FGT) poverty indices, which are calculated as follows:

$$P_{\alpha t} = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{z_t - y_{it}}{z_t}\right)^{\alpha}$$

where $P_{\alpha t}$ is the headcount index ($\alpha = 0$), the poverty gap index ($\alpha = 1$), and the squared poverty gap index ($\alpha = 2$), z_t is the poverty line at time t, and y_{it} is the consumption level of household i at time t. Here, the poverty line is derived from the monthly poverty line suggested by the Department of Census and Statistics of Sri Lanka, namely Rs 1293 in 2001, Rs 1423 in 2002, and Rs 2233 in 2007.

We can see that all incidences of poverty declined over time. Although 76 per cent of households were below the poverty line in 2001, this declined to 31 per cent in 2007. In addition, all incidences of poverty were smaller for households that had irrigation access. Note that Table 4 shows the results of owned irrigated land only (including rented irrigated land has little effect on our results).

Table 5 shows the poverty head count ratio according to irrigation accessibility. Among households that had no irrigation access in 2002, the poverty headcount ratio decreased by 17 percentage points (0.45–0.28) by 2007 under the assumption that irrigation access is determined exogenously. We can see that the poverty head count ratio of households that had irrigation access is lower than that of households that did not. As mentioned before, some households had irrigated land in one year, but not in the next. However, because the number of these households was very small, this effect of 'losing' irrigated land is unclear from the sample.

Figure 2 displays the treatment effect on distribution by showing the cumulative distribution function of the log of expenditure. The difference between households that have irrigation access and those that do not highlights the impact of irrigation access on expenditure. The difference is larger for lower expenditure households, but it is unclear for higher expenditure ones. This means that irrigation access has a large impact on the poor, although it has hardly any impact on the better off.

3.3 Poverty transition

For all of the 184 households whose poverty statuses can be traced between 2001 and 2007, a poverty transition matrix was constructed (Table 6). By adopting a method similar to that proposed by Bird and Shepherd (2003), we defined four categories of poverty measures based on Sri Lanka's national official poverty line (NOPL): 'very poor' (average monthly consumption below 0.5 of NOPL); 'poor' (above 0.5 of NOPL but below NOPL); 'average' (above NOPL but below 1.5 of NOPL); and 'better off' (above 1.5 of NOPL). In order to compare the impact of access to irrigation, we separated the newly irrigated area (Block 5) from the rest. As Table 6 shows, the upper diagonal elements dominated the overall shares. While the shares of 'very poor' and 'poor' decreased dramatically from 2002 to 2007, the proportions of 'average' and 'better off' increased remarkably. This implies that households moved out of poverty during the survey period. Intriguingly, transient poverty captured by the 'poor' category is still an important issue in this area.

4. Livelihood Dynamics

4.1 Categorisation of livelihood activities

According to the sustainable livelihoods framework, as livelihood activities are usually considered to generate an income (DFID, 2001), for the purpose of the livelihoods assessment, the different livelihood activities engaged in by households were categorised. This categorisation was based on the breakdown of income sources that Hussain *et al.* (2002, 2007) applied, culminating in the following five categories: (i) paddy cultivation (rice crops), (ii) non-paddy cultivation (all non-rice crops grown on the site including sugarcane, banana, vegetables, and other field crops), (iii) natural resource related livelihoods (non-crop farm incomes from fishing and livestock rearing), (iv) labour work related to paddy cultivation (agricultural wages), and (v) all other non-farm livelihood activities (non-farm income from trade, services including the government sector, self-employment and shop keeping). As explained in Hussain *et al.* (2007), in a rural setting in Sri Lanka, as is typical to the one in this study, households engage in multiple livelihood activities, i.e., derive income from multiple sources that are both agricultural and non-agricultural. The broad categorisation of income sources as indicated above, were based on what was appropriate in the local context, and we followed a similar categorisation in our study to maintain consistency with and comparability to the earlier studies.

4.2 Defining primary livelihood activities

Empirical evidence suggests that in rural communities households often engage in more than one livelihood activity at a time (Ellis, 1999; Bryceson, 2000; Ellis *et al.,* 2003). From the selection of livelihood activities a household may undertake, we define the **primary livelihood activity** of the household as the activity that generates the highest proportion of the household's overall income. Each household was categorised based on their primary livelihood activities in 2001, 2002, and 2007. These particular time periods were selected in order to determine the changes in primary livelihood activities that coincided with obtaining access to the improved irrigation infrastructure.

4.3 Livelihood strategies

The range and combination of livelihood activities and choices that people make in order to achieve their livelihood outcomes are termed **livelihood strategies**. This is a dynamic process, in which people combine livelihood activities in order to meet their various needs at different times (Scoones, 1998; DFID *et al.,* 2002). According to previous studies, people's access to different levels and combinations of assets (capitals) is a major influence on their choices of livelihood strategies (Scoones, 1998). In other words, a household's choice of livelihood strategy is determined by fixed or slowly changing factors including its natural capital and human capital (Jansen *et al*., 2006).

We next investigated the relationships between the different portfolios of livelihood assets that households possessed (that is, human, social, physical, economic, and natural capital) and the determinants of livelihood strategies. We adopted a method similar to that described by Jansen *et al.* (2006), who grouped households based on the uses of their main livelihoods assets. The regression was run for six cropping seasons (that is, Maha 2000/01, Yala, 2001, Maha 2001/02, Yala 2002, Maha 2006/07, and Yala 2007) with the livelihood categories as the dependent variable and the different capitals as the various explanatory variables.

4.4 Empirical analysis of livelihood choices

In the model, the human capital variables included household size, age, gender, and educational level of the head of household, Under physical capital, since we are interested in looking at access to irrigation, we included the cross term of Mayurapura and dummy variable which takes one in year 2007. By controlling block dummies and season dummies, this cross term represents the difference-in-difference estimator in the multinomial logit model (Puhani 2012). Thus, this variable shows the treatment effect of irrigation access on livelihood choice. The natural capital variables we used with regard to location were geographic location in terms of the irrigation block or stratum the household belonged to, distance to the nearest daily market and paved road, and the size of the cultivable plot owned (ha). In terms of economic capital, the total value of a household's agricultural assets in the previous period was included because farmers who go into farming would be expected to acquire farm equipment. Because of this, the observations in the first season (Maha 2001-2002) are automatically dropped from this analysis. Under social capital, the variable included was being a member of a farmer's organisation.

As indicated by Jansen *et al.* (2006), these coefficients represent the effect of each explanatory variable on the probability of the household selecting the particular livelihood strategy relative to the probability of selecting the base category, which in this case was the agricultural wage livelihood strategy. We selected this livelihood category as the base because households without irrigated land tended to rely on this income source as explained in the following sections.

Table 7 shows the composition of livelihood activities. We use pooled data from six seasons, namely the Maha and Yala seasons in 2001, 2002, and 2007. The main livelihood activity in this area is paddy and non-paddy cultivation. In fact, few households had a livelihood activity that was natural resource related.

We conducted a quantitative analysis to show the impact of irrigation access on the choice of livelihood activities. The descriptive statistics are shown in Table 8. Because we do not have data on age, gender, and educational level in Yala in 2002, we replace them with those in Maha in 2002. We specify the multinomial logit model as follows:

$$\Pr(z_i = j) = \frac{\exp(\alpha_t + \beta_{block} + \gamma T \cdot 1(t \geq 5) + X_i\theta_j)}{\sum_j \exp(\alpha_t + \beta_{block} + \gamma T \cdot 1(t \geq 5) + X_i\theta_j)}, j=0,\ldots, 3,$$

where z_i is an indicator variable denoting the choice of livelihood for household i with respect to livelihood j, α_t is season fixed effect, β_{block} is block fixed effect, γ is the difference-in-difference parameter, which is a coefficient on the cross term of treatment group dummy, T, and year 2007 dummy (fifth and sixth season), i.e., $1(t \geq 5)$, X_i is a vector of household characteristics including human, physical, natural, social, or economic capital, θ_j is a vector of coefficients to be estimated, associated with choice $j \in$ {non-farm, agricultural wage employee, paddy cultivation, non-paddy cultivation}. We omitted the sample for the natural resource related livelihood category because it was too small for the estimation.

The results of the multinomial logit regression (Table 9) indicate that a household's choice of its primary livelihood strategy is determined by the combination of the biophysical and social variables that broadly fall within its livelihood assets (capitals) or those it has access to. Importantly, household head's education level has significantly positive effect in all categories, implying that better educated household heads tend to choose these livelihoods relative to agricultural wage. Inversely, those with less education tend to choose the agricultural wage, which is least profitable in our case.

With respect to a household's physical livelihood capital, our main interest is the difference-in-difference parameter representing the treatment effect of irrigation access. As expected, the effect is significantly positive in paddy and non-paddy livelihood relative to agricultural wage category. In contrast, irrigation access does not affect the choice of non-farm related livelihood.

Based on Puhani (2012), the treatment effect on the probability of choosing paddy as the main livelihood is calculated as follows:

$$\frac{\exp(\alpha_t + \beta_{block} + \gamma T \cdot 1(t \geq 5) + \overline{X}_i \theta_j)}{\sum_j \exp(\alpha_t + \beta_{block} + \gamma T \cdot 1(t \geq 5) + \overline{X}_i \theta_j)} - \frac{\exp(\alpha_t + \beta_{block} + \overline{X}_i \theta_j)}{\sum_j \exp(\alpha_t + \beta_{block} + \overline{X}_i \theta_j)}$$

where $\overline{X}_i$ is the mean level of each household characteristic. Using the estimated coefficients above, this treatment effect is 0.210, which indicate that irrigation access increases the probability of choosing paddy category by 21% relative to agricultural wage category.

4.5 Poverty levels and livelihood strategies

Next, we integrate the canonical poverty dynamics framework and livelihoods approach using regression analysis. We conduct quantitative analyses at two stages using the multinomial logit regression results in the previous section as the first stage. In the second stage, we explore the nexus between each livelihood and income level. In doing so, we correct the self selection bias that arises from endogenously determined livelihood strategies.

Based on Kurosaki and Khan (2006), the correction term can be calculated using the predicted values estimated in the multinomial logit model as follows:

$$\widehat{\lambda_{ijt}} = \frac{\phi[\Phi^{-1}[\widehat{Pr}(z_{it} = j)]]}{\widehat{Pr}(z_{it} = j)}$$

where $\widehat{Pr}(z_{it} = j)$ is the predicted value of household *i* at time *t* that chooses livelihood *j*, and φ[・] and Φ[・] are the density and distribution functions for a standard normal variable. Using these correction terms, the second stage regression is estimated as follows:

$$\log(y_{it}^{P}) = \sum_j \beta_j 1(livelihood_{it} = j) + Z_{it}\delta + \sum_j \rho_j \widehat{\lambda_{ijt}} + \alpha_i + \varepsilon_{ijt} \quad (1)$$

$$\log(y_{it}^{T}) = \sum_j \beta_j \log(income_{it} | incomesource_{it} = j) + Z_{it}\delta + \sum_j \rho_j \widehat{\lambda_{ijt}} + \alpha_i + \varepsilon_{ijt} \quad (2)$$

where y_{it}^{P} is household *i*'s income from its primary livelihood at time *t*, y_{it}^{T} is the total income of *i* at *t*, z_{it} is the set of covariates, and α_i is the household fixed effect. Note that the irrigation dummy is included in the first stage only. The results of these estimations are shown in Table 10[19].

[19] As noted in the previous section, we omit the natural resource related category because of the feasibility of the multinomial regression. However, we can predict the sample

Column 1 of Table 10 indicates the impact of each livelihood choice on the income from the primary livelihood. Standard errors are clustered at household level. The base category of livelihood dummies is agricultural wage. All of the livelihood dummies are significantly positive, indicating that agricultural wage is the least profitable livelihood. Together with the first stage results, households that have smaller plots of land or less educated heads tend to obtain a major part of their incomes from agriculture wage labour, rather than from paddy and/or non-paddy cultivation and thus they are more likely to remain poor. Of all the categories, non-paddy cultivation has the largest impact because the main crops other than paddy in this area are sugar cane and banana, and these are more profitable than paddy.

As before, the marginal effect of irrigation access on choosing the paddy crop as the livelihood strategy is 21%. Since the effect of choosing paddy on total income is 80.5%, we conclude that the impact of irrigation access through paddy cultivation is 17.85% compared with the base category, agricultural wage livelihood.

Column 2 indicates the effect of income from each source on total income. Because income from cultivation can be negative because of the large initial costs, the sample is smaller than that of column 1[20]. Agricultural wage has the smallest effect on total income. This also indicates that the agricultural wage is not profitable in this area. Other income sources significantly affect total income. Note that the coefficient of non-farm income is the largest among the livelihood categories. This indicates that the increase in non-farm income has the largest effect on total income.

In order to look into the transition of the effect of non-farm income, we include the

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selection term by using the estimated coefficient vector. For this reason, we can include the natural resource related category in the second stage regression. We also estimated the second stage regression without the natural resource related category, but it has had little effect on our results.

[20] The results are robust even if we control for the bias arising from dropping negative income households (Appendix C).

cross term of non-farm income and the linear time trend. Column 3 shows that this cross term is significantly positive, indicating that the effect of non-farm income on total income has increased from 2001 to 2007. Considering that non-farm livelihood is not directly linked to the improvement of the irrigation infrastructure, this finding implies that other factors contribute to income growth.

5. Qualitative Analysis of Livelihood and Poverty

Undertaking in-depth interviews with outliers from the panel survey data, based on the poverty mobility categories described in Section 3.3, enabled us to gain a better understanding into the factors causing the particular type of poverty mobility, outlier households were experiencing. For example, why are certain households that have access to the improved irrigation infrastructure still poor? Thus, the qualitative livelihoods analysis provided some useful insights on why differences may still exist amongst households with seemingly similar irrigation conditions.

Furthermore, by comparing the key characteristics that emerged from these in-depth interviews, we gained a better understanding of certain common factors that appeared to emerge in households belonging to each of the poverty mobility groups (that is, those that remained poor; those that remained better off and those that moved from poor to better off between 2002 and 2007). For example, it was apparent that households that remained poor in the study period (from Mayurapura and Tissapura), had exceptionally large families. By contrast, households that moved out of poverty or remained better off had average family sizes. These findings are consistent with those reported in previous studies, where severe poverty has been associated with larger families and a greater number of children (Bird and Shepherd, 2003).

While certain household characteristics such as being a female headed household are generally associated with a higher level of vulnerability and thereby poverty (Bibars, 2001), our case studies, similar to other studies (Chant, 2008), have illustrated that this is not necessarily always the case, and may vary depending on the overall circumstance of a household. For example, in our study, this appeared to be true when the number of dependents is high and when there are young school attending family members. By contrast, when the female head of household had lost her husband only after her children had completed their higher education and had stable employment and incomes, this did not cause them to fall into poverty. Therefore, the overall circumstances of the household play a role in determining poverty level, and these need to be assessed carefully in order to understand its particular requirements.

Some households that moved out of poverty between 2002 and 2007 showed the highest educational levels for both heads of households and spouses compared with poor or better off households. In these cases, a higher education might have helped motivate these individuals to engage in better paid income generating activities or more stable employment, and thereby move out of poverty. Furthermore, there seemed to be a higher dropout rate of school children in poor households, whereas in the case of those who had managed to move out of poverty or remain better off, children had completed their primary, secondary and in one case even tertiary level education. Therefore, in these cases, the educational levels of the children seemed to be higher overall compared with those of their parents, providing them with a better chance of staying out of poverty.

Households in rural agricultural settings usually depended on informal social networks, especially family networks, to help undertake their daily activities and cope with any challenges that they may have faced (Warren *et al*., 2001). For various reasons, family networks seemed to be weak in the case of households that remained poor. There was a breakdown in relations with immediate family members or with extended family members. By contrast, family networks seemed to be strong overall for households that moved out of poverty and remained better off. Family members usually provided both financial support (contributions towards household expenses and purchases) and non-financial support (grandparents helped look after grandchildren, married children helped look after elderly parents, and so forth).

Although some of these relations and networks are intangible and thus difficult to measure, they seem to play an important role in enhancing poverty mobility, namely helping households or individuals move out of poverty or remain better off. This is the case in both those that had access to irrigation for many years (in Sevanagala, Sooriyawewa, and Kiriibbanwewa) and those who had enjoyed better irrigation access only more recently (in Mayurapura and Tissapura).

In terms of community level relations and networks, it seemed that poor households did not hold positions of influence within the community. For example, even if they were members of community based organisations (CBOs) such as farmer's organisations, they were unable to get some of their grievances listened to. By contrast, those belonging to the mobility category that had moved out of poverty held positions of responsibility in local CBOs and therefore influenced the decision-making process. This factor distinguished between households in Mayurapura that were able to move out of poverty after accessing improved irrigation and those that continued to remain in poverty. In better off households, individuals held positions of influence and responsibility in local CBOs; in fact, some individuals in this category were also politically influential. Having a position of responsibility also seemed to be linked to how well established a family was within its community. For example, as expected, early settlers were usually better established than were those that had resettled more recently. However, in the case of poor households, even being an original settler did not necessarily mean they were able to gain influence within their communities.

With regard to the livelihood strategies followed by the three poverty mobility groups, one common feature was their mutual adoption of 'livelihood diversification'. This included one family member engaging in more than one livelihood activity, several members engaging in different livelihood activities, or a combination of both. In the case of those households that remained poor, livelihood activities usually comprised low income generating activities or unstable incomes that were perhaps seasonal. By contrast, in the case of those who experienced an upward mobility in terms of poverty, their livelihood activities seemed to be more stable and generated higher incomes. In some cases, however, households in this category were engaged in a combination of high and low income generating activities. Those who remained better off also seemed to engage in high income generating activities or enjoy more stable employment. There was also access to certain non-farm related income sources (such as state sector jobs) because of the relatively good educational levels of the second generation. Some households attributed their diversification into crop related livelihood activities such as paddy and non-paddy cultivation to their improved access to the irrigation system. Nevertheless, some households were still unable to move out of poverty, despite this because of other social conditions prevailing in the household as described earlier.

Another feature that emerged for both the households that moved out of poverty and those that were better off was that household members seemed to make a collective effort to make financial savings. It could be argued that this effort to save demonstrated that these households aspired to a better future and managed their finances accordingly. Households that remained poor, by contrast, did not save for the long term; in fact, many of these households described their difficulties in meeting their daily expenses. Once again, in the Mayurapura extension area, the ability shown by certain poor households to manage their finances in a prudent manner may have provided them with the additional financial resources and necessary skills required to exploit the improved irrigation infrastructure, as opposed to those poor households that had access to improved irrigation but remained in the poor category.

In terms of political influence, those households that remained poor held little political clout and described themselves as being voiceless and discriminated against (in instances such as land distribution), even if they supported the 'correct' political party. By contrast, those who remained in the better off category carried considerable political influence at the community level, including running for office in local elections.

6. Concluding Remarks

Having access to the improved irrigation infrastructure in the study area was a crucial factor that provided many households with the opportunity to diversify their livelihood activities and thereby increase their levels of income. The presented quantitative analysis shows that irrigation access is associated with declining poverty indices. We also find that the effect of irrigation access on consumption level is notable for the poor, although its effect is unclear for the better off.

The findings of both the quantitative (multinomial logit model) and qualitative (case studies) approaches presented here imply that households that were allocated cultivable land and irrigated water were able to grow their own crops as opposed to engaging in livelihood activities such as agricultural wage labour or depending on rain-fed cultivation. However, consistent with the trends reported in farming communities elsewhere in southern Asia (Ellis, 1999; Otsuka *et al*., 2008), we find that an important share of income has long been derived from non-farm related livelihood activities across the entire study site.

This clearly illustrates that other factors that are not linked to improved irrigation infrastructure contribute to the discussed changes in livelihood portfolios. For example, through the in-depth interviews we learned that many of the younger generation from these areas were joining the armed forces or working in the garment industry. The former is as a result of the socio-political conflict in Sri Lanka that prevailed at the time of the study and the latter is a reflection of global market trends and preferential trade policies.

Furthermore, the case studies identified several factors or combinations of factors that may result in some households being unable to move out of poverty even in the presence of an improved irrigation infrastructure. In particular, belonging to more vulnerable groups such as female headed households that have many dependents and poor family support or being voiceless in the community with no position of influence are scenarios that appeared to be associated with higher poverty levels.

Therefore, although the importance of investing in irrigation development in order to alleviate poverty in rural communities is non-debatable, it is crucial that other suitable supporting investments must also be made. For example, certain targeted non-agricultural interventions could be introduced in order to offer alternative income generating livelihood activities to local residents, especially the more vulnerable groups. For such non-agricultural interventions, existing marketing networks (if any) should be identified and joined in order to ensure their long-term sustainability. These interventions could be targeted to help diversify the livelihood portfolios of households that have remained poor even in the presence of irrigation development.

Another important point that emerged from the presented findings is that improved educational levels of the second generation are associated with an ability to find stable, well paid employment outside the farming sector. These individuals therefore have the necessary human capital and skills to obtain employment that is more remunerative compared with agriculture. One implication that arises from this finding is that it may be useful for integrated irrigation development projects to focus on enhancing educational or vocational training facilities in these rural areas in addition to investing in physical infrastructure development. These aspects are worthy of additional exploration and discussion.

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Figure 1. Map of the study site

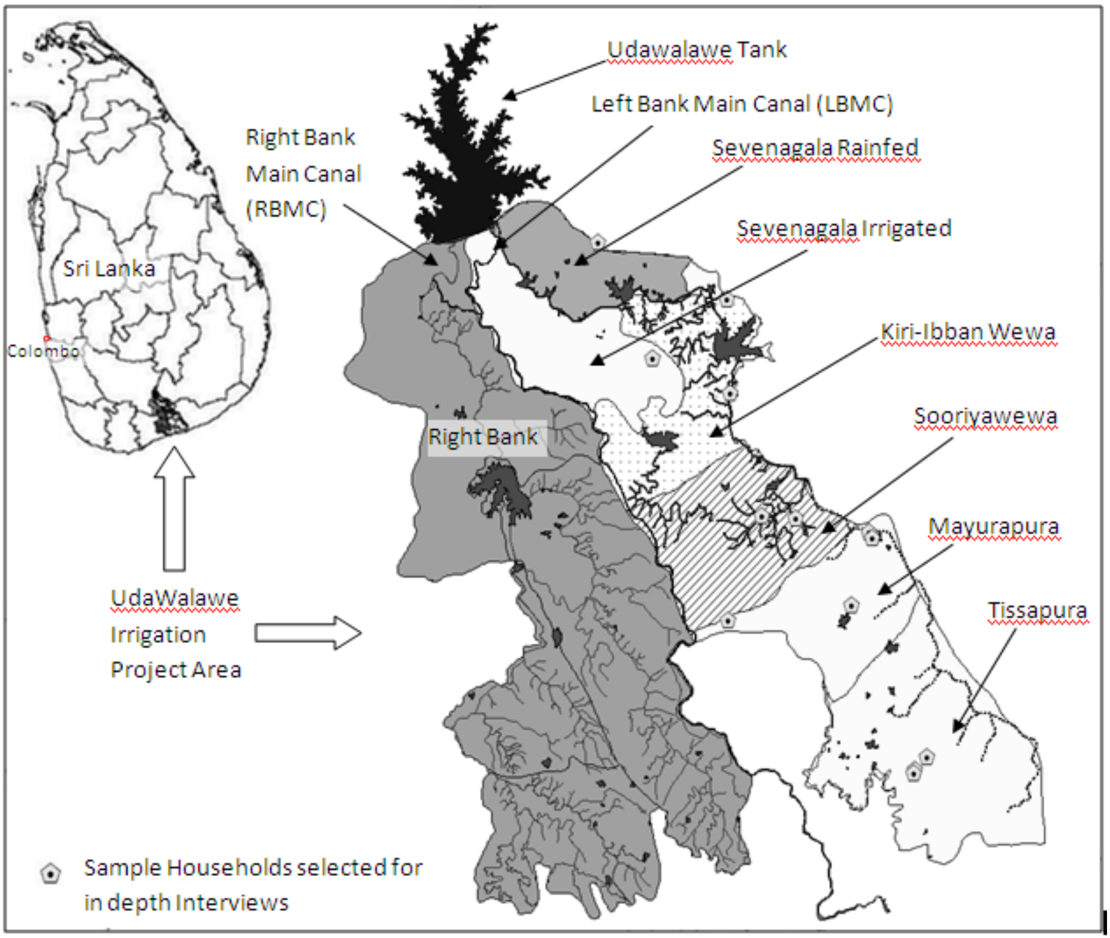

Figure 2. Treatment effect on distribution

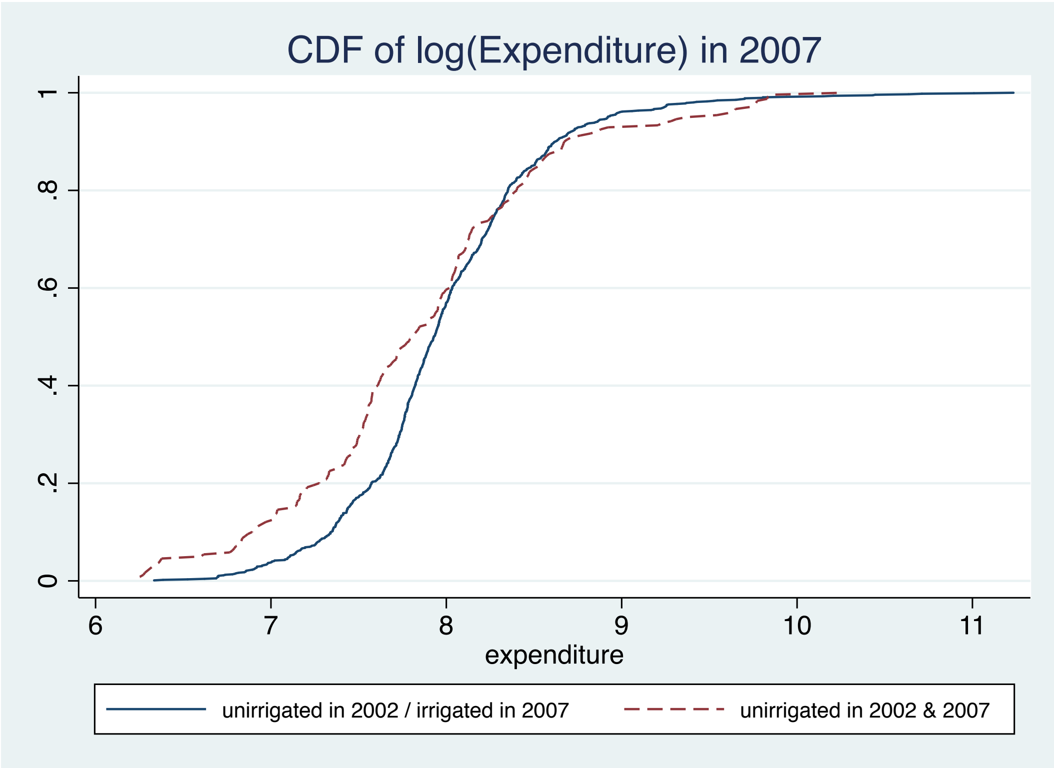

Table 1: Sample size and irrigation access of each block

	Sample size	Irrigation Access 2001 Maha/Yala	2002 Maha/Yala	2007 Maha/Yala
Control group 1				
Sevanagala (irrigated)	25	YES	YES	YES
Kiriibbanwewa	22	YES	YES	YES
Sooriyawewa	36	YES	YES	YES
Control group 2				
Tissapura	16	NO	NO	NO
Treatment group				
Mayurapura	85	NO	NO	YES
Omited group				
Sevanagala (rain-fed)	9	NA	NA	NA

Table 2: Transition of irrigated landownership

2001 Irrigated land	Percentage	2001 Irrigated land	Percentage
NO	49.91	NO	46.47
YES	50.09	YES	53.53
Total	100	Total	100
2002 Irrigated land	Percentage	2002 Irrigated land	Percentage
NO	54.35	NO	47.83
YES	45.65	YES	52.17
Total	100	Total	100
2007 Irrigated land	Percentage	2007 Irrigated land	Percentage
NO	10.33	NO	7.07
YES	89.67	YES	92.93
Total	100	Total	100

Table 3: Average consumption level per adult (in Rs)

Irrigated land (owned)	Total	Food	Non-food
2001			
NO	1050.546	702.4789	348.067
YES	1184.773	728.4112	456.3616
t-value of the difference	-2.6607***	-1.5096	-2.5053**
2002			
NO	1155.531	812.6323	339.4695
YES	1312.214	772.5323	539.6821
t-value of the difference	-2.8998***	2.4272**	-4.2400***
2007			
NO	1711.497	1067.122	644.3749
YES	1970.624	1150.982	819.6415
t-value of the difference	-1.3026	-2.1134**	-0.9217

<note> We use the age-sex weights in Townsend (1994). *** p < 0.01, ** p < 0.05, * p < 0.1

Table 4: Statistical poverty measure

FGT poverty indices(a)	a=0	a=1	a=2
2001	0.76132	0.32075	0.17045
2002	0.72996	0.27889	0.13436
2007	0.30661	0.07861	0.03014

Irrigated land (owned)	a=0	a=1	a=2
2001			
Non-irrigated	0.80399	0.36175	0.20214
Irrigated	0.71881	0.27991	0.13886
2002			
Non-irrigated	0.76599	0.29102	0.14002
Irrigated	0.6875	0.26461	0.12769
2007			
Non-irrigated	0.41228	0.14371	0.06999
Irrigated	0.29444	0.07112	0.02555

Table 5: Poverty head count ratio by the transition of irrigation accessibility

	Irrigated land (owned)	
2001		
Irrigated	0.8039927	
Non-irrigated	0.7188065	
2001–2002	Irrigated in 2002	Non-irrigated in 2002
Irrigated in 2001	0.6871981	0.7465278
Non-irrigated in 2001	0.7388889	0.7622222
2002–2007	Irrigated in 2007	Non-irrigated in 2007
Irrigated in 2002	0.296875	0.3958333
Non-irrigated in 2002	0.2760417	0.45

Table 6: Poverty transition matrix

Control group 1 2002 | 2007	Very poor	Poor	Average	Better off	Total
Very poor	0%	2.41%	4.82%	1.20%	8.43%
Poor	0%	7.23%	28.92%	10.84%	46.99%
Average	0%	2.41%	10.84%	15.66%	28.92%
Better off	0%	1.20%	3.61%	10.84%	15.66%
Total	0%	13.25%	48.19%	38.55%	100%

Control group 2 2002 | 2007	Very poor	Poor	Average	Better off	Total
Very poor	1.18%	2.35%	5.88%	3.53%	12.94%
Poor	0%	12.94%	25.88%	21.18%	60%
Average	0%	3.53%	5.88%	10.59%	20%
Rich	0%	0%	2.35%	4.71%	7.06%
Total	1.18%	18.82%	40%	40%	100%

Treatment group 2002 | 2007	Very poor	Poor	Average	Better off	Total
Very poor	0%	6.25%	12.50%	0%	18.75%
Poor	6.25%	12.50%	12.50%	12.50%	43.75%
Average	0%	0%	12.50%	12.50%	25%
Better off	0%	0%	6.25%	6.25%	12.50%
Total	6.25%	18.75%	43.75%	31.25%	100%

Table 7: Composition of livelihood activities

	Mean	Std. Dev
Agricultural wage (N=117)		
Total income	709.3845	1644.146
Agricultural wage	764.8029	660.2521
Nonfarm	181.5671	292.912
Noncrop	22.57835	129.3005
Paddy	4.853515	583.3283
Non_paddy	-264.4173	1302.95
Non-farm (N=371)		
Total income	2764.928	4568.475
Agricultural wage	102.1348	231.5177
Nonfarm	2523.718	4145.946
Noncrop	64.99775	615.2561
Paddy	231.3953	1019.23
Non_paddy	-157.3179	2884.221
Non-crop (N=48)		
Total income	9760.963	13571.34
Agricultural wage	129.3837	388.019
Nonfarm	1011.837	2000.042
Noncrop	7820.793	11426.02
Paddy	423.8421	1513.957
Non_paddy	375.1071	2478.259
Paddy (N=255)		
Total income	6722.843	7346.606
Agricultural wage	148.5073	449.4281
Nonfarm	817.1534	1230.735
Noncrop	149.326	805.639
Paddy	5466.335	5705.047
Non_paddy	141.522	2720.978
Non-paddy (N=328)		
Total income	9264.393	12136.39
Agricultural wage	171.1168	401.8782
Nonfarm	781.349	1624.802
Noncrop	175.5744	1399.025
Paddy	825.8642	2201.525
Non_paddy	7310.488	10477.37

Table 8: Descriptive statistics of the variables used in the analyses

Variable	Unit	Obs.	Mean	Std. Dev.
First and second stage				
Size of household	#	1104	5.182367	1.844339
Age of household head	Year	1095	47.71689	11.83472
Male household head	Binary	1095	0.9324201	0.2511383
Schooling years of household	Year	1093	5.511436	3.333577
Irrigated land holding (owned)	Binary	1104	0.634058	0.4819116
Sevanagala irrigated	Binary	(default category) (default category)		
Kiriibbanwewa	Binary	1104	0.1195652	0.3245995
Sooriyawewa	Binary	1104	0.1956522	0.3968817
Mayurapura	Binary	1104	0 .4619565	0. 4987765
Tissapura	Binary	1104	0. 0869565	0 .281899
Land size	ha	1104	2.81653	1.492772
Distance to daily market	km	1104	1.539839	2.631718
Distance to paved road	km	1100	3.538927	21.67813
Member of Farmer's	Binary	1104	0.8508454	0.3478195
Log(agricultural asset)		1104	2.114966	7.118592
Maha2001	Binary	(default category)		
Yala2001	Binary	1104	0.1666667	0.3728469
Maha2002	Binary	1104	0.1666667	0.3728469
Yala2002	Binary	1104	0.1666667	0.3728469
Maha2007	Binary	1104	0.1666667	0.3728469
Yala2007	Binary	1104	0.1666667	0.3728469
2nd Stage only				
Log(income from primary livelihood)		1066	7.661144	1.298832
Log(total income)		1035	7.721353	2.144174
Agricultural wage livelihood	Binary	1104	0.0987319	0.2984369
Natural resource related	Binary	1104	0.0425725	0.2019827
Paddy livelihood	Binary	1104	0.2273551	0.4193137
Non paddy livelihood	Binary	1104	0.2744565	0.4464422
Log(income from agricultural wage)		1104	-0.9960249	5.005858
Log(income from non farm)		1104	4.089598	4.862254
Log(income from natural resource related)		1104	-3.240645	3.727104
Log(income from paddy)		1064	0.7171861	6.132401
Log(income from non_paddy)		888	3.39199	5.565084

<note> We add 0.01 to compute logs

Table 9: First-stage estimation: the determinants of livelihood strategies

VARIABLES	(1) Non farm	(2) Paddy	(3) Non paddy
Human Capital:			
Size of household	-0.00922	-0.0159	-0.0363
	(0.0807)	(0.0893)	(0.0811)
Age of household head	0.0295*	0.000176	-0.0100
	(0.0170)	(0.0181)	(0.0182)
Male household head	-0.279	0.471	0.206
	(0.639)	(0.689)	(0.675)
Schooling years of household	0.143***	0.133**	0.105**
	(0.0527)	(0.0601)	(0.0512)
Physical Capital:			
Treatment effect of irrigation	0.295	1.998***	1.714***
	(0.625)	(0.660)	(0.631)
Natural Capital:			
Kiriibbanwewa	-0.864	-0.0736	-0.469
	(1.026)	(1.044)	(1.042)
Sooriyawewa	2.446**	2.129*	1.526
	(1.184)	(1.187)	(1.200)
Mayurapura	-1.165*	-3.380***	-2.888***
	(0.676)	(0.772)	(0.693)
Tissapura	-1.111	-2.330**	-2.211***
	(0.868)	(0.976)	(0.838)
Land size	0.354**	0.330*	0.379**
	(0.155)	(0.173)	(0.160)
Distance to daily market	0.119*	0.0492	0.0911
	(0.0691)	(0.0789)	(0.0762)
Distance to paved road	0.130*	0.136*	0.138*
	(0.0764)	(0.0764)	(0.0763)
Social Capital:			
Member of Farmer's	0.0454	1.722***	1.688***
	(0.427)	(0.503)	(0.470)
Economic Capital:			
Log(agricultural asset)$_{t-1}$	0.0302	0.0883***	0.101***
	(0.0254)	(0.0269)	(0.0256)
Constant	-0.314	-0.502	-0.348
	(1.101)	(1.205)	(1.123)
Period fixed effect	YES	YES	YES
Observations	843	843	843

Standard errors in parentheses are clustered at household level. *** p < 0.01, ** p < 0.05, * p < 0.1

Table 10: Livelihood strategies and incomes

VARIABLES	(1) Ln(income from livelihood)	(2) Ln(total income)	(3) Ln(total income)
Non farm livelihood	0.337**		
	(0.166)		
Natural resource related livelihood	0.903***		
	(0.221)		
Paddy livelihood	0.805***		
	(0.175)		
Non paddy livelihood	1.164***		
	(0.168)		
Log(income from agricultural wage)		0.0256**	0.0299**
		(0.0130)	(0.0127)
Log(income from non farm)		0.134***	0.116***
		(0.0299)	(0.0297)
Log(income from non farm)*season			2.43e-05***
			(4.51e-06)
Log(income from natural resource-related)		0.0888**	0.0914**
		(0.0381)	(0.0381)
Log(income from paddy)		0.100***	0.101***
		(0.0176)	(0.0178)
Log(income from non_paddy)		0.0769***	0.0721***
		(0.0105)	(0.0106)
Size of household	0.133***	0.0696	0.0636
	(0.0388)	(0.0864)	(0.0860)
Age of household head	0.0341**	0.00787	0.00521
	(0.0165)	(0.0285)	(0.0286)
Male household head	-1.429*	-1.083	-1.152
	(0.818)	(0.801)	(0.753)
Schooling years of household head	0.0523	-0.115	-0.120
	(0.0474)	(0.0725)	(0.0727)
Land size	0.0222	0.0176	0.0185
	(0.0901)	(0.0936)	(0.0945)
Distance to daily market	0.00258	0.0284	0.0172
	(0.0390)	(0.0550)	(0.0553)
Distance to paved road	-0.0182	-0.0168	-0.0139
	(0.0134)	(0.0143)	(0.0145)
Member of Farmer's Organization	-0.649***	-0.787**	-0.690*
	(0.246)	(0.359)	(0.358)
Log(agricultural asset)$_{t-1}$	-0.0580***	-0.0845***	-0.0742**
	(0.0161)	(0.0318)	(0.0321)
Constant	3.687**	7.933***	8.481***
	(1.595)	(2.976)	(3.007)
Correction terms	YES	YES	YES
Season fixed effect	YES	YES	YES
Observations	887	694	694
Number of household	184	179	179
R-squared	0.351	0.422	0.439

Standard errors in parentheses are clustered at household level. *** p < 0.01, ** p < 0.05, * p < 0.1

Appendix A: Survey Questionnaire

The survey instrument in all phases was a multi-topic questionnaire that included seven modules. The first module on basic information asked for the key characteristics of household (size, land ownership, and other household traits) and basic profiles of household members (age, schooling, employment, non-farm income). The second module on infrastructure got information on the operating environment of the household such as sources of water, irrigation infrastructure, cultivated area, operation and maintenance of infrastructure, and health facilities in the study area. The third module on agricultural production obtained information on the farming situation, farm assets, cost and value of agricultural production, household organizations, and marketing of inputs and produce. The fourth module on expenditure asked about household expenditure on food, clothing, medical care, transportation, education and other living expenses. The fifth module on credit collected information on loans, sources, repayment and problems in obtaining credit. The sixth module on risk coping asked questions about the household head's level of trust of others, support obtained from different sources, and his sociability.21 The last module on social capital included questions on support and benefits received from government and non-government institutions, and membership and active participation in people or community-based organizations.

[21] The 2001/2002 surveys also obtained the historical information (10 years prior) on production of main crops, yields and related problems as the original sixth module.

Appendix B: Conditional Independence Test of Irrigation Access

Our next concern is the exogeneity of the treatment. As mentioned above, our natural experimental setting may allow some systematic differences between already irrigated and newly irrigated areas. In order to confirm that endogeneity issue is not serious in our case, we show the conditional independence test, which is based on Imbens and Wooldridge (2012). This test implies that the outcomes in the treatment group are comparable with the control group conditional on observed household characteristics. This approach requires a group, which does not have irrigation access for an exogenous reason. In our case, households in Tissapura serve as this control group because both Mayurapura and Tissapura are in the Extension area, and irrigation was not available in both areas initially.

This test employs samples of originally non-irrigated areas, i.e., Mayurapura and Tissapura. We are interested in whether there is a systematic difference in outcome between these two groups conditional on observed household characteristics, thus we estimate the following:

$$\Pr(z_i = j) = \frac{\exp(\alpha_t + \delta Tissapura + X_i\theta_j)}{\sum_j \exp(\alpha_t + \delta Tissapura + X_i\theta_j)}$$

Table B shows the results of this test. Tissapura dummy is not significant in all categories, implying that there is no systematic difference in livelihood choice between Mayurapura and Tissapura. Thus, conditional independence holds in our case.

Table B: Conditional Independence Test

VARIABLES	(1) Non farm	(2) Paddy	(3) Non paddy
Human Capital:			
Size of household	0.0450	0.0253	0.0114
	(0.0869)	(0.110)	(0.0889)
Age of household head	0.0379*	0.0231	-0.0173
	(0.0197)	(0.0228)	(0.0213)
Male household head	-0.374	1.577	0.685
	(0.692)	(1.280)	(0.756)
Schooling years of household	0.123**	0.158**	0.0315
	(0.0561)	(0.0699)	(0.0498)
Conditional Independence Test:			
Tissapura	-0.0537	-0.0453	0.0829
	(0.597)	(0.725)	(0.538)
Natural Capital:			
Land size	0.359**	0.466**	0.255
	(0.170)	(0.203)	(0.161)
Distance to daily market	0.147*	0.0567	0.147*
	(0.0817)	(0.0945)	(0.0862)
Distance to paved road	0.116	0.124*	0.125*
	(0.0747)	(0.0749)	(0.0746)
Social Capital:			
Member of Farmer's	0.131	2.002*	1.538***
	(0.534)	(1.053)	(0.570)
Economic Capital:			
Log(agricultural asset)$_{t-1}$	0.0356	0.0665**	0.0870***
	(0.0288)	(0.0333)	(0.0288)
Constant	-1.788	-5.330***	-1.067
	(1.394)	(2.012)	(1.449)
Period fixed effect	YES	YES	YES
Observations	447	447	447

Standard errors in parentheses are clustered at household level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

Appendix C: Sample Selection Model for Negative Income

Finally, we need to check the selection bias resulting from dropping households who report negative income from each livelihood. In order to handle this bias, we also estimate the Heckman-type canonical sample selection model (Heckman 1976). As we mentioned already, negative income represent large initial cost, which is often the case of banana or other farming crop cultivation. Since these crops require less water than paddy cultivation, non-irrigated land size positively affects introduction of these crops. Thus, non-irrigated land size serves as a key variable that is only included in the first stage selection equation. As shown in Table C, the results are qualitatively unchanged. In addition, the coefficients on the inverse Mill's ratio are all insignificant statistically, confirming that the sample selection bias of dropping negative income households is not serious for our study.

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Heckman, J. (1976) The common structure of statistical models of truncation, sample selection, and limited dependent variables and a simple estimator for such models. *Annals of Economic and Social Measurement* 5, pp.475-492.

Table C: Livelihood strategies and incomes
(Heckman selection model for negative income)

VARIABLES	(1) Ln(income from livelihood)	(2) Ln(total income)	(3) Ln(total income)
Non farm livelihood	0.337***		
	(0.128)		
Natural resource related livelihood	0.902***		
	(0.203)		
Paddy livelihood	0.805***		
	(0.144)		
Non paddy livelihood	1.163***		
	(0.134)		
Log(income from agricultural wage)		0.0295	0.0331
		(0.0231)	(0.0202)
Log(income from non farm)		0.134***	0.116***
		(0.0209)	(0.0193)
Log(income from non farm)*season			2.36e-05***
			(7.99e-06)
Log(income from natural resource-related)		0.0925***	0.0945***
		(0.0310)	(0.0271)
Log(income from paddy)		0.0991***	0.0998***
		(0.0193)	(0.0169)
Log(income from non_paddy)		0.0771***	0.0724***
		(0.0183)	(0.0161)
Size of household[1]	0.134***	0.115	0.103
	(0.0319)	(0.0962)	(0.0841)
Age of household head[1]	0.0344**	0.00951	0.00673
	(0.0143)	(0.0395)	(0.0346)
Male household head[1]	-1.430***	-0.801	-0.903
	(0.366)	(1.066)	(0.932)
Schooling years of household head[1]	0.0521	-0.150	-0.150*
	(0.0345)	(0.100)	(0.0876)
Land size[1]	0.0219	-0.102	-0.0858
	(0.0552)	(0.180)	(0.158)
Distance to daily market[1]	0.00283	-0.0306	-0.0340
	(0.0269)	(0.0848)	(0.0741)
Distance to paved road[1]	-0.0181**	-0.0194	-0.0163
	(0.00820)	(0.0224)	(0.0196)
Member of Farmer's Organization[1]	-0.650***	-1.040*	-0.914*
	(0.196)	(0.588)	(0.516)
Log(agricultural asset)$_{t-1}$[1]	-0.0579***	-0.0819**	-0.0723**
	(0.0127)	(0.0348)	(0.0306)
Constant	2.706*	6.564	7.319*
	(1.622)	(4.427)	(3.880)
Correction terms	YES	YES	YES
Season fixed effect	YES	YES	YES
Mills ratio	0.114	2.348	2.052
	(1.005)	(1.761)	(1.542)
Observations	906	906	906

Standard errors in parentheses. *** p < 0.01, ** p < 0.05, * p < 0.1. Excluded instrument for the first stage is the non-irrigated land size. [1]variables included in both first and second stage.

Chapter 4:

Spatial vs. Social Network Effects in Risk Sharing

ABSTRACT. Although substantial research has been conducted on informal consumption smoothing within villages or within social clusters such as family and friends, few studies have compared the effects of these spatial and social networks. Employing spatial panel econometric models, this study extends the empirical test of the full risk-sharing hypothesis to incorporate spatial and social network effects and quantifies the diffusion of income shocks in each network. Estimation results based on household survey data in Southern Sri Lanka show that consumption smoothing performs better in spatial networks than in social ones, because income shocks defuse better among neighboring households. This study also shows the limitations of the conventional test when it is considered a special case of a spatial econometric model.

Keywords: Risk sharing; network; distance; kinship; spatial panel econometrics; externality

[†]This research was conducted as a project of the JICA Research Institute and supported by a Grant-in-Aid for JSPS Fellows (12J10183). I am grateful to Olugbenga Ajilore, Hidehiko Ichimura, Hitoshi Matsushima, Alistair Munro, Toru Nakanishi, Yasuyuki Sawada, Masahiro Shoji, Yasuyuki Todo, Koichi Ushijima, Wataru Yamamoto, Chikako Yamauchi, and participants at the VII World Conference of the SEA and JEA 2013 Autumn Meeting for their constructive comments on the earlier draft of this paper. I am also grateful to Deeptha Wijerathna and Prabhath Wickramaratne for data collection. All remaining errors are my own.

1. Introduction

Although rural households in developing countries face various types of risks, formal institutions that can mitigate these risks are often weak. Under such situations, informal consumption smoothing, that is, risk sharing, is critical. Townsend (1994) conducted the seminal work in this field by applying the full risk-sharing hypothesis (FRSH) to micro data in India. Although he rejects the FRSH, he also finds that the effects of income shocks on individual consumption are very small. Despite some cases where the FRSH cannot be rejected, many subsequent studies reach almost similar results to those of Townsend (1994) (e.g., Udry 1994; Townsend 1995; Ravallion and Chaudhuri 1997; Grimard 1997; Deaton 1997; Jalan and Ravallion 1999; Kurosaki 2001). To investigate the mechanism of this "partial risk-sharing" situation, several studies have focused on types of frictions in risk-sharing arrangements, such as private information (Ligon 1998) and limited commitment (e.g., Kocherlakota 1996; Foster and Rosenzweig 2001; Ligon et al. 2002; Dubois et al. 2008; Laczó 2013), and others have recently compared the effects of these barriers (Kinnan 2012; Karaivanov and Townsend 2013).

This study provides an alternative approach to the risk-sharing test that incorporates spatial and social network effects by employing a spatial panel econometric approach. These networks are important to mitigate the problems of asymmetric information and limited commitment.

Spatial networks are important because of transaction costs in risk-sharing arrangements. Because financial systems and infrastructures are underdeveloped in developing countries, the issues of transaction costs are more salient (e.g., Jack and Suri 2011). Under such conditions, spatial distance serves as a proxy of transaction costs, because it increases costs associated with asymmetric information and contractual enforcement problems (Rosenzweig 1988; Townsend 1995). Murgai et al. (2002) analyze the optimal risk-sharing group size under the existence of two types of transaction costs: "association" costs of establishing links with insurance partners and "extraction" costs of implementing transfers, such as monitoring and rule enforcing. They find that these transaction costs, measured by physical distance, have a negative effect on risk-sharing group formation. De Weerdt (2004) and Fafchamps and Gubert (2007) also test the effects of spatial distance on dyadic risk-sharing network formation, and find that higher costs (i.e., larger distance) prevent households from forming links. However, these studies mainly focus on group formation and do not analyze co-movement in consumption or the effect of individual income shocks. Thus, bridging these studies and the conventional tests of the FRSH should be addressed.

Although many previous studies have focused on intra-village risk sharing, social networks also play an important role especially under the limited commitment problem, because family ties and altruism facilitate income transfer among households with different realized income (e.g., Cox and Fafchamps 2008; Fafchamps 2011). For example, Grimard (1997) applies the FRSH to ethnic groups in Cote d'Ivoire and confirms a partial risk-sharing situation. Foster and Rosenzweig (2001) show that altruism based on family ties serves to ease the commitment problem. Fafchamps and Lund (2003) show that households receive gifts and informal loans through networks of friends and relatives. Angelucci et al. (2012) show that resources are well shared in extended family networks and that the positive spillover effect through the risk-sharing mechanism leads to higher human capital investment. In terms of network formation, De Weerdt (2004) and Attanasio et al. (2012) find that close friends and relatives tend to form risk-pooling groups.

Although these previous studies have emphasized the importance of both spatial and social networks, few have compared the effects of these networks based on the FRSH test. In order to fill this gap and incorporate these spatial and social network factors into an empirical model, this study employs a spatial panel econometric approach. Spatial econometrics focuses on spatial effects resulting from spatial dependence and heterogeneity (e.g., Anselin 1988; LeSage and Pace 2009). Recently, studies have been shifting to panel data analysis, and estimation methods have been developed (e.g., Elhorst 2003, 2010; Kapoor et al. 2007; Anselin et al. 2008). By employing these models, this study analyzes whether there are any spatial and social network effects in risk-sharing arrangements.

One of the most important objectives of employing spatial econometric models is the estimation of direct and indirect effects. If risk-sharing mechanisms work, albeit partially, individual income shocks have externalities, affecting other households' consumption. Angelucci and De Giorgi (2009) and Angelucci et al. (2012) show that a cash transfer program indirectly affects ineligible households' consumption through the risk-sharing mechanism. They articulately identify the treatment effect by comparing the outcomes of the ineligible in the treatment and control villages. In contrast, this study quantifies the external effects of income shocks based on the FRSH test, providing a mechanism treated as a black box in previous studies. By estimating direct and indirect effects, which are common approaches in spatial econometrics literature, we can quantify this external effect as well as direct effects of individual shocks, and we can compare the effects of income shock diffusion in spatial and social networks.

The remainder of this paper is organized as follows. Section 2 describes the conventional empirical test of the FRSH and the empirical strategy of this study. Section 3 describes the dataset used in this study, and Section 4 discusses the empirical results. The final section offers a summary and concluding remarks.

2. Empirical Strategy

The benchmark model is the conventional FRSH test, which is a standard model adopted in previous studies[22] (e.g., Mace 1991; Cochrane 1991; Townsend 1994; Kurosaki 1999). Suppose that an economy consists of *N* households (i = 1, …, *N*) with a von Neumann-Morgenstern utility function, u_i, where $u_i' > 0$ and $u_i'' < 0$. There is a finite set of states s = {1, …, S}, each of which occurs with probability π_{st}. In each state, households receive stochastic income y_{ist} and consume c_{ist}. The Pareto optimal resource allocation is obtained by solving the following social planner's problem:

[22] The following notation is based on Kurosaki (1999).

$$\max \sum_{i=1}^{N} \lambda_i \sum_{t=1}^{\infty} \rho_i^t \sum_{s=1}^{S} \pi_{st} u_i(c_{ist})$$

with the resource constraint

$$\sum_{i=1}^{N} c_{ist} \leq \sum_{i=1}^{N} y_{ist}$$

where λ_i is a Pareto weight and ρ_i is the discount factor of household i. The interior solution of this problem requires satisfying the following first order condition:

$$\lambda_i \rho_i^t u_i'(c_{ist}) = \mu_{st}, \quad \forall i,$$

where μ_{st} is the Lagrange multiplier divided by π_{st}. This condition means that the weighted marginal utility is equalized for all *i*, implying that idiosyncratic income shocks do not affect individual consumption under the FRSH.

Assuming the forms of a utility function, empirical tests of the FRSH can be derived from these conditions. If the utility function is the constant absolute risk aversion (CARA) type, individual consumption level co-moves with the average consumption level in the economy, and idiosyncratic shocks in income should not affect consumption[23]. Assuming homogenous preference parameters, the empirical test equation is as follows:

$$c_{it} = \beta \overline{c_t} + \gamma y_{it} + \eta_i + \varepsilon_{it}$$

where $\overline{c_t}$ is the within-cluster average of consumption level at *t*, y_{it} is household *i*'s income at *t*, and η_i are individual fixed effects. In order to avoid a spurious correlation problem, these average values are calculated without household *i*. If the FRSH holds, individual consumption should perfectly co-move with the average income, and idiosyncratic income shock should not affect individual consumption. Therefore, we can

[23] See Appendix for the results employing a CRRA utility.

test the FRSH by estimating this model and testing $\beta = 1$ and $\gamma = 0$.

In order to incorporate spatial and social network factors into the empirical test model, this study employs a combined spatial lag and error model, also called as an SAC model (LeSage and Pace 2009), with household fixed effects:

$$c_t = \beta W c_t + \gamma y_t + \eta + u_t$$
$$u_t = \lambda W u_t + \varepsilon_t$$

where W is a spatial weight matrix and η is a vector of household fixed effects. This model nests a spatial autoregressive model (SAR) when $\lambda = 0$. For estimation, this study employs a maximum likelihood approach. In order to handle the incidental parameter problem, the transformation approach proposed by Lee and Yu (2010) is used for bias correction.

The important point of this approach is that conventional FRSH tests are special cases of this model when there is no spatial correlation in the error term ($\lambda = 0$), and the weight matrix is defined as

$$w_{ij} = 1/N_c \text{ if } (i,j) \in c \text{ for } \forall i \neq j$$
$$w_{ij} = 0 \text{ otherwise}$$

where c is the set of risk-sharing clusters, and N_c is the number of households in the same cluster. Thus, the conventional models implicitly assume that (1) there are no spatial correlations in the error term, (2) changes in consumption have identical effects among the members in the same cluster, and (3) there is no risk sharing across clusters. Note that this matrix is the row-standardized version of the adjacency matrix whose element is 1 if i and j belong to the same cluster, and 0 otherwise.

Considering the conventional tests as spatial econometric models causes another problem in the estimation. Previous studies employing the conventional tests have estimated the models using ordinary least squares (OLS). However, under the existence of spatial dependence, OLS estimators are known to be inconsistent (Anselin 1988). By comparing the estimation results of the OLS and spatial econometric versions, this study can discuss the bias of the conventional tests.

In addition to the block-based weight matrix, this study uses an inverse distance matrix as another method for capturing the spatial network effect. In the case of risk sharing, it is natural to assume that transaction costs are increasing functions of the distance among each household (e.g., Rosenzweig 1988; Murgai et al. 2002; Fafchamps and Gubert 2007). For example, neighboring households can easily monitor each other to mitigate the moral hazard problem and to implement risk-sharing contracts. Thus, under the existence of transaction costs, the consumptions of neighboring households are more likely to co-move than those of distant households. Note that the conventional test assumes perfect co-movement of the consumptions of households in the same cluster regardless of distance. Regarding the spatial correlation in unobserved factors, neighboring households tend to face the same spatially covariate shocks. In order to reflect these factors and assign larger values to nearer households, an inverse distance matrix based on GPS data is used as a weight matrix.

Regarding social networks, this study uses an adjacency matrix based on kinship. This type of network is important because extended families might be connected altruistically, and the tie can facilitate income transfer in a risk-sharing arrangement (e.g., Foster and Rosenzweig 2001; Cox and Fafchamps 2008; Fafchamps 2011). Thus, households connected in terms of kinship tend to share risks, which results in co-movement of consumption. Using this matrix enables us to analyze these effects quantitatively.

In addition to estimating these models, this framework enables us to estimate direct and indirect effects. Under the existence of a risk-sharing mechanism, individual income shocks not only affect consumption of the said household but also that of neighboring households. However, few studies examine these effects quantitatively. Using the estimation results of spatial econometric models, this study estimates the direct

($=\partial c_{it}/\partial y_{it}$) and indirect effects ($=\sum_{i\neq j}\partial c_{it}/\partial y_{jt}$). Based on the literature of spatial econometrics (e.g., LeSage and Pace 2009), our study specifies these effects as follows:

$$\bar{M}_{direct} = n^{-1}tr(S(W))$$
$$\bar{M}_{total} = n^{-1}\iota_n'(S(W))\iota_n$$
$$\bar{M}_{indirect} = \bar{M}_{total} - \bar{M}_{direct}$$

where $S(W) = (I_n - \beta W)^{-1}I_n\gamma$ and ι_n is a vector of ones. Comparing these effects, this study can quantify the spatial and social externalities of income shocks.

Table 1 summarizes the expected results from each hypothesis. In the case of the FRSH, the coefficient on the spatial lag is 1, and that on income is 0. Thus, both direct and indirect effects are also 0. In a partial risk-sharing case, the coefficients on both spatial lag and income are positive, which results in positive direct and indirect effects. If there is no risk sharing (i.e., autarky), i's consumption is determined only by his/her own income, implying that the coefficient on the spatial lag is 0. Thus, the indirect effect is also 0 despite that the direct effect is equal to the coefficient on income.

3. Data

This study uses a dataset collected by JICA (former JBIC) as part of the research project "Impact Assessment of Infrastructure Projects on Poverty Reduction"[24]. The study site is Walawe Left Bank (WLB), which is located in the southern part of Sri Lanka. Using Japanese ODA loans, the government started to construct the Left Bank Main Canal in 1995, and most households had received access to irrigation water by 2008.

In order to assess the effects of this project, JICA conducted eight household surveys covering seven cropping seasons, collecting data that included the households' demographic information and their seasonal income and consumption. Because the

[24] See JBIC Institute (2007) for details of this project.

consumption module of the questionnaire was modified in the last survey round, this study uses panel data of the former seven rounds. The original sample size was 858 households in the first four rounds, and 193 households in the next two rounds. Of the 193 households, both GPS and balanced panel survey data were available for 171 households after dropping missing observations. The locations of each household are shown in Figure 1. The average distance among households is 10.17 km with a standard deviation 7.35.

Figure 2 shows the kinship network among the heads of the sample households[25]. The network density, defined as $2m/n(n-1)$, where m is the number of edges in the network, is 0.279. Among 171 households, 49 do not have kin in the sample.

The study site is divided into five blocks according to their accessibility to irrigation: Sevanagala Irrigated, Sevanagala Rainfed, Kiriibbanwewa, Sooriyawewa, Mayurapura, and Tissapura. This study uses these blocks as clusters of risk sharing. Because the irrigation canal was originally constructed from the upstream area and gradually extended downstream, there are time lags in the irrigation access among each block. Table 2 summarizes the timing of the irrigation access in each block. Specifically, Sevanagala Irrigated, Kiriibbanwewa, and Sooriyawewa were already irrigated by the first round. Mayurapura accessed irrigation water by the sixth round, and Tissapura did so by the last round. Because of topographical constraints, irrigation access was not available in Sevanalgara Rainfed for the sample period.

Table 3 shows the descriptive statistics of the variables used in this study. The total sample size is 1026 (171 households × 6 cropping seasons). Following previous studies, this study uses adult-equivalent consumption and income based on the age and sex weights in Townsend (1994). This consumption includes self-produced items, and both

[25] In this study, the definition of kinship is father/mother, uncle/aunt, cousin, grandfather/grandmother, son/daughter, nephew/niece, grandson/granddaughter, brother/sister, and other extended relationship. Because of reporting errors, the matrix is not symmetric. I tested robustness by replacing the asymmetric entries with 0, 0.5, or 1, and found that the qualitative results of the main findings were not affected very much.

consumption and income levels are adjusted for the price index based on 2005 Sri Lanka Rupees[26]. The net incomes are negative for 7.4% of the samples, because their agricultural input costs exceed the total value of production. This is typically true of farmers who started banana cultivation, which is the second most popular crop in the region after paddy, because of the large initial cost.

Table 4 shows Moran's *I* for the transient change in income and consumption, which is defined as the difference between the adult-equivalent income/consumption at time *t* and its average over six seasons.[27] Changes in income tend to co-move according to the spatial network, that is, the block-based and inverse distance matrices, though the magnitudes are very small. Because a substantial number of households earn the largest share of their income from agriculture in the study area (Sellamuttu et al. 2013), there are some spatially covariate shocks that affect agricultural productivity, such as bad weather and crop disease (e.g., Druska and Horrace 2004). Food consumption tends to co-move both spatially and socially. In some cases, correlation in food consumption is significant even when income changes are not correlated. This implies that idiosyncratic shocks are diffused in networks because of the risk-sharing mechanism. Non-food consumption is also correlated, especially according to the inverse distance matrix. Although these casual observations support the existence of a risk-sharing mechanism, formal testing based on the FRSH models is still required.

4. Estimation Results

4.1 Baseline Results

Using the described dataset, this section estimates the conventional FRSH test and the SAR and SAC models. This study uses three different weight matrices: (1) the

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[26] The source is http://www.indexmundi.com/facts/sri-lanka/consumer-price-index

[27] The Moran's *I* statistic is a measure of spatial correlation defined as

$$I = \frac{n}{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(x_j - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})}.$$

block-based matrix, whose element takes 1 if i and j live in the same block; (2) the inverse distance matrix, whose elements are calculated based on GPS data; (3) the kinship matrix, whose element takes 1 if i and j are kin. (1) and (2) capture spatial networks and (3) captures social networks. These matrices are row-standardized for the estimation. As previously mentioned, the estimation results of the conventional test might be biased when the test is regarded as a spatial econometric model. Thus, comparing the results of the conventional test and the SAR model with the block-based matrix, which corresponds to the spatial econometric version of the conventional test, shows the degree of this bias.

Table 5 shows the estimation results when the dependent variable is food consumption. Both the conventional test and the SAR models cannot reject the FRSH because the coefficient on income is not significant. However, the co-movement of consumption is not perfect in all cases because the coefficient is significantly different from 1. The point estimate changes from the conventional test and the SAR model. The spatial lag term, which corresponds to the village-level average consumption, decreases from 0.916 to 0.721, and the coefficient on income increases from 0.0187 to 0.0212. These differences result from the bias in the conventional test. Once the spatial error term is introduced (Column 5 to 7), the qualitative results change drastically. Income has a significantly positive effect on food consumption and strongly rejects the FRSH. Furthermore, the spatial error term is significant in models with the inverse distance and kinship matrices, suggesting that ignoring the spatial correlation in unobservables leads to the wrong results.

Table 6 shows the results of the same specifications when the dependent variable is non-food consumption. All of the results reject the FRSH, because the coefficient on income is significantly different from zero. Similar to the food consumption case, the point estimate of income changes from the conventional test to the SAR with the block-based matrix. The spatial correlation in the error term is significant in Column 6. However, it is not significant in the SAC with the block-based and kinship matrices, which rather support the SAR model.

4.2. Handling Measurement Error

One possible concern in the results of Tables 5 and 6 is measurement error in the income variable. The measurement error, which is uncorrelated with the error term, causes attenuation bias in the regression coefficient. To address this issue, using an instrument correlated with true income but uncorrelated with the measurement error is necessary (Ravallion and Chaudhuri 1997; Kinnan 2012). This study uses the irrigation access dummy as the excluded instrument. As previously mentioned, there is variation in the timing of irrigation access among blocks. It is possible to assume that the portion of the income change explained by improved irrigation access is not correlated with the measurement error. This study employs a two-step procedure for the estimation. The first-stage model is estimated by regressing the income level on the irrigation access dummy and the individual fixed effects. The first-stage F test for the excluded instrument strongly rejects the null hypothesis that the coefficient is zero (F =17.46). Using the predicted values from this estimation, $\widehat{income}$, the previous specifications are re-estimated as the second stage[28].

Table 7 shows the two-step estimation results for food consumption. Except for the conventional test, all specifications reject the FRSH because the coefficient on income is significantly positive. Furthermore, the magnitude of coefficients is larger in the two-step estimation than in Table 5, confirming the existence of the attenuation bias. The spatial error term is significant in the SAC for both the inverse distance and the kinship matrices. Thus, omitting this term can cause problems in the FRSH tests.

Table 8 shows the results for non-food consumption. The coefficients on income become larger than those in Table 6, also confirming the attenuation bias, and the FRSH is rejected. The spatial lag term in the SAR with the inverse matrix is not significant, which rather supports the autarky situation. However, the SAC is superior to the SAR model because the spatial error is significant in Column 5. Regarding the kinship weight matrix,

[28] Since the two-step estimation of the SAC model with the block-based matrix does not converge for both food and non-food consumption, they are not reported in the tables.

the SAC model supports autarky, but the spatial error term is insignificant.

4.3. Quantifying the Diffusion of Income Shocks

Using the results of the two-step estimation in Tables 7 and 8, the direct and indirect effects of an income shock can be estimated. Table 9 summarizes these effects for each specification. The last column shows the ratio of the indirect effect to the total one. For food consumption, the indirect effect is larger for the block-based and inverse matrices than for the kinship one. This implies that income shocks diffuse better in spatial network than in a social one. Regarding non-food consumption, the indirect effect is insignificant in the SAR model with the inverse distance matrix and in the SAC one with the kinship matrix. This is because the spatial lag term is insignificant for these specifications in Table 8. Although the contrast is less clear than in the food consumption case, spatial networks also play an important role for diffusing income shocks to smooth non-food consumption.

Because these direct and indirect effects summarize the feedback effect of an income shock, investigating each element of the feedback effect matrix $S(W) = (I_n - \beta W)^{-1} I_n \gamma$ is also useful. Figures 3 and 4 show the relationship between the spatial distance and the elements of $S(W)$ in the SAC specifications using the inverse distance matrix for food consumption and non-food consumption, respectively. Although the results of the kernel-weighted local polynomial regression show a very flat and small-magnitude relationship, there are peaks at approximately 7 and 24 km. These non-linear relationships imply that there is a trade-off between the scope and effectiveness of risk sharing (e.g., Fafchamps and Gubert 2007). Although spatial distance increases transaction costs, it also reduces the possibility of facing covariate shocks. Therefore, the degree of risk sharing is a mixture of these positive and negative features.

4.4. Robustness Check

As a robustness check, the same specifications are re-estimated after dropping households with no kin from the sample. For these households, the spatial lag variable

(Wc_t) is zero in the previous estimation because the entries in the corresponding row are all zero. This treatment might cause bias in the results with the kinship matrix. Table 10 shows the re-estimation results employing a two-step procedure, and Table 11 shows the direct and indirect effect using the results in Table 10. As shown in these tables, the qualitative results are virtually unchanged, which supports the robustness of the previous findings.

5. Concluding Remarks

By employing spatial panel econometric models, this study extends the empirical tests of the FRSH to incorporate spatial and social network effects. This approach enables us to quantify the diffusion of income shocks in both spatial and social networks and to compare the effect of these networks. In addition, the conventional test can be regarded as a special case of a spatial econometric model, which implies an estimation bias in the conventional test.

The results after controlling for the attenuation bias of the income variable reject the FRSH in most cases. The point estimate changes from the conventional test to the spatial econometric model, confirming the bias in the conventional test. The results also show the existence of the spatially correlated unobservables, which are neglected in previous studies. These findings strongly support the effectiveness of the spatial econometric approach to the risk-sharing analysis.

The estimated direct and indirect effects show that income shocks are diffused in each network. Furthermore, the diffusion of income shocks in the spatial networks is larger than that in the social networks, especially for food consumption. This result suggests that consumption smoothing within spatial networks works better than that within social networks, implying that the reduction of transaction costs by living close together has a larger effect than facilitating transfers through the kinship network does. Therefore, mitigating individual risks by introducing formal insurance programs has a strong externality to boost welfare of neighboring households through a spatial risk-sharing mechanism.

Appendix: CRRA Specification

Another standard specification of the conventional test employs a CRRA utility function. In this case, the empirical test model is used to regress the log of consumption and income instead of these variables in level form, that is,

$$\log(c_{it}) = \beta\overline{\log(c_t)} + \gamma\log(y_{it}) + \eta_i + \varepsilon_{it}$$

One problem of this specification is that logarithms cannot be defined for negative values. As shown in Table 3, the reported income is negative for 7.4% of the samples because of large input costs in agriculture. Because the logarithm of these negative income cases cannot be defined, they are replaced with the value 1 before taking the log. In order to handle the bias arising from this treatment, a dummy variable that identifies these negative income cases is also included in the estimation.

Tables A1 and A2 show the estimation results for food and non-food consumption, respectively. The coefficient on income is significantly positive, which strongly rejects the FRSH. The spatial error term is significant when the weight is an inverse distance or kinship matrix. The spatial lag term is larger for the block-based and inverse distance matrices than for the kinship one, implying that households' consumption is better connected in spatial networks than in social ones. Table A3 summarizes the direct and indirect effects. Similar to the CARA specifications, the indirect effect is larger for the block-based and inverse distance matrices, implying that income shocks diffuse better in spatial networks than in social ones.

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Table 1: Summary of Expected Results

	Coefficient		Direct effect	Indirect effect
Hypothesis	Spatial lag	Income		
Full risk sharing	1	0	0	0
Partial risk sharing	+	+	+	+
No risk sharing (Autarky)	0	+*	+*	0

Note: In the case of autarky, the coefficient on income is identical to the direct effect.

Table 2: Irrigation Accessibility in Each Block

Year	2001		2002		2007		
Season	Maha	Yala	Maha	Yala	Maha	Yala	Sample Size
Survey round	1& 2	3	4	5	6	7	(total 171)
Sevanagala Irrigated	X	X	X	X	X	X	20
Sevanagala Rainfed							8
Kiriibbanwewa	X	X	X	X	X	X	16
Sooriyawewa	X	X	X	X	X	X	31
Mayurapura				X	X	X	82
Tissapura						X	14

Figure 1: Location of Sample Households

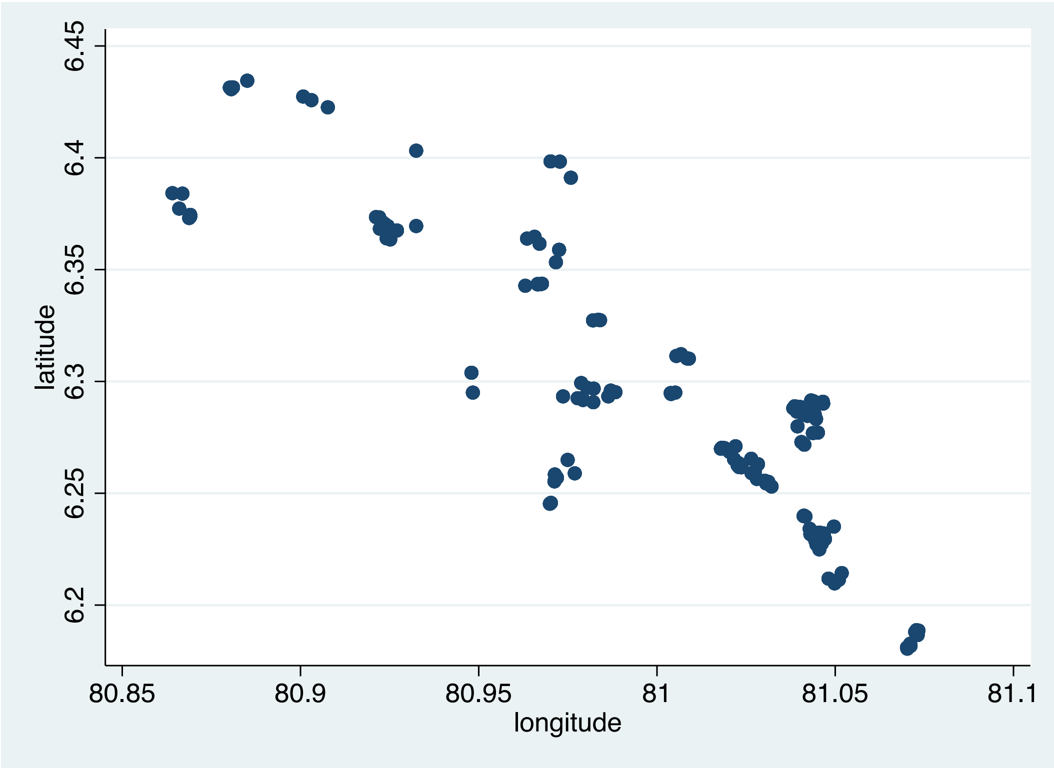

Figure 2: Graph of Kinship Network

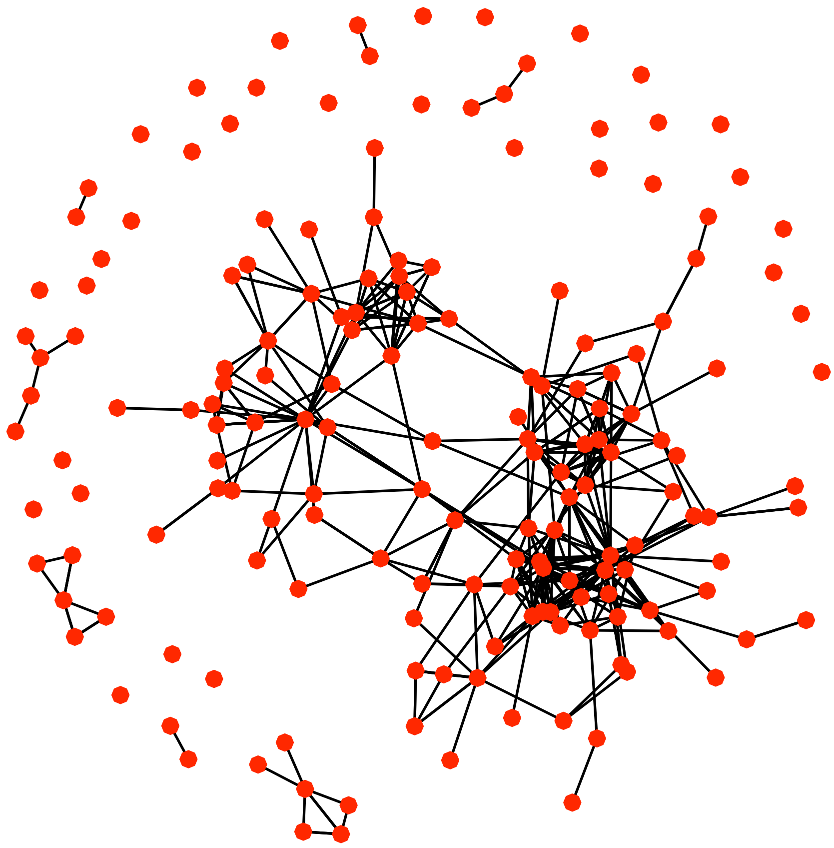

Table 3: Descriptive Statistics

Variable	Unit	Obs	Mean	Std. Dev.
Adult equivalent scale		1026	4.437914	1.572229
Food consumption	Rs.	1026	31488.09	16067.27
Non-food consumption	Rs.	1026	20003.52	33612.68
Income	Rs.	1026	35070.84	50461.43
Negative income dummy	Binary	1026	0.0740741	0.2620191
Irrigation access dummy	Binary	1026	0.5516569	0.4975669

Note: Both consumption and income are in real terms and based on 2005 Sri Lanka Rupees.

Table 4: Moran's *I* of Consumption and Income Shocks by Cropping Seasons

	Season					
Weight Matrix	Maha 2001	Yala 2001	Maha 2002	Yala 2002	Maha 2007	Yala 2007
Income change						
Block based	0.008	0.009	-0.004	0.131***	0.031**	0.028**
	(0.734)	(0.84)	(0.151)	(7.17)	(1.982)	(1.763)
Inverse distance	0.036*	0.015	-0.01	0.078***	0.01	0.033*
	(1.487)	(0.802)	(0.197)	(2.947)	(0.576)	(1.364)
Kinship	-0.068	0.054	0.001	0.086	0.055	0.005
	(0.881)	(0.889)	(0.14)	(1.276)	(0.864)	(0.155)
Food consumption						
Block based	0.029**	-0.022	-0.015	0.004	-0.006	0.032**
	(1.851)	(0.847)	(0.499)	(0.538)	(0.018)	(2.01)
Inverse distance	0.029	-0.013	-0.009	-0.018	0.031*	0.04*
	(1.224)	(0.266)	(0.882)	(0.437)	(1.314)	(1.625)
Kinship	0.023	0.054	-0.07	0.118**	-0.055	0.152**
	(0.399)	(0.838)	(0.882)	(1.724)	(-0.684)	(2.207)
Non-food consumption						
Block based	-0.017	0.017	-0.024	-0.011	-0.021	-0.014
	(0.662)	(1.261)	(0.981)	(0.259)	(0.989)	(0.474)
Inverse distance	0.042**	0.049**	0.076***	-0.014	-0.068***	-0.038
	(1.839)	(2.009)	(2.99)	(0.274)	(2.796)	(1.194)
Kinship	0.337	0.071	0.027	-0.051	-0.043	0.122**
	(0.655)	(1.115)	(0.473)	(0.631)	(0.654)	(1.888)

The absolute values of the z-statistics are in parenthesis. *** p<0.01, ** p<0.05, * p<0.1

Table 5: Model Estimation Results for Food Consumption (One-step)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Model	Conventional	SAR	SAR	SAR	SAC	SAC	SAC
Weight Matrix	NA	Block	Inv. Dist.	Kinship	Block	Inv. Dist.	Kinship
Average consumption	0.916***						
	(0.0718)						
Spatial lag		0.721***	0.701***	0.385***	0.838***	0.901***	0.607***
		(0.0332)	(0.0434)	(0.0513)	(0.0665)	(0.0244)	(0.0572)
Income	0.0187	0.0212	0.0242	0.0276	0.0203***	0.0164**	0.0245***
	(0.0143)	(0.0149)	(0.0153)	(0.0174)	(0.00751)	(0.00703)	(0.00854)
Spatial error					-0.696	-0.797***	-0.321***
					(0.635)	(0.108)	(0.0864)
Observations	1,026	855	855	855	855	855	855
R-squared	0.266	0.033	0.049	0.026	0.029	0.081	0.022
Number of households	171	171	171	171	171	171	171

The dependent variable is the adult-equivalent food consumption. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 6: Model Estimation Results for Non-Food Consumption (One-step)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Model	Conventional	SAR	SAR	SAR	SAC	SAC	SAC
Weight Matrix	NA	Block	Inv. Dist.	Kinship	Block	Inv. Dist.	Kinship
Average consumption	0.570***						
	(0.0897)						
Spatial lag		0.351***	0.150**	0.184***	0.565***	0.865***	0.0976
		(0.0492)	(0.0686)	(0.0654)	(0.196)	(0.0363)	(0.117)
Income	0.0648*	0.0694*	0.0744*	0.0731*	0.0685***	0.0486***	0.0736***
	(0.0378)	(0.0382)	(0.0392)	(0.0389)	(0.0205)	(0.0167)	(0.0215)
Spatial error					-0.504	-1.171***	0.110
					(0.655)	(0.0792)	(0.118)
Observations	1,026	855	855	855	855	855	855
R-squared	0.043	0.035	0.033	0.032	0.036	0.040	0.032
Number of households	171	171	171	171	171	171	171

The dependent variable is adult equivalent non-food consumption. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 7: Model Estimation Results for Food Consumption (Two-step)

	(1)	(2)	(3)	(4)	(5)	(6)
Model	Conventional	SAR	SAR	SAR	SAC	SAC
Weight Matrix	NA	Block	Inv. Dist.	Kinship	Inv. Dist.	Kinship
Average consumption	0.875***					
	(0.0912)					
Spatial lag		0.644***	0.601***	0.228***	0.855***	0.380***
		(0.0449)	(0.0504)	(0.0532)	(0.0348)	(0.0885)
Income (predicted)	0.0855	0.243***	0.273***	0.564***	0.110***	0.479***
	(0.0987)	(0.0848)	(0.0843)	(0.0738)	(0.0398)	(0.0717)
Spatial error					-0.766***	-0.192*
					(0.113)	(0.107)
Observations	1,026	855	855	855	855	855
R-squared	0.293	0.090	0.114	0.066	0.186	0.063
Number of households	171	171	171	171	171	171

The dependent variable is adult-equivalent food consumption. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 8: Model Estimation Results for Non-food Consumption (Two-step)

	(1)	(2)	(3)	(4)	(5)	(6)
Model	Conventional	SAR	SAR	SAR	SAC	SAC
Weight Matrix	NA	Block	Inv. Dist.	Kinship	Inv. Dist.	Kinship
Average consumption	0.352***					
	(0.0858)					
Spatial lag		0.193***	0.0368	0.114**	0.836***	0.0752
		(0.0435)	(0.0488)	(0.0579)	(0.0451)	(0.105)
Income (predicted)	0.511***	0.636***	0.761***	0.722***	0.154**	0.746***
	(0.168)	(0.156)	(0.151)	(0.134)	(0.0727)	(0.160)
Spatial error					-1.151***	0.0514
					(0.0841)	(0.107)
Observations	1,026	855	855	855	855	855
R-squared	0.041	0.046	0.044	0.045	0.067	0.045
Number of households	171	171	171	171	171	171

The dependent variable is adult-equivalent non-food consumption. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 9: Direct and Indirect Effect of the Income Variable (Two-step)

	Direct	Indirect	Total	Indirect / Total
Food consumption				
Model: SAR				
Block	0.252***	0.435***	0.687***	63.32%
	(0.0738)	(0.125)	(0.186)	
Inv. Dist.	0.282***	0.409***	0.690***	59.28%
	(0.0734)	(0.115)	(0.172)	
Kinship	0.566***	0.116***	0.682***	17.01%
	(0.0626)	(0.0366)	(0.0778)	
Model: SAC				
Inv. Dist.	0.122***	0.663***	0.785***	84.46%
	(0.0363)	(0.204)	(0.221)	
Kinship	0.487***	0.198***	0.685***	28.91%
	(0.0588)	(0.0602)	(0.0687)	
Non-food consumption				
Model: SAR				
Block	0.635***	0.152***	0.786***	19.34%
	(0.132)	(0.0431)	(0.150)	
Inv. Dist.	0.759***	0.0318	0.791***	4.02%
	(0.128)	(0.0428)	(0.126)	
Kinship	0.722***	0.0691*	0.791***	8.74%
	(0.114)	(0.0417)	(0.132)	
Model: SAC				
Inv. Dist.	0.170**	0.838**	1.008**	83.13%
	(0.0664)	(0.420)	(0.452)	
Kinship	0.745***	0.0496	0.794***	6.25%
	(0.135)	(0.0699)	(0.135)	

Standard errors are in parentheses. *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Figure 3: Spatial Distance and Income Shock Diffusion (Food Consumption)

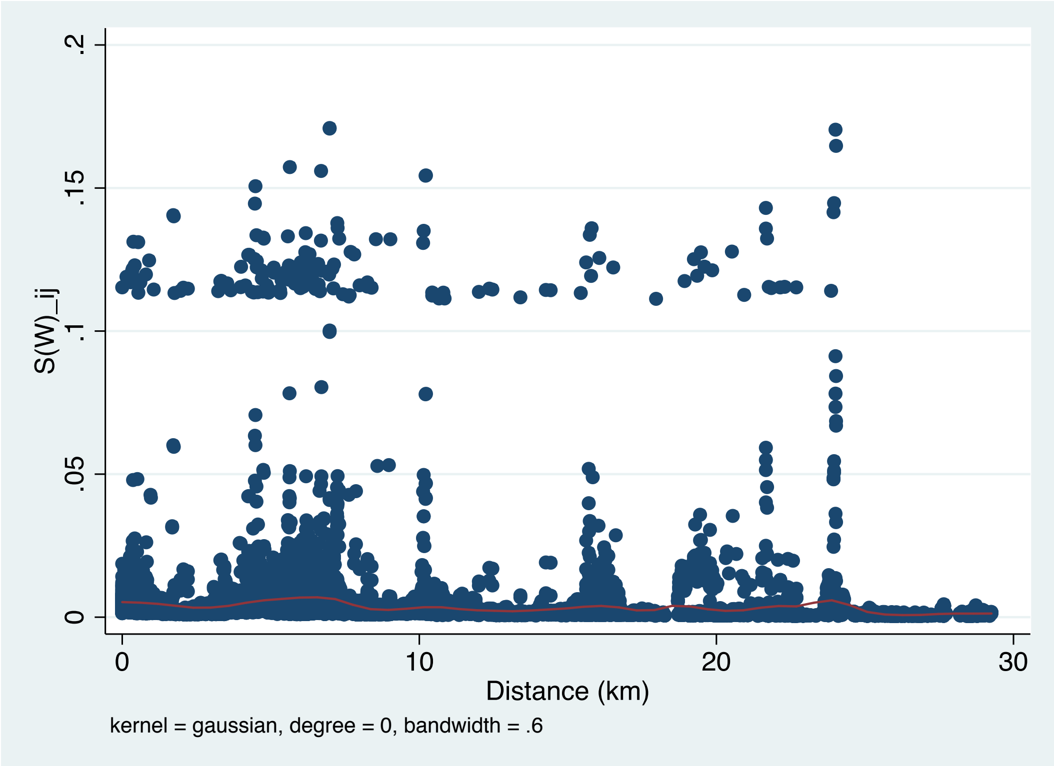

Figure 4: Spatial Distance and Income Shock Diffusion (Non-food Consumption)

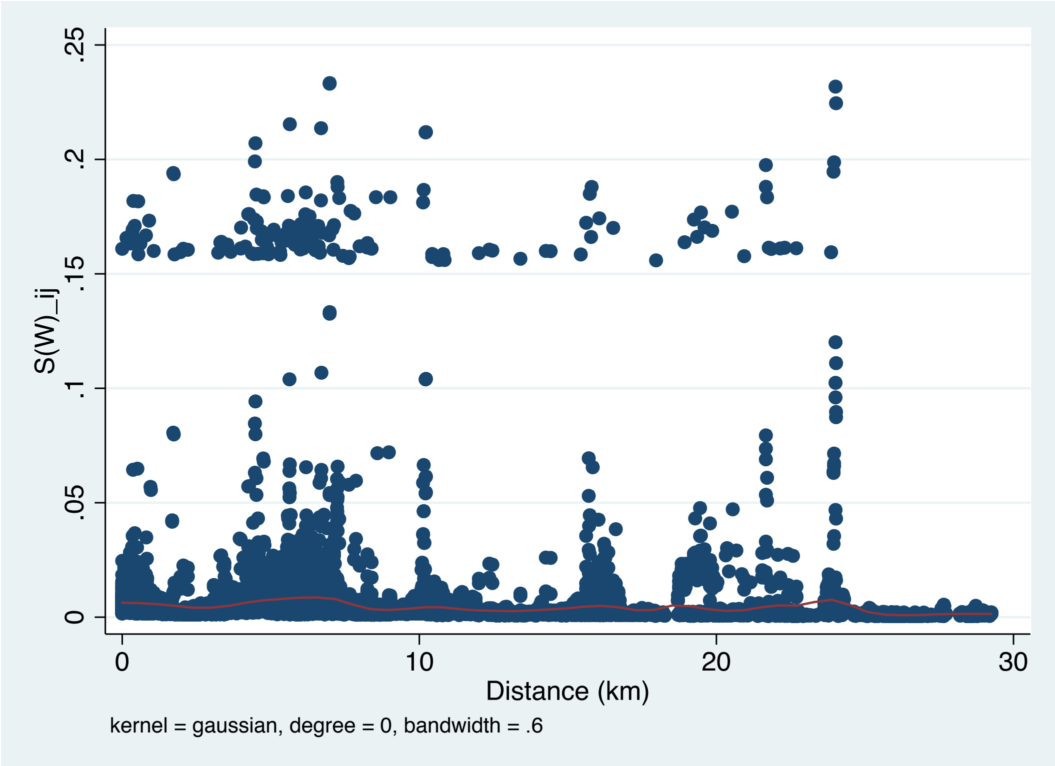

Table 10: Robustness Check for the Kinship Matrix (Two-step)

	(1)	(2)	(3)	(4)
	SAR	SAC	SAR	SAC
Weight Matrix	Kinship	Kinship	Kinship	Kinship
VARIABLES	Food	Food	Non-food	Non-food
Spatial lag	0.203***	0.380***	0.0717*	0.0533
	(0.0522)	(0.0902)	(0.0374)	(0.103)
Income (predicted)	0.576***	0.460***	0.720***	0.733***
	(0.0808)	(0.0770)	(0.158)	(0.178)
Spatial error		-0.218**		0.0259
		(0.110)		(0.104)
Observations	570	570	570	570
R-squared	0.069	0.068	0.042	0.042
Number of households	114	114	114	114

Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table 11: Robustness Check

	Direct	Indirect	Total	Indirect / Total
Food consumption				
Model: SAR				
Kinship	0.579***	0.148***	0.727***	20.36%
	(0.0686)	(0.0508)	(0.0926)	
Model: SAC				
Kinship	0.474***	0.279***	0.753***	37.05%
	(0.0619)	(0.0854)	(0.0857)	
Non-food consumption				
Model: SAR				
Kinship	0.719***	0.0581*	0.777***	7.60%
	(0.134)	(0.0350)	(0.147)	
Model: SAC				
Kinship	0.732***	0.0498	0.781***	5.96%
	(0.151)	(0.0917)	(0.155)	

Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table A1: CRRA Specification for Food Consumption

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Model	Conventional	SAR	SAR	SAR	SAC	SAC	SAC
Weight Matrix	NA	Block	Inv. Dist.	Kinship	Block	Inv. Dist.	Kinship
Average consumption	0.902***						
	(0.0620)						
Spatial lag		0.717***	0.693***	0.355***	0.858***	0.896***	0.623***
		(0.0326)	(0.0400)	(0.0465)	(0.0491)	(0.0239)	(0.0503)
Income	0.0410***	0.0460***	0.0466***	0.0565***	0.0356***	0.0319***	0.0451***
	(0.0156)	(0.0157)	(0.0150)	(0.0172)	(0.0123)	(0.0102)	(0.0126)
Negative income dummy	0.392***	0.457***	0.465***	0.607***	0.377***	0.324***	0.494***
	(0.142)	(0.142)	(0.137)	(0.157)	(0.113)	(0.0978)	(0.119)
Spatial error					-0.994	-0.828***	-0.384***
					(0.630)	(0.104)	(0.0752)
Observations	1,026	855	855	855	855	855	855
R-squared	0.310	0.076	0.112	0.019	0.071	0.184	0.003
Number of households	171	171	171	171	171	171	171

The dependent variable is the adult-equivalent food consumption. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table A2: CRRA Specification for Non-food Consumption

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Model	Conventional	SAR	SAR	SAR	SAC	SAC	SAC
Weight Matrix	NA	Block	Inv. Dist.	Kinship	Block	Inv. Dist.	Kinship
Average consumption	0.831***						
	(0.0830)						
Spatial lag		0.590***	0.495***	0.252***	0.532**	0.826***	0.538***
		(0.0478)	(0.0573)	(0.0508)	(0.240)	(0.0371)	(0.0636)
Income	0.0833**	0.0985***	0.107***	0.118***	0.0985***	0.0910***	0.106***
	(0.0375)	(0.0377)	(0.0386)	(0.0402)	(0.0333)	(0.0281)	(0.0321)
Negative income dummy	0.695**	0.866**	0.959***	1.087***	0.858***	0.827***	1.011***
	(0.338)	(0.343)	(0.355)	(0.370)	(0.320)	(0.267)	(0.301)
Spatial error					0.129	-0.843***	-0.364***
					(0.451)	(0.112)	(0.0855)
Observations	1,026	855	855	855	855	855	855
R-squared	0.185	0.081	0.090	0.048	0.076	0.109	0.016
Number of households	171	171	171	171	171	171	171

The dependent variable is the adult-equivalent non-food consumption. Robust standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1

Table A3: CRRA Specification of Direct and Indirect Effects

	Direct	Indirect	Total	Indirect / Total
Food consumption				
Model: SAR				
Block	0.0489***	0.116***	0.165***	70.30%
	(0.0142)	(0.0387)	(0.0516)	
Inv. Dist.	0.0491***	0.106***	0.155***	68.39%
	(0.0135)	(0.0370)	(0.0487)	
Kinship	0.0571***	0.0208***	0.0779***	26.70%
	(0.0148)	(0.00712)	(0.0210)	
Model: SAC				
Block	0.0428***	0.234**	0.277**	84.48%
	(0.0112)	(0.106)	(0.111)	
Inv. Dist.	0.0366***	0.287***	0.323***	88.85%
	(0.00992)	(0.107)	(0.114)	
Kinship	0.0479***	0.0457***	0.0936***	48.82%
	(0.0113)	(0.0134)	(0.0233)	
Non-food consumption				
Model: SAR				
Block	0.101***	0.143**	0.244***	58.61%
	(0.0331)	(0.0572)	(0.0871)	
Inv. Dist.	0.109***	0.106**	0.216***	49.07%
	(0.0336)	(0.0435)	(0.0732)	
Kinship	0.118***	0.0273**	0.145***	18.83%
	(0.0344)	(0.0113)	(0.0435)	
Model: SAC				
Block	0.111	0.417	0.528	78.98%
	(0.263)	(7.153)	(7.415)	
Inv. Dist.	0.100***	0.450***	0.550***	81.82%
	(0.0262)	(0.167)	(0.185)	
Kinship	0.111***	0.0793***	0.190***	41.74%
	(0.0283)	(0.0273)	(0.0517)	

Standard errors are in parentheses. *** p<0.01, ** p<0.05, * p<0.1