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Impact Assessment of Infrastructure Projects on Poverty Reduction

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The Role of Infrastructure in Mitigating Poverty Dynamics: A Case Study of an Irrigation Project in Sri Lanka

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Abstract

Although it is known that access to physical infrastructure enhances household welfare, there are very few micro-econometric studies that analyze the role of infrastructure in mitigating chronic and transient poverty. This paper aims to close this gap in the existing literature by evaluating the impact of a large-scale irrigation project implemented in Sri Lanka. To this aim, we collected household-level monthly panel data over a period of two years. According to the point estimates, with irrigation accessibility, the per capita income and the per capita food and non-food consumption expenditures increase by around 17.8%, 12.2% and 37.6%, respectively, evaluated at the average level among the treated. Also, the probability of binding credit constraints is reduced by 5.6% during the dry season. The latter result implies that irrigation enhances household access to credit which in turn contributes to further reduction in transient poverty. These empirical results suggest that irrigation infrastructure has a positive impact on reducing both chronic and transient poverty. The structural estimation results support the validity of our theoretical framework. We also perform robustness tests on these results. The qualitative results are comparable even when we adopt these alternative estimation approaches.

Keywords: Poverty Reduction, Role of Infrastructure, Monthly Panel Data

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Introduction

Our aim in this paper is to evaluate the role of irrigation infrastructure in mitigating the negative impact of poverty dynamics using household panel data from Sri Lanka. Such research and analysis is largely missing from the literature, although development economists consider physical infrastructure to be an indispensable precondition of industrialization and economic development (Murphy, Shleifer, and Vishny, 1989).[1] Many empirical studies demonstrate that the development of physical infrastructure improves an economy's long-term production and income levels (Canning and Bennathan 2000; Esfahani and Ramirez 2003; Lipton and Ravallion 1995; Jimenez 1995). For instance, Hulten, Bennathan, and Srinivasan (2006) find that in India from 1972 to 1992 highways and electricity accounted for almost half of the growth of the Solow residuals of manufacturing industries. The positive productivity effects of physical infrastructure development can be found even in rural areas and agricultural sectors (Jimenez, 1995; Fan and Zhang, 2004; and Zhang and Fan, 2004). From these findings, it is evident that infrastructure is likely to reduce poverty by enhancing growth because a strong positive correlation between income growth and poverty reduction has repeatedly been found in studies such as Besley and Burgess (2003), Dollar and Kraay (2000), and Ravallion (2001).

In fact, an increasing amount of empirical literature has started to focus on the role of infrastructure in reducing poverty directly. Existing studies include Datt and Ravallion (1998) on state-level poverty in India, Van de Walle (1996) on the poverty reduction effect of irrigation infrastructure in Vietnam, Jalan and Ravallion (2003) on water supply systems, and Lokshin and Yemtsov (2004, 2005) on the poverty reduction effect of community-level infrastructure improvement projects on water supply systems in Georgia. In addition, Brockerhoff and Derose (1996) and Jalan and Ravallion (2003) investigate the role of water supply and public health systems; and Jacoby (2000), Gibson and Rozelle (2003), and Jacoby and Minten (2008) investigate

[1] Physical infrastructure in general consists of two parts; namely, economic infrastructure such as roads, irrigation, and electricity; and social infrastructure such as water supply, sewer systems, hospitals, and school facilities.

the effectiveness of road and transportation infrastructure.

While these micro-econometric studies are insightful in uncovering the role of infrastructure in reducing poverty, two important issues remain unaddressed. The first issue is a proper identification of the causal impact of irrigation infrastructure on poverty reduction (Duflo and Pande 2007). This issue may be unaddressed because randomized evaluation, which has been increasing rapidly (Duflo, Glennerster, and Kremer 2008), is difficult to implement in the context of large-scale infrastructure. The second remaining issue is that to the best of our knowledge all the preceding micro studies of the nexus between infrastructure and poverty reduction employ a static concept of poverty even though most recent poverty studies have started focusing on its dynamic and stochastic nature (Dercon ed., 2005; Fafchamps 2003).[2] It has been established that policy analyses based on static poverty can yield substantial inefficiencies in policy interventions (Jalan and Ravallion 1998).

This paper aims to close these gaps in the literature by evaluating the role of irrigation infrastructure in mitigating the negative impact of poverty dynamics; that is, in reducing chronic and transient poverty by regulating water availability across seasons. The data we use on household accessibility to irrigation infrastructure is from a unique monthly household panel data set which was collected in Sri Lanka through extensive field surveys using standard questionnaires modified by us specifically for this study. We first employ propensity score matching to quantify the impacts of irrigation infrastructure access on individual livelihoods. We then investigate the various channels through which irrigation reduces chronic and transient poverty. To do this, we extend the model of the life-cycle permanent income hypothesis for a seasonal expenditure decision, similar to Paxson (1993), by including the differences in irrigation accessibility and endogenous credit constraints. We then evaluate the impact of irrigation infrastructure on poverty dynamics. We conduct a wide variety of robustness tests, such as nonnormal error terms.

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[2] Using district-level data from India, Duflo and Pande (2007) find that constructing a dam upstream reduced the adverse effect of variability in rainfall, possibly through improved irrigation accessibility.

The rest of the paper is organized as follows. In Section 2, we describe our data collection procedure in the field and the basic descriptive and poverty statistics data employed in this paper. Section 3 uses propensity score matching to show the poverty reduction effect of irrigation. Section 4 explains our theoretical framework, and in Section 5, we present the regression strategy and results. Section 6 concludes the paper.

1. The Field Surveys

As the sample for our evaluation study, we selected the Walawe Left Bank (hereafter, WLB) irrigation system in the underdeveloped area of southern Sri Lanka (Mahaweli Authority of Sri Lanka, 2002). The WLB Irrigation Upgrading and Extension Project for this system was initiated in 1997 with the help of concessional loans from the Japan Bank for International Cooperation (JBIC), formerly Overseas Economic Cooperation Fund (OECF).[3] The irrigation construction was implemented in the north first and then gradually extended to the south.

The government used lotteries to distribute land for some one third of the farmers. Based on the lottery results and without regard to their own wishes, these households were allotted plots for certain crops (Aoyagi, et al., 2010). Household who obtained plots in the north were able to have the earlier access to irrigation. This establishes a natural experimental situation of exogenously given irrigation placements, which helps us identify the causal impact of irrigation construction. At the time the data used in this paper was being collected, the WLB system was divisible into two areas: the first has adequate access to irrigation and the second is a rainfed area with provisions for irrigation in the near future. The entire irrigation infrastructure in the first area already had been rehabilitated and the rainfed area was adjacent to it. Given this arrangement, the former and latter areas can be considered treatment and control groups, respectively, for this irrigation construction project. The type of farming in the study area is varied, ranging from

[3] JBIC, formerly OECF, provided a total of ¥2.57 billion (approximately US$ 25 million) for five years starting from 1997. This covered about 85% of the total irrigation development cost in this region. The government of Sri Lanka provided ¥0.45 billion (US$ 4.4 million).

irrigated to rainfed and *chena* (slash and burn) cultivation, and the project area exhibits considerable variability in cropping patterns. The main crops grown include paddy, sugarcane, banana, and other upland crops. This situation is suitable for evaluating the role of infrastructure in reducing poverty.

Approximately 75,000 residents are covered under the WLB, including government allottees, encroachers, and members of nonfarm households, i.e., landless people. In order to select the representative sample households, we adopted a multistage stratified random sampling strategy using a complete list of all the households. The actual samples consist of 858 households, including 660 farm and 198 nonfarm households. In the WLB area, the *Yala* (dry) season begins in February and ends in September and the *Maha* (rainy) season begins in October and extends up to January. Therefore, to capture seasonality, household surveys were conducted five times in 2001 and 2002. The first, second, and third surveys took place in June, August, and October 2001, respectively. The first was conducted specifically to obtain monthly data for the previous *Maha* season while the second and third were designed to gather data for the *Yala* season. The fourth and fifth surveys were conducted in June and October 2002, respectively, to capture information on the 2002 *Maha* and *Yala* seasons.

Descriptive Statistics

As in JBIC and IWMI (2002), the households have several basic characteristics. With regard to household livelihoods information, approximately 75% of household heads perform agricultural work as their primary occupation. Consumption is divided into two main categories: food consumption and nonfood consumption (Table 1).[4] Income is calculated by aggregating income from the sale of crops, the imputed value of self-production, income from noncrop agriculture such as livestock, and wages from agricultural and nonagricultural sources. Our data

[4] Nonfood consumption broadly defined includes nondurable expenditures comprising such items as medical care and education.

include information on monthly income only for the latter twelve months, i.e., from October 2001 to September 2002, while on monthly consumption we have information for twenty-four months, from October 2000 to September 2002. For the purposes of our econometric analysis, we use the data pertaining to the congruent twelve months.[5] Irrigation coverage is measured by the percentage of population that uses water from the irrigation canal. There is an important variation in the irrigation rate, ranging from the broadest coverage of 88% in the Sooriyawewa area to merely 13% and 2% in the extension and rainfed Sevanagala areas, respectively. While, in Table 1, irrigation accessibility appears to be positively and systematically correlated with income and assets, further careful investigation is necessary to identify a causal effect of this infrastructure on chronic and transient poverty.

Table 1. Selected Household Characteristics by Credit and Irrigation Accessibility

Variable	Credit Constrained				Credit Unconstrained			
	Irrigated		Rainfed		Irrigated		Rainfed	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Head's Years of Schooling	5.30	3.36	5.56	3.32	5.75	3.30	5.82	3.38
Head Count of Adult Males	2.03	1.18	1.54	0.95	2.05	1.11	1.48	0.89
Head Count of Adult Females	1.92	0.99	1.51	0.85	1.90	1.03	1.50	0.89
Head Count of Children	1.41	1.44	1.86	1.34	1.34	1.40	1.74	1.32
Monthly Food Cons. per Adult Male (Rs.)	1033.1	581.7	963.4	508.9	1135.0	617.0	1080.2	535.6
Monthly Nonfood Cons. per Adult Male (Rs.)	384.4	1015.9	280.6	827.2	487.9	1277.8	349.1	995.5
Monthly Income per Adult Male (Rs.)	1990.8	4977.7	1587.4	2010.4	1930.6	4618.6	1493.9	5043.5
Age of Head	52.37	11.25	42.0	11.3	52.4	11.7	41.53	12.04
Female Head Dummy	0.13	0.34	0.10	0.30	0.12	0.32	0.09	0.28
Land Holding per Adult Male (Acre)	0.71	0.48	0.53	0.49	0.74	0.55	0.57	0.58
Years since Settlement	28.38	11.94	20.51	12.59	28.77	11.86	20.37	13.61
Experience of Agriculture (Year)	27.98	10.14	18.17	10.44	27.43	11.15	18.35	10.37

In Table 2 we provide decomposition results of an expenditure-based poverty index using the framework of Ravallion (1988) and Kurosaki (2006). We can define aggregate measures of

[5] We also utilize a set of income and expenditure variables expressed as those per adult male equivalent.

total poverty, P, chronic poverty, P^C, and transient poverty, P^T, for a population of N households: $P \equiv (1/N)\sum_N E[1 - (E_i/z)]^\alpha$, $P^C \equiv (1/N)\sum_N [1 - E(E_i/z)]^\alpha$ and $P^T \equiv (1/N)\sum_N \{E[1 - (E_i/z)]^\alpha - [1 - E(E_i/z)]^\alpha\}$ where E_i is the consumption level of individual i and z is a poverty line. We use total expenditure data for the consumption level, E_i, and calculate the expected values by computing sample averages for the twelve months October 2001-September 2002. We utilize the poverty gap measure by setting that α=2. The poverty line is set at 1.25 US dollars based on the World Bank's purchasing power parity adjusted by the local consumer price index (Chen and Ravallion, 2008). The decomposition results for the entire sample, both irrigated households and unirrigated households, are given in Table 2. This table shows households without irrigation are more likely to suffer from both transient and chronic poverty than households with irrigation. Also, the impact of irrigation infrastructure on reducing chronic poverty may be more significant than the impact on transient poverty.

Table 2. Poverty Decomposition

	Whole Sample	Irrigated	Unirrigated
Total Poverty	0.029	0.026	0.035
Chronic Poverty	0.006	0.005	0.011
Transient Poverty	0.022	0.022	0.024

The decomposition is based on the poverty gap measure. The poverty line is set at 1.25 US dollars.

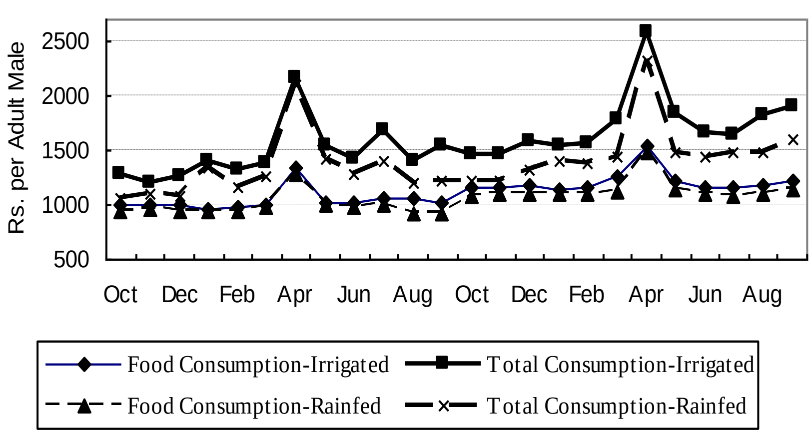
In this study, measurement of the extent of access to credit is important; yet regular household surveys do not include credit information that directly enables an identification of the prevailing credit conditions (Scott 2000). To deal with this issue, we carefully designed a special credit module in our questionnaire to directly identify credit-constrained households. In particular, we asked two related questions. First we queried the amount of credit a household obtained in a particular period; then, among those who had not obtained credit, we asked the reasons for not

We employ the age-sex weights used by Townsend (1994) in the context of Southern India.

borrowing. Households responding that they did not need to borrow are labeled noncredit constrained, while households listing such reasons as fear of default or impossibility of borrowing are identified as credit constrained. Of the households that had borrowed, those able to borrow as much as they wanted are considered unconstrained while the others are considered constrained.

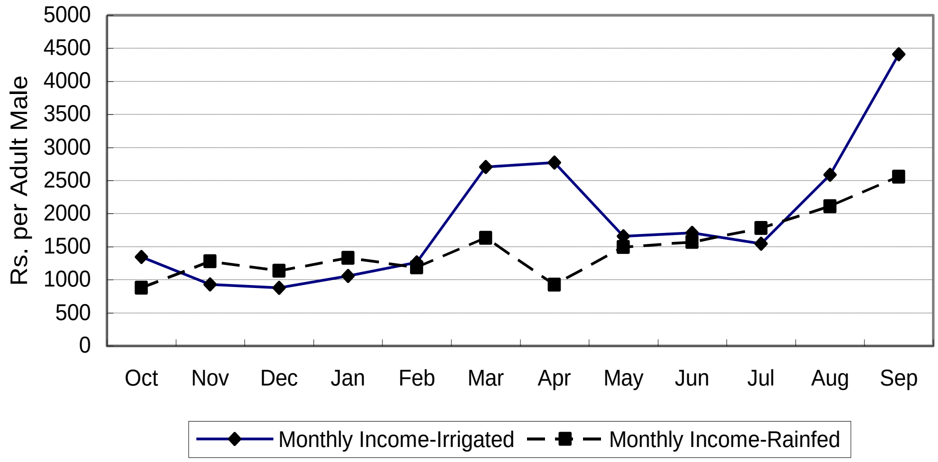
Average monthly consumption by irrigation accessibility is shown in Figure 1. Firstly, it is evident that households in rainfed areas have systematically lower expenditures throughout the year than those in the irrigated areas. This suggests that the incidence of chronic poverty may be more serious in the rainfed areas than in the irrigated areas.[6] Secondly, while the expenditure levels vary significantly depending on the accessibility of irrigation infrastructure, the pattern of monthly expenditure fluctuations appears to be fairly similar across areas. Expenditure levels are stable from October through February, increasing in April immediately after the *Maha* harvesting, decreasing during May and June, and increasing slightly in September after the *Yala* harvesting. A similar pattern is illustrated in Figure 2, which presents the pattern of monthly income fluctuations. It shows a marked increase in income in April and September, following the harvests.

Figure 1. Monthly Consumption (per Adult Male equivalent: in Rs.)



[6] We also calculate the head count ratio by using the poverty line of $2.00 per day, converted by the PPP. The overall incidence of poverty is approximately 12%. The highest head count ratio is observed in the Extension area with 14% and the lowest poverty rate is found in Kiriibbanwewa with 8%. These figures indicate that accessibility to irrigation infrastructure is systematically related to the incidence of poverty.

Figure 2. Monthly Income (per Adult Male equivalent; in Rs.)



2. Matching Analysis

As pointed out by Banerjee (2005) and Duflo and Kremer (2003), while randomization has become a *de facto* standard for program evaluation in development economics, there are some types of programs that cannot be evaluated using randomization methods. Irrigation infrastructure may be this type. In WLB, the area covered by our survey, the central government distributed irrigated land to the poor based on a set of criteria, a nonrandomized distribution of irrigated land that might bias estimation of the program effect. Land eligibility criteria were set by the Government as follows: recipients should be married, Sri Lankan citizens aged eighteen years or older, landless or smallholder with holdings of less than 0.8 ha, and have an annual income of less than Rs. 9,000.[7] Additional considerations included length of residence in the project area, household size, and recorded current or past participation in any government organized poverty reduction program. Government officials were categorically ineligible.

Beneficiaries were chosen by the government on the basis of these criteria. To address the potential problem of bias caused by this nonrandomized distribution, we employ the propensity

[7] This threshold is significantly lower than the poverty lines set by government agencies (JBIC and IWMI 2002) and the PPP-converted one-dollar-per-day poverty line.

score matching of Rosenbaum and Rubin (1983). In the matching analyses, we estimate the average treatment effect on the treated (*ATT*), defined as $E\left(E_s^1 - E_s^0 \mid Z = 1\right)$, where Z takes the value of unity if a household owns irrigated land and zero otherwise, $E_S{}^Z$ is a household's expenditure during a season, *S*, with the irrigated land ownership status, *Z*.[8]

In the present analysis, the propensity score is estimated using a probit model for each season; that is, for the rainy season (*Maha*) and the dry season (*Yala*). While this enables us to examine changes in seasonal effects arising from access to irrigation, our data do not include information regarding the pretreatment period, such as income and assets prior to irrigation placements. Hence, we use a set of covariates that are considered to be almost time-invariant; such as age, education level, gender of household head, and the number of male members aged sixteen and above. Table 3 presents the results of the propensity score estimation.[9] It indicates that households with older and more educated household heads are likely to have better access to irrigation and that households with more male members are more likely to own irrigated land. These results reject the assumption of exogenous or random placement of irrigation facilities. Our following regression estimations, therefore, control for unobserved nonrandom factors by adding several controlling variables.

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[8] Since $\left(E_s^0 \mid Z = 1\right)$ is an unobservable counter-factual situation, we postulate the conditional independency assumption that the log expenditure of rainfed observation, $\ln E_s^0$, is independent of access to irrigation, *Z*, conditional on the set of observed determinants of access to irrigation.

[9] We estimate the propensity score for each season separately. Hence the number of observations is 845 for each season.

Table 3. Propensity Score for Irrigation Accessibility

	Maha October to April	Yala May to September
Age	0.042*** (0.004)	0.043*** (0.004)
Sex	0.189 (0.156)	0.118 (0.156)
Education	0.040*** (0.015)	0.041*** (0.015)
Headcount of Males over 16	0.179*** (0.050)	0.130*** (0.049)
Constant	–2.241*** (0.240)	–2.200*** (0.237)
N	845	845

*** denotes significance at the 1% level; ** at the 5% level; and * at the 10% level.Robust standard errors are indicated in parentheses

It is straightforward to verify the validity of the estimated propensity score using the balancing score test of Rosenbaum and Rubin (1983) and Dehejia and Wahba (1999, 2002). Conditional on the propensity score, the covariates are independent of accessibility to irrigation. The estimated propensity scores do not reject the null hypothesis; the means of covariates are the same between the irrigated and rainfed areas for any bundle of propensity scores.[10] This implies the validity of selection on observables assumption. Moreover, there is a positive probability of either owning or not owning irrigated land for any stratum of the propensity score. This indicates that the common support condition $0 < \Pr(Z = 1 | M) < 1$ is satisfied in our specifications.

We quantify the *ATT* for income, food consumption, nonfood consumption, total consumption, and the indicator value of credit constraint. Table 4 presents the estimated *ATT* of access to irrigation on seasonal and monthly variables.

[10] These figures are available from the corresponding author upon request.

Table 4. Estimated Seasonal ATT
Method: Propensity Score Matching with a Matching Radius of 0.025

	Monthly Income		Food Cons.		Nonfood Cons.		Total Cons.		Credit Constraint	
	N	ATT	N	ATT	N	ATT	N	ATT	N	ATT
Seasonal/Annual										
Maha (Rainy)	528	310.9* (173.1)	527	134.9*** (42.3)	528	174.0*** (38.8)	527	296.8*** (66.2)	494	–0.042 (0.03)
Yala (Dry)	534	381.8** (159.2)	532	153.1*** (43.0)	531	197.6*** (59.7)	533	342.4*** (80.7)	506	–0.056* (0.029)
Annual	489	338.4*** (115.7)	527	137.2*** (38.2)	528	180.2*** (35.9)	527	305.1*** (60.5)		
Monthly										
Oct	528	445.77** (222.60)	525	136.3*** (41.7)	512	169.8*** (41.3)	525	290.0*** (63.9)		
Nov	528	-479.9 (355.4)	527	127.3*** (41.7)	511	160.7*** (39.7)	524	281.3*** (62.4)		
Dec	527	-157.0 (233.2)	527	132.5*** (43.9)	513	208.2*** (72.1)	526	329.8*** (90.5)		
Jan	527	-252.1 (255.4)	526	104.0** (42.5)	519	151.3* (82.3)	526	197.3** (81.9)		
Feb	528	75.0 (210.1)	526	91.1** (45.0)	512	107.4 (83.8)	524	190.1* (99.7)		
Mar	527	925.8** (387.9)	526	207.0*** (46.9)	517	151.9 (97.9)	525	346.1*** (119.2)		
Apr	528	1613.7* (861.1)	525	133.5** (60.0)	526	283.3*** (102.6)	525	425.8*** (140.1)		
May	534	185.9 (312.1)	531	155.3*** (48.0)	524	232.8* (120.1)	531	386.5*** (139.7)		
Jun	534	144.1 (256.7)	530	156.6*** (45.3)	528	127.9 (133.1)	531	262.4* (144.5)		
Jul	534	-379.1 (284.6)	531	148.5*** (43.5)	525	133.0 (87.1)	532	279.3*** (103.2)		
Aug	534	142.8 (272.9)	532	161.5*** (44.9)	522	235.5** (109.3)	531	386.2*** (121.4)		
Sep	534	1815.2*** (434.2)	532	149.4*** (47.5)	528	249.7** (112.1)	533	391.7*** (128.1)		

Outcome variables are monthly averaged values.

*** denotes significance at the 1% level; ** at the 5% level; and * at the 10% level.

The radius matching method with a radius of 0.025 is used to construct the matching group.[11] A series of matching estimations indicates that the effects of irrigation on income and consumption are positive and statistically significant for all seasons; this implies that accessibility to irrigated land significantly reduces poverty. Not surprisingly, the estimated impacts are greater in the dry season. While in the late- and post-harvest months of March, April, September and October we observe positive and significant effects of irrigation on income; in the non-harvest months the *ATT* estimates are statistically insignificant. According to the point estimates, with irrigation accessibility, per capita income, per capita food and per capita non-food consumption expenditures increase by around 17.8%, 12.2% and 37.6%, respectively, evaluated at the average level among the treated. The estimated effects on credit constraints during the rainy and dry seasons are –0.042 and –0.056, respectively. The effect is statistically significant in the dry season at the 10% significance level, suggesting that accessibility to irrigation decreases the probability of binding credit constraints by 5.6% during the dry season.

3. Modeling the role of infrastructure in poverty reduction dynamics

Given the overall poverty reduction effects shown in the previous section, we aim in this section to capture the channels through which irrigation reduces poverty. To do this, we extend Paxson's (1993) seasonal consumption model by introducing endogenous credit constraints. Each household determines seasonal consumption by maximizing its lifetime utility subject to its intertemporal budget constraints. Here we assume that all the households have perfect credit market accessibility. A household has a time-separable constant relative risk aversion (CRRA) utility function, $U(C_{st}) = \alpha_s(C_{st})^{1-a}(1–a)^{-1}$, of the household consumption, C_{st}, in season s in year t. For purposes of exposition, we exclude the year subscript in the following presentation. α_s

[11] We also attempt various alternative specifications of matching estimations, as follows: the radius matching with a wider radius (r = 0.05), the nearest neighbor matching with replacement, consumption level rather than logarithm, and the first stage covariates consistent with the previous structural estimation. These estimations generate comparable qualitative results to the benchmark matching estimation result.

represents a taste parameter, and a is the coefficient of relative risk aversion. The household's decision problem is to choose C_{st} that maximizes the discounted lifetime utility with a seasonal discount factor, β, subject to an intertemporal budget constraint with seasonal income, Y_{st}, household assets at the beginning of the period, W, and exogenous seasonal interest rate, $r \equiv R-1$. Assuming no consumption tilting, i.e., $\beta R = 1$, we have the following optimal expenditure for season s:

(1) $$E_s{*} = \omega_s R \Pi \,,$$

where $E_s{*} = P_s C_s$ with P_j representing the price of consumption in season s; ω and Π are utility weights assigned to consumption in season s and total household assets, respectively; i.e., they correspond to the sum of human and initial physical assets. Note that Equation (1) is an extended version of the life-cycle permanent income hypothesis. The utility weight involves the taste parameter in the utility function and the relative consumption prices in the two periods. Defining Y as the sum of expenditures in different periods, we have $Y = R\Pi$ because $\sum_s \omega_s = 1$. Note that Y measures the total annual income, inclusive of net annual interest earnings for the year.

Thus far we have assumed perfect credit market accessibility. In order to introduce the possibility of binding credit constraints captured by income volatility, we follow Flavin (1981) and Paxson (1993) and assume that the expenditure at s is a weighted average of the optimal expenditure at s and income in that season:

(2) $$E_s = (1-\pi)E_s{*} + \pi Y_s$$

where π represents the degree of credit constraint. If $\pi = 0$, then the credit constraint is not binding, and if $\pi = 1$, it is perfectly binding. Recalling that $Y = R\Pi$, Equation (2) can be rewritten as $E_s = Y[\omega_s(1-\pi) + \pi A_s]$, where $A_s \equiv Y_s/Y$; i.e., the fraction of annual income earned in season s. By log-linearizing this equation, we obtain the structural form of the seasonal expenditure model:

(3) $$\ln E_s = \ln Y + \omega_s(1-\pi) + \pi A_s - 1$$

Irrigation increases consumption and reduces chronic and transient poverty through multiple paths. Conceptually, we consider four channels for evaluating the role of irrigation infrastructure: first, impact on permanent income, Y; second, demand for credit by changing income fluctuation patterns, A_s; third, supply of credit through changes in creditworthiness; and, finally, other channels such as preferences and time allocation. To quantify the relative importance of the different channels, we consider the following estimation equation:

$$\ln E_s = \gamma^Y \ln Y_s + X_s \gamma^X + \gamma^Z Z_s + \gamma_s^0 + \gamma_k^Z H_k Z_s + u_s \tag{4}$$

where, X_s includes demographics, household head characteristics, and geographic characteristics; Z_s is the size of irrigated land and its coefficient; γ^Z, represents time-invariant impacts of irrigation through non-income channels, such as changes in preferences; and, following Paxson (1993), γ_s^0 denotes common month-specific effects, reflecting month-specific preferences and prices. The three terms, $X_s \gamma^X$, $\gamma^Z Z_s$, and γ_s^0, on the right-hand side of Equation (4) correspond to the second term on the right-hand side of Equation (3). The fifth term on the right-hand side of Equation (4), $\gamma_k^Z H_k Z_s$, captures the income fluctuation term in Equation (3), i.e., πA_S, where H_k (k = 1, 2, 3) are the binary variables representing the harvest period of the rainy season (March and April), planting period of the dry season (May and June), and harvest period of the dry season (July to September), respectively. The remaining season (October to February) is the planting period of the rainy season which is used as the reference season. Hence, the coefficients, γ_k^Z, on the interaction term of the binary variables, H_k, and irrigated land size, Z_S, capture the remaining time-dependent impact of irrigation which mainly includes changes in income fluctuation patterns. In other words, as can be seen in the fifth term on the right-hand side of Equation (4), we take the interaction term, $H_k Z_S$, as the instrument for the endogenous variable A_s. Following the theoretical implications, if the credit constraint is not binding, i.e., $\pi = 0$, then the parameters γ_k^Z should jointly be zero. This is a joint test for credit accessibility and effectiveness of irrigation on increasing income. As to the identifying instrumental variables to handle the endogeneity problem of permanent income, after careful investigation of sixteen types of agricultural assets and eighteen types of nonagricultural assets, we decide to employ the holding of sewing machines and small tractors.[12]

Endogenous Credit Constraints

In the development literature, it is commonly accepted that poor households in developing countries, which typically are comprised of landless farmers, have only limited access to credit. While irrigation accessibility potentially affects the demand for credit by affecting income fluctuation patterns, it could also affect the supply of credit as determined by creditworthiness. This study examines the overall impact of irrigation on the credit constraint.

A conventional empirical approach for incorporating credit constraints into estimation models ignores the endogeneity of the constraints and exogenously splits the sample into those constituents likely to be credit constrained and those not likely to be so (Foster 1995). In contrast, following Jappelli (1990), we introduce an empirical model of endogenous credit constraint. Recall that E^* represents the optimal LC-PIH consumption in the absence of current credit constraints. Then, $E^* = E$ holds if the credit constraint is not binding, while $E^* > E$ holds if the credit constraint is binding. A discrete model of credit constraint is obtained as follows:

(5) $$cc_s = 1[X_s\beta_1 + Z_s\beta_2 + S_s\beta_3 + \varepsilon_s > 0]$$

where $1[\cdot]$ denotes an indicator function for a discrete variable of credit constraint, *cc*; *S* includes binary variables to represent unanticipated negative shocks such as damage to plots from wild animals or water shortage; and ε denotes an error term that captures unobserved elements and a measurement error.

Program Placements

Note that Equation (4) can be viewed as a linear program evaluation equation (Lee 2005).

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[12] The criteria for choosing these two variables are high adoption rate and low possibility of violating the exclusion restriction. Compared to other assets such as motor-cycles and electric cookers, sewing machines and small tractors are productive assets and are less likely to affect consumption dynamics through channels other than income. Also, the adoption rates of sewing machines and small tractors are 39.4% and 12.5%, respectively, while only 2.0% of households, for instance, own hand threshers.

The parameters, γ_k^Z, capture the extra amount of expenditure that farmers can achieve with irrigation access; these are expenditures that are enabled by the irrigation infrastructure, or, simply, by the season-specific treatment effect of irrigation infrastructure. However, an endogeneity issue remains to be addressed. Since our data are taken from a newly developed farming area, irrigation accessibility has been determined by the government's land allocation rules. Specifically, the government provided irrigated land mainly to the poor as described above in Section 2. The correlation between consumption and unobserved determinants of irrigation accessibility has the potential to generate bias in the estimated coefficients. Yet, the correlation is likely to be negative, and therefore from the viewpoint of this study, the irrigation accessibility variable may underestimate rather than overestimate irrigation's impact. In order to mitigate this endogeneity problem, we conduct robustness tests using, among others, the fixed effects model in addition to the propensity score matching method.

4. Regression Analysis

One of the most important effects of access to irrigation is likely to be an increase in annual income overall. Not only will irrigation allow farmers to grow more valuable crops in the dry season, but it may also allow more intensive cultivation in the rainy season. To address this income effect of irrigation, we estimate a linear regression model of permanent income in which we regress average household income over twelve months on a set of household human and physical asset variables. Table 5 reports the estimation results of the permanent income model. Irrigated land size has positive and statistically significant coefficients on permanent income. While the seasonal effects of irrigated land size on permanent income are negative during dry season planting and harvesting stages, our joint test results show that the total effects of irrigated land size are positive and statistically significant. Human and physical asset variables, such as level of education of the head of household, number of adult male members, and ownership of sewing machines and tractors, also are positively related to the level of permanent income.

Table 5. Permanent Income Regression

Dependent Variable: Permanent Income	Coef.		Std. Err.	
Irrigated Land	0.122		0.011	***
Unirrigated Land	0.045		0.006	***
Age of Head	-0.007		0.001	***
Female Head	0.050		0.127	
Age of Head x Female Head	0.003		0.002	
Education of Head	0.011		0.003	***
Head Count of Adult Males	0.062		0.008	***
Head Count of Adult Females	-0.055		0.009	***
Head Count of Children	-0.175		0.007	***
Distance to Local Bus Terminal	-0.017		0.007	**
Distance to Daily Market	0.014		0.006	**
Seasonal Effect of Irrigated Land Size				
Harvest in Rainy Season	0.001		0.019	
Planting in Dry Season	-0.033		0.019	*
Harvest in Dry Season	-0.031		0.017	*
Value of Sewing Machines	0.236		0.030	***
Value of Small Tractors	0.808		0.428	*
F-statistics for zero Total Seasonal Irrigation				
Harvest in Rainy Season	57.97	***		
Planting in Dry Season	27.92	***		
Harvest in Dry Season	42.38	***		
Joint Test	52.90	***		
N			8168	

*** denotes significance at the 1% level; ** at the 5% level; and * at the 10% level.
Month effects, which are not reported in the table, are also included in the estimation.

Our main econometric analysis is comprised of the following three models: first, we conduct reduced form estimation for the seasonal expenditure based on Equation (4); second, to test the validity of our model framework, we estimate the structural model of Equation (3); and finally, we conduct a wide range of tests for robustness.

Estimation Results 1: *Reduced Form Estimation*

We first attempt to estimate Equation (4) by addressing two endogeneity problems: firstly, we mitigate the endogeneity of the permanent income variable using the instrumental variable method. Secondly, in order to cope with the sample selection bias arising from endogenous credit constraints, we combine the dummy endogenous variable specification for credit constraint in Equation (5) with the seasonal expenditure model in Equation (4). Accordingly, we have the following econometric models of expenditure with and without endogenous credit constraints in which sample selection correction terms are included under joint normality of error terms (Lee, 1978; Amemiya, 1985):

(6) $$\ln E_s = \gamma^{Y,C} \ln Y_s + X_s \gamma^{X,C} + \gamma^{Z,C} Z_s + \gamma_s^{0,C} + \gamma_k^{Z,C} H_k Z_s + \gamma^C \frac{\varphi(X_s\beta_1 + Z_s\beta_2 + S_s\beta_3)}{\Phi(X_s\beta_1 + Z_s\beta_2 + S_s\beta_3)} + u_s^C \qquad if\ cc_s = 1$$

(7) $$\ln E_s = \gamma^{Y,N} \ln Y_s + X_s \gamma^{X,N} + \gamma^{Z,N} Z_s + \gamma_s^{0,N} + \gamma_k^{Z,N} H_k Z_s + \gamma^N \frac{\varphi(X_s\beta_1 + Z_s\beta_2 + S_s\beta_3)}{1-\Phi(X_s\beta_1 + Z_s\beta_2 + S_s\beta_3)} + u_s^N \qquad if\ cc_s = 0$$

where superscripts *C* and *N* denote the credit constrained and unconstrained groups, and $\varphi(\cdot)$ and $\Phi(\cdot)$ represent the probability density and cumulative density functions of standard normal distribution. In Equations (6) and (7), the time-dependent irrigation sensitivity parameters, $\gamma_s^{Z,C}$ and $\gamma_s^{Z,N}$ capture the indirect impact of irrigation on expenditure through changing income fluctuations. The time-invariant irrigation sensitivity parameters, $\gamma^{Z,C}$, and $\gamma^{Z,N}$, capture the direct role of irrigation infrastructure on expenditure.

According to the estimation results of the credit constraint equation reported in Table 6, the probability of binding credit constraints is negatively related to irrigated land size. This result implies that loan provisions are positively affected by access to irrigation facilities, possibly through enhanced land value as collateral. After controlling the endogenous permanent income and credit constraints, Panel A of Table 7 reports the reduced form estimation result for the household expenditure model. While the season-specific effects of irrigated land size through income on expenditure, $\gamma_s^{Z,C}$ and $\gamma_s^{Z,N}$, are not always positive and significant, the joint F test for these effects shows that irrigation has an overall positive and significant effect on household expenditure for the constrained group. By contrast, for the unconstrained group, the overall season-specific irrigation effects are not different from zero. These results are consistent with the theoretical implications of the intertemporal model of expenditure with and without binding credit constraints. Intriguingly, the time-invariant irrigation effects are positive and statistically significant only for the constrained group, i.e., $\gamma^{Z,C} > 0$, suggesting that irrigation accessibility could reduce poverty via paths other than improvement in credit accessibility.

Table 6. Estimated Marginal Effects of the Credit Constraint Equation
Method: Probit model

Dependent Variable: Credit Constraint			
	Marginal Effect	Std. Err.	
Irrigated Land	-0.010	0.003	***
Unirrigated Land	-0.002	0.003	
Age of Head	0.000	0.000	
Female Head	-0.067	0.032	*
Age of Head x Female Head	0.002	0.001	*
Education of Head	-0.003	0.001	***
Head Count of Adult Males	-0.010	0.004	***
Head Count of Adult Females	0.006	0.004	*
Head Count of Children	-0.001	0.003	
Distance to Local Bus Terminal	0.011	0.003	***
Distance to Daily Market	-0.022	0.003	***
Seasonal Fraction of Farming Land with Water Shortage			
Rainy Season	-0.017	0.045	
Dry Season	-0.015	0.046	
Attacked by Wild Animals	0.003	0.010	
N		8168	

*** denotes significance at the 1% level; ** at the 5% level; and * at the 10% level. For female head and attacked by wild animals dummy variables, discrete marginal effects when the variable shifts from zero to one is reported.

Table 7. Estimated Results of the Reduced Form and Structural Form Expenditure Equation

	Panel A: Reduced Form						Panel B: Structural Form					
	Credit Constrained			Credit Unconstrained			Credit Constrained			Credit Unconstrained		
	Coef.	Std. Err.		Coef.	Std. Err.		Coef.	Std. Err.		Coef.	Std. Err.	
Permanent Income	0.433 #	0.175	**	0.987 #	0.147	***	0.633##	0.194	***	0.910##	0.137	***
Income Ratio (π)							0.089##	0.044	**	-0.005##	0.071	
Irrigated Land	0.279	0.084	***	-0.099	0.034	***	0.208	0.106	*	-0.074	0.030	**
Unirrigated Land	0.033	0.017	**	-0.055	0.010	***	0.009	0.022		-0.051	0.010	***
Age of Head	-0.006	0.002	**	0.000	0.001		-0.004	0.003		0.000	0.001	
Female Head	-0.032	0.017	*	0.025	0.004	***	1.059	0.925		-1.425	0.211	***
Age of Head x Female Head	1.204	0.773		-1.474	0.225	***	-0.027	0.020		0.024	0.004	***
Education of Head	0.091	0.030	***	-0.026	0.008	***	0.073	0.037	**	-0.024	0.007	***
Head Count of Adult Males	0.153	0.080	*	-0.224	0.023	***	0.115	0.094		-0.217	0.021	***
Head Count of Adult Females	-0.231	0.054	***	0.029	0.020		-0.221	0.064	***	0.022	0.020	
Head Count of Children	-0.046	0.031		0.055	0.026	**	-0.019	0.036		0.042	0.025	*
Distance to Local Bus Terminal	-0.272	0.089	***	0.086	0.021	***	-0.225	0.107	**	0.081	0.020	***
Distance to Daily Market	0.545	0.188	***	-0.131	0.028	***	0.477	0.224	**	-0.124	0.027	***
Seasonal Effect of Irrigated Land Size												
Harvest in Rainy Season	-0.036	0.033		0.000	0.021							
Planting in Dry Season	0.065	0.036	*	0.036	0.022							
Harvest in Dry Season	0.069	0.032	**	0.028	0.019							
Sample Selection Correction Term	-4.963	1.937	**	-4.832	0.999	***	-4.063	2.328	*	-4.595	0.936	***
Monthly Effects		Yes			Yes			Yes			Yes	
F Statistics for no Seasonal Irrigation Effect		9.81	**		4.15							
F Stat. for 1st Stage Instruments (Permanent Income)		7.48	***		25.49	***		3.45	***		10.99	***
F Stat. for 1st Stage Instruments (Income Ratio)								2.61	**		2.44	**
Sargan Statistics for Over-identification		0.227			0.063			3.02			4.69	
N		955			7213			955			7213	

*** denotes significance at the 1% level; ** at the 5% level; and * at the 10% level. # denotes an endogenous variable where the identifying instrumental variables include value of sewing machines and value of small tractors. ## denotes endogenous variables where the identifying instrumental variables include three seasonal effects of irrigated land size (i.e., harvest in rainy season, planting in dry season, and harvest in dry season), value of sewing machines and value of small tractors.

Estimation Results 2: *Structural Estimation*

The reduced form model results cannot directly quantify the degree of credit constraint. Hence, we investigate the seasonal effect by estimating the structural model of Equation (3) with the endogenous credit constraint of Equation (5). By including the sample selection correction terms under joint normality of error terms, the estimation versions of Equations (3) and (5) become:

(8) $$\ln E_s = \delta^{Y,C} \ln Y + X_S \delta^{X,C} + \delta^{Z,C} Z_S + \delta_s^{0,C} + \pi^C A_s + \delta^C \frac{\varphi(X_s\beta_1 + Z_s\beta_2 + S_s\beta_3)}{\Phi(X_s\beta_1 + Z_s\beta_2 + S_s\beta_3)} + v_s^C \qquad \text{if } cc_j = 1$$

(9) $$\ln E_s = \delta^{Y,N} \ln Y + X_S \delta^{X,N} + \delta^{Z,N} Z_S + \delta_s^{0,N} + \pi^N A_s + \delta^N \frac{\varphi(X_s\beta_1 + Z_s\beta_2 + S_s\beta_3)}{1-\Phi(X_s\beta_1 + Z_s\beta_2 + S_s\beta_3)} + v_s^N \qquad \text{if } cc_j = 0$$

where δ_s are captured by monthly dummy variables. The income share variable, A_s, is treated as an endogenous variable which is instrumented by the interaction variable of season dummies and irrigated land size, $H_k Z_S$ as well as productive asset variables as before. The tests on the theoretical hypotheses $0 < \pi^C < 1$ and $\pi^N = 0$ will provide further direct evidence of the extent to which consumption is smoothed against income fluctuation.

Panel B of Table 7 reports the estimation results of the structural model. For consumption of the credit constrained groups, the coefficients of monthly income fluctuation π^C are positive and significant. Further, their 95% confidence intervals are [0.003, 0.176] and located within the range of [0,1]. On the other hand, the monthly income coefficient for the unconstrained households, π^N, is not statistically different from zero. Consumption by the constrained group tracks the fluctuated income path, suggesting that people under credit constraint cope with negative economic shocks by reducing consumption. By contrast, the unconstrained group are able to smooth their consumption paths under income fluctuation. The results summarized here provide supportive evidence for our theoretical framework.

Estimation Results 3: *Robustness Tests*[13]

Here we perform three robustness tests on our results: an alternative specification, non-normality of error terms, and nonrandom irrigation placements. For the first robustness test, we employ an alternative model specification in which we do not control for the time-invariant direct effect of the irrigated land size, i.e., $\gamma^Z Z_s$. While this alternative model is comparable to the one developed by Paxon (1993), the model is restricted in the sense that it considers only the indirect effect of irrigation infrastructure on expenditure through increased permanent income, eased credit constraints and smoothed monthly consumption. Basically, the qualitative results are comparable to the results of the previous models presented in this paper, with the notable exception of the over-identification test result in the structural estimation. Without the time-invariable direct effect, we reject the orthogonality condition of the Sargan over-identification test. This result may support the inclusion of the direct effect variables in our regression analyses.

Thus far, the seasonal expenditure model with the endogenous credit constraint has been estimated under the assumption that the error terms in the reduced and structural form models follow trivariate joint normal distribution. However, if this assumption does not hold, it is likely that the second step estimators are seriously biased. Hence, for the second robustness test we relax the normality assumption by adopting the approach proposed by Lee (1982) and Newey, Powell, and Walker (1990). The qualitative results are comparable even under a relaxed normality assumption.

For the third robustness test, to correct bias arising from the nonrandomized distribution of irrigated land we mitigate the correlation between unobserved heterogeneity and program placement by including household fixed effects. We reserve the endogeneity issue of the credit constraint and simply estimate the reduced form model of Equations (6) and (7) by

[13] The results of these robustness tests are not presented in this paper but are available in the electronic Appendix.

incorporating household fixed effects.[14] The estimation results are the same qualitatively as without household fixed effects.

Conclusion

In this paper, we identify a relationship between infrastructure development and poverty reduction with regard to seasonal fluctuations in consumption expenditure. We find that irrigation reduces chronic poverty by enhancing permanent income and that it also eliminates the negative impact of transient poverty by reducing the downside expenditure risk. The point estimates derived by the propensity score matching method show that with irrigation accessibility, per capita income and per capita food and non-food consumption expenditures increase by around 17.8%, 12.2% and 37.6%, respectively, when evaluated at the average level among the treated, and that the probability of binding credit constraint is reduced by 5.6% during the dry season. Our results provide evidence in support of the role of infrastructure in reducing both chronic and transient poverty. Since very few micro-econometric studies have analyzed the role of infrastructure in mitigating chronic and transient poverty, we believe that this paper will close an important gap in the existing literature.

Intriguingly, we find that there is a positive and significant time-invariant irrigation effect on expenditure only for the credit constrained group. This finding suggests that irrigation access can reduce poverty via multiple paths, apart from improvement in credit accessibility. Usually, when irrigation infrastructure is constructed, other types of infrastructure, such as roads and electricity facilities, are developed alongside. The unexplained positive irrigation effects on the credit constrained group may be attributable to this aspect of infrastructure development. Further exploration of these broader external effects of irrigation infrastructure should be pursued in future studies.

[14] Since inclusion of household fixed effects renders the permanent income coefficient unidentifiable, we include the two asset variables used as the exclusion restriction in the expenditure equation.

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Abstract (in Japanese)

要約

物的なインフラへのアクセスが家計の厚生を高めることは広く理解されている。しかしながら、インフラの貧困削減効果をミクロデータを用いて実証的に分析した既存研究は非常に少なく、とくに貧困動態という観点からはほとんど分析されてこなかった。本稿は、こうした既存研究の穴を埋めるべく、スリランカで実施された大規模な灌漑事業をケースとして、独自に収集された世帯レベルの月次パネルデータを用い、計量経済学的な分析を行った。傾向スコアマッチング法（propensity score matching method）を用いた解析の結果、灌漑へのアクセスが改善することによって、一人当たり所得、一人当たりの食糧、非食糧の消費支出がそれぞれ平均的に 17.8%、12.2%、37.6%増加するという強い慢性的貧困削減効果を持つことが判明した。同時に、流動性制約に陥る確率が 5.6%減少するという結果も得られ、信用市場を通じた一時的貧困の削減効果も見出された。これらの結果は、灌漑というインフラが、慢性的貧困・一時的貧困の両方の削減に寄与し得ることを示している。さらに、構造モデルの推計によって、我々の理論枠組みが妥当であるという結果も得られた。

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