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IDE DISCUSSION PAPER No. 596

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April 2016

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Keywords: impact evaluation of infrastructure, tertiary canals, cultivation
JEL classification: Q12, Q15

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Impacts of tertiary canal irrigation: Impact evaluation of an infrastructure project

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Abstract In this paper, we have described the challenge in impact evaluation of infrastructure and estimated the economic impacts using the panel data set from rural Thailand. We employed difference-in-differences estimation and showed that tertiary irrigation has unexpected impacts. Contrary to the local experts predicitions that it should have substantial productivity impacts as it allows better water controls for farmers, we found largely zero profitability impacts. Another unexpected finding is that, while profitability is not affected, we see an increase in cultivation probability with the construction of tertiary canals. This is observed in both wet and dry seasons but its magnitude is larger for the latter. This finding suggests that Thai farmers, despite its aging population and relative relaxed attitude toward cultivation, are willing to expand operation scale once they get water.
Keywords impact evaluation of infrastructure, tertiary canals, farm profits

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1 Introduction

Infrastructure is one of the main driving forces of economic growth. Since Rosenstein-Rodan (1943) and Hirschman (1958), in theoretical models in development economics, infrastrucutre has been assumed to have the key role in promoting economic growth. Huge proportion of government budget has been spent for infrastructure investment in many countries and most of them have big impact on the economic development process in the countries.

Donor agencies, as well as the government of developing countries, have been published a lot of evaluation reports on the effect. Most of them, however, do not intend to do robust estimation, or impact evaluation which is mainstreamed in evaluation researches for development projects. Since the size of infrastructure investment is huge, the impact spreads in wide area and we cannot distinguish beneficiaries and non beneficiaries clearly. That is the reason why impact evaluation, or analytically robust estimation using randomized data, for infrastructure are rare. It does not mean there are no impact evaluation for infrastructure. There are some trials to do rigorous estimation for infrastructure projects. Estache (2010) surveys extensively the previous studies on the impact evaluation for infrastructure projects. The paper covers energy, drinking water and sanitation and transport sectors as examples of infrastructure projects.

Estache (2010), however, does not mention irrigation projects so much mostly because there are only a few examples of impact evaluation for irrigation projects. One of the examples is Sawada, Shoji, Sugawara and Shinkai (2008) which discusses the impact of large-scale irrigation project in Sri Lanka. Bandyopadlhyay, Shyamsundar and Xie (2007) examines the impact of irrigation management transfer in the Philippines. Dillon (2008) analyzes the impact on household welfare in Mali. In all of the examples, large scale irrigation projects are chosen for the poverty analysis.

We, in this paper, focus our analysis on the effect of tertiary canal construction on farmers' net income. A tertiary canal is a low level canal drawing water from high level canals, and its width is about 30 to 50 centimeters in the area in Central Thailand, our study area (hereafter Study Area), where pumping station, main and lateral canal were constructed in the period between 2001 and 2005. The pumping station pumps up the water from a large river and let the water run the highland area through main and lateral canals. After the construction of main and lateral canals, the Royal Irrigation Department (RID), who has been in charge of irrigation management in Thailand, started to extend the system. The main reason is that the RID had to find how to collect electrical fee for the pumping. In tradition the RID did not collect any water use fee from farmers. In the case of Study Area which pump size is huge, the RID has to collect the fee for the sustainability of the project and the RID would like water users groups (WUGs) as the fee payers. Now the the RID or Thai government adopts participatory irrigation management policy and promotes to establish water user groups in all of the irrigation projects area. Study Area is also one of the project sites. In order to establish water users groups, the construction of tertiary canals was considered to be necessary. Without tertiary canals, the RID cannot convince farmers the benefit of main and lateral canals and fails to collect pumping cost for the water. Therefore, the RID has decided to construct tertiary canals and persuade farmers to have water users groups and pay pumping cost.

Farmers assumed the tertiary canals help them a lot and thought in the following way: The supply of water from pumping station is not reliable if there is no tertiary canals. With only main and lateral canals, only farmers who have their plots close to main and lateral can benefit from the project very well. If there is a tertiary canal which is attached to their own plots, then water supply is reliable and they can start dry season cultivation and pay electrical fee for the project. Many farmers can be sure for their dry season cultivation productivity only when there are tertiary canals attached to their plots.

Does it mean the tertiary canals have significant impact on farmers' production? If tertiary canals do not have productivity impact significantly, then the construction is not efficient in actual. Clarifying the impact of tertiary canals is very important for future irrigation designing. Wichelns (2000) assumes the heterogeneity of the size in impact of tertiary canals on productivity in each plot and analyzes the optimal way of collecting water use fee. In the analysis the productivity is assumed to be positively related to the existence of tertiary canal. Our study estimates the size or the conditions for the size to be positive.

Focusing on the effects of tertiary canals has one clear advantage for our analysis. By the nature of low level canals, a tertiary canals affect the water use conditions of contiguous plots locally and only in a confined way. Therefore, if there are variations in timing of the construction of tertiary canals within the project area, we can find both the treated and control group of farmlands that are geographically close each other. As we will describe later, it is indeed the case in the study area where tertiary irrigation systems were constructed gradually over the past several years. A four-round survey we conducted includes the treated farmlands that were provided with tertiary canals during the survey period, in addition to the control group that have yet to be provided. We evaluate the impacts of tertiary canals on yield and farmers' income, employing the difference-in-differences estimator that is increasingly popular among policy evaluation literature.

The role of tertiary canals may be different depends on the situation. In some project areas, the canals have productivity impacts. The canals in other areas may have cost reduction effect with no clear impact on yield. It is expected that the productivity impacts of tertiary canals are not as large as those of high level canals, if high level canals can provide a reasonable degree of water control. But one should not misunderstand that impacts of tertiary canals need not be studied. There are two reasons why a policymaker in the development community should care about them. First, in theory, tertiary and lower level canals are usually cited as a labor saver. It is therefore crucial in a rapidly growing economy which faces continuous wage growth, or in an aging economy which may also face sustained wage growth, to know how physical infrastructure supplements farmers' managerial efforts in staying profitable. Second, when a donor government finances an irrigation scheme, it is rarely the case that they provide funding for the lower level canals. There is an obvious rationale for this, as low level canals require finer design which involves negotiations and adjustments among neighboring farmers. In a country with weak governmental capacity, however, it is reasonable that donor governments may be requested to provide assistance to low level canals. Understanding impacts of tertiary canals will clarify if such assistance is justified on an efficiency ground. To the best our knowledge, this study is one of the first attempts to answer these questions by using rigorous evaluation methods.

Our research shows that tertiary canals have no impact on yield. To show the conclusion, we first summarizes the background of our study in section 2. In section 3 we briefly explain our survey design and show descriptive statistics. Estimation results are in section 4. After discussing the results in section 5, final section concludes.

2 Empirical strategy

2.1 Institutional background

Our study area is located in Central Thailand. The province has experienced relatively rapid industrialization. The study area benefits from an pump irrigation scheme which was first planned by the Royal Irrigation Department (RID) in 1960s.

The area has good soil and weather conditions for paddy cultivation. Only the problem before the project was the shortage of water in dry season. A river with sufficient water runs close to the area. The altitude of the area, however, is high and farmers could not use the water from the river and their cultivation relied only on rain water. The cultivation in dry season is very rare in the area while the productivity in wet season is quite high. When the RID planned to construct the dam in the upper stream of the river, the construction of pumping irrigation project in Study Area was planned as a by product.

The project was financed by the the Japanese government and the loan agreement between the Thai and the Japanese governments was signed in 1995. After the completion of the a neighboring dam construction, the construction of 1 main and 12 lateral canals started in 2001 and have ended in 2005. A lateral canal called 2L, the second closest to the pumping station, has never been created because its beneficiary farmlands were eventually converted to industrial use during the construction period. The system is finally equipped with 11 lateral canals (i.e. 1L and 3L to 12L). The main canal has length of 34 kilometers and 11 lateral canals have total length of slightly less than 100 kilometers.

During the project period, the Thai government, proposed by Agriculture Sector Program Loan (ASPL) by Asian Development Bank, has adopted participatory irrigation management policy and started to organize farmers' groups in all of the irrigation project sites.

Water users group formation is highly important in Study Area for the collection of electrical fee. The project is unique project in the sense that it is the only irrigation project with big pumping machines in Thai.Collection of water use fee or electricity for pumping is highly necessary for the project to be sustainable. Before the project, however, there are no water users groups in the area. Farmers rely only on rain water for their cultivation and they did not do any coordination for water allocation. The cultivation was only in wet season. The RID had to convince farmers to organize the groups. Also the RID had to convince farmers that dry season cultivation can be possible with the water from pumping station. The RID promised farmers the construction of tertiary canals for the persuasion. Also demonstration farm with tertiary canals was constructed to show the validity of tertiary canals.

During each agricultural season, wet and dry, irrigation water is distributed on the basis of rotating supply to different laterals and the irrigation interval is typically 7 days. The timing and order of irrigation should be agreed upon among whole WUGs and the RID at the beginning of each season. The amount of water distributed to each lateral is determined based on the cropping area associated with it. The RID obtains information on cropping area from the plan submitted every season by WUGs. In this respect, WUGs play important roles in formulating and supporting the rule in which irrigation water can be distributed without serious conflicts between different laterals. A WUG is formed also in order to facilitate coordination of water use among its members. Each lateral usually has more than one WUG. The number of WUGs was initially 15 and it increased to 21 as of year 2008. After the first survey was conducted, the number of WUGs has further increased and reaches to 26 as of year 2011. Another important role of WUGs is to collect lateral maintenance fee as well as electricity fee for pumping in the dry season for the RID. It is worth pointing that farmers are charged nothing for electricity during the wet season. The collection rate of electricity fee in the dry season has been almost 100 percent. At least in this sense, the WUGs are well organized and play the desired roles.

A tertiary canal usually serves contiguous plots that share the dikes, and can exert finer control on water utilization and drainage than high level canals. Even without tertiary canals, water is available over ancestor plots that receive water from high level canals (plot-to-plot irrigation). The construction process of tertiary canals starts with discussions between the RID and land owners to decide which part of land is given up for canal construction. Then the RID draws a blueprint and dispatches a construction team. The construction of tertiary canals was initiated from the upper stream of 7L in 2004 as a small demonstration phase. In addition, in a part of 9L and 10L, there had already been tertiary canals constructed through the old project other than Study Area. They were easily integrated into the Study Area irrigation systems in 2006. Except for these cases, the RID began with the construction of tertiary systems along 1L which was at the eastern end of the project area and afterward proceeded westbound. In 2009, lateral canals up to 5L and a part of 6L, 7L, 9L and 10L had completed their tertiary canal construction.

2.2 Econometric identification of impacts

In assessing the productivity impacts of tertiary canals, we notice that, despite the canals are not placed randomly, its order of construction can be considered as exogenous to farmers. The tertiary canal construction started in the east, at 1L, end and proceeded westbound to 12L, with the exception of 7L where the upper stream WUGs have been chosen in a pilot scheme.[*1] There is no reason to expect the farmers in the east have different productivity than the west if we control the water availability where the east has more volume.

Therefore we take the difference-in-differences to estimate the impacts. Since the tertiary canals were constructed up to 5L when we started the baseline survey in 2008, we set our population as the plots in 6L - 12L. The canals were constructed in 2009 dry season and 2010 dry season. As stated in the introduction, farmers were asked to form a WUG and construct dirt ditch tertiary canals in exchange for the RID to construct the concrete ditch tertiary canals on top of them. In expectations for higher yield and smaller costs, farmers followed the RID's conditions and waited for construction. RID announced the construction of concrete ditch tertiary canals in 2009 dry season and asked the farmers not to plant paddy as the construction required to stop the water supply. Farmers accepted the RID's request and did not plant paddy in 2009 dry season. However, the funding for construction dried up before RID could complete the construction. In 10L, 11L, and 12L (need to recheck), construction was postponed to 2010 dry season in which RID requested not to cultivate, yet another time. Not surprisingly, thid did not make farmers happy and some rejected the construction of canals over their plots. So the design of the tertiacy canals had to be modified and some of them just run pararell to the lateral canal, making it less effective in supplying water to the plots away from the lateral.

These hick ups resulted in construction over two consecutive dry seasons. For 10L-12L plots, some farmers planted paddy despite the request from RID, and this forms the baseline in our DID

[*1] 7L is placed in the center of irrigation system where all farmers have relatively easy access to observe.

estimation for the dry season. For other plots, we do not have the baseline in the dry seasons and we only have the ex post information. For the wet seasons, we have the baseline in 2008 wet season, and post-construction information in 2009 wet season for 6L-9L plots. We will therefore estimate DID using wet season data.

There are several possiblities to implement estimation. First is difference-in-differences (DID) estimation. Given that order of tertiary construction is decided unilaterally by RID and is expected to be uncorrelated with farmer's individual traits, DID should be a reasonable estimation strategy. This is the approach we use in this paper.

Using Wooldridge notation:

$$y_{ijt,k} = c_o + c_i + c_{ij} + c_k + \lambda_t + g(\mathbf{x}_{ij0})t + h(\mathbf{x}_{ij0})d_k t + \tau w_{ijt} + \boldsymbol{\gamma}'\mathbf{x}_{ijt} + u_{ijt}.$$

w_{ijt} is a treatment variable. c_o, c_i, c_{ij}, c_k are fixed parameters; intercept, i fixed effect, $i-j$ fixed effect, and k^{th} arm fixed efefct, respectively. $g(\mathbf{x}_{ij0})$ is a function of a vector of individual trend terms which differ by the initial values of $\mathbf{x}_{ij0}$, and $h(\mathbf{x}_{ij0})d_k$ is another function of individual trending terms which is common only within k^{th} treated arm with an associated binary indicator d_k. To further note, $d_k = 1$ if $w_{ij0} = 0$, $w_{ijt} = 1$ for some $t > 0$ and $d_k = 0$ if $w_{ijt} = 0$ for all t. In a two period ($t = 0, 1$) setting with a single treatment ($d_k = d$), $dt = w_{ijt}$, hence $\Delta(dt) = d = \Delta w_{ijt}$.

Taking a first-difference,

$$\Delta y_{ijt,k} = \eta_t + g(\mathbf{x}_{ij0}) + \left\{h(\mathbf{x}_{ij0}) + \tau\right\}\Delta w_{ijt} + \boldsymbol{\gamma}'\Delta\mathbf{x}_{ijt} + \Delta u_{ijt}.$$

We take a first order approximation to the unknown functions g and h. Then

$$\Delta y_{ijt,k} = \eta_t + \mathbf{g}'\mathbf{x}_{ij0} + \left(\boldsymbol{h}'\mathbf{x}_{ij0} + \tau\right)\Delta w_{ijt} + \boldsymbol{\gamma}'\Delta\mathbf{x}_{ijt} + \Delta u_{ijt}.$$

If we demean individually, we have:

$$\tilde{y}_{ijt,k} = \tilde{\lambda}_t + \mathbf{g}'\mathbf{x}_{ij0}\tilde{t} + \boldsymbol{h}'\mathbf{x}_{ij0}d\tilde{t} + \tau\tilde{w}_{ijt} + \boldsymbol{\gamma}'\tilde{\mathbf{x}}_{ijt} + \tilde{u}_{ijt},$$

where $\tilde{x}_{ijt} = x_{ijt} - \frac{1}{T}\sum_{t=1}^{T} x_{ijt}$, and $\tilde{t} = t - \frac{T+1}{2}$ if $t = 1, \ldots$ and $\tilde{t} = t - \frac{T}{2}$ if $t = 0, \ldots$. So in a two period case with $t = 0, \ldots$, $\tilde{t} = -\frac{1}{2}, \frac{1}{2}$. So one prepares $(y_{ijt}, \boldsymbol{\lambda}', \mathbf{x}'_{ij0}t, \boldsymbol{d}' \otimes \mathbf{x}'_{ij0}t, w_{ijt}, \mathbf{x}'_{ijt})$ and demean all elements at i, j level, and running a regression will give parameters, where $\boldsymbol{\lambda}$ is $T-1$ dimensional vector of time effects, $\boldsymbol{d}$ is $K-1$ dimensional vector of treatment arms.

3 Data and Descriptive Statistics

3.1 Survey design

The purpose of our study is to evaluate the imapct of tertiary irrigation system on farming profits in the Study Area project area. To achieve this goal, we need panel data on agricultural production in farm plots both with and without construction of tertiary canals during survey periods. Fortunately, the location decision associated with where to construct tertiary canals can be largely attributed to the RID policy as described earlier, and thus is exogenous for farmers. As of the 2008 wet season , the tertiary canals had been completed up to 5L. In addition, the upstream of 6L, 7L, 9L and 10L had also been partially equipped with tertiary canals. Based on this observation, we decided to focus on two districts under 6L to 11L in order to estimate the impact of tertiary canals, taking advantage of the different timing in tertiary canal construction. In othe words, we expected that some farmers from 6L to 11L would get access to tertiary canal immediately after the baseline survey and thus becoming the treated group.

The list of agricultural farmers was available from the Department of Agricultural Extension (DOAE). The DOAE database contains farmers who have registered themselves to be eligible for receiving financial as well as technological assistance by the Ministry of Agriculture and Cooperatives. We had 2,431 farmers who were in our targeted districts as of November 2008. Whereas we easily find farmers' name and addresses from the database, actual location of their farm plots cannot be known a priori. Since the land rental markets are highly active in Thailand, we suppose that some farmers outside our targeted districts may have farm plots in the area. Similarly, it is quite possible for some farmers in our targeted districts to cultivate plots outside the area. We omit non-resident farmers from the sample population simply because we cannot identify them in advance. On the other hand, for sampled farmers in our targeted districts, we collect information on every farm plot, irrespective of its location.

We compiled an integrated list from the DOAE database and the membership information of WUGs in the project area by matching social identification numbers. WUG members are formal beneficiaries of the Study Area scheme, in which their farm plots are irrigated either through a main canal, (sub) lateral canals, ter- tiary canals or plot-to-plot system. Non-WUG members are the farmers who either lack access to any kind of irrigation or have access to irrigation other than the Study Area scheme. The compiled list contains 621 WUG members and 1,810 Non-WUG members. We have tried to survey all the WUG members (i.e. 621 farmers) and obtained 562 responses from this group. Additionally, 999 Non-WUG members were randomly selected and were visited. However, we discovered a considerable number of them were currently inactive in agricultural production and therefore only 264 Non-WUG members were identified as active farmers. We retain these 826 farmers in total for our main analysis.

The survey was conducted in four rounds. The first round was carried out from January to April, 2009, for collecting data on the 2008 wet season. The data pertain to household characteristics, land area, cropping pattern, agricultural output as well as input at each plot level, financial transactions, and other non-agricultural activities. Subsequently, the second round was carried out from July to

October, 2009, for collecting data on the 2009 dry season. The data on wet season in 2009 and dry season in 2010 were collected through the third and fourth round, respectively, using the same questionnaire. The third round was carried out from June to August, 2010, and the fourth round was done during from November, 2010, to January, 2011. We finally obtain a four-round panel dataset for the impact evaluation of tertiary canals. The sample attrition rate is relatively low, apporoximately 7% during from the first to forth round. The decrease of respondents is mainly due to their exits from agricultural sector, which may reflect the effect of rapid industrialization in the survey area and aging of farmer population.

3.2 Decriptive statistics

We summarize the area under the concrete tertiary canal irrigation in Table 1. We see the coverage of concrete tertiary canals increases slowly, due to the slow progress of construction. In Figure 1, we see that there is still significant fraction of paddy area that are not under tertiary irrigation in 2010 dry. In fact, due to the second request by RID to stop paddy cultivation, tertiary-unirrigated area increased and tertiary-irrigated area decreased from the 2009 dry season.

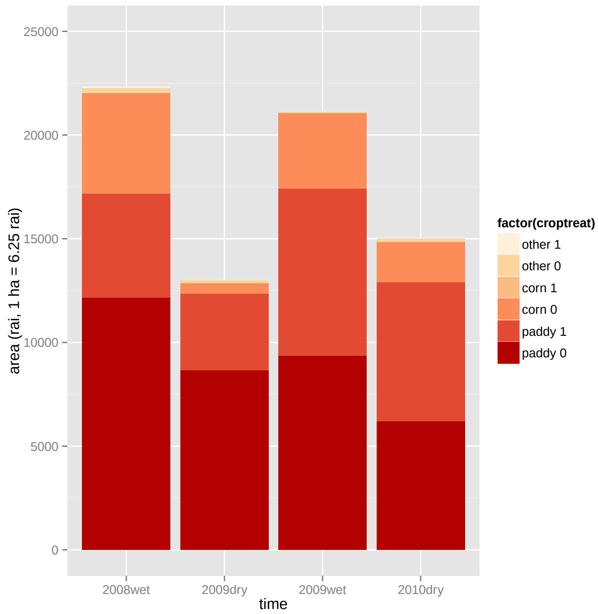
Table 1: Tertiary Concrete Treatments

	FALSE	TRUE
2008wet	1580	444
2009dry	1588	436
2009wet	1343	681
2010dry	1370	654

Source Survey data.

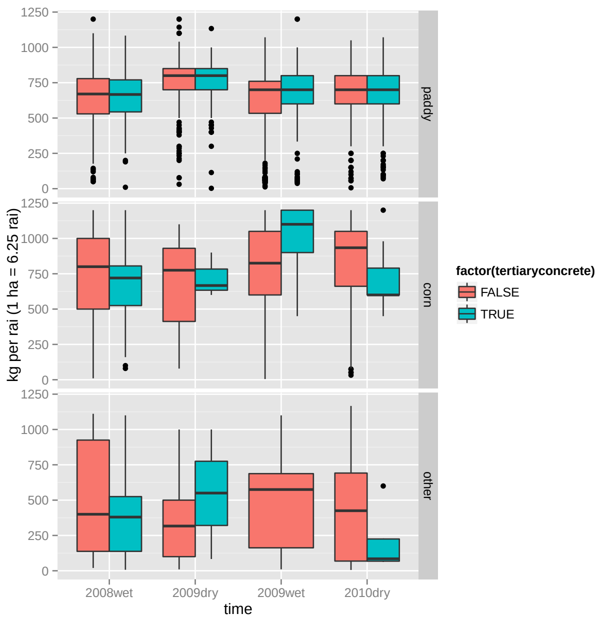
Note The numbers indicate the number of plots under each regime.

FIGURE 1: TERTIARY CONCRETE TREATMENTS BY CROP



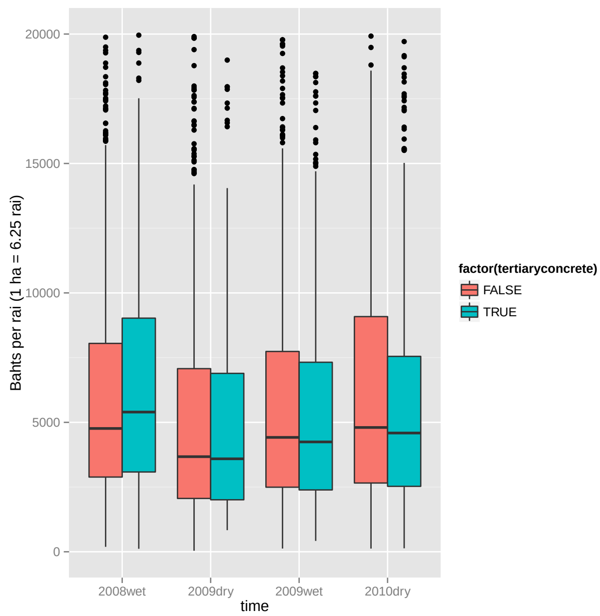
Notes Suffixes 0,1 indicate with and without access, respectively, to a tertiary concrete canal. For example, paddy0 indicates the share of paddy fields without tertiary access. Areas are shown in rai (1 rai= .16 ha).

FIGURE 2: TERTIARY CONCRETE TREATMENTS AND YIELD



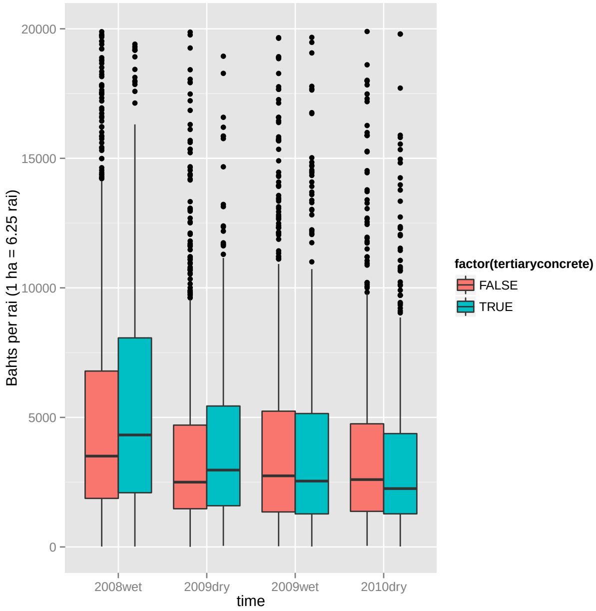
Notes TRUE,FALSE indicate with and without access, respectively, to a tertiary concrete canal. Yield is shown in kg per rai (1 rai= .16 ha).

FIGURE 3: TERTIARY CONCRETE TREATMENTS AND LABOR COSTS



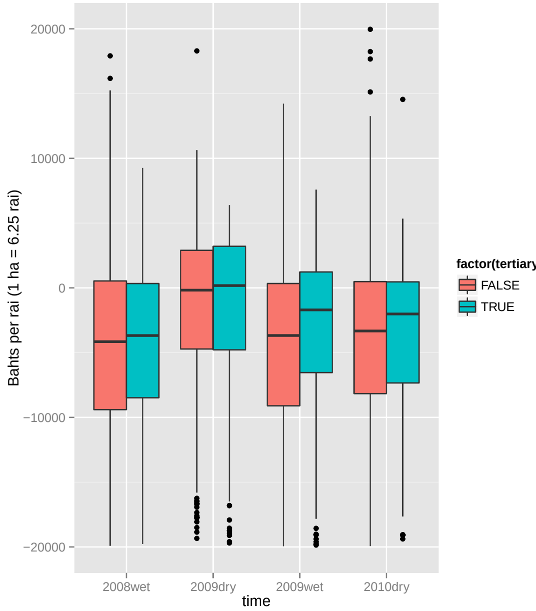
Notes Total labor costs in Bahts per crop cycle per rai. See also the footnote of FIGURE 2.

Figure 4: Tertiary Concrete Treatments and Material Costs



Notes Total material costs in Bahts per crop cycle per rai. See also the footnote of Figure 3.

Figure 5: Tertiary Concrete Treatments and Profits



Notes Profits in Bahts per crop cycle per rai. also the footnote of Figure 3.

Impacts on yield, or kilogram production per rai, is not visibly present in box plots in Figure 2. This is contrary to what we heard before we undertook our study, as many local experts, especially who are knowledgeable about the area and how an irrigation system works, have claimed that full benefits of an irrigation scheme will not be realized without the construction of tertiary canals. So it is surprising to see so little difference between the treated and the control group.

Once we look at the labor costs in Figure 3, we see small reduction in 2009 wet and 2010 dry seasons, but they do not appear to be large. As one may expect the labor costs to be reduced once tertiary canals become available, this is another unexpected result. In Figure 4, we also see little difference between two groups for material input costs. These are consistent with our findings in our field survey that farmers point to the main benefits of tertiary canals as shorter waiting period of up to two days, and they do not claim to have saved costs by having access. Overall, in terms of inputs, tertiary canals may have some impacts but they do not seem to provide noticeable differences.

We examine per rai profit in Figure 5 across time and treatment arms. Rather surprisingly, the bulk of plots show negative profits in both arms. If we look at the mean of each bars, we see that the level of negative profits is about 5000 per rai, which corresponds to mean labor costs we see in Figure 3. This indicates that the mean farm incomes are approximately zero, and if one subtracts payment to farmer oneself, the profits become negative. This is consistent with the notion that the Thai paddy farmers mostly care about incomes rather than profits. While the precise reason behind why farmers would cultivate for negative profits remains unknown, it fits to the casual observations that aging farmers care mostly about keeping the land cutivable rather than earning higher profits.

4 Results

In Table 2, estimated results for cultivation probability are shown. We have used the wet season panel at the plot level. Given that farmers cultivate scattered plots, we expect that unobservable characteristics of plots of a given farmer to be relatively uncorrelated. Therefore we choose to cluster the standard errors at the plot level rather than at the farmer level. We note that the tertiary canal construction is positively correlated in all specifications. From (2) onward, we added the interaction terms with the treatment and time dummies to control for heterogeneous growth trends by using area, educational attainment, and crop choice in the first period. With or without these controls, the estimated impacts of tertiary canal remain positive and statistically significant. If we are successful in controlinog for heterogeneous growth trends between the treated and control plots, the construction of tertiary canals will result in an increased cultivation probability by 12% to 60% points in the wet season.

It is surprising to see statistically significant impacts in Table 2, because in wet seasons, water is abundant and some plots even have to deal with excessive water. The general understanding of farmers and farming experts is that tertiary canals can be useful only in the dry seasons. A possible explanation of the above estimated results are capturing the impacts of having tertiary canals for drainage, despite most of the tertiary canals are constructed at an elevated level than the plots that require a pump to jack up water to canals.

Another surprising result is the statistically negligible estimates on the plot area. Tertiary canals are meant to allow fine tuning of water control. It is therefore expected to have a greater impact on the larger plots due the difficulty in the water management. Such conventional wisdom seems to be at odds with our data. We see no impact of tertiary canal construction on cultivation that is magnified with the plot size.

In Table 3, cultivation probability is estimation with dry season data. Since there was a delay in canal construction and some farmers had to face the extended period of forced production termination, we have smaller sample size. Once we include the interaction terms with land and household variables, the impacts of tertiary canal on dry season cultivation becomes strongly positive with a large enough magnitude. It is negative if we do not use other covariates to control for heterogeneous growth trends. Tertiary canal impacts among larger plots are negative on cultivation for the treated group, yet it will be indistinguishable from zero once we control for the household demographics. Farmers who have large areas in total tend to cultivate more in the dry seasons. More female adults in the household will reduce the cultivation chance. Ths indicates smaller household size with fewer fe-

Table 2: Impacts on Cultivation Probability, Wet Seasons

	(1)	(2)	(3)	(4)
(Intercept)	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
trend	−0.108***	−0.181***	−0.207**	−0.531***
	(0.012)	(0.019)	(0.083)	(0.116)
tertiary canal	0.227***	0.167***	0.183***	0.353***
	(0.023)	(0.022)	(0.025)	(0.118)
trend × no tertiary at t=1 group		0.132***	0.117***	0.559***
		(0.020)	(0.023)	(0.122)
trend × area (100 rai) at t=1			0.019	−0.038
			(0.057)	(0.052)
trend × paddy at t=1			−0.026	−0.074
			(0.063)	(0.060)
trend × corn at t=1			0.012	−0.041
			(0.064)	(0.061)
trend × number of adults at t=1			0.016	−0.023
			(0.052)	(0.055)
trend × primary school			0.019	0.065
			(0.043)	(0.042)
trend × secondary school			0.057	0.085
			(0.054)	(0.054)
trend × high school			0.165**	0.194*
			(0.068)	(0.114)
trend × area (100 rai) at t=1 (0 → 1)				−0.069
				(0.078)
trend × paddy at t=1 (0 → 1)				−0.120
				(0.089)
trend × number of adults at t=1 (0 → 1)				−0.089
				(0.083)
trend × primary school				−0.148**
				(0.059)
trend × secondary school				−0.180**
				(0.077)
trend × high school				−0.299**
				(0.125)
trend × area (100 rai) at t=1 (1 → 1)				0.068
				(0.167)
trend × paddy at t=1 (1 → 1)				0.356***
				(0.083)
trend × number of adults at t=1 (1 → 1)				0.135
				(0.115)
trend × primary school				0.037
				(0.088)
trend × secondary school				−0.107
				(0.126)
trend × high school				0.116
				(0.158)
N	1542	1542	1542	1542

Notes: 1. Linear fixed effect estimation of cultivation probability. Data drom 2008 wet and 2009 wet seasons are used. *, **, *** indicate statistical significance at 10%, 5%, and 1%, respectively. Robust standard errrors clustered at the plot level are used.

2. All time invariant covariates, area, total area, primary school attainment, secondary school attainment, high school attainment, vocational school attainment, and crop choice of paddy are interacted with time and treatmet dummy variables. Omitted category of school attainment is NA and tertiary education.

3. 0 → 1 and 1 → 1 in the brackets show the treatment status changes. So trend × paddy at t=1 (0 → 1) indicates an interaction term between time trend, a group changing from untreated to treated (0 → 1), and an indicator function of growing paddy at t=1. It controls for the growth pattern of paddy growers at t=1 whose plots had no access in t=1 but gained access in t=2.

Table 3: Impacts on Cultivation Probability, Dry Seasons

	(1)	(2)	(3)	(4)
(Intercept)	0.000	0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
tertiary canal	−0.150***	0.039	0.288***	0.277***
	(0.026)	(0.042)	(0.065)	(0.066)
area (100 rai)		−0.062***	−0.005	−0.002
		(0.010)	(0.014)	(0.014)
total area (100 rai)		0.086***	0.091***	0.094***
		(0.020)	(0.020)	(0.020)
number of children			0.034**	0.036**
			(0.016)	(0.017)
number of adults			−0.044	−0.056
			(0.055)	(0.055)
adult female proportion			−0.104***	−0.106***
			(0.021)	(0.021)
primary				0.070***
				(0.016)
secondary				0.056***
				(0.009)
highschool				0.060***
				(0.012)
vocational				0.006
				(0.026)
paddy				−0.134**
				(0.064)
N	779	779	779	779

Notes: 1. See the footnotes of Table 2.
2. All terms are interaction terms with the trend variable.

Table 4: Impacts on Per Rai Profits (Bahts), Wet Seasons

	(1)	(2)	(3)	(4)
(Intercept)	0	0	0	0
	(0)	(0)	(0)	(0)
tertiary canal	4114	4114	4114	4114
	(3030)	(3030)	(3030)	(3030)
N	1016	1016	1016	1016

Notes: 1. Linear fixed effect estimation of per rai profits. Data drom 2008 wet and 2009 wet seasons are used. *, **, *** indicate statistical significance at 10%, 5%, and 1%, respectively. Robust standard errrors clustered at the plot level are used.
2. All time invariant covariates, area, total area, primary school attainment, secondary school attainment, high school attainment, vocational school attainment, and crop choice of paddy are interacted with time and treatmet dummy variables. Omitted category of school attainment is NA and tertiary education.
3. Level variables are omitted for brevity. All terms are interaction terms with the trend variable.

male adults is correlated with larger cultivation probability. The negative and statstically significant estimates on paddy is due possibly to the fact that paddy is more prone to discontinued cultivation in dry seasons than other crops such as corn.

Table 4 shows the impacts on per rai profit during wet seasons. Covariates are same as the previous tables. We have statistical insignificant yet positive point estimates of tertiary canal. It implies that level impacts on profits have been negligible after the construction of tertiary canals for wet seasons. This is not surprising given that there is little impact on productivity and cost saving as seen in FIGURE 2, FIGURE 3, and FIGURE 4. [*2]

5 Discussion

In this paper, we have described the challenge in impact evaluation of infrastructure and estimated the economic impacts using the panel data set from rural Thailand. We employed difference-in-differences estimation and showed that tertiary irrigation has unexpected impacts. Contrary to the local experts predicitions that it should have substantial productivity impacts as it allows better water controls for farmers, we found zero profitability impacts across the board. In fact, the point estimates were just barely positive and their statistical significance was rejected at the conventional level. This new finding is informative to policymakers who are contemplating on similar projects.

However, we do not intend to generalize our finding beyond reasonable limit of application. One needs to remind oneself that Study Area project is small in comparison to other irrigation projects, such as these of full scale dam irrigation in Thailand. The length of tertiary canals is short in comparison, and one should not expect tertiary canals to convey more volume of water than plot-to-plot irrigation. In fact, our informal interviews suggest that farmers see the benefits of less negotiation in deciding water use timing and less waiting time of water delivery for the duration of a half to 2 days. Farmers were appreciative of tertiary canals but they could not come up with sizeable productivity gains or cost reduction due to construction. Therefore, failing to detect the profitability impacts should not be treated as the recommendation to stop construction of tertiary canals in other parts of the world. One of the reasons we suspect is that the rich water volume available in the area, especially in wet seasons, makes the tertiary canals irrelevant to production. This should not apply to dry seasons, so we are going to check the profitability impacts after we collect the dry season data in the follow up survey currently implemented.

Another unexpected finding is that, while profitability is not affected, we see an increase in cultivation probability with the construction of tertiary canals. This is observed in both wet and dry seasons but its magnitude is larger for the latter. This finding suggests that Thai farmers, despite its aging population and relative relaxed attitude toward cultivation, are willing to expand operation scale once they get water. With little cash income earning possibility, farmers may find it beneficial, despite there is no profit increase, because they still get labor incomes as a laborer (hired by oneself). Due to more intensive use of land, tertiary canal helps improve the land productivity per year. Again,

[*2] While not shown, plot size is strongly positive and total area is strongly negative. This implies the economy of scale at the plot level but not at the household level. This may be due to the scattered location of plots cultivated by the farmers. Tertiary impacts among high school graduates are, again, positive. Choice of paddy does not seem to be associated with larger tertiary impacts.

we need to caution ourselves that we should not overgeneralize the implications. The willingness to expand should be dependent on other institutions such as land markets, crop pricing policies, and supply environment of other inputs. Thailand is known for protection of paddy production, and it is possible to attribute more intensive land utilization to the protectionist policies.

As the impact evaluation of infrastructure is rarely found, it is important to carry out one with sound evaluation design whenever possible. This paper is one of the first attempts to show the impacts of nonrandomly placed infrastructure. We encourage policymakers to incorporate evaluation components to their projects to learn more from this relatively unknown field.

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付録 A　Other possibble estimation strategies

For the reference to the future work, we will consider structural estimation strategies.

Another possible way is to estimate the factor demand functions using methods of Olley and Pakes (1996); Levinsohn and Petrin (2003) using algorithm developed, for example, by Berry et al. (1995). This essentially assumes a functional relationship between unobservable effect and flexible inputs, and inverts the function to proxy it. This ingeneous way of estimation has a problem that a parameter on labor may not be identified separately. See Ackerberg et al. (2006, 2007); Aguirregabiria and Mira (2010) for more discussions.

The last way we consider is to estimate macrunutrient factor demand function using its factor prices as instruments. This is not implemented in this paper but will be incorated in future revisions once we obtain the market price series of macronutrients. Consider a farmer with a production function:

$$Y = A(\boldsymbol{\theta})F\left\{b(\boldsymbol{\theta})L, c(\boldsymbol{\theta})\boldsymbol{M}, d(\boldsymbol{\theta})N\right\},$$

where A is a general productivity term, L is labor, $\boldsymbol{M}$ is a vector of materials, N is land, with b, c, d are efficiency coefficients for respective factors of production, and $\boldsymbol{\theta}$ is a vector of productivity parameters. We assume that the coefficient is common c for all material inputs. We also assume homogeneity of degree one in inputs, so dividing with N gives:

$$y = A(\boldsymbol{\theta})\left\{b(\boldsymbol{\theta})l, c(\boldsymbol{\theta})\boldsymbol{m}, d(\boldsymbol{\theta})\right\},$$

where $y = \frac{Y}{N}$, $l = \frac{L}{N}$, $\boldsymbol{m} = \frac{\boldsymbol{M}}{N}$. Assuming $d(\boldsymbol{\theta})$ and other inputs are multiplicatively separable, we can let $A(\boldsymbol{\theta})F\left\{b(\boldsymbol{\theta})l, c(\boldsymbol{\theta})\boldsymbol{m}, d(\boldsymbol{\theta})\right\} = A(\boldsymbol{\theta})f\left\{b(\boldsymbol{\theta})l, c(\boldsymbol{\theta})m\right\}\tilde{f}\left\{d(\boldsymbol{\theta})\right\} = a(\boldsymbol{\theta})\left\{b(\boldsymbol{\theta})l, c(\boldsymbol{\theta})m\right\}$ with $a(\boldsymbol{\theta}) = A(\boldsymbol{\theta})\tilde{f}\left\{d(\boldsymbol{\theta})\right\}$. So, noting the dependence on $\boldsymbol{\theta}$ of b and c,

$$y = a(\boldsymbol{\theta})f(l, \boldsymbol{m}|\boldsymbol{\theta}).$$

Given that our data set has information on production, factor inputs and their prices, and relatively homogeneous production technology, we are in a position to estimate a production function (to tackle the primal problem).

The common concern in production function estimation is endogeneity of input use. If we cannot observe everything that producers do, which we cannot, the chosen inputs will be correlated with the variables that are unovservable (to econometricians). This will be seen in the first-order conditions of profit maximization which gives factor demand functions:

$$l = l(w, \boldsymbol{v}|\boldsymbol{\theta}),$$
$$\boldsymbol{m} = \boldsymbol{m}(w, \boldsymbol{v}|\boldsymbol{\theta}),$$

where w is wage rate, and $\boldsymbol{v}$ is a vector of material prices. Use of raw input data will therefore create an endogeneity bias in estimation.

Input prices are the usual choice of instrumental variables for inputs being used, because they are considered to be determined in the market where an individual farmer and plot characteristics do not affect the equiibria. Even if this is true, factor demand parameters are not indentifiable because the factor prices that appear in all equations are identical, i.e., there is no excluded variable in each equation. Furthermore, farmers observe what econometricians do not, and choose the inputs accordingly. So there is an obvious correlation between $\boldsymbol{\theta}$ with the choice of materials, and therefore with their prices. This follows as the plots with lower nitrogen (N), phosphorus (P), and potash (K) contents will need to be enriched more with each macronutrients, resulting in higher prices, or underestimation of fertilizer's producvitity contributions. So we cannot use own product prices in factor demand estimation as a first step of production function estimation.

Fortunately, our data on fertilizers come with the contents of macronutrients, N, P, and K. We have information on fertlizer prices, its NPK contents, and unit prices of each N, P, and K. These pieces of information will give us a detailed way to identify the productivity parameters.

If we assume that there exists an optimal amount in the soil for each macronutrients, farmers will try to purchase the deficit amount. Then, the amount purchased by the farmers will be negatively correlated with the existing amount in the soil. The existing amount will be positively correlated with the productivity, the raw macronutrient inputs will have a negative correlation with the regression residuals. Demand for each macronutrients take own unit prices but not others, as each macronutrient serves a distinct function, and complementarity or substitutability between them, if any, will be expressed with their interaction terms but not as the dependence of demand on unit prices on other macronutrients. So if there is any composite impact of NPK, we will capture them with interactions of projected demand, such as $\hat{N}(v_N)\hat{P}(v_P)$, but not as $\hat{N}(v_N, v_P)$ nor $\hat{P}(v_N, v_P)$. While the aggregate fertilizer input prices will be invalid as an instrument, unit prices for each macronutrients are valid as they should not be correlated with the characteristics of individual plots. Other contents in the fertilizers they use will be correlated to unobservable productivity parameters of individual plot, and we will use only the portion of fertilizer use that is projected by the instruments.

Labor use on each plot can largely be seen as uniform for the major tasks of paddy production. Land preparation is usually done with tractors, with operator services bundled together in the case of hire. Seeding, fertilizer application, pesticide spraying, and harvesting are highly standardized, with some tasks such as harvesting are even mechanized. These would not give large differences in labor use per unit area. The possible causes of different labor use may come from water management, weed, pest, and disease controls. We have labor use data for weed, pest, and disease controls. We proxy the water management labor use by adding GIS information in the estimation, in which we presume that water management is more difficult if the plots are not attached to the tertiary canals and are away from the tertiary head. Just as the composite fertilizers, the estimated parameters on labor in these tasks may be downwardly biased. To minimize the risk of having inconsistent estimates, one can drop the labor use for these tasks in the production function estimation and use only labor for other tasks.