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Contents

Preface

Ex-post evaluation of ODA projects has been in place since 1975 and since then the coverage of evaluation has expanded. Japan's ODA charter revised in 2003 shows Japan's commitment to ODA evaluation, clearly stating under the section "Enhancement of Evaluation" that in order to measure, analyze and objectively evaluate the outcome of ODA, third-party evaluations conducted by experts will be enhanced.

Recently in the context of increasing concern on development outcomes, in order to implement more effective and efficient assistances, impact evaluation that precisely measures change that occurs as the result of an intervention or project implementation is beginning to receive more attention. JICA has been working on promoting the utilization of impact evaluation methods.

This volume shows the results of the impact evaluation of an ODA Loan project. The lessons and recommendations drawn from this evaluation will be shared with the JICA's stakeholders in order to improve the quality of ODA projects.

Lastly, deep appreciation is given to those who have cooperated and supported the creation of this volume of evaluation.

July 2011

Nobuhiro HOBO

Vice President

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Disclaimer

This volume of evaluation shows the result of impact evaluations made by external evaluators. The views and recommendations herein do not necessarily reflect the official views and opinions of JICA.

Minor amendments may be made when the volume is posted on JICA's website.

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Glossery of terms	
ATT	average treatment effects on the treated
DID	difference-in-differences
DOAE	Department of Agricultural Extension
FE	fixed effects
FE-DID	fixed effect difference-in-differences
GPS	global positioning system
IE	irrigation efficiency
JICA	Japan International Cooperation Agency
KKBM	Kaeng Khoi Ban Mo
PN	Pattananikom
RID	Royal Irrigation Department
PSM	propensity score matching
RCT	randomized control trial
RDD	regression discontinuity design
WUE	water use efficiency
WUG	water users group

Abstract

Under the commission from JICA, we conducted a four-round household survey from 2009 to 2010 to estimate the impacts of Kaeng Khoi-Ban Mo (KKBM) Pump Irrigation scheme. Total of 826 households were selected and interviewed. As primary and secondary canals were already in operation at the time of survey, we focused on the impacts of tertiary canals.

It is well known that impact evaluation of infrastructure is difficult. This is due to difficulty in randomization and broad spillover of program impacts that effectively wipes out the control group. Our focus on the tertiary canal was strategically determined in light of these difficulties: First, tertiary canals are partially constructed and we could expect to employ plot-level difference-in-differences (DID) estimator. Ordering of tertiary canal construction was determined administratively, started from the closest area to the pump to the furthest. This ordering is expected to be uncorrelated with farmer ability, and provides credible ground for implementing DID estimator. Second, smaller program impacts due to limited capacity of tertiary canals to serve plots simultaneously allow us to find the control group within the irrigation scheme. The availability of control group in the neighborhood of the treated group lends support for credible impact evaluation.

DID estimates of all crop profits indicate large impacts of tertiary canals. Depending on estimation equation specifications, impacts range from 68,663 - 70,316 Bahts in 2009 dry season, 44,712 - 45,693 Bahts in 2009 wet season, and 62,276 - 62,930 Bahts in 2010 dry season, although 2009 wet season impacts are not statistically significant. These large impacts can be conceptually divided to two steps: First, farmers began to utilize the previously uncultivated plots in the dry seasons. Tertiary impacts on cultivation probability are large, an increase of 20% - 30% points in dry seasons (all tertiary canals) and an increase of 10% points in wet seasons (only concrete tertiary canals). Second, conditional on cultivation, accessibility to tertiary canals provides equally large profits as cultivated control plots, and accessibility *per se* does not seem to give extra profitability over the cultivated control group plots. Estimated results are robust to various specification changes.

The results confirm that the initial goal of the project in increasing land use intensity is achieved successfully. However, it is achieved under shrinking irrigated area due to industrialization and urbanization that allowed RID to operate at low irrigation efficiency with limited water supply capacity. With modest productivity and profitability impacts of tertiary canals conditional on cultivation, tertiary canal construction in KKBM is best described as having an encouragement impact.

While tertiary canals' impacts on profits are positive and statistically significant in KKBM, one should not conclude that JICA should always invest in the future tertiary canal projects. One must be reminded that there are conditions that helped KKBM tertiary canals to have impacts at plot level: smaller pressure on water supply capacity due to shrinking command area in the face of industrialization and urbanization, existence of uncultivated plots in dry seasons, good relationship between RID and farmers, and well governed and well functioning WUGs. In the future tertiary irrigation projects, one is advised to compare with KKBM if similar conditions exist. In addition, as it requires fine tuned consensus in constructing tertiary canals, it is recommended to assist WUGs and government officers in providing capacity boosting training and operations to increase their governance abilities.

Given the general aversion towards impact evaluation of infrastructural projects by other donors, it is recommended that JICA to continue its evaluation of infrastructure projects for its unique contribution to the knowledge base of development policies. Under the general infeasibility of randomized control trials of infrastructure, use of triple difference estimator is expected to ameliorate endogeneity issues to some extent, which can be achieved by conducting baseline survey two periods ahead of project operation. Feasibility studies can be used as a part of baseline, whose contents can also be used for policy development to give immediate feedback even before the project becomes operational. Use of feasibility studies for evaluation and policy development requires closer collaboration between operation department and evaluation department within JICA.

要約

国際協力機構 (JICA) からの委託の下、本調査では 2009 年から 2010 年にかけて 4 次にわたる家計調査を実施し、パーサック灌漑事業 [ケンコイ・バンモ (Kaeng Khoi-Ban Mo, KKBM) ポンプ灌漑] のインパクト評価を行った。家計調査では 826 家計を対象にインタビューを実施した。1 次および 2 次水路がすでに建設されて運用されていたため、インパクト評価では 3 次水路に焦点を当てることにした。

よく知られているように、灌漑のようなインフラストラクチュアのインパクト評価は困難である。なぜならば、インフラストラクチュアをランダムに建設すること (治験) がほぼ不可能であることに加え、建設すると波及効果が広範囲に及ぶために、比較対象とすべき統御群が無くなってしまうためである。本調査が 3 次水路に焦点を絞るのも、こうした配慮を念頭においている。3 次水路に着目する方法論的な理由は以下に基づく。第一に、調査が開始された時点で 3 次水路建設はすでに進行していたが、耕作地単位では difference-in-differences(DID) が推計可能である。3 次水路建設の順序はポンプの近傍から遠隔地、というように行政的に決められている。この順序は農民の能力と無相関であることが期待されるため、DID 推計値の信頼性は高い。第二に、3 次水路のインパクトの地理的広がりが限定的であるため、同じ灌漑区域内で統御群を見つけるのが容易である。実施群の近傍で統御群を見つけることができるため、インパクト評価の信頼性を高めることができる。

3 次水路建設が全作物利潤に与える DID 推計値は大きい。推計式の特定化に応じて、インパクトは 2009 年乾季に 68,663 - 70,316 バーツ、 2009 年雨季には 44,712 - 45,693 バーツ、2010 年乾季には 62,276 - 62,930 バーツである。ただし、2009 年雨季の推計値は統計的に有意ではない。こうした大きなインパクトは 2 つの過程に分解できる。第一に、農民は以前は乾季に耕作していなかった土地を耕作するようになった。3 次水路が耕作確率に与える影響は大きく、乾季には 20% - 30% ポイント (3 次水路全般) 、雨季には 10% ポイント (コンクリート製 3 次水路のみ) に上る。第二に、耕作をする場合には、3 次水路は統御群耕作地と同程度の利潤をもたらす。これは 3 次水路それだけでは統御群よりも高い利潤をもたらさないことを示している。推計結果は推計特定化を変更しても頑健である。

推計結果からは、土地利用率を高めるという灌漑プロジェクト企画当初の目標が成功裏に実現したといえる。しかし、この目標は、工業化と都市化によって農地が減少したからこそ、限られた水源と低い灌漑効率の下でも実現できたことに留意すべきである。そして、耕作をする場合には利潤や生産性に与える効果が小さいことから、KKBM における 3 次水路建設は、生産性よりも乾季耕作促進に効果があったと捉えるべきであろう。

KKBM における 3 次水路の利潤に与える効果は有意であっても、今後の 3 次水路建設への JICA の関わり方には考慮が求められる。なぜならば、KKBM では耕作地での灌漑効果を高める条件があったことを無視し得ないからである。都市化と工業化の進展による農業用水需給逼迫の緩和、乾季休耕地の存在、農民と RID との良好な関係、よく統治された水利組合などである。今後、KKBM を参考に類似事業を実施する際には、同等の条件が揃っているか検討することが望ましい。また、一般に 3 次水路建設には細かな利害調整が必要なため、水利組合や行政官の能力強化事業を実施し、相手国政府のガバナンス能力を高めることも重要であると考えれられる。

他の援助機関がインフラストラクチュアのインパクト評価を忌避しているなかで、JICA がインフラストラクチュア案件を評価することの意義は高い。今後もインフラストラクチュア評価を実施して開発政策へのユニークな知的貢献を続けるべきである。評価のためのランダム化試験が不可能であるため、2 階差分の差 (triple difference) 推計値を利用すれば、内生性の問題は一定程度の対処が可能である。このためにはプロジェクト建設の 2 期前からベースライン調査を実施する必要がある。建設のためのフィージビリティ調査をベースライン調査の一部として実施し、ベースライン調査から判明した事実をプロジェクト開始前にフィードバックすることも考えてよいはずである。フィージビリティ調査を評価とプロジェクト運営に役立てるためには、オペレーション部門と評価部門が緊密に協力しあうことが必要となる。

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1 Introduction

Over the past half a century, substantial resources and considerable efforts have been devoted to the development of irrigation infrastructure in many countries. The total farm area equipped for irrigation in the world increased from 167.9 million hectare in 1970 to 300.9 million hectare in 2009, indicating the unprecedented increase in water available for agriculture. The most significant change was seen in Asia where the farm area equipped for irrigation increased from 116.2 million to 211.8 million hectare, which accounted for above 70 percent of the total expansion of irrigation during this period (FAO, 2010).

A well functioning irrigation system plays a key role in the growth of agricultural production and farmers' income. Irrigation can extend cultivable farmland and at the same time promote multiple cropping in the field which otherwise should be dependent on rain fed farming. Irrigation systems are also thought to be effective in improving crop yield through the better control of water usage along with increased inputs such as fertilizer and pesticide. It is expected that these benefits to be large in the case of paddy crops, because they require a lot of standing water with the need of proper control over its level to grow. In fact, in Thailand, 84.9 percent of the harvested irrigated area was paddy field in 2007 and paddy production during the dry season has steadily increased since the mid-1990. In a peri-urban area that we study, the benefits of irrigation can go beyond paddy, as proximity to consumers encourages diversified crop production. We will therefore analyze how crop production as a whole, not just paddy production, changes with irrigation investments.

Despite the importance of irrigation, however, rigorous impact evaluation of this infrastructure has been surprisingly rare. One primary reason behind this gap comes from the fact that it is difficult to find the appropriate control group of farmers without irrigation that can be compared to the treated group of farmers with irrigation. To obtain the better control group is a central issue in applying the rigorous evaluation framework. Due to the infeasibility of random assignment of large-scale infrastructure, an evaluator should choose comparison areas which have similar characteristics, except for the presence of irrigation, to that of interested irrigation areas. The comparison areas should be selected from regions far from any irrigation projects, since irrigation have wide-reaching effects. However, geographically distant areas possibly have very different agronomic environments as well as different economic conditions. Therefore, it is practically difficult to find the desired control group in the evaluation of irrigation systems.

In this study, instead of evaluating irrigation systems as a whole, we examine the effects of tertiary irrigation canals using detailed plot-level data from area with large pump-irrigation systems in central Thailand. Although an apparent limitation arises from our narrow scope of study, focusing on the effects of tertiary canals has one clear advantage. By the nature of low level canals, a tertiary canal affects 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 deference-in-differences estimator that is increasingly popular among policy evaluation literature.

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 policy-maker 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 low 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.

In the following sections, we will discuss how we can undertake the impact evaluation study. In Section 2, we describe our study area. We also show the principles of impact evaluations and propose the estimation strategy for this study. In Section 3, we explain the survey and data details. In Section 4, we examine the estimated results and discuss possible economic mechanisms behind them. In Section 5, concluding remarks and the future agenda are provided.

FIGURE 1: LATERAL AND TERTIARY CANALS

2 Study Area and Evaluation Framework

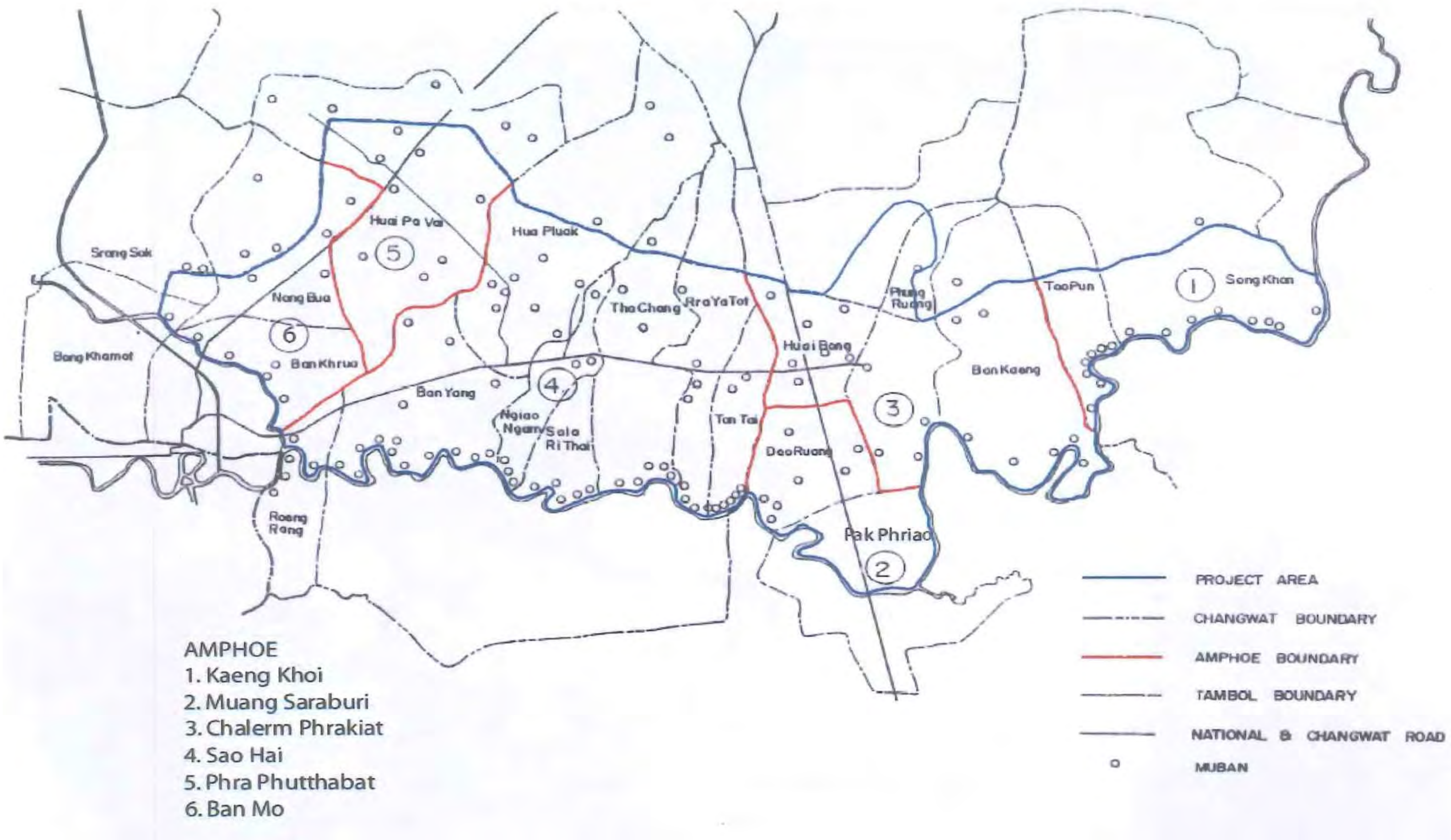
2.1 Study Area

Our study area is located in Saraburi province in central Thailand. The town of Saraburi is around 100 kilometers from Bangkok and the province has experienced relatively rapid industrialization. The study area benefits from the Kaeng Khoi - Ban Mo (KKBM) Pumping Irrigation Project which was first planned by the Royal Irrigation Department (RID) in 1976. Japan International Cooperation Agency (JICA) initiated a feasibility study (F/S) in 1982, and agreed on a loan for project design in 1985. Due to construction of Pasak Cholasit Dam in the upper stream of Pasak River, the project had come to a stop. In 2001, the project was restarted with a loan from JICA. The loan financed the construction of main (primary), lateral (secondary) and sub-lateral (sub-secondary) canals, and have ended in 2005. Construction of tertiary canals and maintenance of the irrigation scheme are designed and financed by the Thai Government, namely the RID.

The project aims at increasing agricultural productivity and land utilization. It is therefore important to understand project's impacts on these outcomes. In 1982 when JICA conducted an F/S, the project also eyed at crop diversification as another aim. However, our research found that policy goal has lost in a way, and was not shared when the project began in 2001. It is observed that paddy production is currently prevailing in the project area. We will show the crop choice by farmers in our sample later.

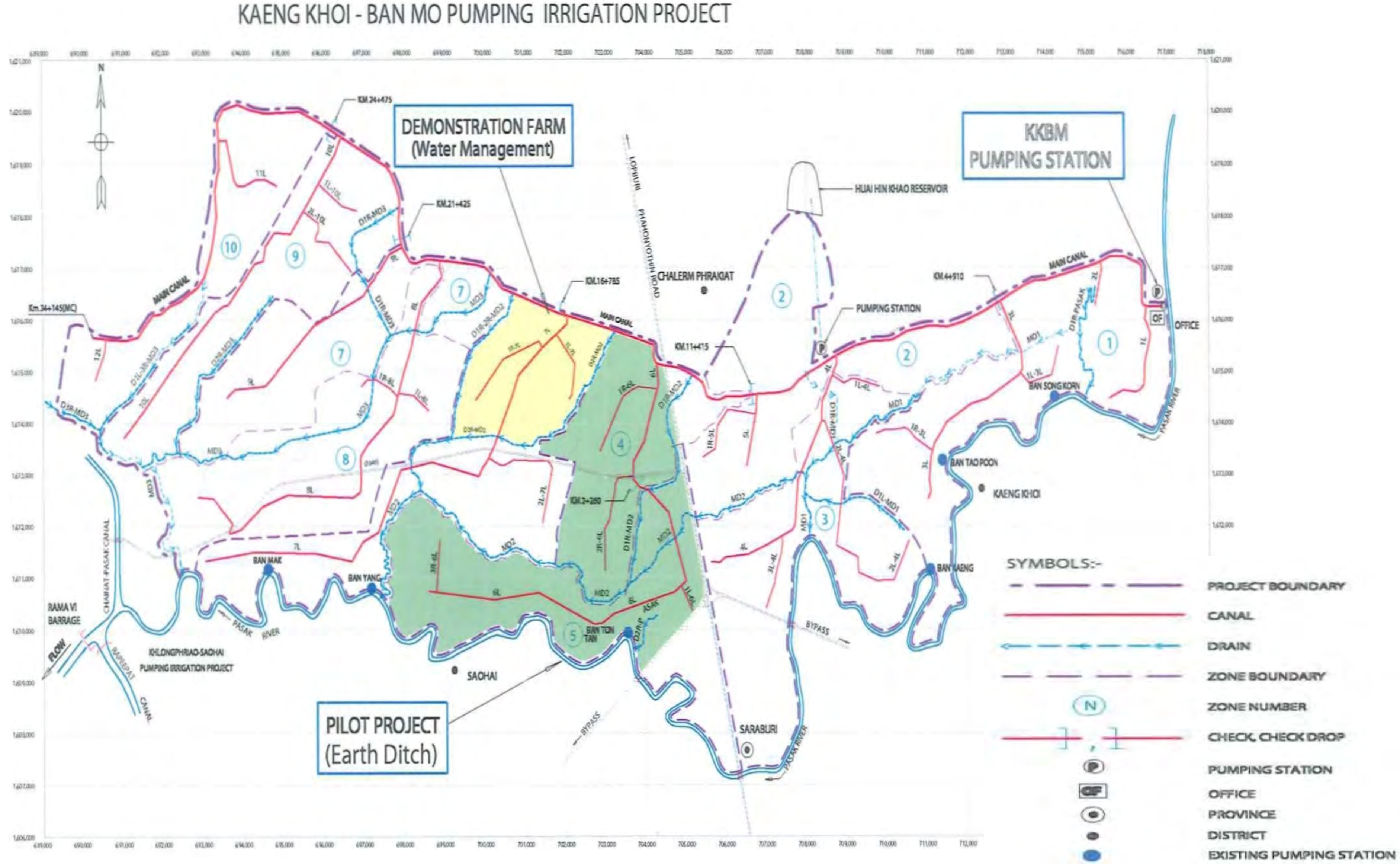
The project involves 6 districts. FIGURE 2 shows the administrative boundary in the project area. The project was originally designed to have 1 main canal and 12 lateral canals. However, a lateral canal called 2L, the second closest to the pumping station, has never been created because its beneficiary 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). FIGURE 3 depicts the water distribution system of the KKBM irrigation project. The main canal has length of 34 kilometers and 11 lateral canals have total length of slightly less than 100 kilometers.

FIGURE 2: KKBM ADMINISTRATIVE MAP



Source: RID document.

FIGURE 3: KKBM SCHEME MAP



Source: RID document.

Box: Summary of KKBM Operation Information

- Feasibility studies (F/S): 1982, 1985, 1991-1993
- Construction of main and lateral canals: September, 1995 - June, 2005
- Budget: 2.607 billion yen, of which 1.799 billion yen was financed by ODA
- Irrigated area (rai):

season	projected	actual (2008)
wet	85,695	36,311
dry	27,900	20,121
dry/wet	0.326	0.554

- Irrigation efficiency (2005-2009, water volume demanded / supplied): wet seasons dry seasons
- Per rai profits (2005 - 2008, Bahts): wet seasons dry seasons
- Canal length: 34 km (main), approximately 100 km total length (lateral)
- Number of Laterals: 11
- Number of water users group (WUG): 26 (2011)
- Fee collection: no fees in wet seasons, 100% collection in dry seasons

Source: Japan International Cooperation Agency (2011), summarized by authors.

There are substantial variations in the scale of irrigation projects in Thailand. Irrigation schemes are classed as large-scale if they can irrigate at least 80,000 rai or there is a store capacity of more than 100 million cubic meters. Thailand had 83 large-scale irrigation projects by the year 2002 (FAO, 2010). The KKBM project was also classified into this large-scale group in the planning phase as its irrigation area was projected to be 85,695 rai in the wet season (see Box). However, its actual irrigation area has shrunk to 36,311 rai by the year of 2008 due to the massive conversion of agricultural land. These facts taken together imply that the scale of the KKBM project is not extraordinary large in Thailand and its current capacity of water supply is abundant at least in the wet season. One should be careful, therefore, when extending our results to other projects. We will discuss about the external validity of estimation results to different scale of irrigation projects briefly in the Appendix D of this report.

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 Water Users Groups (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.

When we started the evaluation of the KKBM irrigation scheme in 2009, the main, lateral, and sub-lateral canals were already constructed. This eliminates the control group for impact evaluation of these canals. So we decided to focus on estimating the impacts of tertiary canals which had not been fully constructed. 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 KKBM area. 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 Ditch and Dike Section of 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 KKBM. They were easily integrated into the KKBM 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.

All the tertiary canals that the RID has constructed are concrete ditch. However, in order to accelerate the realization of benefits from tertiary canals, some farmers around 6L were encouraged to construct earth ditch by farmers' efforts through a pilot project before concrete ditch was to be provided by the RID. In total 154 farmers were involved with this pilot project. After observing this project, there were similar efforts by other farmers on different laterals, whereas a large number of earth ditch have been replaced by concrete one as the RID has expanded the construction of tertiary canals following the original plan. Nevertheless, there still remain a non-negligible number of tertiary canals of earth ditch in the project area.

2.2 General principle of impact evaluation

In evaluating a policy on an outcome y_{it} of an individual i in period t, a general framework can be defined as below:

$$TE_{it} = (y_{it} \mid D_{it} = 1) - (y_{it} \mid D_{it} = 0). \tag{1}$$

TE_{it} is what is called as a treatment effect by policy, and $y_{it} \mid D_{it} = 1$ is an outcome of individual i under the policy in period t and $y_{it} \mid D_{it} = 0$ is an outcome of individual i in the absence of the policy in same period. D_{it} is an indicator variable of the policy, or a treatment status indicator, so $D_{it} = 1$ is under the policy and $D_{it} = 0$ is not. People with $D_{it} = 1$ are called the *treated* group, and $D_{it} = 0$ are called the *control* group. TE_{it} is the change in the potential outcomes between with and without the policy.

The fundamental problem in impact evaluation is that (1) is never possible to observe, because an individual is either under the policy or not, not both at the same time. One way out is not to estimate the individual treatment effect, but to estimate an effect for a group of individuals that resembles with each other. In this way we can use the outcome of a different individual under different treatment status as a counterfactual outcome.

Naturally, the most important care is that one needs to choose the counterfactual that resembles very closely with i. If we use a very different individual for a counterfactual of i, then the estimated treatment effect for i can be grossly different from the true treatment effect. So *credibility* of evaluation depends crucially on the precision of counterfactual that the evaluator uses for each individuals. The primary challenge of an evaluation study is to convince readers that its choice of counterfactual is precise.

An evaluation study that employs very similar individuals as counterfactual is said to satisfy *internal validity*, whose estimated results are perceived as highly credible. It is now a general concensus in development community that an evaluation study should pursue internal validity as best as one can (under feasibility and ethical constraints, Evaluation Gap Working Group, 2006). This follows because it is almost meaningless to do an evaluation study whose conclusion is based on errorneous assumptions on the choice of counterfactual.

The "gold standard" of an evaluation method is randomized control trials (RCTs), because, in large sample data, an evaluator can always find precise counterfactual by the virtue of randomization. Unfortunately, RCT is not always possible due to political and feasibility constraints. Infrastructure projects are a well known example of policies that are difficult to conduct RCT, because one cannot expect infrastructure, say, dams, to be randomly placed or access to it is given to random individuals. It is also well known that impacts of a big project may spillover to control groups, which violates the oft used stable unit treatment value assumption (SUTVA) in statistics (Rubin, 1974) or the policy invariance assumption in econometrics (Hurwicz, 1966).

So evaluation of infrastructure has rarely been studied rigorously, with an exception of Duflo and Pande (2007). They use district level data of India to estimate dam construction impacts on economic activity levels, by observing river gradient is strongly correlated with the former but not with the latter, thus satisfying the assumptions of instrumental variables estimator. Their estimate gives impacts at the district level, whose size is as big as prefectures in Japan. In light of SUTVA, their choice of unit is consistent with the expected impacts of dam construction.

In our study, the impacts we would like to estimate are at the household level, much disaggregated than Duflo and Pande (2007). This requires us to collect data at household level, and also seek for a different estimation strategy, because river gradient is almost identical in the Pasak river basin in the KKBM area and cannot be used as an instrumental variable. The feasible estimator choice includes propensity score matching (PSM), regression discontinuity design (RDD), and difference-in-differences (DID). PSM and RDD allow estimation using cross-section data while DID requires panel data. For PSM estimates to be credible, it should satisfy a common support condition which requires sufficient overlap of propensity score distributions between treated and control groups. It in turn implies that the probability of getting tertiary canals in the control group should be strictly greater than zero. However, the RID has followed the deterministic schedule of tertiary construction and therefore the probability for access to tertiary canals was exactly zero in the control group during survey periods. It should also be noted that conditional exogenous program assignment (no omitted variables) must be satisfied for the PSM estimator to be consistent, and there is rarely a case in convincingly showing exogeneity to hold, except when treatment status is randomly assigned, which is what the developer of this methodology had in mind. The failure of a common support and conditional exogenous treatment assignment precludes the use of PSM in this study. RDD requires finding a boundary between serviced and unserviced areas. Although the boundary is not difficult to define, RDD effectively shrinks the sample size to a few dozen households, which leads to unreliable estimates. So DID is the only feasible choice.

2.3 The Difference-in-Differences estimator

The framework of difference-in-differences estimator can be well understood with a linear parametric model. For a household i, suppose output y_{it} is explained by availability of irrigation services $D_{it} \in \{0, 1\}$ in period t. In a reduced form, it can be written as:

$$y_{it} = a + bD_{it} + \boldsymbol{z}_i'\boldsymbol{\eta} + \boldsymbol{x}_{it}'\boldsymbol{\beta} + \lambda_t + u_{it}. \tag{2}$$

The constant vector $\boldsymbol{z}_i$ captures the contribution of plot i's time-invariant traits, such as farmer's characteristics, number of household members, asset ownership, unobservable land fertility, and most importantly the location of the plot. The vector $\boldsymbol{x}_{it}$ represents time varying observables. λ_t captures the season fixed effect which is common to all plots. b is the parameter of interest, as it measures the contribution of tertiary canal construction on y_{it}. As production choices can be correlated with any element in $\boldsymbol{z}_i$, failing to include all elements in (2) will result in inconsistent estimates on all parameters. However, as we have a panel data, we can eliminate any fixed effects by taking a deviation from household means:

$$y_{it} - \bar{y}_i = b(D_{it} - \overline{D}_i) + (\boldsymbol{x}_{it} - \overline{\boldsymbol{x}}_i)'\boldsymbol{\beta} + (\lambda_t - \overline{\lambda}) + u_{it} - \overline{u}_i. \tag{3}$$

For b in (3) to be estimable, we need some households' D_{it} to change through time. In our irrigation construction context, the change must be from 0 to 1. So we need some households whose data is collected before (as baseline) and after (as follow-up) tertiary canal construction. For the remainder of the households, it can be collected from any lateral whose D_{it} does not change.

If we can assume the correlation between $(D_{it} - \bar{D}_i)$ and $u_{it} - \bar{u}_i$ are zero, then we can estimate b consistently. Zero correlation with $u_{it} - \bar{u}_i$ means that irrigation is not placed systematically according to low or high disturbance deviation areas. For example, a policy maker may want to enhance productivity of farmers of certain lateral who are known to have negative productivity shocks more often than others. By targeting these farmers, it induces a negative correlation between $D_{it} - \bar{D}_i$ and $u_{it} - \bar{u}_i$. After discussions with farmers, RID officials, and WUG leaders, we confirmed that the order of tertiary canal construction was administratively determined from areas closest to furthest of canal intake, or from 1L (eastmost) to 12L (westmost). There was no targeting of farmers in canal construction. Because major productivity shocks are considered to be uniform in KKBM, and even if residual shocks are not uniform, they are not correlated with location. So we can safely assume zero correlation between $(D_{it} - \bar{D}_i)$ and $u_{it} - \bar{u}_i$, giving credibility to our estimation strategy.

The beauty of DID estimator is that it can safely exclude the effects both of time-invariant factors specific to each plot and of time-variant factors which are common to all. The latter advantage in DID rests on the assumption of common time trend (parallel shift). One important deviation from (2) is taking into account the heterogeneous treatment effects. This is easily done with the inclusion of interaction term between treatment status and other variables of interest. We include $z_i(D_{it} - \bar{D}_i)$ and $\mathbf{1}(t = \tau)(D_{it} - \bar{D}_i)$, where $\mathbf{1}(t = \tau)$ is indicator variable that takes a value 1 if $t = \tau$ and 0 otherwise, in order to take into account the possibility that the treatment effect varies depending on time period and plot i's time-invariant traits.

Having successfully addressed the identification strategy of irrigation impacts, we may also want to ask a different question: how likely can we expect the estimated impacts to be applicable to surrounding areas? This is a question of *external validity* which considers the extent of generality of estimated results. As JICA is actively engaged in development assistance in many countries, an evaluator is asked the applicability of lessons of an evaluation study to other areas. In responding to this request, one needs to compare the characteristics of KKBM to other areas. This can be accomplished by two means, comparison of KKBM and surrounding districts using district level data, and conducting another household survey in surrounding areas. In this report, we will take the second approach and compare household characteristics of KKBM and Pattananikom areas, where a part of latter area is under another major pump-irrigation scheme.

3 Data and Descriptive Statistics

3.1 Survey design

3.1.1 KKBM1 (2008 wet), KKBM2 (2009 dry), KKBM3 (2009 wet), KKBM4 (2010 dry)

As noted, we are interested in the treatment effect of tertiary irrigation system on farming productivity in the KKBM project area. To implement the DID estimator, we need panel data on agricultural production by farmers both with and without changing treatment status during survey periods. Fortunately, the distinction between the treated and control can be largely attributed to the construction policy by the RID and thus is exogenous for farmers. Except for the upper stream of 7L, 9L and 10L, the construction of tertiary irrigation canals was to begin at eastern part and to sequentially move westward within the project area. In this schedule, 12L (a lateral canal, or the 12th lateral canal, at the western boundary of the project area) is last to be provided with tertiary canals. As already noted earlier, while there are some earth ditch used as tertiary canals in the project area, the majority of tertiary canals are concrete ditch constructed by the RID.

As of the wet season 2008, the tertiary canals have been completed up to 5L. In addition, the upstream of 6L, 7L, 9L and 10L have also been partially equipped with tertiary irrigation canals. Based on this observation, we focus on two districts (Sao Hai and Phra Phutthabat) under 6L to 11L to estimate treatment effect by taking the advantage of the different timing in tertiary canal construction. In other words, we expected that part of 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 is 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 have 2,431 farmers who reside in our targeted districts (i.e. Sao Hai and Phra Phutthabat) as of November 2008.

For our sampling purpose, however, there are two caveats to be aware of when using the DOAE database. Firstly, while we easily find farmers' name and addresses from the database, actual location of their farming 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 farming 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 farming plot, irrespective of its location. Secondly, the DOAE database possibly includes currently inactive farmers due to infrequent updating. The concerns for inactive farmers prompted us not to undertake simple random sampling of farmers in the DOAE database.

To avoid inefficiency associated with picking up many inactive farmers, we employ stratified random sampling. One stratum consists of WUG members of the KKBM irrigation scheme and another stratum consists of Non-WUG members. We compiled an integrated list from the DOAE database and the membership information of related WUGs by matching social identification numbers. WUG members are formal beneficiaries of the KKBM scheme, in which their farming plots are irrigated either through a main canal, (sub) lateral canals, tertiary canals or plot-to-plot system. They are expected to be active farmers with a high degree of certainty, as one must pay a due to be a member to get water in a dry season. Non-WUG members are the farmers who either lack access to any kind of irrigation or have access to irrigation other than the KKBM scheme. We did not have any prior information whether a Non-WUG member is currently active or inactive in agricultural production.

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 stratum. Additionally, 999 Non-WUG members were randomly selected and were visited. However, as mentioned above, 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 high proportion of inactive farmers and resulting selection of samples may raise concerns. This is valid if the inactive farmers have exited from production due to smaller irrigation impacts on their plots. However, one should note that our aim of estimation is to assess the impacts of tertiary canal construction, not the impacts of KKBM irrigation construction in general. In line with our limited scope of consideration, our population is a group of farmers who operate or have operated under KKBM system with and without tertiary canals. In other words, farmers who have exited before the construction of lateral canals are excluded. Still, it is possible, in the control area where tertiary canal construction had completed before our survey, that farmers with low impacts may have exited already, hence we are picking up only farmers with relatively high impacts. This indicates that our estimates may be downwardly biased and thus may justifiably be content with small or marginally significant impact estimates.

The survey was conducted in four rounds. The first round was carried out from January to April, 2009, for collecting data on the wet season 2008. Subsequently, the second round was carried out from July to October, 2009, for collecting data on the dry season 2009. In both surveys, 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. The data on wet season 2009 and dry season 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 unique four-round panel dataset for the impact evaluation of tertiary canals in the KKBM project area.

Table 1: Variable Description

variables	description
age0-5	number of household members in ages 0 - 5.
age6-15	number of household members in ages 6 - 15.
age16-40	number of household members in ages 16 - 40.
age41-60	number of household members in ages 41 - 60.
age61	number of household members in age 61 and older.
nuclear	number of nuclear household members.
extended	number of extended household members.
below 9	number of household members with educational achievement below 8.5th grade.
below high school	number of household members with educational achievement below high school diploma.
university or higher	number of household members with educational achievement above university or higher.
cultivated (rai)	area under cultivation.
owned (rai)	area of plots owned by the household.
total output (Bahts)	revenue from the plot.
total area (rai)	area of the plot.
mean yield (Bahts/rai)	mean revenue per rai.
mean yield, rainfed (Bahts/rai)	mean revenue per rai of rainfed plots.
mean yield, KKBM (Bahts/rai)	mean revenue per rai of KKBM-irrigated plots.
hh	housheold ID.
total value (1 mill Bahts)	total asset value.
non-land asset value (1 mill Bahts)	total non-land asset value.
number of plots	number of plots owned.
total area (rai)	total area owned.
per plot area (rai)	mean area per plot (rai).
number of tractors (small)	number of small sized tractors owned.
number of tractors (medium)	number of medium sized tractors owned.
number of tractors (large)	number of large tractors owned.
number of trucks	number of trucks owned.
number of electronic pumps	number of electronic pumps owned.
number of fuel pumps	number of fuel pumps owned.

3.2 Descriptive Statistics

Table 2 shows the characteristics of sampled households. Out of 826 households that we sampled for 2008 wet season, we see that oldest settler is 1887 (2420 in Thai calendar) and the newest is 2007 (2550). At the 75 percentile, the settlement year is 1978. These indicate that most of our sample were not aware of KKBM irrigation scheme at the time of settlement. This fact indicates that there is little scope of self-selection bias in our population, in which farmers with high ability choose to reside in upstream of irrigation. Age structure of each household is similar to nuclear, with 0.82 elderly (ages 61 and older), 2.75 adults (ages 16-60), 0.73 children (ages 0 - 15). So there are about 3.57 adult and elderly members, implying relatively small location parameter of farm operations. nuclear indicates number of household members whose relationship to household head is within nuclear family relationship (spouse, children), and extended indicates number of non-nuclear family members. There are on average 3.06 nuclear family members and 1.22 extended family members. Having one elderly cohabitating with a nuclear family does not show imminent aging problem of agricultural industry.

Table 2: 2008 Wet Season Households

variables	min	25%	median	75%	max	mean	std	0s	NAs	n
hh	1	207.25	413.5	619.75	826	413.5	238.59	0	0	826
settlement year	2420	2481	2495	2521	2550	2499.81	24.352	0	22	826
age0-5	0	0	0	0	4	0.219	0.516	673	3	826
age6-15	0	0	0	1	3	0.516	0.688	480	3	826
age16-40	0	1	1	2	6	1.375	1.083	197	3	826
age41-60	0	1	2	2	5	1.375	0.859	170	3	826
age61	0	0	1	1	4	0.823	0.836	358	3	826
nuclear	1	2	3	4	6	3.06	1.071	0	3	826
extended	0	0	1	2	7	1.22	1.409	371	3	826
below 9	0	2	3	4	9	3.216	1.442	7	3	826
below high school	0	0	0	1	5	0.614	0.811	449	3	826
university or higher	0	0	0	1	5	0.435	0.74	567	3	826
cultivated (rai)	1	12	24	40	230	30.003	25.235	0	1	826
owned (rai)	0	0	7	20	102	11.927	13.927	265	1	826
total area (rai)	1	12	24	40	230	30.012	25.238	0	5	826

below 9 indicates education achievement below 9th grade. This is the majority of household education level. Higher education achievement sums up to 1.05 members. Education level is not high relative to current young generation's schooling level, and this may indicate relatively older age structure of our sampled households and Thai education that has advanced rapidly in the last few decades.

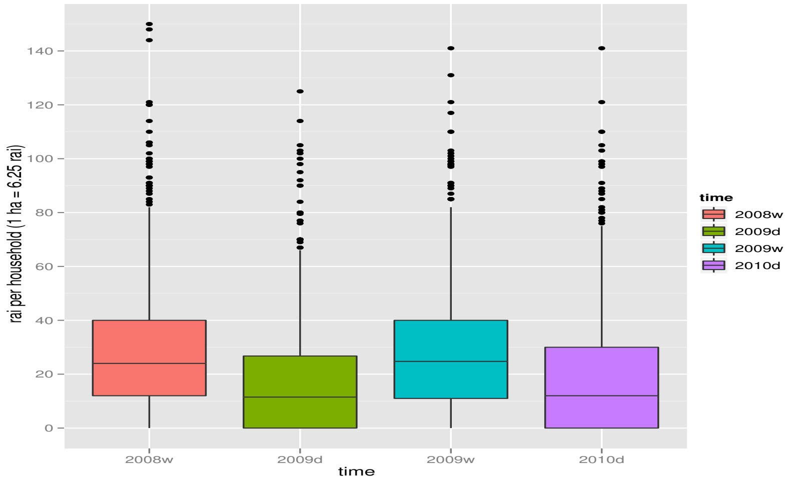
cultivated indicates area under cultivation in 2008 wet season. As there are a few extremely large holders, mean may not be the best statistic that represents the scale of distribution. We will use median statistic that is considered to be more robust to outliers. Median area under cultivation is 24 rai, which is about 3.84 hectares. Among all cultivated land owned land area owned is smaller and its median is 7 rai (1.12 hectares).

Table 3 shows the summary of household asset variates. Median of total area of operational land is 24 rai or 3.84 hectares, indicating relatively small scale of operations. Other machineries also shows small scale nature of operations where relatively few have large sized tractors while 92% of households have either small or medium size tractors. Holding of irrigation pump sets is a defining nature of the sample. They are used not just for water intake but also for removing excess water out, because concrete tertiary canals are not suited for drainage.

Figure 4 shows distribution of cultivated area per household. It can be seen that there is a systematic change in distribution between wet and dry seasons. When rainfall is sufficient during the wet seasons, per household cultivation area increases. In both dry seasons, it is found that many household scaled down their operations. This is reasonable when water is insufficient, especially in the areas where tertiary canal is not constructed.

As expected, we look at Figure 5 to find that total cultivated area has decreased in both 2009 and 2010 dry seasons. These dips are not just due to water shortage, but also due partly to tertiary canal construction where RID officials, upon consent from WUG members, instructed to stop cultivation during construction. We also notice from Figure 5 that, as expected, paddy is the predominant crop

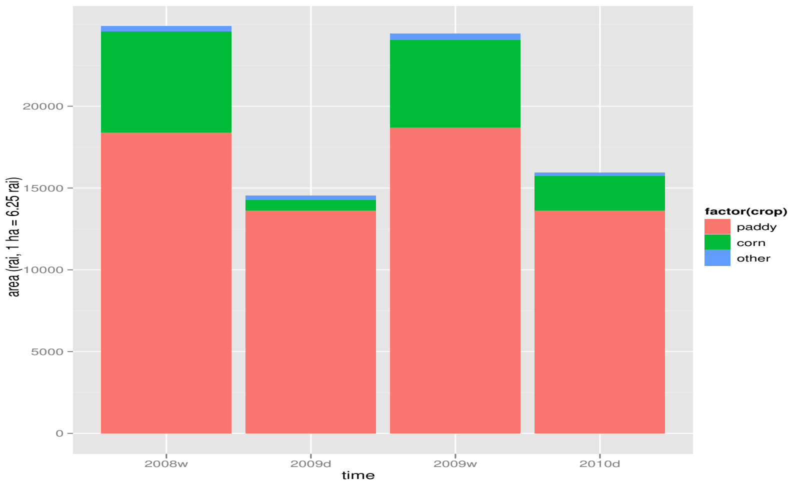
Figure 4: Cultivated Area Distributions



Notes: 1. Cultivated area in rai.

2. Boxes indicate center 75 percentile, bars indicate 95 percentile band, and dots indicate all other observations.

Figure 5: Cultivated Area by Crop and Season



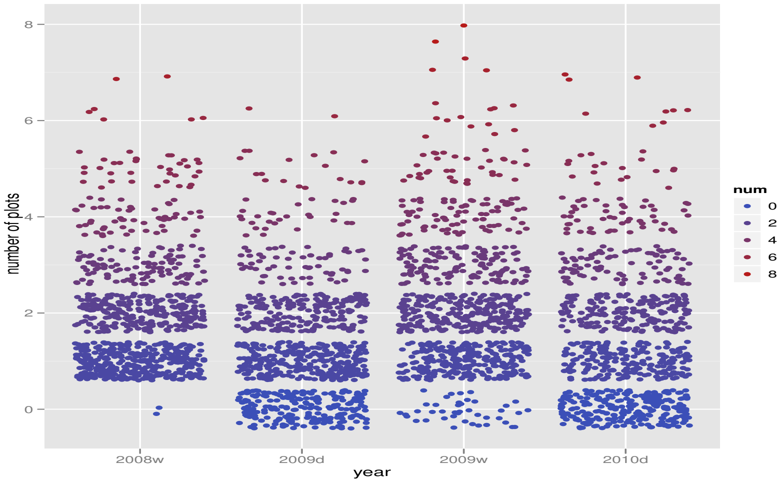
Notes: 1. Cultivated area in rai.

2. Other crops include: bamboo, banana, basil, cassava, chili, cucumber, dragon fruits, egg-plant, grass, kra chai, lettuce, long beans, mango, mint, morning glory, okra, phak pang, sesame, winged beans, sugarcane, and tomato.

of choice. It is interesting to see that paddy is still dominating other field crops even during the dry seasons. In fact, in both dry seasons, cultivated area under paddy stays almost constant, indicating the presence of die-hard paddy choosers. This may reflect that in some areas of KKBM scheme, especially around canal heads, farmers have plenty of water even during the dry season. In contrast, farmers seem to prefer planting corns during the wet seasons, due probably to their requirement to be sufficiently watered at least twice in their crop cycle. Corn is expanding its area following the price hike preceeding 2010.

In Figure 6, number of cultivated plots per household is shown as jittered dot plots. We see significant increase in zero cultivation in dry seasons. Correspondingly, all households seem to reduce the number of plots during the dry seasons. This shows that, even after construction of secondary and some tertiary

Figure 6: Number of Cultivated Plots



Notes: 1. Cultivated plots per household.

2. Plots are randomly jittered around each integer values to show clustering. Different integer values are assigned to different colors.

Table 3: 2008 Wet Season Households Assets

variables	min	25%	median	75%	max	mean	std	0s	NAs	n
hh	1	207.5	413	620.5	826	413.813	238.614	0	0	823
total value (1 mill Bahts)	0	0.508	1.111	2.3	48.413	1.753	2.644	0	0	823
non-land asset value (1 mill Bahts)	0	0.265	0.56	0.965	6.657	0.757	0.742	0	0	823
number of plots	0	0	1	1	5	0.976	0.857	240	0	823
total area (rai)	0	0	9	20	102	12.82	14.146	240	0	823
per plot area (rai)	0	0	7.5	15	70	9.695	10.455	240	0	823
number of tractors (small)	0	0	1	1	1	0.64	0.48	296	0	823
number of tractors (medium)	0	0	0	1	1	0.283	0.451	590	0	823
number of tractors (large)	0	0	0	0	1	0.084	0.277	754	0	823
number of trucks	0	0	0	1	1	0.443	0.497	458	0	823
number of electronic pumps	0	0	0	0	1	0.196	0.397	662	0	823
number of fuel pumps	0	0	1	1	1	0.559	0.497	363	0	823

canals, water supply is still not sufficient to increase land utilization in dry seasons to the same level as the wet seasons. And, as there are many farmers who plant paddy which is a crop of low water use efficiency (WUE)[*1], water scarcity may have been exacerbated.

In Figure 7, we draw Tukey box-plots of paddy yield in Bahts between groups and seasons. Paddy yield in Bahts is computed by multiplying paddy yield per rai with output price. In the left, treatment groups are with or without tertiary (be it earth or concrete), and in the right, treatment groups are with or without concrete tertiary. There is virtually no big difference between both figures. The common feature is that there is very little difference in yield between groups in all seasons. This is by no way surprising, because selection of paddy plots is made by conditioning on growing paddy, which in turn effectively is conditioning on cultivation. Given that cultivation decision is made endogenously to prof-

[*1] Water use efficiency is defined as the ratio of harvested dry matter (kg) per unit of water (m^3) delivered.

its and productivity, comparison between the treated and the control is expected to give underestimated impacts of tertiary canals. This follows as there should be stronger positive selection into cultivation among the control plots than treated plots, because control plots are expected to be disadvantaged than the treated plots due to its lack of access to tertiary canals, and cultivation of them requires above average 'natural' productivity.

Also in Figure 9, we see little difference in per rai paddy profits between groups in all seasons, due possibly to the same reason argued in the above. As in Figure 7, left figure shows impacts of tertiary and right figure shows the impacts of concrete tertiary. Profits are computed by subtracting per rai costs of material, machinery, (imputed) land and (imputed) labor inputs from per rai revenue. As we allow in the survey questionnaire that input information to be given in either by plot or total of all cultivated plots, input costs given in the latter manner are allocated according to area weights (i.e., if 2 plots of 1 rai and 2 rai are cultivated, information given in total cost questions are allocated by 1/3 and 2/3, respectively). As in previous figures, left is earth or concrete tertiary "treatment" and right is concrete tertiary "treatment". From these figures, a naïve observer who would not take cultivation decision into account may expect very little to almost no impact of tertiary canals on any of productivity measures including profits. This can be a rather shocking and disturbing prospect, as one would want to see some impacts out of infrastructural investments that are endorsed strongly by all the stakeholders.

In contrast to paddy profits, profits from all crops show significant difference between the treated and the control plots. In Figure 3.2, we have drawn a series of Tukey box-plots for all crop profits. In this figure, uncultivated plots whose production is aborted due to canal construction, or involuntarily uncultivated plots, are dropped. Other uncultivated plots whose production is aborted by reasons other than canal construction, or voluntarily uncultivated plots, are included. Because uncultivated plots do not make any profit, the distribution includes zero profit. The difference between treated and control plots originates partly from the presence of uncultivated plots in the latter. Through the contrast between the treated and the control, one can expect that tertiary canal construction to induce farmers to cultivate the plots that were previously abandoned in the dry seasons. This conjecture is supported in Figure 3.2 where we drop all uncultivated plots from the sample. This figure shows a similar pattern to paddy profit of Figure 9, and suggests little profitability impacts of tertiary canals on the general crop profits.

Figure 7: Paddy Yield between Treatment Groups (Bahts)

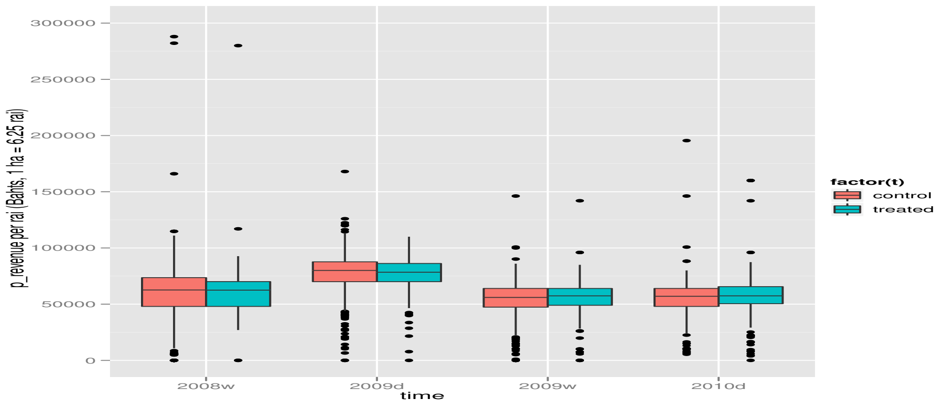
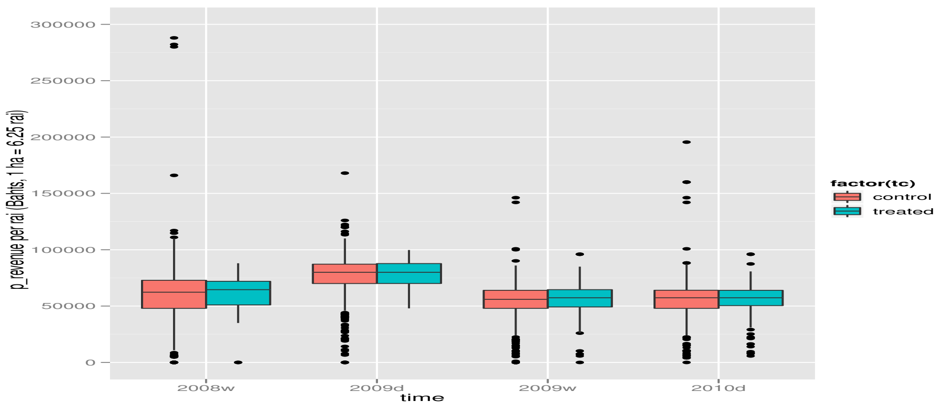


Figure 8: Paddy Yield between Concrete Treatment Groups (Bahts)



Notes: 1. Revenue = yield per rai × output price (Bahts). Profit per rai = revenue - costs (Bahts). All uncultivated plots are excluded.

2. Red Tukey box-plots indicate control group and blue Tukey box-plots indicate treated group. Boxes indicate center 75 percentile, bars indicate 95 percentile band, and dots indicate all other observations.

3. Treatment in Figure 7 is farmers with earth or concrete tertiary canal access, control is farmers without tertiary canals. Treatment in Figure 8 is farmers with concrete tertiary canal access, control is farmers without concrete tertiary access.

Figure 9: Paddy Profits between Treatment Groups (Bahts)

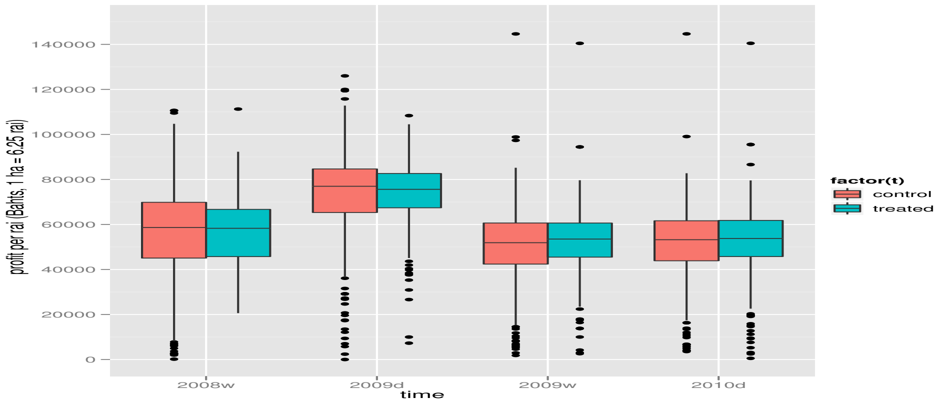
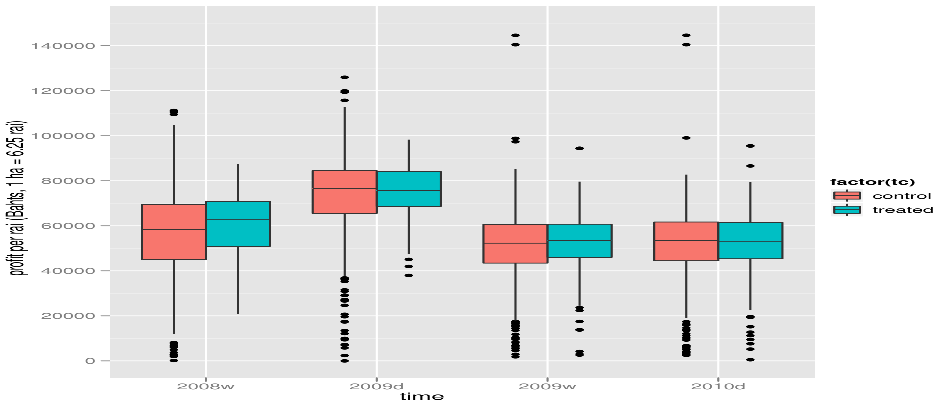


Figure 10: Paddy Profits between Concrete Treatment Groups (Bahts)

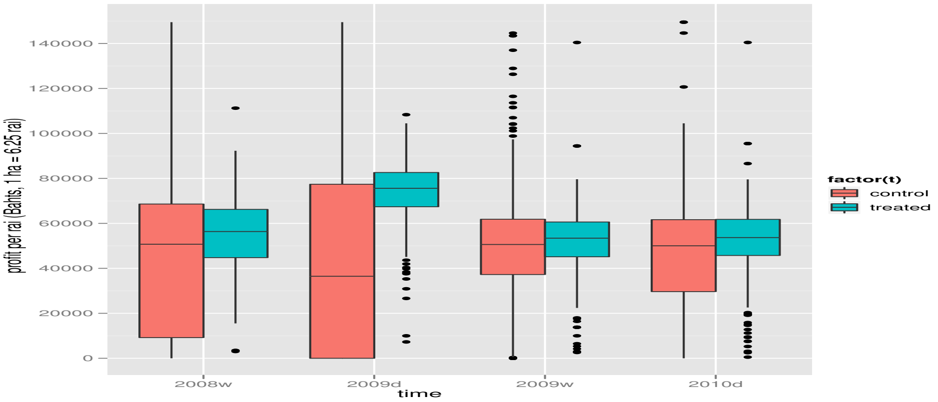


Notes: 1. Revenue = yield per rai × output price (Bahts). Profit per rai = revenue - costs (Bahts). All uncultivated plots are excluded.

2. Red Tukey box-plots indicate control group and blue Tukey box-plots indicate treated group. Boxes indicate center 75 percentile, bars indicate 95 percentile band, and dots indicate all other observations.

3. Treatment in Figure 9 is farmers with earth or concrete tertiary canal access, control is farmers without tertiary canals. Treatment in Figure 10 is farmers with concrete tertiary canal access, control is farmers without concrete tertiary access.

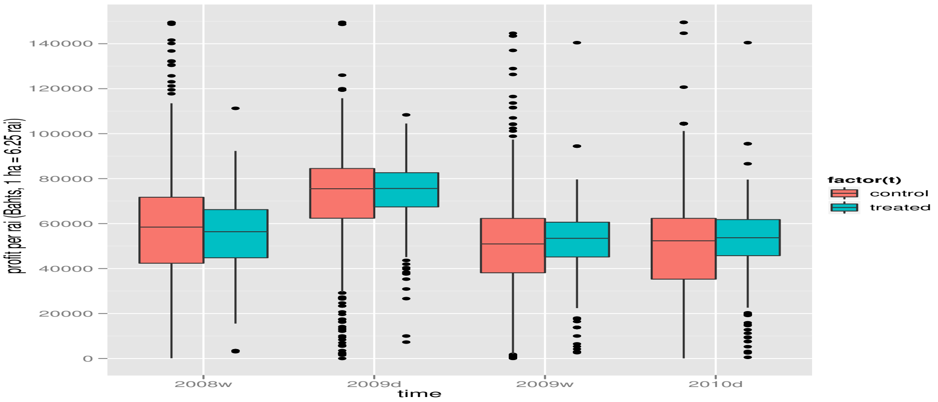
FIGURE 11: PROFITS BETWEEN TREATMENT GROUPS, ALL CROPS, INCLUDING VOLUNTARILY UNCULTIVATED PLOTS (BAHTS)



Notes: 1. Profit per rai (Bahts). Uncultivated plots due to canal construction are excluded in both FIGURE 3.2 and FIGURE 3.2. Uncultivated plots included in FIGURE 3.2 are due to reasons other than canal construction, or voluntary reasons.

2. See note 2 of FIGURE 7.

FIGURE 12: PROFITS BETWEEN TREATMENT GROUPS, ALL CROPS, EXCLUDING VOLUNTARILY UNCULTIVATED PLOTS (BAHTS)



Notes: 1. Profit per rai (Bahts). Uncultivated plots due to canal construction are excluded in both FIGURE 3.2 and FIGURE 3.2. Uncultivated plots included in FIGURE 3.2 are due to reasons other than canal construction, or voluntary reasons.

2. See note 2 of FIGURE 7.

4 Estimation

4.1 Profits

In Table 4, estimated results of plot-level fixed-effect difference-in-differences (FE-DID) on per rai profits are shown. We exclude from our sample the uncultivated plots that are instructed by RID due to canal construction. All uncultivated plots are thus for voluntary reasons. All the standard errors are robust to within-cluster correlations. Covariates tertiary, per rai rent, per rai in-kind rent are level variables while all other covariates are interacted with tertiary. As expected, the results are in contrast to the descriptive statistics that we saw earlier in Figure 7 and Figure 9, both of which are conditional on cultivation, but conform with Figure 3.2, which is not conditional on cultivation. In the first column (1), we have as regressors an intercept term, a treatment variable ($D_{i,t}$ in our estimating equation), season dummies, and tertiary treatment variable interacted with seasonal dummies. (1) indicates that having tertiary canal access increases per rai profit at the point estimate of 70,316 Bahts in 2009 dry season, 62,276 Bahts in 2010 dry season. Impacts in 2009 wet season is statistically insignificant, but its point estimate is 44,712 Bahts. Given the median of per rai profit is around 60,000 Bahts, these impacts are large. The large impacts of tertiary canal access remains robust in the table. After adding rents in (2) to reflect the unobservable land quality, adding land related variables in (3), adding household related variables in (4), non-land assets in (5), and adding other various agricultural assets in (6), the estimates are large and statistically significant at 5% level.

Readers may wonder if it is fair or an econometrically valid procedure to compare the treated with the control where the latter includes uncultivated plots. It is. But it requires a caution in interpreting the results. We should note that comparison is based on earned profits. So our estimates of FE-DID in Table 4 (and Table 5) show the impacts of having tertiary access on realized profits, which may include zero if cultivation is aborted. So we interpret the estimated parameter values as impacts of two decisions, cultivation (or "participation" in evaluation lingo) and production. Having tertiary access increases the chance of cultivation, which we will estimate more rigorously in the next subsection, and out of cultivated plots, the estimated impacts on profits are shown as the estimates. With a reference to our results on conditional paddy profit and yield indicate in the previous section, productivity or profit impacts of tertiary canals conditional on cultivation may be small. We also note that estimated profit impacts are as large as median profit, implying impacts equaling to an additional cultivated plot. So we interpret the results of FE-DID as stemming largely from inducement of cultivation, mostly during the dry seasons.

Interestingly, in Table 4, while money-rent is positively correlated with profits, in-kind rent is negatively correlated. This may be due to tenants who cultivate under in-kind rent may suffer from classic incentive problems. The estimates on in-kind rent show that its increase is detrimental to profit increase, while increase in money-rent is not. The latter is probably due to productivity effects where

Table 4: DID Estimation Results of Tertiary Construction on All Crop Profits

covariates	(1)	(2)	(3)	(4)	(5)	(6)
(Intercept)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
tertiary	−13497 (18269)	−14125 (18345)	−9252 (18777)	−11548 (20187)	−7254 (18675)	−13392 (18605)
2009 dry	−49308** (20945)	−50164** (21128)	−50147** (21133)	−50159** (21139)	−50165** (21136)	−50136** (21163)
2009 wet	−53222** (23457)	−53379** (23486)	−53359** (23497)	−53357** (23504)	−53368** (23500)	−53358** (23529)
2010 dry	−69062*** (22520)	−69223*** (22543)	−69192*** (22557)	−69190*** (22563)	−69196*** (22559)	−69157*** (22595)
2009 dry * tertiary	70316** (28664)	68685** (28431)	68862** (28470)	68663** (28447)	68991** (28486)	69101** (28484)
2009 wet * tertiary	44712 (29078)	45525 (29201)	45637 (29176)	45669 (29190)	45693 (29183)	45152 (29152)
2010 dry * tertiary	62276** (28864)	62792** (28951)	62869** (28923)	62853** (28933)	62930** (28931)	62553** (28871)
per rai rent		3567*** (1123)	3529*** (1132)	3525*** (1133)	3562*** (1139)	3587*** (1138)
per rai in-kind rent		−437.6*** (123.1)	−435.8*** (123.0)	−486.6*** (126.5)	−442.4*** (122.8)	−375.9*** (143.2)
distance to main canal			−2.2 (3.7)	−2.8 (4.2)	−2.3 (3.7)	−1.3 (3.6)
distance to lateral canal			−0.8 (0.7)	−0.8 (0.7)	−0.8 (0.7)	−0.8 (0.7)
area (rai)			−257.7 (278.3)	−247.5 (271.6)	−226.1 (276.3)	−258.3 (315.8)
number of males				−4788* (2450)		
number of ages 15-55				2502 (1853)		
head gender (female = 1)				−1832 (7672)		
number of farming members				2834 (2075)		
total asset value (Bt. 1 million)					−1185 (728.7)	−714.0 (1007)
non-land asset value (Bt. 1 million)						2082 (2851)
total area of HH (rai)						−448.0** (210.6)
average area per plot of HH (rai)						160.0 (283.3)
number of small tractors						4611 (5325)
number of medium tractors						−3058 (7551)
number of big tractors						4015 (7226)
number of trucks						5214 (6682)
number of pumps (electronic)						−1544 (8069)
number of pumps (fuel)						5414 (6280)
n	1885	1885	1885	1885	1885	1885

Notes: 1. Profit per rai (Bahts). See Table 1 for description of all variables.

2. Standard errors in parentheses. *, **, *** indicate statistical significance at 10%, 5%, 1%, respectively. n indicates sample size.

Table 5: DID Estimation Results of Concrete Tertiary Construction on Profits

covariates	(1)	(2)	(3)	(4)	(5)	(6)
(Intercept)	0.0	0.0	0.0	0.0	0.0	0.0
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
tertiary	−7519	−7848	−6512	−5907	−5875	−6647
	(5930)	(5906)	(5175)	(5181)	(5054)	(5567)
2009 dry	−48616**	−49436**	−49839**	−49955**	−49952**	−49854**
	(19945)	(20121)	(20371)	(20764)	(20438)	(20759)
2009 wet	−52520**	−52643**	−53022**	−53122**	−53122**	−53038**
	(22517)	(22541)	(22792)	(23168)	(22852)	(23133)
2010 dry	−68255***	−68379***	−68778***	−68886***	−68883***	−68774***
	(21500)	(21517)	(21785)	(22194)	(21848)	(22185)
2009 dry * tertiary	61468***	59426***	65077***	66150***	66357***	65395***
	(16930)	(16738)	(20860)	(24332)	(21432)	(23298)
2009 wet * tertiary	35242**	35605**	41629**	43019*	42939**	41210*
	(14568)	(14614)	(18784)	(23876)	(19556)	(23017)
2010 dry * tertiary	53169***	53251***	59139***	60483**	60427***	58874***
	(14642)	(14657)	(18728)	(23651)	(19483)	(22784)
per rai rent		3555***	3508***	3509***	3551***	3575***
		(1111)	(1099)	(1114)	(1121)	(1130)
per rai in-kind rent		−439.9***	−440.8***	−504.8***	−448.7***	−388.8***
		(124.4)	(123.8)	(123.6)	(123.0)	(140.3)
distance to main canal			−3.7	−3.3	−3.4	−2.9
			(5.5)	(4.6)	(5.4)	(4.5)
distance to lateral canal			−1.1	−1.0	−1.1	−1.1
			(0.7)	(0.7)	(0.7)	(0.8)
area (rai)			−348.7	−288.2	−285.0	−343.6
			(331.3)	(267.6)	(308.3)	(333.1)
number of males				−5039**		
				(2433)		
number of ages 15-55				2002		
				(2096)		
head gender (female = 1)				−3025		
				(8169)		
number of farming members				1502		
				(2953)		
total asset value (Bt. 1 million)					−1314	−790.6
					(1057)	(1006)
non-land asset value (Bt. 1 million)						2646
						(3039)
total area of HH (rai)						−447.3**
						(207.5)
average area per plot of HH (rai)						159.9
						(282.8)
number of small tractors						1453
						(6592)
number of medium tractors						−4519
						(7580)
number of big tractors						3577
						(7171)
number of trucks						4407
						(6797)
number of pumps (electronic)						−4046
						(8789)
number of pumps (fuel)						4011
						(7718)
n	1885	1885	1885	1885	1885	1885

Notes: See footnotes of Table 4.

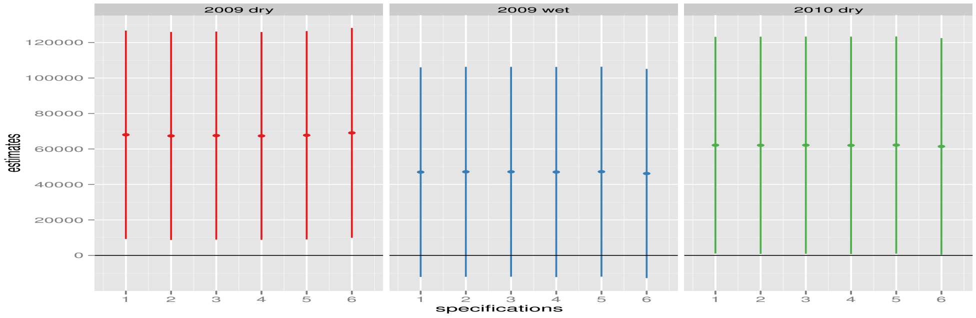
higher productivity is associated with higher rents. Another interesting result is that number of male members in a household is negatively associated with profits increase. This is hard to interpret as male members are usually considered superior in brawl requiring labor. However, with considerable mechanization in agriculture in this part of the country, such natural advantage may be ignorable and more innate earnestness may matter more. From casual observations, Thai women are more hard working than Thai men when it comes to agricultural production. The estimates do not conflict with such a view.

In Table 5, we show that results of having concrete tertiary canals. Similar to Table 4, the estimates on tertiary and seasonal dummy interactions are stable between specifications, but only at smaller values. A notable difference is that most of standard errors are smaller than in Table 4. This may be due to concrete canals are more uniform than general tertiary canals, among which earth ditch canals are constructed voluntarily by farmers. Smaller standard errors explain why wet season impacts are now statisitically significant despite the point estimates are smaller, and readers should not interpret the results to be qualitatively different from Table 4. It is surprising for concrete tertiary canals to have similar or even smaller estimates than tertiary canals, because the former is expected to have larger impacts on profitability than the latter.

Similarity in profitability impacts between concrete and earth canals may be closely related to the flooding problem observed in 7L and 8L areas. The (mis)design of concrete tertiary canals and a consequent problem of flooding are expected to reduce farm profits. This may be accountable for concrete canals to have no different impacts than earth ditch canals. During our field trips, we have seen instances of flooding at the end of 6L, 7L, and 8L. This is due to valley-like topography and narrow area between 7L and 8L. Some farmers are complaining about the flooding water from the upstream and from other WUGs. Most of down stream farmers have to rely on pumps to get the water out of their plots, which increases the fuel costs significantly. The root cause, which we believe, behind it is probably the philosophy of equal irrigation access.

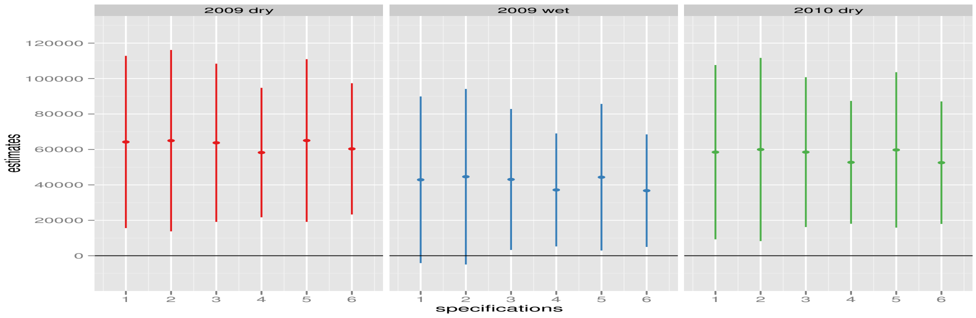
Flooding becomes a problem when water level is high and drainage capacity is low. While the former cannot be controlled fully at the down stream where they receive all water dumped from the upstream plots, the latter can be the way to ameliorate flooding. Unfortunately, when RID constructed the concrete tertiary canals, they established the structure at the elevated level, about half a meter higher from the plots. This makes it difficult for farmers to utilize concrete tertiary canals as a drainage, which forces them to rely on expensive pumps. The reason, as we interpret, behind such design can have roots to insufficient capacity of KKBM pumping station. As our ex-post evaluation report revealed after a careful document search, the initial goal of the project was to provide water to field crops, not solely to paddy. The designer of the project were aware of water level was not sufficient to flood the entire paddy plots of the target area. However, as we see from the figures such as Figure 5, paddy production is most preferred by farmers. So RID sits in a difficult position where they need to manage irrigation and achieve productivity gains, but do not have enough water volume to supply to all plots. Had they

Figure 13: Estimates on Profits, All Crops, Tertiary (Bahts/rai)



Notes: 1. Estimates on seasonal dummies * treatment dummy.
2. 1 - 6 on the horizontal axis indicates the specifications (1) - (6) in the FE-DID.
3. Points indicate point estimates, bars indicate 95% confidence intervals.

Figure 14: Estimates on Profits, All Crops, Concrete Tertiary (Bahts/rai)



Note: See footnotes of Figure 13.

been equipped with sufficient volume, they could have made the canals at lower level so farmers can use it as drainage. But such usage necessarily involves greater volume of water when they supply (rather than drain) water to the plots, as they need to increase the level of water to use gravitational force. In other words, it entails low irrigation efficiency (IE).[*2] This is something RID could not do. So the second best, and more equitable than using up all water at upstream plots, is to set the canal at higher ground so they do not use higher volume when they supply water to the plots, at the cost of disabling the canal's capacity to be used as drainage. This equitable yet inefficient philosophy may be behind the flooding problem. And if this is the case, the fundamental solution can be difficult to find because RID lacks sufficient volume of water. At the same time, the total area in the region is getting smaller, and starting to reach the balance between water use and supplies which may serve to dissipate the problem.

4.2 Cultivation Decisions

As suggested in the previous section, tertiary canal construction seems to induce farmers to start cultivating in the dry seasons, and the bulk of estimated impacts in FE-DID may be attributed to an increase in land use intensity. In Table 6, the results of tertiary canal construction impacts on

[*2] Irrigation efficiency is defined as the ratio (percentage) of water delivered or used to water entering the irrigation system.

Table 6: DID Impacts of Tertiary Construction on Cultivation Decisions

covariates	(1)	(2)	(3)	(4)	(5)	(6)
(Intercept)	0.0*	0.0**	0.0	0.0	0.0	0.0
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
tertiary	0.1***	0.1***	0.2***	0.2***	0.2***	0.2***
	(0.0)	(0.0)	(0.0)	(0.1)	(0.0)	(0.1)
2009 dry	−0.3***	−0.3***	−0.3***	−0.3***	−0.3***	−0.3***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
2009 wet	0.1***	0.1***	0.1***	0.1***	0.1***	0.1***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
2010 dry	−0.2***	−0.2***	−0.2***	−0.2***	−0.2***	−0.2***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
2009 dry * tertiary	0.3***	0.3***	0.3***	0.3***	0.3***	0.3***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
2009 wet * tertiary	−0.1***	−0.1***	−0.1**	−0.1***	−0.1**	−0.1**
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
2010 dry * tertiary	0.2***	0.2***	0.2***	0.2***	0.2***	0.2***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
per rai rent		33.9***	33.2***	33.1***	33.6***	33.9***
		(5.6)	(5.8)	(5.8)	(5.8)	(5.7)
per rai in-kind rent		6.3***	6.2***	6.0***	6.1***	6.8***
		(1.0)	(1.0)	(1.0)	(1.0)	(1.0)
distance to main canal			0.0	0.0	0.0	0.0
			(0.0)	(0.0)	(0.0)	(0.0)
distance to lateral canal			0.0	0.0*	0.0	0.0
			(0.0)	(0.0)	(0.0)	(0.0)
area (rai)			−4.4***	−4.6***	−4.0***	−4.0***
			(1.5)	(1.5)	(1.5)	(1.5)
number of males				−2.4		
				(15.8)		
number of ages 15-55				3.5		
				(14.1)		
head gender (female = 1)				−73.7**		
				(30.7)		
number of farming members				13.5		
				(17.7)		
total asset value (Bt. 1 million)					−14.1*	−6.8
					(7.3)	(9.4)
non-land asset value (Bt. 1 million)						−13.2
						(27.9)
total area of HH (rai)						−3.4**
						(1.5)
average area per plot of HH (rai)						0.5
						(2.4)
number of small tractors						3.2
						(31.6)
number of medium tractors						0.4
						(32.3)
number of big tractors						114.1***
						(44.1)
number of trucks						79.7**
						(34.7)
number of pumps (electronic)						−8.3
						(46.3)
number of pumps (fuel)						−78.4**
						(36.0)
n	1789	1789	1789	1789	1789	1789

Notes: 1. Linear probability model of cultivation decisions. Treatment = concrete tertiary access.

2. All covariates other than seasonal dummy variables and their interactions are divided with 1000.

3. Cluster-robust standard errors in parentheses. *, **, *** indicate statistical significance at 10%, 5%, 1%, respectively. n indicates sample size.

Table 7: DID Impacts of Concrete Tertiary Construction on Cultivation Decisions

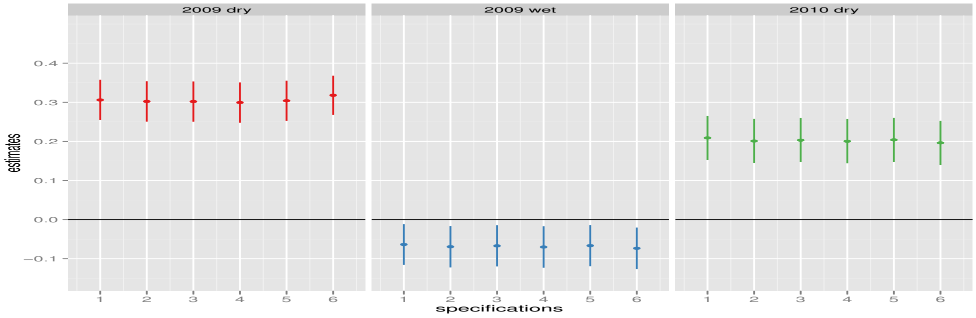
covariates	(1)	(2)	(3)	(4)	(5)	(6)
(Intercept)	0.0***	0.0*	0.0	0.0	0.0*	0.0
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
tertiary	0.0	0.0	0.0	0.0*	0.0	0.0
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
2009 dry	−0.3***	−0.3***	−0.3***	−0.3***	−0.3***	−0.3***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
2009 wet	0.1***	0.1***	0.1***	0.1***	0.1***	0.1***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
2010 dry	−0.2***	−0.2***	−0.2***	−0.2***	−0.2***	−0.2***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
2009 dry * tertiary	0.4***	0.4***	0.4***	0.4***	0.4***	0.4***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
2009 wet * tertiary	0.0**	0.1**	0.1**	0.0	0.1**	0.0
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
2010 dry * tertiary	0.3***	0.3***	0.3***	0.3***	0.3***	0.3***
	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)	(0.0)
per rai rent		34.0***	33.7***	33.4***	33.9***	34.1***
		(5.7)	(5.7)	(5.8)	(5.7)	(5.7)
per rai in-kind rent		6.1***	6.0***	6.1***	5.9***	6.9***
		(1.0)	(1.0)	(1.0)	(1.0)	(1.1)
distance to main canal			0.1*	0.0	0.1*	0.1*
			(0.0)	(0.0)	(0.0)	(0.0)
distance to lateral canal			0.0	0.0	0.0	0.0
			(0.0)	(0.0)	(0.0)	(0.0)
area (rai)			−1.5	−3.5**	−1.2	−2.4
			(1.2)	(1.4)	(1.3)	(1.5)
number of males				4.6		
				(16.0)		
number of ages 15-55				15.6		
				(14.0)		
head gender (female = 1)				−44.9		
				(29.3)		
number of farming members				38.9**		
				(15.6)		
total asset value (Bt. 1 million)					−5.1	−8.3
					(6.4)	(9.3)
non-land asset value (Bt. 1 million)						−8.2
						(28.7)
total area of HH (rai)						−3.3**
						(1.5)
average area per plot of HH (rai)						1.2
						(2.4)
number of small tractors						59.4**
						(27.8)
number of medium tractors						23.1
						(32.4)
number of big tractors						107.1**
						(43.7)
number of trucks						98.1***
						(34.9)
number of pumps (electronic)						23.3
						(44.7)
number of pumps (fuel)						−21.1
						(33.1)
n	1789	1789	1789	1789	1789	1789

Notes: 1. Linear probability model of cultivation decisions. Treatment = concrete tertiary access.

2. All covariates other than seasonal dummy variables and their interactions are divided with 1000.

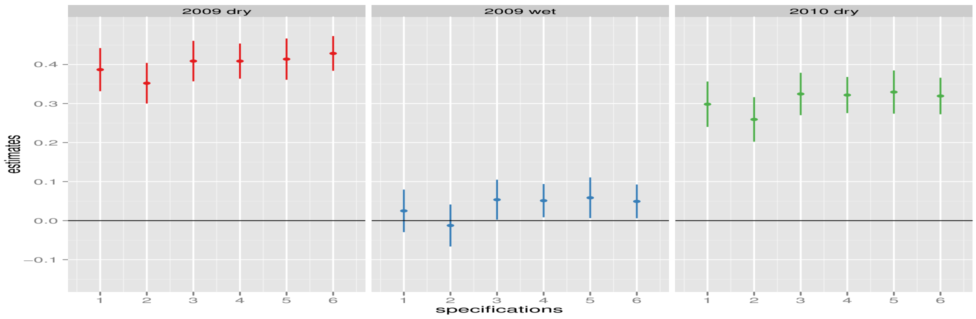
3. Cluster-robust standard errors in parentheses. *, **, *** indicate statistical significance at 10%, 5%, 1%, respectively. n indicates sample size.

Figure 15: Estimates on Cultivation Decisions, Tertiary



Note: See footnotes of Figure 13.

Figure 16: Estimates on Cultivation Decisions, Concrete Tertiary



Note: See footnotes of Figure 13.

cultivation decisions are shown. Estimates of concrete tertiary canals are given in Table 7. This is done by estimating a linear probability fixed effect model of cultivation decision index variable $1[\text{cultivate}_{it}]$ on treatment status D_{it}, seasonal dummies $\boldsymbol{\lambda}_t$, their interactions $D_{it}\boldsymbol{\lambda}_t$, and other covariates $\mathbf{x}_{it}$, namely:

$$1[\text{cultivate}_{it}] = a_0 + a_1 D_{it} + \boldsymbol{a}_2' \boldsymbol{\lambda}_t + \boldsymbol{a}_3' D_{it} \boldsymbol{\lambda}_t + \boldsymbol{a}_4' \mathbf{x}_{it} + e_i + w_{it}.$$

We apply a linear probability model, rather than logit or probit models, to incorporate individual fixed effects. The estimates of interest are $\boldsymbol{a}_3$ which show percentile increase in cultivation probability. As we use a fixed effect model, an individual effect e_i is eliminated and estimates are consistent if the first-difference (or deviation from mean) of cultivation decisions are homogeneous (or follows the same distribution) between the control plots and the treated plots in the absense of tertiary canal construction, which we assume to hold. This assumption is almost identical to the identification assumption required in DID, because if the trend of profits in the absense of interventions is parallel, then cultivation decision in the absense of interventions should also be parallel.

The estimated impacts on cultivation decisions are large: 30% points in 2009 dry season, and 20% points in 2010 dry season. Estimated impacts in the 2009 wet season for concrete tertiary canals are positive, while, puzzlingly, they are negative for tertiary canals. Although we do not have good explanation why impacts are negative for tertiary canals in 2009 wet season, overall trend shows that tertiary access increases the probabilities of cultivation. This can be the most significant impacts of tertiary canals. It was envisaged in the original planning documents that irrigation would increase land use intensity by inducing farmers to cultivate in dry seasons. This is confirmed in our data. This is made possible due to shrinking size of cultivable areas, despite farmers' fixation with paddy, a crop with low WUE, and low IE of irrigation system in dry seasons. In other words, the impacts on increased land utilization would not have realized had the project area remained the same at planned 85,695 rai, as water supply is clearly inadequate to irrigate to all paddy plots.

There are other interesting results in Table 6 and Table 7. It is found that distance to main canal is positively associated with cultivation decision if concrete tertiary access is given, but not the general tertiary access. This is conformable with our general expectation that impacts of tertiary access are larger on plots that are far from the main canal with concrete, rather than earth, canals. This is because of smaller seepage rates. Estimates on both rent and in-kind rent are shown to be positive, which indicate that better quality plots respond more strongly to tertiary access. Estimated impacts on seasonality reaffirms our observation that dry seasons see a decrease in cultivation probability, by 20% to 30%, and wet season sees an increase, by 10%.

In Figure 13, Figure 14, Figure 15, and Figure 16, a summary of DID estimates on each season*treatment are shown with point estimates and 95% confidence intervals. In Figure 13, we see that results of 2009 dry and 2010 dry are robustly significant. It is also notable that all of 95% confidence intervals have similar length, and statistical insignificance of 2009 wet estimates are due to their closer location of point estimates to zero. In Figure 14, 2/3 of 2009 wet season estimates are statistically significant. As discussed in Table 5, confidence intervals are shorter for concrete tertiary canals. In Figure 15 and Figure 16, impacts on cultivation probability are summarized. Concrete canals have higher point estimates, and 2009 wet season impacts are mostly positive and significant as opposed to genearl tertiary canals.

5 Conclusion

When we initiated preliminary estimation exercise at the end of second round, all we saw was little difference in productivity between "with tertiary" plots and "without tertiary" plots. So it is rather surprising to find large impacts of tertiary canals on profits in DID estimates for KKBM. The mechanism behind it is that tertiary canals encourage farmers to cultivate plots in dry seasons, and additional cultivation of a given plot increases the farmer profits. Although it was suggested that tertiary canals *per se* may not have extra profitability impacts over the cultivated control plots in KKBM, more intensive land use is not to be dismissed lightly under rapid industrialization and urbanization context.

The results confirm that the initial goal of the KKBM project in increasing land use intensity is achieved successfully. However, it is achieved under shrinking irrigated area due to industrialization and urbanization that allowed RID to operate at low irrigation efficiency with limited water supply capacity. With modest productivity and profitability impacts of tertiary canals conditional on cultivation, tertiary canal construction in KKBM is best described as having an encouragement impact. But, again, this is major departure from pre-tertiary dry seasons when only limited number of farmers cultivated.

While tertiary canals' impacts on profits are positive and statistically significant in KKBM, one should not conclude that JICA should always invest in the future tertiary canal projects. One must be reminded that there are conditions that helped KKBM tertiary canals to have impacts at plot level: smaller pressure on water supply capacity due to shrinking command area in the face of industrialization and urbanization, existence of uncultivated plots in dry seasons, good relationship between RID and farmers, and well governed and well functioning WUGs. In the future tertiary irrigation projects, one is advised to compare with KKBM if similar conditions exist. In addition, as it requires fine tuned consensus in constructing tertiary canals, it is recommended to assist WUGs and government officers in providing capacity boosting training and operations to increase their governance abilities.

As most of bilateral and multilateral donors backing away from impact evaluation of infrastructural projects, it is important that JICA continues with its unique contribution in evaluating them. JICA has natural advantages: First, the portfolio of projects is concentrated on infrastructure, so JICA is endowed richly with materials. Accordingly in evaluation of irrigation projects with the scale similar to KKBM, JICA is advised to focus more at primary and secondary canal levels. Second, as the feasibility study (F/S) of infrastructure projects precede actual implementation by about two years, it gives a good opportunity to conduct the baseline survey. As DID relies on the so-called pararell trend assumption, which is sometimes questionable to hold, it is ideal to start the baseline survey two periods ahead of *ex post* period to allow implemenation of triple difference (DIDID) estimator. Another possible and credible choice of estimator for infrastructural impacts is RDD. Some network infrastructure, such as electricity, water, and gas is characterized with segmentation for operational purposes. This nature fits well with RDD in satisfying abrupt jumps in treatment variables in small regions. But even with RDD, baseline data is invaluable in cross-validating the estimated results in contrasting *ex post* and *ex ante* outcomes.

By conducting the baseline ahead of project construction, one can obtain information vital in designing the operational aspects to give immediate feedback to the infrastructure project. For starters, as water users groups throughout the developing world are plagued with inability to collect user fees, one can examine, by using collected information of baseline, novel collection schemes based on the acceptance and availability of devices. An example of such scheme includes the use of IT devices that allows on-spot transaction of user fees at the point of use in the field, or incentivising payment by taking deposits or offfering early payment discounts. Knowledge on produce sales can provide a way to reach an agreement with the buyers so RID can receive fees at the time of farmer's produce sales. Running pilot schemes can give further insights to refinement of the payment scheme.

It is advised that JICA continues with its effort on evaluating infrastructural projects, not just to obtain lessons for future but to obtain immediate feedback on policy making before the project starts. F/S and baseline surveys can be made to be more productive for both policy development and evaluation. It is important for operational departments and evaluation department to jointly work from the beginning of the project to achieve this. With its unique contribution in infrastructure impact evaluation, JICA is expected to continue supplying new knowledge to the development arena.

Appendix

A Characteristics Comparison of the Treated and the Control

As stated in the main text, identification with DID depends crucially on what one may call as the parallel trend assumption. That is, in the absense of interventions, both the treated and the control exhibit the same growth. This relaxes the level homogeneity assumption required in cross-sectional methods, such as various matching estimators and control function approaches, to requiring only the first-difference homogeneity. An oft heard argument in examining homogeneity between the treatment groups is to perform similarity checks between them. This can have a root in the work of Smith and Todd (2005) who found that, using NSW data of the US, DID matching estimator robustly outperformed DID or PSM.

The results are summarized in Table A1. We can note that there are statistically significant differences in area, non-land asset holding, number of medium-sized tractors, number of electronic pumps and number of fuel pumps, all but electronic pumps in excess with the treated group. This is not surprising because the control group is defined as the plots without any change in tertiary canal accessibility during the survey period, thus includes plots both with and without access to tertiary canals. As shown in the main text that the tertiary access increases the chance of cultivation in dry seasons to increase the profits, asset holding is expected to improve after the tertiary canal accessibility is obtained. The only assets that the control has in excess, electronic pumps, are inferior to fuel pumps due to higher variable costs, and its holding may not be considered as a sign of being better off. So there is a subtle difference between these two groups when we compare the levels, and it is in line with our estimated results that tertiary canals can result in larger profits.

That being said, readers should not misunderstand that this exercise has not given *any* information regarding the parallel trend assumption. It is not testable without further data. Smith and Todd (2005)'s work is suggestive, but it does not mean that matching provides less biased estimates in other data sets. What has been examined in Table A1 is level comparison, not the first-difference comparison. Levels and their first-differences do not need to be correlated. Hence level comparison does not have an informational content of first-difference comparison.[*3] The similarity or the small, subtle differences in characteristics shown in the table may give an impression to readers that the parallel trend assumption is valid, but, unfortunately, this is not the case. This exercise is provided to show the consistency of estimated results with between group characteristic comparison that the control group is better endowed with assets.

[*3] In fact, one can think of connection between levels and first-difference in the way we cannot employ. When we consider a dynamic model, the initial value of a state variable is a determinant of ensuing dynamics. This implies that levels and subsequent growth are related by difference equations. However, the state variables in our context are assets and other stock variables, and they are affected by the construction of tertiary canals. So we do not have the "initial values" of state variables and hence cannot infer the dynamics with our data.

TABLE A1: COMPARISON OF CHARACTERISTICS BETWEEN TREATMENT GROUPS

	control	treated	diff	p-value
area	11.185	13.286	-2.101^{***}	0.000
per rai rent	517.378	469.183	48.195	0.276
yield (kg)	620.782	649.747	−28.964	0.546
household size	4.441	4.409	0.032	0.617
number of male members	2.114	2.126	−0.012	0.786
household head age	55.737	56.201	−0.464	0.261
number of farming members	2.215	2.251	−0.036	0.309
total asset value (Bt. million)	2.038	2.113	−0.075	0.399
non-land asset value	0.876	0.960	-0.083^{**}	0.012
average area per plot (rai)	10.718	10.202	0.516	0.190
number of tractors, small	0.667	0.669	−0.002	0.927
number of tractors, medium	0.382	0.455	-0.073^{***}	0.000
number of tractors, large	0.130	0.143	−0.013	0.336
number of trucks	0.511	0.506	0.005	0.800
number of electric pumps	0.200	0.118	0.082^{***}	0.000
number of fuel pumps	0.590	0.756	-0.166^{***}	0.000

Notes: 1. Treatment status is defined at plot-level. To operationalize comparison of associated household characteristics, household-level attributes are attached to each plot. If a household has both control and treated plots, the same household characteristics appear in both groups. So this is not a valid test, and readers are asked to take the results on household-level characteristics only as suggestive evidence. Plot-level characteristics can be interpreted straightforwardly. Plot-level characteristics are area, per rai rent, and yield.

2. Control plots are defined as the plots which did not experience change in access to any tertiary canals. Treated plots are defined as otherwise. Note that the control group includes plots which had been given access to tertiary canals before the survey began.

3. Standard errors in parentheses. *, **, *** indicate statistical significance at 10%, 5%, 1%, respectively. n indicates sample size.

B Robustness Checks

A robustness check was conducted to test if a restriction of same parameter values between dry and wet seasons is valid. We have added an additional set of covariates which are produced by interacting $\mathbf{x}_{it}$ with a dry season dummy variable. The coefficients on these dry season covariates will show the difference between dry and wet season parameter values. As the results in TABLE A2 show, almost all the estimates on dry season covariates are not statistically different from zero with exceptions of number of male members (at 10% level) and working age members (at 5% level). The point estimates of interest remain unchanged, about 70,000 for 2009 dry, 45,000 for 2009 wet (insignificant), and 60,000 for 2010 dry. The standard errors are larger as lifting the restriction diminishes the efficiency of estimates. Because we have no effective changes in point estimates but with increased standard errors, we will keep the restriction throughout our analysis.

C Practical Issues Encountered in Survey Implementation

C.1 Peculiar advantages of this survey

In the usual JICA *ex post* evaluation which follows DAC evaluation criteria, in some countries it happens at times that an evaluator is left alone with little effective cooperation from the partner

Table A2: DID Impacts of Tertiary Construction on Profits, Seasonal Regressors

covariates	(1)	(2)	(3)	(4)	(5)	(6)
tertiary	−14836	−15423	−13066	−9551	−11214	−15912
	(17734)	(17773)	(18585)	(19828)	(18391)	(19106)
2009 dry	−47352**	−48314**	−48301**	−48297**	−48331**	−48295**
	(21969)	(22225)	(22241)	(22256)	(22250)	(22305)
2009 wet	−53322**	−53503**	−53481**	−53471**	−53497**	−53493**
	(23974)	(24016)	(24039)	(24054)	(24046)	(24103)
2010 dry	−66902***	−67174***	−67155***	−67142***	−67177***	−67146***
	(24624)	(24679)	(24705)	(24721)	(24713)	(24773)
2009 dry * tertiary	69072**	67375**	71971**	59733*	72363**	69025**
	(30168)	(29869)	(33583)	(33021)	(33820)	(31036)
2009 wet * tertiary	46170	47017	46972	46567	47019	46468
	(30078)	(30215)	(30179)	(30152)	(30192)	(30160)
2010 dry * tertiary	61431**	62036**	66891**	55203*	67173**	63302**
	(31144)	(31267)	(33092)	(33360)	(33334)	(31764)
per rai rent		3654***	3628***	3593***	3665***	3702***
		(1231)	(1243)	(1245)	(1253)	(1251)
per rai in-kind rent		−466.8***	−466.2***	−520.3***	−471.9***	−376.1**
		(137.8)	(138.4)	(144.8)	(138.0)	(166.2)
distance to main canal, dry			4.0	3.1	3.8	3.1
			(3.0)	(3.3)	(3.0)	(3.8)
distance to lateral canal, dry			0.2	0.5	0.2	0.4
			(0.7)	(0.6)	(0.7)	(0.6)
area (rai), dry			−438.1	−411.5	−436.9	−458.8
			(397.8)	(380.6)	(395.4)	(438.2)
number of males, dry				−4850*		
				(2809)		
number of ages 15-55, dry				4742**		
				(2097)		
head gender (female = 1), dry				9068		
				(10598)		
number of farming members, dry				2832		
				(2560)		
total asset value (Bt. 1 million), dry					−80.0	−1819
					(492.2)	(1329)
non-land asset value (Bt. 1 million), dry						693.6
						(4013)
total area of HH (rai), dry						−18.5
						(257.3)
average area per plot of HH (rai), dry						427.1
						(328.1)
number of small tractors, dry						4768
						(5673)
number of big tractors, dry						10292
						(12690)
number of trucks, dry						−2390
						(8233)
number of pumps (electronic), dry						12422
						(12833)
number of pumps (fuel), dry						−2395
						(7031)
n	1789	1789	1789	1789	1789	1789

Notes: 1. Profit per rai (Bahts). Treatment = concrete tertiary access.

2. All covariates other than seasonal dummy variables and their interactions are divided with 1000.

3. Level covariates are omitted from the table for brevity.

4. Cluster-robust standard errors in parentheses. *, **, *** indicate statistical significance at 10%, 5%, 1%, respectively. n indicates sample size.

government. In our survey, however, we have benefited from issuance of official reference letters from JICA Bangkok office to Ministry of Agriculture and Cooperatives and its subdivision, Royal Irrigation Department (RID). RID in Bangkok then forwarded the reference letters to its local office. Of course, these letters are issued in all *ex post* evaluations, but what stood out in this survey was that they were quite effective in obtaining permissions and necessary information from the local authorities. With these arrangements and personal endorsement from director of RID Bangkok office, the survey team obtained full cooperation from the local RID office. In addition to official reference letters, acceptance of impact evaluation by the director of RID Bangkok significantly enhanced the feasibility of the survey.

Another important aspect in survey implementation is the existence of local coordinator who has a wide network with the farmers. We have hired the coordinator to manage the survey. Extensive knowledge of the area and irrigation, together with familiarity with farmers have helped the survey team to be accepted for the interviews that lasted 2 hours in each round. Presence of well-connected coordinator is not a prerequisite for the survey, but it has simplified operations of the survey significantly.

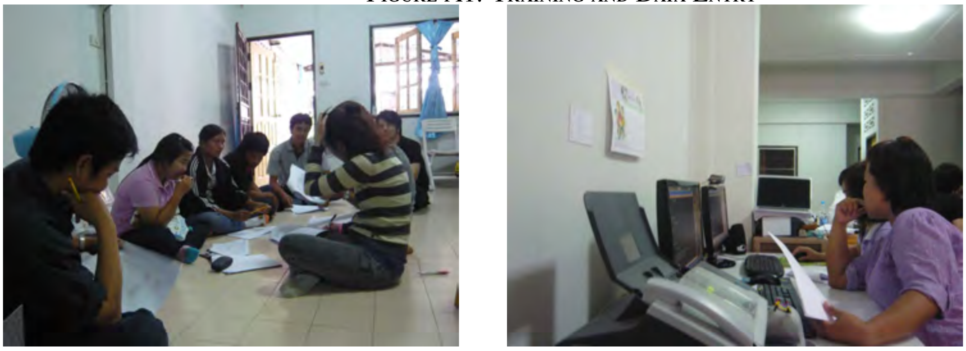
C.2 Difficulties resulting from tertiary canal evaluation

In deciding the design of evaluation project, the most fundamental determinant is the timing. If an evaluator is consulted before the program initiation, we have an opportunity to collect the baseline information which gives the glimpse of pre-program states. This provides an evaluator with a superior piece of information that allows her to control the time-invariant fixed effects in estimating the impacts.

In addition to collecting the baseline information, if one is given a power to randomly decide the program beneficiaries, this will provide the highest credibility in evaluation results. A randomized control trial (RCT) is the "gold standard" of evaluation design, although RCT-based policies are different from regular policies that makes interpretation not straightforward. However, such an opportunity almost never exists in evaluation of infrastructure programs, because randomizing the placement of infrastructure is hardly defensible on any ground.

The timing we were consulted for evaluation was after the construction of secondary (lateral) canals. In the pump irrigation system, water is provided from upstream pumping station through various levels of canals, starting from main (primary), lateral (secondary), and in the case of KKBM, tertiary. This naturally narrowed the scope of impact evaluation to tertiary canals. As main and lateral canals are considered to offer the largest impacts, this created a challenge to an evaluator. As a statistical matter of fact, smaller impacts are harder to capture. This is because modest measurement errors can swamp the impacts. This is reflected in larger standard errors and so called attenuation bias in econometrics. There is another difficulty in evaluating tertiary impacts. While main and lateral canals are visible and remembered well by the farmers, construction of tertiary does not provide the same magnitude of drastic change in water flows. The observability of tertiary canal "treatment" is less clearer than the main and lateral canal "treatments". So both the impacts and treatments are harder to observe. In

Figure A1: Training and Data Entry



order to identify tertiary canal treatment precisely, we design the surveys carefully at the plot level. By measuring impacts at the plot level, we can control the individual plot characteristics that are often masked and averaged out in the household level data.

C.3 Difficulties resulting from multi-round survey

Training of enumerators has been the key in ensuring the quality in surveys. We have provided detailed instructions and a few days long training, but it seems it requires, for interviewers whose educational achievements are as high as college graduates, at least a week to get accustomed to the questions and responses. In addition, there are always cases whose response does not fit well with the questionnaire. We have established a work flow in collecting and sending questions from the field to the evaluation team in Japan. While we made it clear the intentions of each question, close monitoring and supports of researchers or her assistant are necessary for enumerators to move beyond the steep learning curve at initial stages. We have also learned to sacrifice some space in our questionnaire to be allocated to confirmatory questions, so we can correct mistakes in front of respondents.

Collecting information at plot level, however, turned out to be more difficult and complex than we first imagined. Farmers in KKBM cultivate multiple plots due to fragmented plot holding and the difficulty in consolidating neighboring plots. The turnovers of land rental markets are high, and farmers are prone to change plots. These make farmers to confuse at times which of multiple plots they are responding about, and give unmatching information. Training of enumerators was not ready for such errors at the early rounds of surveys that they did not confirm the respondents how a plot matches with another across the rounds. To rectify this problem, we had to create a plot cultivation history table from collected data for each and every respondent to confirm precision of our information. In constructing a panel data set, we employed GPS measurement to add spatial dimension in our analysis. This should help enumerators to find the plots more easily in the future.

During the long and periodic span of multiple round survey, we encountered the turnover of enumerators. This was partly unavoidable as we were hiring recent college graduates for four to six months in a year. Once they find a better job, we had no means to retain them. Except for a few key personnel hired under a long-term contract by our local consultant throughout two years of survey period, almost all enumerators left by the beginning of 2009. This was particularly difficult and wasteful in survey operations as we had to train the newly recruited enumerators from scratch. Difficulty in matching the farm plots may have resulted from annual turnover of enumerators.

Continuity in management and its staff team is essential. Had we lost few key personnel in the local consultant firm, operation could have taken longer than we experienced. As we provided a specialized data input program created by evaluation team, data entry and associated file management were potential risks in the quality of data submitted to us. We have utilized all the available tools in maintaining order of data and file handling. Beyond email, which was our basic communication tool, we utilized cloud-based utilities. The most useful utility was Dropbox®, which allows users to share a folder in the cloud. So data entrant and evaluation team were sharing the same set of data files and data input program files. In the absence of team members on the ground, it was apparent that we needed programming capacity and cloud-based utilities.

There are two alternative survey implementation arrangements to improve operational efficiency of data. First is to make use of professional enumerators. While connection with local farmers requires our local consultants, enumerators can be provided through a survey firm. As most of enumerators in these firms are trained and experienced, we only need to train them in particular aspects of interviews. Another nice feature of using professional enumerators is that they can be employed for other survey projects while our survey is not taking place. So we can maintain our expertise and experience over the rounds. A drawback to this is that they can be costly, and pecuniary incentives will be reduced for the local consultant. Another drawback is that we have to mesh the enumerators with the local consultant in managing the survey coherently. As we are introducing another agent in surveys, responsibility between agents can easily become ambiguous, and this will put burden on the evaluation team, the principal.

Second is to offer a regular employment contract to fewer enumerators, and ask them to do a larger number of interviews. In this way, each enumerator spends more time in the field to achieve the required sample size, which will allow them to accumulate more experiences while preserving continuity over the rounds. A drawback of this strategy is that it takes longer time to reach the target sample size, and for surveys like ours, timing cannot be misplaced as we are collecting concurrent agricultural production information.

As a lesson, it will be beneficial for evaluation to sign a multi-period contract with the local consultant, if we know that the survey has multiple rounds. This will ensure that personnel, including enumerators, will continuously employed. Further, by attaching a revision clause after the first year, it provides a strong incentive for local consultant to manage the operations efficiently in a schedule-honoring manner. Evaluation team also may need to devise a way to control the integrity of information that can be used throughout the survey rounds.

D Pattananikom (2010 dry)

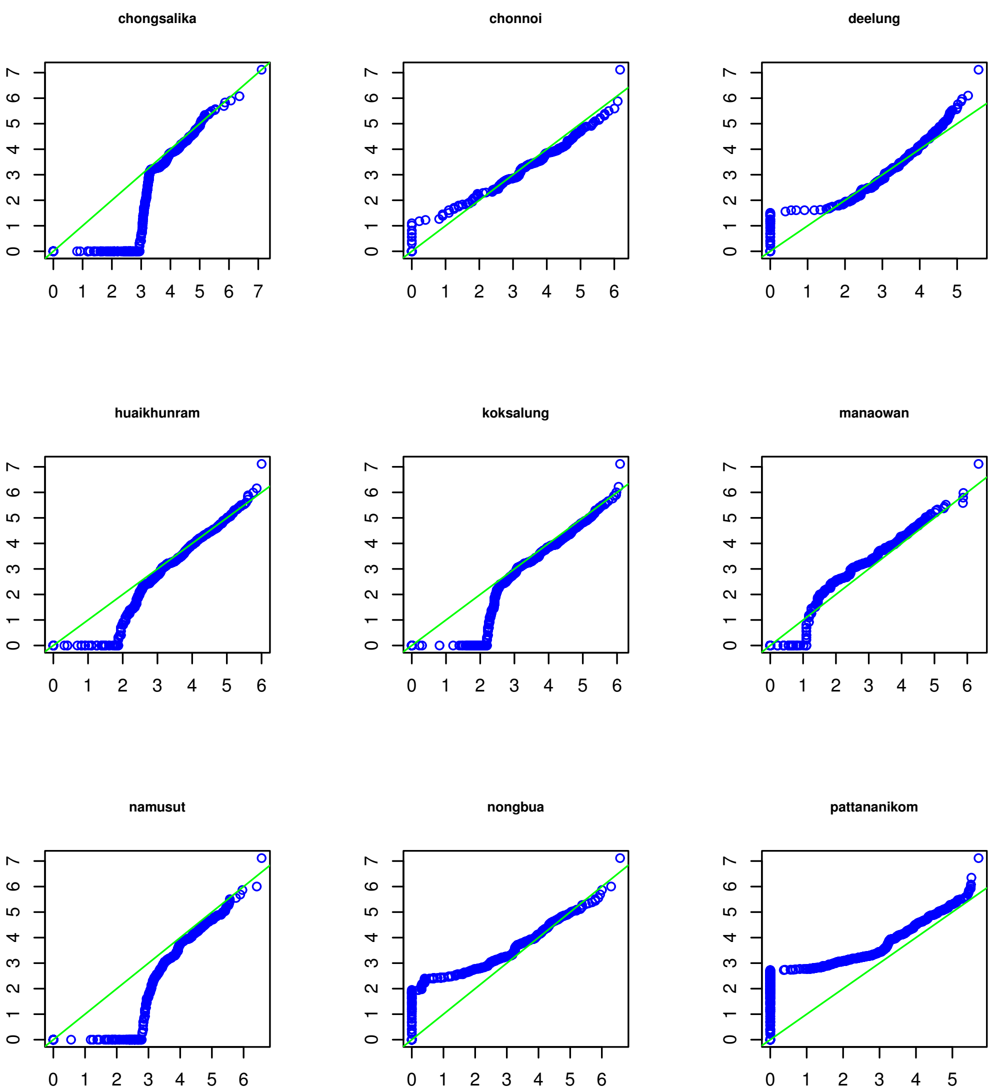
D.1 Background on Pattananikom area

In exploring the external validity of our study's results, we have conducted a supplemental survey in neighboring districts of Ropburi. We set the sample frame to include following tambon: Chongaliska, Chonnoi, Deelung, Huaikhunram, Koksalung, Manaowan, Namusut, Nongbua, and Pattananikom. *Tambon*s, or subdistricts, are administrative units in Thailand below district (*amphoe*) and province (*changwat*). There are on average 10 villages in each *tambon*. Reasons for selecting these *tambon*s are twofold: First, it is reasonably close to (about 100 km away from) KKBM area so we can expect continuity in agro-climatic conditions. Second, they are under Pattananikom Pump Irrigation Scheme which may be the biggest pump irrigation project in the country. In addition to the existence of a similar pump irrigation scheme, high level canal network is much sparse than KKBM and tertiary canals are not constructed in the eastern *tambon*s. This provides an interesting point of comparison to KKBM with insights on before-irrigation status, if not the exact counterfactual. Tambons in the eastern part are Huaikhunram, Manaowan, and Namusut. In the end, we have selected approximately 900 households from Chonnoi, Huaikhunram, Koksalung, Manaowan, and Pattananikom.

In sampling households, we have used multi-stage stratified random sampling. First stage strata are eastern and western *tambon*. Among these strata, we have further classified each *tambon* to a "zero cultivator" stratum with many zero land holder/cultivator households, a "non-zero cultivator" stratum with little zero holders/cultivators, and "population" stratum where zero holders exist at the rate approximately equal to entire sample frame. This is done as we have found dairy production is operating at an unignorable scale in place of cultivation, after investigating the tambon level agricultural production.

In Figure A2, we have draw quantile-quantile plots of land holding distributions for all *tambon*s. Reference distribution is entire sample frame and is depicted on horizontal axis. As we can see, there are three distinct groups: similar to population (Chonnoi, Manaowan), less zero-holders than population (Chongaliska, Huaikhunram, Koksalung, Namusut), and more zero-holders than population (Deelung, Nongbua, Pattananikom). In the eastern *tambon*s, we have randomly selected Manaowan for "population" and Huaikhunram for "less zero-holders" strata, and in the western *tambon*s, we selected Chonnoi for "population", Koksalung for "less zero holders" and Pattananikiom for "more zero-cultivator" strata. Finally, we have stratified all households on Department of Agricultural Extension (DOAE) damage compensation list. DOAE damage compensation list is a census of farmers who are eligible for compensation for damages from natural calamities. Due to its nature of the list, it is very unlikely that any active agricultural and dairy farmers to be off the list. We used land holding information in the list and stratified households into 4 land holding strata, and chose households randomly. As in DOAE list of KKBM, we have many dormant farmers on the list. Thus we have excluded zero holders as most

Figure A2: Tambon Land Holding Distributions in Pattananikom Area (ha)



Notes: 1. Quantile-quantile plot of land holding per household.

2. Horizontal and vertical axises show quantiles of entire Pattananikom and of each Tambon, respectively.

of them are not engaged in production. This stratification will ensure that we have a balanced sample from all land holding classes.

D.2 Comparison with Pattananikom Area

Table A3 describes household characteristics of Pattananikom sample. Since Pattananikom has a unique history of large inward immigration flows from Bangkok Metropolitan area, the fraction of household head that was born in his/her village is relatively small. In Pattananikom, like in KKBM area, land rental market is active, resulting in larger cultivation area than farmer's own land. However, total cultivation area per household is only slightly larger than that of KKBM farmers. The stark difference we can see between KKBM and Pattananikom is the current composition of crop, as in shown in Table A4. While there is a single dominant crop, paddy, in KKBM area, Pattananikom is

Figure A3: Pattananikom

Table A3: Household Characteristics, Pattananikom

variables	min	25%	median	75%	max	mean	std	NAs	n
Demographic condition									
Household size	1	3	4	5	8	3.69	1.51	7	707
Members of working age (16-60)	0	2	2	3	6	2.45	1.26	3	707
Age of head	18	45	53	62	92	53.90	12.61	8	707
Head born in this village (=1)	0	0	0	1	1	0.34	0.48	2	707
Head with secondary education or higher (=1)	0	0	0	0	1	0.20	0.40	7	707
Land use									
Number of plots	1	1	2	2	7	1.85	1.08	100	707
Total land area owned (rai)	0	10	23	40	306	29.20	29.29	100	707
Total land area cultivated (rai)	2	18	30	53	306	39.98	33.91	100	707
Crop diversification in wet season (=1)	0	0	0	0	1	0.19	0.39	113	707

Source: Summary of collected data from Pattananikom households.

Table A4: Crop Production, Pattananikom

crops	area	area per plot							
	(rai)	min	25%	median	75%	max	mean	std	n
Sugarcane	10733	2	4	20	30	120	24.67	16.91	435
Corn	6321	1	10	20	24	70	18.65	10.67	339
Paddy	4473	2	10	17	25	100	19.28	14.31	232
Cassava	2790	2	10	20	25	120	20.97	15.30	133
Other	1637	4	10	20	24	50	18.82	9.41	87

Notes: See footnote in Table A3.

characterized by the considerable degree of crop diversification at the regional level. Sugarcane and corn are two major crops, followed by paddy and cassava. Crop diversification can be also observed at farmer level. 19 percent of farmers grow different crops in the same agricultural season.

The diversified agricultural activities reflect to some extent the water availability condition. Table A5 shows the limited availability of irrigation water in Pattananikom. Most farmers rely on rainfall for farming in the wet season and many plots (around 37 percent) lack sources of water in the dry season. Same is true for the subsample of plots where paddy is planted in the wet season. In those plots, production of dry season paddy are completely abandoned. Furthermore, even in the case of dry paddy production with irrigation, the amount of water may not be sufficient or unstable. Table A6 indirectly suggests this possibility. The yield of dry season paddy is lower than that of wet season paddy, which

Table A5: Sources of Irrigation, Pattananikom

	all plots		plots planted paddy in wet season	
source	wet	dry	wet	dry
Natural rain	1021	-	157	-
Main canal	14	412	3	80
(Sub) Lateral canal	30	41	24	19
River and natural drainage	10	58	5	6
Pond	6	38	4	8
Plot-to-plot	5	19	5	7
other	10	131	3	9
Not available	3	400	0	72
Total	1099	1099	201	201

Notes: See footnote in Table A3.

Table A6: Paddy Yield, Pattananikom (kg/rai)

variety	min	25%	median	75%	max	mean	std	n
Wet season paddy	1	344	700	1000	7000	748.40	669.52	206
Dry season paddy	22	160	600	725	2000	532.04	44.19	28

Notes: See footnote in Table A3.

is unusual in case of Thailand. Although a very small number of observations in the dry season makes it difficult to test the significance of this difference in yield, it is highly plausible that the severe water condition limits the scope of efficient land use in the dry season.

What can we learn from the comparison between KKBM and Pattananikom as for the role of irrigation systems? We do not claim that Pattananikom is a proper control area in terms of rigorous impact evaluation. However, the situation of Pattananikom tells us following two points. First, the lack of wide-reaching irrigation systems, in particular the main and lateral canals, imposes a severe constraint in the dry season farming. It precludes the opportunity for double-cropping of paddy. In addition, the lack of irrigation water also suppresses yield potential of other crops. For example, sugarcane needs water when it is planted and achieves higher yield due to longer growing periods if it has access to water earlier than wet season begins. Hence, most important impacts of irrigation arise as the enhancement of dry season agriculture. In this regard, the benefits of the construction of main and lateral canals in KKBM area are supposed to have been enormous. Second, however, the demand for water in terms of amount and timing will be different across crops. Since the management of irrigation systems is easier when the beneficiary area produces same crop such as paddy, agricultural diversification may have negative impacts on the coordination of water use among farmers. Therefore, irrigation systems should be carefully designed, considering the capacity of coordination in the diversified rural agricultural area. In this sense, the experience of agronomically more homogeneous KKBM area cannot be universally applicable, despite being one of the most successful examples that exhibits the potential benefits of irrigation infrastructure.

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