# Impact Evaluation (IE) Concept Note

# Impacts & Sustainability of Irrigation in Rwanda

Rwanda

P154433

January 2016

**Keywords:** [1] Choose one of more keywords/categories that describe your IE.[2] (R)

[1] Please refer to JEL classification codes http://papers.ssrn.com/sol3/displayjel.cfm .

[2] The concept note is aligned to Ethical clearance (E) and Registry (R) indicative requirements. These indicative requirements are referenced throughout the document.

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# IE Profile Indicators

| No. | Indicator | Description |
|---|---|---|
| 1 | IE code | P154433 |
| 2 | IE Title | DIME RWA Irrigation |
| 3 | IE TTL | Florence Kondylis |
| 4 | IE Contact Person | Florence Kondylis, DECIE |
| 5 | Region | AFR |
| 6 | Sector Board/Global Practice | ARD |
| 7 | WBG PID (if IE is evaluating a WBG operation) | P147543 |
| 8 | WBG Project Name (if IE is evaluating a WBG operation) | Land Husbandry, Water Harvesting and Hillside Irrigation AF |
| 9 | Project TTL (if IE is evaluating a WBG operation) | Valens Mwumvaneza |
| 10 | Intervention | Hillside irrigation scheme |
| 11 | Main Outcomes | Agricultural productivity, technology adoption, income |
| 12 | IE Unit of Intervention/Randomization | Hillside irrigation scheme |
| 13 | Number of IE Units of Intervention | 3 |
| 14 | IE Unit of Analysis | Plot |
| 15 | Number of IE Units of Analysis | Approximately 6,197 |
| 16 | Number of Treatment Arms | 2 |
| 17 | IE Question 1 (Treatment Arm 1) | What are the impacts of irrigation on smallholder welfare? |
| 18 | Method IE Question 1 | Spatial regression discontinuity |
| 19 | Mechanism tested in IE Question 1 | Package |
| 20 | IE Question 2 (Treatment Arm 2) | What is the impact of escalating irrigation fees on farmer behavior? |
| 21 | Method IE Question 2 | Randomized Controlled Trial |
| 22 | Mechanism tested in IE Question 2 | Constraint-relaxing – Tax burden |
| 23 | IE Question 3 (Treatment Arm 3) | Do self-demonstration kits encourage experimentation and long-run adoption? |
| 24 | Method IE Question 3 | Randomization |
| 25 | Mechanism tested in IE Question 3 | Constraint-relaxing – Human capital skills inputs |
| 25 | Gender-specific treatment (Yes, No) | No |
| 27 | Gender analysis (Yes, No) | Yes |
| 28 | IE Team & Affiliations | Florence Kondylis (DECIE); Maria Jones (DECIE); John Loeser (University of California – Berkeley); Jeremy Magruder (University of California - Berkeley) |
| 29 | Estimated Budget (including research time) | $800,000 |
| 30 | CN Review Date | February 2016 |
| 31 | Estimated Timeframe for IE | January 2015 – December 2019 |
| 32 | Main Local Counterpart Institution(s) | Rwanda Ministry of Agriculture & Animal Resources |

# 1. Executive Summary

Irrigation investments have enormous potential to improve the lives of smallholder farmers who otherwise depend on rain-fed agriculture, both through increasing yields, adding additional cultivating seasons, and reducing risk (Burgess et al., 2014). Large-scale irrigation is different from many of the projects in the current DIME-AADAPT portfolio in that adoption decisions are often not individual but instead completed at the state level, where governments debate whether the impacts of irrigation can offset its enormous cost. Even where cost recovery is not an objective, smallholders are ultimately responsible for the recurring costs coming from the operation and maintenance (O&M) and usage control of the irrigation schemes. Governments must weigh the costs against the benefits of the second-best product that may be delivered as commons problems affect water delivery.

We propose a research program around 3 irrigation schemes that have just been constructed in Rwanda, as part of Land Husbandry, Water Harvesting and Hillside Irrigation (LWH) Project. Our focus is three-fold: first, we will provide estimates of the impacts of irrigation on farmers' welfare, captured by yields, profits, labor markets, rental and land markets, migration, and education.

Second, we test mechanisms designed to address the two primary concerns about the sustainability of irrigation investment. Within this class of mechanisms, we first test the impact of escalating irrigations fees on farmers' adoption of a high-value cropping system. Here we hypothesize that progressively increasing fees makes the importance of adoption of high value crops salient, and that certain patterns of subsidies over time may lead to a more efficient equilibrium path. Second, we test the impact of experiential learning, through the offer of demonstration mini-kits, on adoption behavior and fee repayment.

Third, we will also answer several questions about irrigation operations and maintenance. While higher-level maintenance functions are to be paid for through the farmer fees, effective usage of the irrigation system additionally requires farmers to maintain and enforce an operation schedule, as well as perform some routine maintenance. Solving this classic common pool resources problem has been a challenge for irrigation systems historically, and led to some seminal work (e.g. Ostrom 1993). Through a RCT, we will test whether water user groups (WUGs) are better able to achieve high quality operations and maintenance outcomes through one of two different structures: either a decentralized structure, where farmers develop, monitor, and control their own schedule and maintenance, or an agency-assisted structure, where irrigation employees take on these tasks. This component will be randomly assigned at the WUG level, the relevant level of collective action for these tasks.

The proposed evaluation design will feature 2-4 rounds of survey data collection on approximately 2900 farmers living in 5 of these sites. Construction of three of the irrigation sites was completed by summer 2015 and a baseline was conducted in those sites already, and co-funding has been raised for a midline in these three sites. This proposal would fund 2 additional rounds in these 3 sites as well as 2 rounds of data collection in three other sites, where construction is scheduled to be completed by late 2016. We supplement survey data collection with qualitative evidence from focus groups and key informants.

## 2. Background and Key Institutional Features

This proposal is for a household survey in the Karongi and Nyanza Districts of Rwanda. The research team is a collaboration between Development Impact Evaluation (DIME) at the World Bank, the Ministry of Agriculture's Land Husbandry, Water Harvesting and Hillside Irrigation project (LWH), the University of California – Berkeley, and Innovations for Poverty Action (IPA). What originally began as an evaluation of the overall impact of the LWH project by DIME has evolved into a portfolio of several different impact evaluations. One of these is an impact evaluation of large-scale irrigation schemes constructed as part of the LWH project. [3]

Our study context is 3 hillside irrigation schemes in two districts of Rwanda. Hillsides in and around these schemes are terraced. These irrigation schemes share similar design features: a main canal is directed from the water source along contours of the hillside. The first, smaller stretch of the main canal is an existing but recently rehabilitated canal. In the remaining majority of the irrigation scheme, the main canal is newly constructed and there was no existing canal system. Secondary pipes then run perpendicular to the main canal, spaced at approximately 200m intervals.[4] Groups of approximately 20 households (range of 5- 50 at baseline; median of 19) will rely on a secondary canal to irrigate their terraces. These groups are referred to as secondary blocks. Along the secondary canal, there is a tertiary inlet with a flexible pipe on every third terrace. Working on the terraces, farmers dig (temporary) tertiary canals in the soil to draw the water from the flexible pipe and irrigate the terrace. In general, households will own plots on multiple terraces and multiple households will own plots on the same terrace being irrigated by the tertiary canal, so that this exercise relies upon terrace-level cooperation.

Construction of the scheme is complete. All farmers in the irrigation area have access to irrigation water. Water usage fees will be charged to all households that irrigate, starting in 2016. To afford the water usage fees, and to make the schemes viable, it will be necessary for farmers to transition to high value crops, such as horticulture, and away from the current staple crops of maize and beans. It may be the case that a few farmers would choose to forego using irrigation water, but high adoption rates will be guaranteed regardless. In our pilot survey (Annex C), 90% of affected farmers expect to see increased income from irrigation, which is supported by evidence from a large literature (for a survey, see Hussain and Hanjra, 2004).

There are three agricultural seasons in Rwanda. In season A, rainfall is sufficient for production in most years. In season B, rainfall is sufficient in an average year but insufficient in dry years. In season C, rainfall is insufficient for agricultural production. Thus, we expect irrigation to directly affect production the most in season C, and also in season B. There may be additional effects throughout the year if farmers alter their investment strategies as a result of wealth or risk-reducing characteristics of irrigation. For instance,

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[3] This project is implemented by the Special Project Implementation Unit (SPIU) of the Ministry of Agriculture and Animal Resources of Rwanda (MINAGRI), and co-financed by IDA, GAFSP, USAID, CIDA, and the Government of Rwanda.

[4] Operation manual indicates that secondary canals are to be constructed at 200m intervals "whenever possible."

farmers are expected to switch to higher value crops that require steady water intake throughout the season (e.g., horticulture).

The two primary challenges to the long-run viability of irrigation schemes are maintenance and overuse, and are relevant to our context. In our pilot survey, these were the two most frequently reported concerns over the viability of the scheme. Approximately 210Water User Groups (WUGs), based at the secondary block level, are currently being formed. WUGs are responsible for the maintenance of the secondary canals and tertiary pipes, and the scheduling of water use within their block.

The irrigation canal scheme was built for smallholder farmers. There are several marginalized groups within the group of farmers who have received irrigation: most notably, the poorest, and renters. We expect to test whether there are heterogeneous impacts for these groups: we will also be interested in whether unequal WUGs have differential outcomes, following insights from a broad literature (for a review see Dayton-Johnson 2000).

## 2.1. Policy Influence

The proposed research project builds on an ongoing program of impact evaluation of Rwanda's LWH Project. The first generation of trials focused on the rural finance and agricultural extension components of the LWH project, and were designed over the course of a DIME workshop during which training was provided on rigorous evaluation methods. Each trial was conducted over the course of 1-2 years, with results informing the project design as it scaled up to new watersheds. For instance, based on these results a hotline to register farmers' feedback on extension visits was scaled up to the entire service area, country-wide, boosting attendance and demand for the service. Now that the irrigation infrastructure construction is completed in four of the watersheds, the LWH team is interested in testing operational strategies to secure higher sustainability of their investment. The influence of the proposed IE on policy will be secured through three main channels: (1) building ownership within the implementation team and line ministry, from permanent secretary down to lead farmer level; (2) ensuring that findings are incorporated in joint donors-GoR strategies, working with a coalition of actors in Rwanda and beyond; and (3) building international awareness of the findings.

First, policy influence is secured by building ownership of the program at all levels of government implementation and decision making, from farmers to minister level. As described above, this is done by including all levels in the conception of the IE design. As the results come out, all levels, from farmers to minister, have ownership of the findings and appropriate them to take decisions.Engagement at all levels are done through day-to-day engagement with the teams on the ground, as well as periodical missions during which dissemination events are organized and briefs are delivered to high-level ministry staff, up to Permanent Secretary and Minister.

Second, the research team is working closely with the WB Country Management Unit in Rwanda to build ownership of the activity and ensure its impact in the policy dialogue both at the country and sector levels. Brown-bag seminars are regularly held by the team at the CMU to ensure that the country office staff is aware of the work and learning coming out of this program, and that the IE work is aligned and informs to the Bank's agricultural strategy in Rwanda. Similar efforts are made to communicate research findings to other donors in Rwanda, including DFID, the Netherlands, and the EU.

Third, high-quality research papers based on this research will be disseminated in international policy and academic circles (e.g. UC Berkeley, WB, international conferences, etc), in the form of events, trainings, as well as international development conferences. Finally, the findings will be published in working paper series and submitted to peer-reviewed economics and field journals, thus reaching a wide audience of researchers and graduate students worldwide. All data will be made available online on the databank for IE, following the Bank's open data policy, influencing empirical work beyond this specific research effort.

# 3. Literature Review (E)

The proposed research project builds on several deep literatures in development economics: the effects of irrigation (for surveys see Hussain and Hanjra 2004 and Dayton-Johnson 2000); ; technology adoption and diffusion; and the role of different governance structures in achieving public good provision (e.g. Alesina, Baqir, and Easterly 2000; Galliani, Gertler, and Schargrodsky 2005; Glennerster, Miguel, and Rothenberg 2013).

We will be able to use weaker assumptions to identify the effects of irrigation than have typically been available. The credibility of our research design stems from both the technical characteristics of irrigation in Rwanda (hillside terraces) and from our early identification of the site for near guaranteed expansion of irrigation and commercial farming, allowing a true baseline.

The recent literature on technology adoption and diffusion suggest moving away from traditional demonstration plots or lead farmers, and taking advantage of peer-to-peer learning and learning-by-doing (e.g. Kondylis, Mueller, and Zhu 2014; BenYishay and Mobarak 2015; BenYishay, Jones, Kondylis and Mobarak 2015; Jones, Kondylis, Mobarak & Stein 2016). This study moves the literature forward by rigorously testing self-demonstration – farmers experimenting with a new technology themselves on a small scale – in lieu of traditional demonstration plots. In addition, by distributing mini-kits for high-value horticulture at different levels of farmer saturation by WUGs, we will contribute to the literature on technology diffusion and learning.

Our contribution to the governance and public goods provision literature includes the randomized design but is also benefited by the context: as we are able to carefully measure an important, homogeneous public good with nearby natural variation in the underlying governance structure across contiguous plots, we will be able to provide a more precise test than has typically been available. Indeed, There is significant variance in the number of members per water user group (mean 10, standard deviation 7.4), and we expect to see different effects of the intervention for groups of different sizes. Because the size of the blocks is largely caused by geography, we will use the slope gradient and distance to the bottom of the valley to instrument for the size of a Water User Group.

## 4. POLICY RELEVANCE

This research project has enormous and immediate policy relevance and can be expected to have a large policy impact in scaling up. The Rwandan government is midway through a multi-year project to complete about 7 hillside irrigation schemes with a potential for more. Given the expense of irrigation systems, the government is extremely concerned with both the cost-effectiveness and the sustainability of these investments. The research team is working with the government to produce rigorous evidence that will guide the scale up decisions, as well as strategies to improve the performance of irrigation schemes.

This project builds on an ongoing program of impact evaluation of Rwanda's Land Husbandry, Water Harvesting and Hillside Irrigation (LWH) Project. LWH, a flagship program of the Rwandan Ministry of Agriculture (MINAGRI), uses a modified watershed approach to introduce sustainable land husbandry measures for hillside agriculture on selected sites, and develops hillside irrigation for sub-sections of each site. The first generation of trials focused on the rural finance and agricultural extension components of the LWH project, as the physical infrastructure for the irrigation component of the project required significant construction time. Each trial was conducted over the course of 1-2 years, with results informing the project design as it scaled up to new watersheds. Now that the irrigation scheme construction is completed in three of the watersheds, the LWH team is interested in turning similar attention to the irrigation component. As the irrigation schemes were very costly to construct, MINAGRI is keen to rigorously measure their cost-effectiveness, and to maximize the impact of that investment by learning how to effectively implement contract farming schemes for high-value horticulture.

## 5. THEORY OF CHANGE (E)

The evaluation targets individuals whose plots are in or near three hillside irrigation schemes in Rwanda. This evaluation has two components. First, to evaluate the impact of access to irrigation on farmers, we will compare the outcomes of farmers whose plots are just inside the irrigation scheme to farmers whose plots are just outside the irrigation scheme. Second, we will evaluate the impact of different usage fee structures and adoption of high value crop varieties with two experiments – one which varies the usage fee structures farmers face, and another in which some farmers receive an agricultural minikit to experiment with high value horticultural crops.

To evaluate the impact of water usage fee subsidies, 5 possible fee structures for agricultural seasons 15B and 15C are randomized across WUGs – 50 RwF/are[5] and 50 RwF/are, 50 RwF/are and 200 RwF/are, 50 RwF/are and 400 RwF/are, 200 RwF/are and 200 RwF/are, and 200 RwF/are and 400 RwF/are. Fees are charged for usage, and all fees will increase to 400 RwF/are in 16A. In the second experiment, some farmers in the irrigation scheme are randomly assigned to receive an agricultural mini-kit for high value

[5] An are is the common unit of area measurement in Rwanda; there are 100 ares in a hectare. Farmers in the irrigated areas typically have a total of approximately 30 ares.

crops that depend on the irrigation water for production – either snow peas or bird's eye chilies, depending on the irrigation scheme. The intensity of treatment is randomized across WUGs.

Figure 3 presents a simplified theory of change behind the interventions to be evaluated, including its main components/inputs, activities, outputs, and the hypothesized causal chain to select outcomes of interest. The main assumption behind this theory of change is that farmers cannot afford the usage fees while cultivating traditional crops, but can while cultivating high value crops. However, adoption of high value crops requires learning, and farmers may avoid experimenting with adoption of high value crops if the gains from adoption are not salient. Additionally, use of the irrigation system is necessary in order to cultivate high value crops. At baseline, very few of the sampled farmers used any type of irrigation on any of their plots. The two graphs below show the low frequency of irrigated plots in the three study sites:

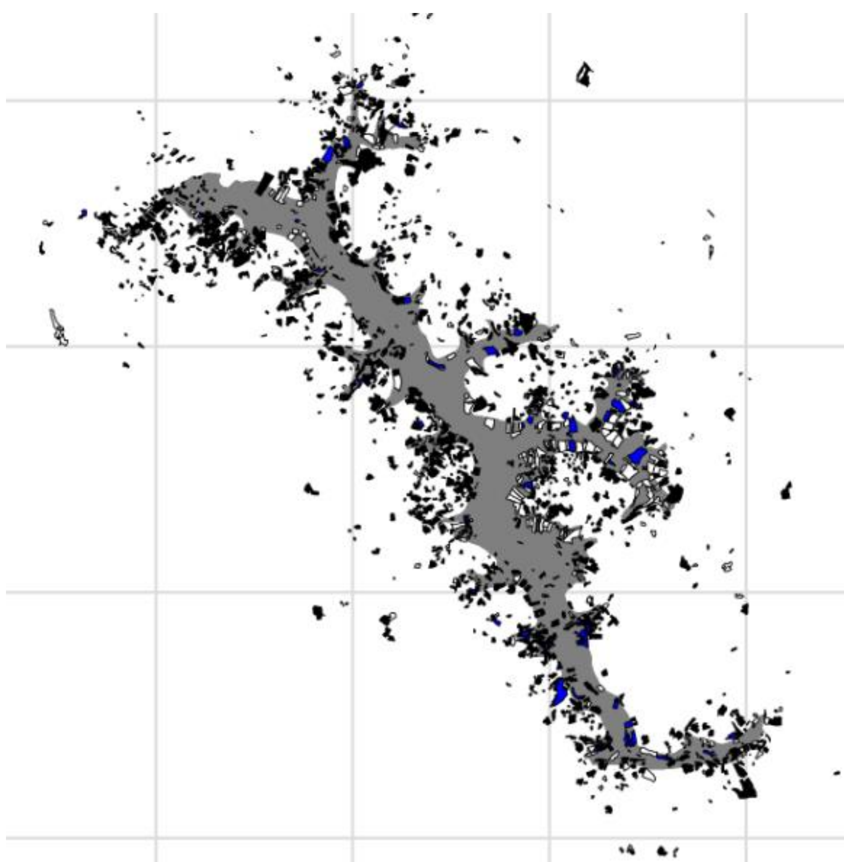

**FIGURE 1: IRRIGATED PLOTS IN NYANZA-23**

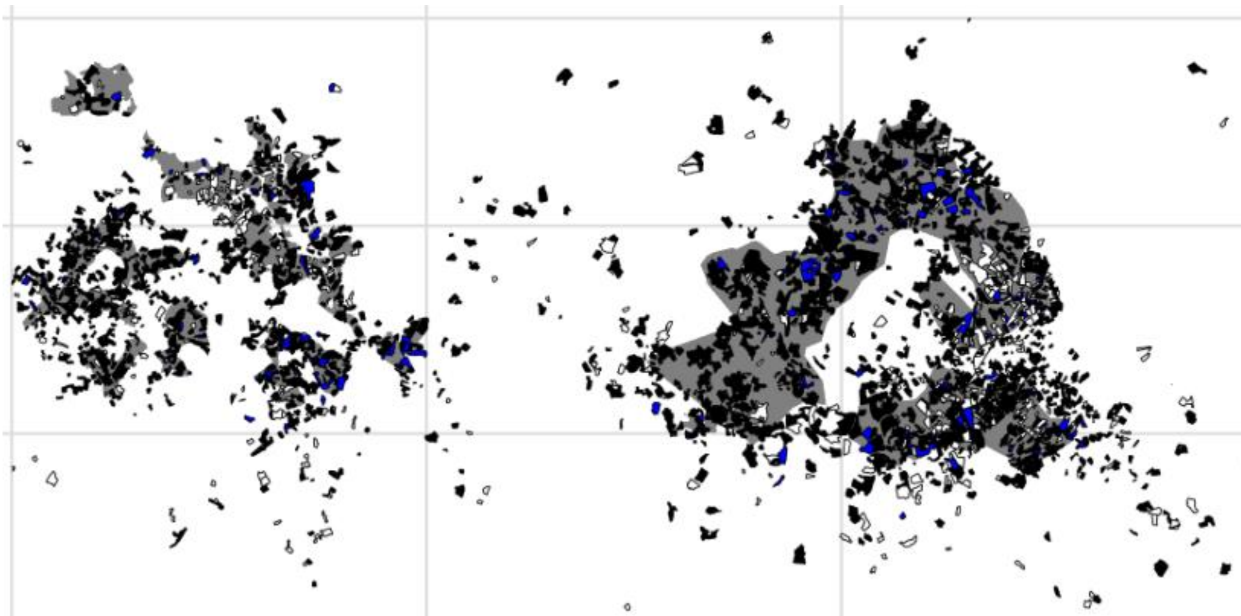

**FIGURE 2: IRRIGATED PLOTS IN KARONGI-12 & 13**

A virtuous cycle occurs when farmers begin to experiment with high value crops – productivities improve as farmers learn how to cultivate high value crops, they use the irrigation system because it is necessary for their cultivation, and they properly use and maintain the irrigation system because their production becomes dependent on it. Additionally, this constant use of the irrigation system allows LWH to collect enough fees to make the irrigation scheme sustainable. Progressively increasing fees makes the importance of adoption of high value crops salient, while mini-kits reduce the cost of experimentation with high value crops. All of this is only possible while the irrigation system is properly maintained and used, since the high value crops are more dependent on access to water than traditional crops. By targeting all of these barriers to adoption simultaneously, we can move households in the irrigation schemes into a new equilibrium where the irrigation infrastructure is actively used to cultivate high value crops year round, significantly increasing profits for these households.

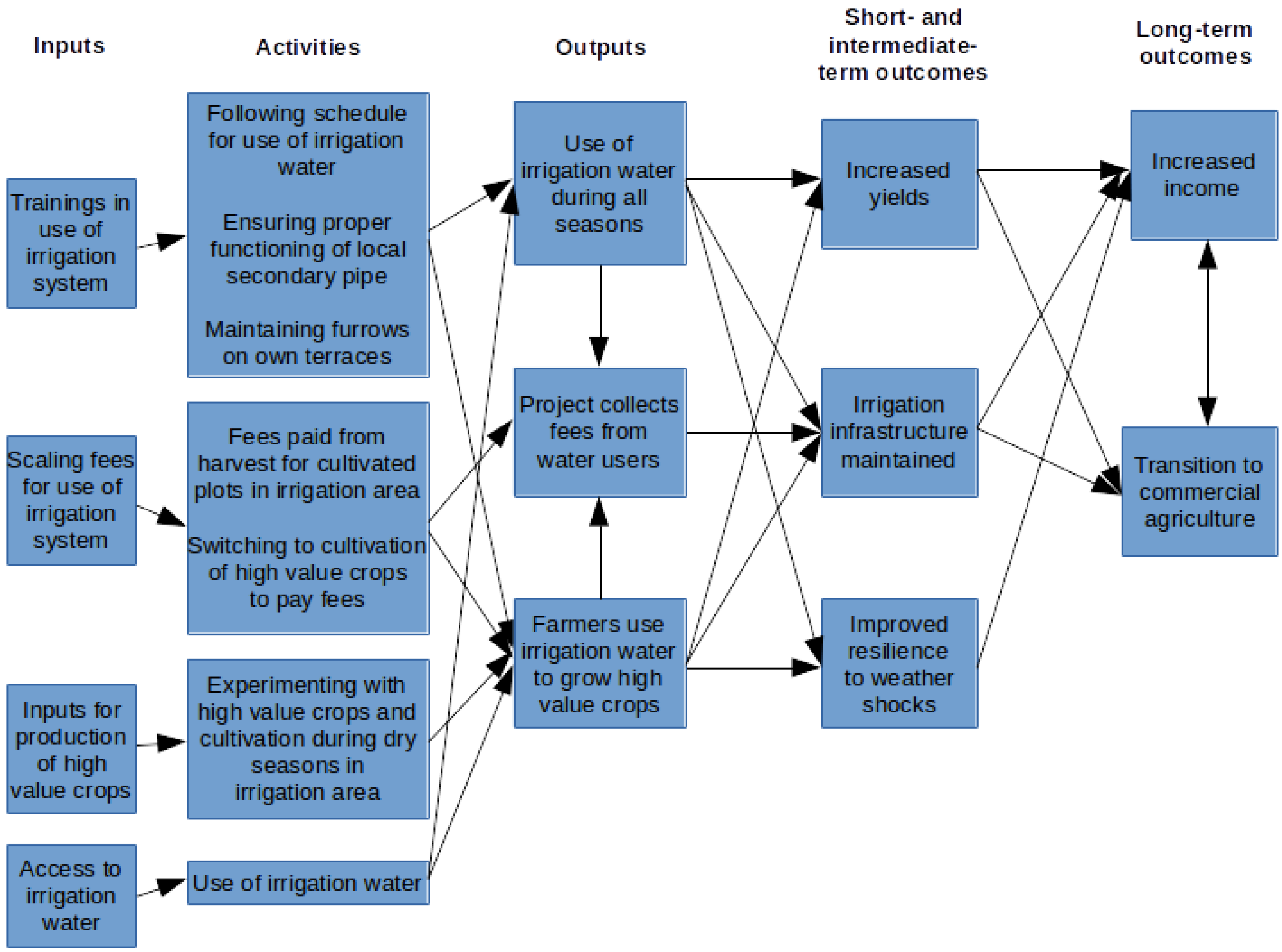


**FIGURE 3: THEORY OF CHANGE**

## 6. Hypotheses/Evaluation Questions (E,R)

There are four primary research questions.

1. What are the impacts of irrigation on smallholder welfare? Specifically, we will examine impacts of large-scale irrigation on yields, cropping and input choices, expenditures, labor supply and employment, land sales and rentals, migration, and whether those impacts differ by gender.

2. What is the impact of escalating irrigation fees on farmer behavior? In the long-run, farmers will have to pay substantial fees. Fees will outweigh benefits if farmers continue to produce low-value crops; therefore, for sustainability, farmers will have to either adopt high-value crops or reallocate land (through sales or rental). We hypothesize that a short window of subsidized fees will induce farmers to experiment with high-value crops.

3. Do self-demonstration kits encourage experimentation and long-run adoption? If so, how does this interact with water usage fees? We hypothesize that farmers who receive minikits will be more likely to experiment with high-value crops, and that effects will be larger when water usage fees are higher. Moreover, we hypothesize that farmers who experiment will be more likely to continue using the irrigated land when charged full water usage fees in the future.

4. Does the placement of a monitor within the irrigation scheme affect resource sharing? A key dimension of heterogeneity in irrigation schemes relates to plot location: people living near the main canal will have different incentives to maintain the secondary and tertiary canals than those who live far from it. They will also have different incentives to (over)use water. We will measure the impact of empowering a monitor within a WUG, and of imposing that the monitor cultivates a plot in the area most likely to be harmed by overuse of the resource.

## 7. Main Outcomes of Interest (E,R)

**TABLE 1: MAIN OUTCOMES OF INTEREST**

| Outcome Type | Outcome Name | Definition | Measurement Level |
|---|---|---|---|
| **Primary/Secondary** | | | |
| **Primary** | Gross Agricultural Yield | Total value of output per hectare | Agricultural plot |
| **Primary** | Net Agricultural Yield | Total value of output per hectare minus total value of inputs (including labor) per hectare | Agricultural plot |
| **Primary** | Expenditures | Household expenditures in the past month (frequent) and year (infrequent) | Household |
| **Secondary** | Adoption of high-value crops | Choice of crop(s) cultivated, per season | Agricultural plot |
| **Secondary** | Payment of water-usage fee | Amount paid as a proportion of the amount owed (given subsidy) | Agricultural plot |
| **Primary** | Primary employment | Primary source of employment, self-reported | Household member |
| **Primary** | Land sales and rentals | Land sales over the past 5 years; ownership status and decision to rent out or in by plot | Agricultural plot |
| **Primary** | Migration | Dummy for whether or not the HH member migrated for work during the reference period | Household member |
| **Primary** | Maintenance of irrigation scheme | Score based on a number of objective measures of level / quality of maintenance performed, directly observed through monitoring | Tertiary Valve |

# 8. Evaluation Design and Sampling Strategy (E,R)

## 8.1 Treatment and Control Groups

Experimental and quasi-experimental evidence on the impacts of irrigation schemes and commercial agriculture is limited in part because these schemes (and the investments of international firms) are too expensive to be randomized, in general. For overall effects, the same is true here: the irrigation network was derived based on physical characteristics of the hillside and water and not at random. Similarly, the international investors are working with the government to choose particular areas of land to be leased; while we will be able to document the criteria used in determining which areas would be leased we will not be able to take the leasing process as exogenous. We will, however, have the capability of intervening randomly in the governance structure of the maintenance. As a result, each research question will use a different method.

*The Impacts of Irrigation*

In the majority of the scheme, the main canal is new construction with the scheme. These canals were built along hillside contours following the water source and a smaller, older existing canal. If we focus on the newly constructed portions of the main canal, the location of the canal on the hillside was determined by the historical accident of altitude relative to a distant and unusable water source. This suggests that before construction, there is little reason to anticipate that the terraces just above the new canal would have been different from the terraces just below the new canal. Following construction, however, the terraces just below the new canal are irrigated where the terraces just above are not. This allows a spatial regression-discontinuity analysis as in Conley and Udry (2010); Goldstein and Udry (2009), and Magruder (2012, 2013).

To perform this analysis, our sampling strategy will oversample households living just above and just below the canal. As many households rent land along these terraces, we will be sure to sample both current operators and land owners for these samples. In the event of recent land sales, we will target land owners at the time of the irrigation development.

*How do escalating usage fees influence technology adoption?*

Cost-recovery via usage fees is a necessary feature for sustainable irrigation systems. The SPIU plans to offer farmers two choices: to cultivate, and pay usage fees, or to not cultivate. Profitable cultivation with these fees requires adoption of high value crops, and the SPIU recognizes that the sudden imposition of these fees could pose a challenge to farmers who may instead stop cultivating altogether. As a result, they are interested in finding the best way to phase in these fees to achieve high adoption.

Our experiment will randomly allocate subsidies to different farmers. Since learning may take more than one season for full results, we will randomize a path of subsidies over two seasons. Fees will be around 40,000 RWF/hectare-season (about $52 per hectare; the average farmer cultivates about 0.3

hectare within the scheme) when all costs are included; this level of fees will be collected from all cultivating plots. After discussing the eventual fee with farmers, they will take a lottery to pay according to one of four schedules:

| Option | 2016 Season C Fee (RWF/hectare) | 2017 Season A Fee (RWF/hectare) | 2017 Season B/C Fee (RWF/hectare) | Approximate Number Farmers |
|---|---|---|---|---|
| 1 | 0 | 0 | 40000 | 300 |
| 2 | 0 | 20000 | 40000 | 300 |
| 3 | 0 | 40000 | 40000 | 300 |
| 4 | 40000 | 40000 | 40000 | 800 |

By comparing farmers who receive different subsidies this season and next, we will test whether higher water usage fees discourage cultivation and/or encourage experimentation with higher value crops. Comparing across treatment groups yields tests of whether short term subsidies can induce experimentation, and whether there is an optimal schedule of subsidies.

If farmers choose not to cultivate in response to the fees, it may have implications for the maintenance and usability of the system. We will also measure and test whether farmers are maintaining the furrows necessary to draw irrigation water along the hillside benches, and whether they are completing local maintenance such as removing sediment from secondary and tertiary inlets.

*Can self-demonstration encourage experimentation? Are there information and coordination barriers to adoption?*

We will randomly distribute mini-kits for self-demonstration of high value crops at the farmer level. We will test whether receiving a mini-kit leads to contemporaneous adoption. Additionally, since farmers are selected at random to receive the mini-kits in season C only, differential re-adoption in later seasons will indicate that farmers learned through experimentation about the benefits of high value crops. Moreover, we will test whether experimentation with minikits interacts with subsidies to reveal whether fees affect the demand for experimentation. Finally, we will test whether any experimentation leads to changes in productive practice by examining whether farmers continue producing on their irrigated plots and are differentially less likely to sell or rent out their land after usage fees have risen to their maximum.

In addition, we expect important coordination issues to be resolved as we encourage more farmers to experiment and, therefore, adopt a new crop within a WUG. As crops have different watering schedules, and farmers along a particular terrace need to coordinate watering, there are complementarities to all growing the same crop on contiguous plots. This is mechanical: at the terrace level, water moves through ditches and furrows, so it is easiest to water all plots at once.

*Can monitors help to overcome collective action problems?*

In her seminal work on governing the commons, Ostrom lists empowering a monitor as a key intervention to induce collective action over the O&M of an irrigation system (Ostrom 1990). Further, theory (Bardhan 1984, Ostrom 1994) suggests that the farmers most exposed to pitfalls of collective action have the greatest incentive to maintain, and monitor the most closely. We design an RCT to test the optimal monitoring structure.

Working with irrigation engineers, we develop a monitoring worksheet and incentivize a WUG member to complete the worksheet on a weekly basis. The randomization will determine which member is empowered as a monitor. In 76 random WUGs, the WUG will elect a monitor from its members. In another 76 random WUGs, the WUG will elect a monitor, but the position will be reserved for a farmer who cultivates land close to the main canal. Counterintuitively, these are the farmers most exposed to collective action problems in our context, since they cannot draw water while farmers below them are using the water. The remaining 100 groups will continue to have an employee of LWH monitoring their water use.

Our primary indicators for this intervention are measures of irrigation performance: both objective measures of water flow taken from enumerator observations of field conditions and data from the worksheets themselves. If access to water improves in response to these interventions, we also expect impacts on the broader set of yield, production, and welfare indices described in the main evaluation.

## SAMPLE SIZE CALCULATIONS

The impact evaluation study consists of the households in the command and water catchment areas of the irrigation schemes. The vast majority of these individuals are small or medium-holder farmers who cultivate in LWH project sites.

For the study, researchers will sample households based on the location of their plots in relation to the primary irrigation canal and secondary irrigation canal. In this sampling approach, enumerators will proceed geographically along the canal and use the location of farmer plots to find the owners/renters of those plots to survey and conduct interviews with them. The sampling procedure is described in detail in section 9.1.

The impact evaluation study sample consists of the households in the LWH irrigation scheme areas, most are smallholder farmers. The household sample is constructed geographically based on plot location. We perform four sets of power calculations, one for each research question. For all power calculations, we assume 80% power, alpha of 5%, and two follow-up surveys. An appendix spreadsheet is available upon request for details on the calculations, including software package used and all assumptions.

*Impacts of Irrigation*

We conduct power calculations for an individual level randomization, using data from a baseline survey conducted in two sites in 2015. We use the assumption that within a narrow range of the cutoff, a discontinuity design behaves like a randomized control trial. Given the fixed location of the canal, there cannot be mis-assignment of plots to treatment or control. We calculate power based on the number of households within a 25m band of the primary canal (359 below; 331 above). The outcome of interest is agricultural production in RWF/hectare, which in our baseline has a mean of RWF12,761 and standard deviation of RWF24,233. Taking into account two rounds of planned follow-up surveys, we find an MDES between 0.13 and 0.18 (depending on the assumed level of autocorrelation). Extrapolating based on our estimate of the full sample size across all six sites, we estimate the final MDES to be between 0.08 and 0.11 standard deviations.

*Water Usage Fee*

The water usage fee subsidy will be randomized at the farmer level. The 1700 farmers will be divided among 3 treatment arms and a control: each treatment group will have 300 farmers, and the control group 800. The outcome of interest is again agricultural production; the mean and standard deviation are the same as reported above. We conduct two types of power calculations: first, comparing one treatment arm to another (e.g. T1 v T2) and second, comparing one treatment arm to the control (e.g. T1 v C). We find an MDES between 0.12 and 0.17 standard deviations for the test of one treatment arm against the control group. We find an MDES between 0.14 and 0.20 for the test of one treatment arm against another treatment arm.

*Mini Kits for Self-Demonstration*

The mini-kits will be randomized at the farmer level. The 1700 farmers will be divided into 2 treatment arms: 850 will receive a mini-kit and 850 will not. The outcome of interest is again agricultural production; the mean and standard deviation are the same as reported above. We find an MDES between 0.08 and 0.12 standard deviations.

*Monitoring*

The randomization for the monitoring intervention will be at the Water User Group (WUG) level. There are 252 WUGs. Those are divided into two treatment arms and one control arm. Each treatment arm has 76 groups, the control has 100 groups. For these power calculations, we use group-level data from a study of rural savings groups among the same population in 2013. From that survey, intracluster correlation for our outcome of interest (agricultural yields) was 0.05. To be conservative, we also estimate with a higher *icc* of 0.15. We find a MDES of between 0.09 and 0.18 standard deviations, depending on the level of *icc* (0.05 - 0.15).

# 9. DATA COLLECTION (E,R)

## 9.1 QUANTITATIVE INSTRUMENTS

The primary source of data will be household surveys with detailed agricultural modules.

*Household Survey Sample Selection*

For two of the sites that will be used for the spatial regression discontinuity analysis (K12 and N23), we broke the site up into 3 areas – Command Area buffer (BCA), Command Area Catchment buffer (BCAC), and Command Area terraces (TCA). BCA is the area inside of the Command Area (CA) within 50m of the boundary of the CA. BCAC is the area outside of the CA within 50m of the boundary of the CA. TCA is the terraced farmland that is in the CA, but more than 50m from the boundary of the CA. The third site will be used for the within-CA experimental designs only, and as a result we focused our sampling in one area – the Command Area terraces (TCA).

We constructed our household sampling by dropping a uniform grid of points across the full site at 2 meter resolution, and then sampling particular points within the grid. After each point was sampled, we excluded any points within 10m of that that point (to keep from selecting multiple points too close together). The number of points listed in each area was:

**TABLE 2: DISTRIBUTION OF SAMPLED POINTS**

| Site | BCA | BCAC | TCA |
|---|---|---|---|
| **N23** | 1260 | 1260 | 840 |
| **K12** | 720 | 720 | 648 |
| **K13** | -- | -- | 1344 |

Enumerators were then given GPS devices with the locations of the points, and sent to each point, with a key informant (often the village leader). For each point, they were asked to identify whether or not the point was on cultivable land (this was to discard forest, swamps, thick bushes, bodies of water, or other terrain which would make cultivation impossible). They were asked to record, for points in cultivable land, in SurveyCTO, the following:

1. The name of the point visited (which was displayed on the GPS)
2. The name of the cultivator, the location of their residence, and their phone number
3. A description of the plot, detailed enough that the cultivator would be able to identify the exact plot described

Additionally, they were asked to save their GPS track at the end of the day, as a way of tracking the number of hours they spent checking points and to verify that they visited each point.

We used the data from this listing to construct a roster of all of the unique names of cultivators, clustering points together when the names seemed identical. This roster (which contained the name of the individual, their village and phone number, the descriptions of the plots, and the villages in which the plots were located (identified using village shapefiles), and were organized by village) were then used to contact village leaders and verify that the listed individuals in fact existed. Multiple follow-ups were sometimes needed when village leaders suggested that one individual lived in a different village, or multiple village leaders said an individual lived in their village.

Finally, a sample plot was selected for each verified 1,879 household. To select this sample plot, one point was randomly selected for each household. The probability of selecting a particular point was weighted – a weight of 1 was assigned to points in the BCA and BCAC, and a different weight was assigned for points in the TCA, to balance the number of sample plots in these areas. The weights used are displayed in the table below.

**TABLE 3: DISTRIBUTION OF SAMPLE PLOTS**

| Site | Sampled Households | Area | Sampling Weight | Number of Sample Plots |
|---|---|---|---|---|
| **N23** | 877 | BCA | 1 | 323 |
| | | BCAC | 1 | 362 |
| | | TCA | 2 | 192 |
| **K12** | 593 | BCA | 1 | 185 |
| | | BCAC | 1 | 211 |
| | | TCA | 0.25 | 197 |
| **K13** | 409 | TCA | -- | 409 |

*Household Survey Description*

The questionnaire will be structured such that agricultural data is collected plot-by-plot, for each agricultural season. The plots will be identified with plot descriptions (from the farmer) and geo-tags, in order to construct a plot-level panel. The household surveys will be conducted annually in October - November, and include modules for each of the three agricultural seasons: Season A (September – February), Season B (March – June) and Season C (July – August).

The Baseline Household Survey includes the following modules:

**TABLE 4: HOUSEHOLD SURVEY MODULES**

| Module | Content | Level |
|---|---|---|
| **Identification** | Identification of enumerator and respondent; informed consent | Household |

| | | |
|---|---|---|
| **Household Roster** | Sex, age, education, employment, migration | Household member |
| **Plot Roster** | Plot identification, ownership status, cultivation by season, past land transactions | Plot |
| **Crop Production** | Crops produced (cash vs. subsistence), amount of seed, amount harvested, amount consume, amount sold, amount lost to spoilage | Crop (by Plot and by Season) |
| **Use of Irrigation** | Use of irrigation, source, method, frequency | Sample plot |
| **Farm Labor** | Use of household and hired labor for agriculture | By plot and by season |
| **Agricultural Inputs** | Quantity, source, and amount spent on all organic and chemical inputs | By plot and by season |
| **Irrigation (general)** | Experience with irrigation, knowledge of maintenance, participation in maintenance activities, participation in trainings | Household |
| **Extension** | Interaction with public, private, and not-for-profit sources of agricultural extension | Household, by season |
| **Housing** | Construction material of walls and floors, source of drinking water, sanitation | Household |
| **Farmer Group** | Participation in farmer group, cooperative, water user group, and water user association | Household |
| **Social Networks** | Interactions, transfers to/from, and loans to/from, community work with neighbors and members of water user groups | |
| **Income & Expenditures** | Disaggregated income over the past 1 year; access to market; disaggregated expenditures over the past 1 month (frequent categories like communications and transportation); disaggregated expenditures over the past 1 year (infrequent categories like school fees and health insurance) | Household |
| **Animals & Assets** | Total owned; sales and purchases over the past one year for: cows, goats, pigs, poultry, radios, mobile phones, furniture, bicycles, hoes and shovels, and other agricultural equipment | Household |
| **Rural Finance** | Bank accounts; formal savings; contributions to ROSCAs | Household |
| **Credit** | Number of loans requested; amount and purpose of loans received | Household |
| **Shocks** | Crop failure in the past year associated with drought; amount of loss and means of coping | Household, by season |
| **Future Expectations** | Future expectations and perceptions of agricultural production, household wellbeing, impacts of irrigation, asset purchases, participation in contract farming | Household |
| **Food Security** | Food Consumption Score (developed by World Food Program) | Household |

## 9.2 Management of Data Quality

The research team has ample experience managing the collection of household surveys. Our field survey partner is the Rwanda office of Innovations for Poverty Action, an internationally recognized research organization that has substantial experience partnering with academics for research purposes and following best practices for data collection.

## 9.3 Ethical Issues

The research team applied for and received ethical clearance from the Human Subjects Committee for Innovations for Poverty Action IRB and the Rwanda National Ethics Committee. We also applied for and received a survey visa from the Rwandan National Institute of Statistics for the baseline data collection.

## 9.4 Qualitative Instruments

Qualitative data collection was conducted to inform the questionnaire design, but the research team does not plan to use qualitative data during the analysis.

## 9.5 IE Implementation Monitoring System (R)

Monitoring information will come from MINAGRI's Special Project Implementation Unit, which will manage and implement all project interventions, and Innovations for Poverty Action (IPA) – Rwanda, which will assist with data collection. The SPIU will train all farmers on the irrigation system and water usage fees through a Training of Trainers (ToT) model, announce the subsidies for water usage fees, and distribute the mini-kits. MINAGRI staff will collect monitoring data during and in support of each of these interventions, such as: training attendance, plot areas (necessary for their water usage fee calculations), participation in the irrigation system's Water User Groups (WUG), and payment of water usage fees.

Innovations for Poverty Action partners will monitor the SPIU's Training of Trainers (ToT) and audit the trainings to ensure randomization is adhered to in the field. IPA enumerators will monitor usage of the irrigation scheme and maintenance issues through a monitoring data collection exercise to be collected once per season, midway through the season (after plants have emerged and before harvest). Enumerators will walk down each secondary pipe, collecting basic data at each tertiary valve: cultivation (yes/no and type of crop), furrows (yes/no and whether correctly dug), and maintenance (e.g. is the flexible pipe available and in good condition?).

The research team will follow the intervention closely through the presence of a full-time field coordinator based in Kigali, who will be in direct contact with these two teams and organizing regular meetings to review the quality and consistency of fee and land data collected.

# 10. Data Processing and Analysis

## 10.1 Data Coding, Entry, and Editing (E)

Our household survey data will be collected using Computer Assisted Personal Interview technology. We programmed our survey instrument in ODK software. In addition, we programmed automated consistency checks over the course of the interview, and enumerators cannot submit their data to the SurveyCTO server unless all checks and data have been entered. Our enumerators are held accountable for meeting a certain number of surveys per day. We achieve that by downloading a day's survey data every evening, verifying the observation against the field plans and supervisors' logbooks, and running routine pre-programmed consistency checks a large number of variables across all modules. When a survey is missing, the enumerator is asked to revisit that household and complete the interview. We also request that a revisit be performed when our consistency checks raise over 3 general flags, or any "critical" flag (e.g., number of plots). Finally, consistency checks are performed that compare main survey responses with the subset of questions used in the back-checks, and revisits (phone or in person) are performed when discrepancies of over 10% are observed on key outcomes, or on a large number of responses. Any survey using CAPI technology implies that we do not need to perform any data entry beyond the interview.

## 10.2 Model Specification for Quantitative Data Analysis

There are two different statistical models which will be used for analysis.

For the usage fee subsidies and saturation intensity, the intervention is randomized at the block level. We can therefore regress for block *b*

$Y_b = \beta T_b + \delta X_b + \epsilon_b$

Where $T_b$ is an indicator for treatment status and $X_b$ are covariates and be guaranteed an unbiased estimate of $\beta$. For observations which vary at the individual level, we will cluster at the level of the block. We also will test robustness of errors to potential spatial correlations between nearby blocks using Conley (1999) clusters. We will additionally test for heterogeneity in treatment effects depending on characteristics of the block, including inequality and number of farmers.

For the effects of receiving the mini-kits themselves, they are randomized at the individual level. For individual *i* in block *b,* we can therefore regress

$$Y_{ib} = \beta T_{ib} + \delta X_{ib} + \alpha_b + \epsilon_b$$

Since the saturation varies at the block level, errors will be clustered at the block level. We will test for productive and learning spillovers by examining the effects of treatment on others in the same block, and on plot neighbors and connected individuals.

For overall impacts, we will complete a spatial regression discontinuity design following Conley and Udry (2010), Goldstein and Udry (2009), and Magruder (2012). This approach suggests that for plots sufficiently close together, placement on one side of the boundary or the other is close to random. More specifically, for each individual *i* with plot *p*, we define *R(p)* to be the set of plots within radius *R* of plot p. Suppose there are $n_{R(p)}$ plots in set *R(p).* The spatial fixed effects used in this approach are specific to the plot and thus cannot be represented by a block diagonal set of binary variables as conventional fixed effects can; however the within estimator is still achievable.

$$(Y_{ip} - \frac{1}{n_{R(p)}} \sum_{p' \in R(p)} Y_{ip'}) = \beta(T_{ip} - \frac{1}{n_{R(p)}} \sum_{p' \in R(p)} T_{ip'}) + (X_{ip} - \frac{1}{n_{R(p)}} \sum_{p' \in R(p)} X_{ip'}) + u_{ip}$$

For time-varying variables, we will complement this analysis by including plot-level fixed effects to use the difference in spatial differences estimator suggested in Magruder (2013). In all cases, errors will be spatially clustered following Conley (1999).

We will complement this analysis with a more traditional distance to the border estimation which ignores the two-dimensional nature of space but does allow a more conventional graphical representation. In our context, where control group areas are not evenly dispersed along the boundary, this approach has some severe limitations which motivates the preference for the spatial fixed effects approach.

Both of these approaches estimate LATE. We are collecting extremely rich baseline data on farm production and profits, income, and demographic variables which will be used to test balance and evaluate the performance of the spatial RD approach. In addition, we will use multi-season, plot-level data to explore inter-temporal and spatial reallocations of risk and production inputs.

The primary source of bias that could affect our estimation would happen if farmers endogenously sort in or out of particular contract or irrigation regimes. To test for this, we are following a panel of plots, and collecting retrospective data. We will know whether there was immediate sorting prior to the completion of irrigation, or subsequent sorting that takes place after the water starts flowing through land sales or rentals. In all cases, we will follow the plot's owners who may sort into other local areas. We will take steps to guarantee low attrition, including collecting multiple contact numbers and are well-enough integrated into the community to be encouraged of a high success rate in finding individuals who move.

We plan to register this IE in the AEA trial registry.

## 11. STUDY LIMITATIONS AND RISKS (E)

For the mini-kit and subsidy studies, risks to internal validity are extremely limited as the interventions are randomized. For the other overall impact of irrigation, there is a possibility that farmers have endogenously sorted on either side of the boundary. As in the previous section, we will examine retrospective data and track farmers to test for whether sorting is taking place in response to the irrigation infrastructure or contract environment. We anticipate trying to conduct analysis for most variables on a sample of farmers who were working on either side of the boundary just before changes in the regime, and track those farmers over time if possible which mitigates this concern. We note that if we do find evidence of sorting, sorting will be a primary outcome of interest for this IE.

Other threats to internal validity include the possibility that land is different in a key way just above the main canal as just below. One potential possibility is that slopes are different, though the engineering specifications of the main canal limit the ability of the engineers to respond to highly local variation in slope. Nonetheless, we will test for differences in baseline characteristics of farmers and of plots, including crop choices, slope, profits, demographics, etc.

There are potentially more serious issues of external validity. Our sample is based on only three irrigation sites in Rwanda. Since variation is at the individual or block level, we can still achieve statistical power in our estimation framework. However, there are not enough sites to guarantee that results would be similar at other sites which may be built. This problem seems likely generic to infrastructure interventions. On the other hand, close work with the SPIU and MINAGRI interest in results suggest that implications from our evaluation will have strong impact on policy, and there are several additional irrigation sites expected to come online over the next several years in Rwanda for which these results will be strongly informative.

# 12. IE Management (E,R)

## 12.1 Evaluation Team and Main Counterparts

**TABLE 5: IE TEAM AND COUNTERPARTS**

| Name | Role | Organization/Unit |
|---|---|---|
| Jeremy Magruder<br>Florence Kondylis<br>Maria Jones<br>John Loeser | PI<br>IE TTL, PI<br>Co-PI<br>Co-PI | University of California - Berkeley<br>DECIE<br>DECIE<br>University of California - Berkeley |
| Anna Kasimatis<br>Christophe Ndahimana | Field Coordinator<br>Field Coordinator | DECIE<br>Innovations for Poverty Action |
| Kevin Crockford | LWH TTL | World Bank |
| Esdras Byiringiro | Project Coordinator | MINAGRI |
| Innocent Musabyimana | Permanent Secretary | MINAGRI |

## 12.2 Work Plan and Deliverables

**TABLE 6: MILESTONES, DELIVERABLES & TIMELINE**

| Milestones | Deliverables | Completion Date |
|---|---|---|
| Peer-reviewed Concept Note | Methodology note | February 2016 |
| Data collection plan and pilot | TORs<br>Questionnaires | June-August 2015 |
| Data collection (Baseline) | Cleaned data<br>Dictionaries | September – November 2015 |
| First data analysis | Presentation<br>Data file<br>Do files<br>Baseline report | June 2016 |
| Implementation of intervention aligned to evaluation | Rollout plan<br>Monitoring reports verifying treatment and control status | February – August 2016 |
| Follow-up data collection plan | TORs<br>Questionnaire | June - August 2016 |
| Data collection (Follow-up) | Cleaned data<br>Dictionaries | September – November 2016 |

| | | |
|---|---|---|
| Endline data collection plan | TORs<br>Questionnaire | June - August 2017 |
| Endline Data collection | Cleaned data<br>Dictionaries | September – November 2017 |
| Final report and policy notes | Technical note<br>Policy note<br>Data file<br>Do files | June 2018 |
| Dissemination of findings | Presentations | December 2018 |

## 13. Plan for Using Data and Evidence from the Study

The direct audience for this IE program and its outputs consists of the MINAGRI team, the Bank operations team, and all the Donors involved with the LWH program including USAID and GAFSP.

Beyond the direct stakeholders, the research will be of interest to the wider community of policymakers in Africa, aid agencies and academic economists. The results will be disseminated via peer-reviewed journals.

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## ACRONYMS

CA: Command Area

CAC: Command Area Catchment

GoR: Government of Rwanda

IE: Impact Evaluation

LWH: Land Husbandry, Water Harvesting and Hillside Irrigation Project

MINAGRI: Rwandan Ministry of Agriculture

O&M: Operations and Maintenance

RCT: randomized controlled trial

SPIU: MINAGRI's Special Project Implementation Unit

SPRD: Spatial Regression Discontinuity Analysis

SWAP: Sector Wide APpproach

WUG: water user group