Highlights

Pumps, Prosperity and Household Power: Experimental Evidence on Irrigation Pumps and Smallholder Farmers in Kenya[⋆]

Julian Dyer, Jeremy Shapiro

- Irrigation pumps increase net farm income by 13% of control mean.
- This effect comes primarily by extending the agricultural season.
- Giving agricultural assets to women improves their empowerment in the household.
- Suggestive evidence that income mechanism drives food security and psychological wellbeing
- Suggestive evidence that asset transfer drives women empowerment.

Pumps, Prosperity and Household Power: Experimental Evidence on Irrigation Pumps and Smallholder Farmers in Kenya

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Abstract

Irrigation is a potentially effective technology to improve agricultural incomes in Sub-Saharan Africa, and hand powered irrigation pumps have received significant interest and investment as a solution appropriate to small-scale farmers in this context. This paper describes the results of an RCT impact evaluation of household irrigation pumps in Kenya, where we randomly allocated free pumps to the female head of household via public lotteries. After two years farmers are still making significant use of their pumps and allocating increased time to irrigated agriculture. We find that pumps increase net farm revenue by approximately 13% of the control mean, and pay for themselves within three years. In addition, we find that farmers with irrigation pumps spent less time on off-farm economic activity. Finally, we find that female decisionmaking power increased and domestic violence decreased among treatment households.

Keywords: irrigation, agriculture, women empowerment

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1. Introduction

Despite the significant potential benefits of irrigation for households currently practising rainfed agriculture (Jones et al., 2022; Dillon, 2011) only four percent of African farmers currently use irrigation in agricultural production (Burney et al., 2013) and the share of land equipped for irrigation in Africa is about one-fifth the global rate (Suri and Udry, 2022). This is in part due to significant constraints to implementing irrigation in Sub-Saharan Africa (You et al., 2010) including issues of management that arise with common-pool irrigation systems (Christian et al., 2022)[1] and population density that is too low for irrigation infrastructure. Understanding the impact of scaled-down irrigation technology that avoids these constraints has been identified as a pressing question for the future of agricultural development in Africa (Suri and Udry, 2022). One potentially effective solution, appropriate to the Sub-Saharan African context, is manually powered irrigation pumps suitable for individual farming households, though little evidence exists on their profitability and how they impact household dynamics.

In this project we provide experimental evidence of the impact of small-scale irrigation pumps on farm profits and estimate the returns to this investment and explore additional non-economic benefits. We conducted a randomized controlled trial across three counties in Kenya, where irrigation pumps (costing approximately 100 USD or 10,000 Kenya Shillings at the time)[2] were given to randomly selected farmers for free. All pumps were allocated to the female head of household, making this a joint intervention intended to both improve agricultural income and shift household decisionmaking power towards women. Data on production, time use, input spending, marketing as well as gendered decisionmaking in the household and incidents of domestic violence were collected prior to pump distribution and at endline after two full years of pump ownership.

We explore the various mechanisms by which irrigation influences agricultural production. One mechanism is that irrigation allows farmers to expand their irrigated production to more marginal plots or into more marginal seasons. Irrigation may also influence the intensive margin of agricultural pro-

[1]See Haseeb (2020) for an example of conflict as a similar challenge to implementing irrigation in Pakistan.

[2]Pumps like this are now listed as costing less, approximately 70 USD: https://www.engineeringforchange.org/solutions/product/moneymaker-hip-pump/

duction in a number of ways. If irrigation pumps are especially effective for particular crops, the share of land allocated to different crops may be another impact of irrigation pumps. Similarly, if irrigation pumps directly influence the returns to other inputs or releases labour that can be reallocated to other agricultural work, another effect may be to increase intensity of input spending. Finally, if irrigation pumps allows farmers to counter negative rainfall shocks, then productivity may increase for a given crop independently of changes to input spending or time use.

We find evidence for a strong effect on agricultural income driven primarily by the extensive margin of agricultural production. We find significant expansion of the number of non-rainfed irrigated crops grown and land cultivated under irrigation. The intervention of giving irrigation pumps to farmers generated, on average, approximately 4,500 Kenya Shillings in additional annual net farm income two years later. On aggregate, total spending on inputs and total time spent working in agriculture increased for treated farmers, but the impacts on input spending and time spent in agriculture per hectare were negative and mostly insignificant across both rainfed seasons and irrigated crops. Finally, we find insignificant effects on the value of agricultural output per cultivated hectare. We also find evidence that treated households earn less from nonfarm economic activity. This project contributes to a growing literature on the benefits of irrigation for improving incomes of smallholder farmers. (Jones et al., 2022; Duflo and Pande, 2007) Existing work mostly focuses on the larger-scale irrigation projects, and Jones et al. (2022) finds evidence of factor market failures and significant substitution of labour and inputs away from non-irrigated crops, which we do not find with smaller-scale irrigation technology. This is similar to Emerick et al. (2016) who look at the introduction of agricultural technology in the form of downside risk reducing seeds, and find that a large amount of the gains of adoption of this technology is due to crowding in other agricultural investments. In this context irrigation does, however, act differently in that it acts through the extensive margin rather than increasing intensity of inputs. These results suggest irrigation pumps act on the extensive margin, enabling more marginal cultivation, and shifting resources from non-agricultural economic activity.

In addition to the effect on agricultural income, we explore non-economic impacts of the irrigation pumps. First, we find that the intervention significantly improved psychological wellbeing, with treated households experiencing reduced depression and improved self-esteem, measured using a number of standard psychometric survey modules. We find that women in treated households experience greater decisionmaking power within the household (including over non-agricultural decisions) and experience fewer incidents of domestic violence. In addition, we find a shift in attitudes towards domestic decisionmaking and domestic violence consistent with greater empowerment of women.

One feature of this intervention was that the irrigation pumps were allocated to the primary woman in the household. As our results on agricultural production show this is an important economic asset, this change to gendered household asset ownership may impact household power and female empowerment. The design of the bundled intervention, however, does not separate this mechanism from the agricultural income effect. We therefore use heterogeneity analysis to provide suggestive evidence on mechanisms. We find that the intervention impact on net farm income, food security, and psychological wellbeing is driven primarily by households where women were already participating heavily in agriculture. We find no such heterogeneous effect for empowerment outcomes. The fact that households having a larger impact on net farm income also have larger effects on food security and psychological wellbeing suggests that agricultural income is the mechanism driving these outcomes. That households with a larger income effect do not have a larger effect on women empowerment suggests that asset transfer is the mechanism driving empowerment. This is similar to the bidirectional relationship in the broader literature on economic development and women empowerment (Duflo, 2012), though the effect on women empowerment seems to be driven more by control of household assets than by income. This suggests the feedback effects from development to empowerment may take longer to realize as they require women to accumulate assets. We find evidence that women maintain control over the pump granted to them, suggesting that their property rights over this asset are stronger than over land where weaker property rights for women leads to inefficiencies (Goldstein and Udry, 2008; Agyei-Holmes et al., 2020). We also find evidence consistent with the literature that technology adoption can impact women empowerment (Alesina et al., 2013) but here we cannot disentangle whether this is due to the allocation of the pumps to women, or due to the technology being usable regardless of gender, or whether increased agricultural income would have this effect regardless of the allocation. Together, this is evidence that the intervention led to significant improvements in female empowerment.

The increase in net revenue from irrigated crops suggests that the cost of the irrigation pump, at 10,000 Kenya shillings, is more than paid for in three years.[3] Using evidence from a long-run evaluation of similar irrigation pumps, we find that these pumps are still heavily in use more than six years after purchase, suggesting that the lifetime returns to this type of asset are significant.

In this paper we provide experimental evidence on the effectiveness of small-scale irrigation pumps for smallholder farmers, and find that they have a significant positive effect on agricultural income. This effect seems to operate primarily through the extensive margin, increasing land cultivated under irrigation, labour inputs and spending on inputs as well as reduced income from nonfarm economic activity. We find, however, little evidence of changes on other margins of agricultural production. These benefits were accomplished with a light-touch intervention that is easily scaled, requires limited capacity to implement and avoids many of the issues involved with implementing and managing large-scale irrigation projects. Together with the non-economic benefits for psychological wellbeing and female empowerment, this is evidence that small-scale irrigation pumps are an effective intervention for reducing poverty and improving wellbeing among smallholding farming households in Sub-Saharan Africa.

2. Context

This experiment took place across three different counties – Machakos, Kiambu and Embu – in central Kenya near to Nairobi with a range of agroecological conditions and agricultural practices.[4] In all regions, farming is primarily a rainfed activity with two main agricultural seasons, the long rains season and the short rains season, with a dry season where for three to four months no rainfed agriculture is possible. In addition to rainfed agriculture, at baseline approximately a third of farmers cultivated crops under irrigation on much smaller amounts of land. The dominant crops produced under rainfed agriculture are staple crops maize, beans, and cowpeas. Under irrigation, farmers tend to grow more fruits and vegetables, with kale,

[3]This may be a conservative estimate, as pumps like this are now listed as costing less, approximately 70 USD: https://www.engineeringforchange.org/solutions/product/moneymaker-hip-pump/

[4]See Figure E.3 for a map of the locations involved in the experiment.

tomatoes, and spinach being the most common crops.[5] Water for irrigation is overwhelmingly drawn from common pool sources, such as rivers or public boreholes, rather than paid sources of water for irrigation, as shown in Figure 1a. Drinking water is also overwhelmingly drawn from rivers and open wells, as shown in Figure 1b. We report summary statistics on the agricultural characteristics and demographics of households in Table 1. The households involved in this experiment are small-scale farmers, farming at baseline on average one and a half hectares in the long rains (the major rainfed season), and less than one half an acre under irrigation. The average farmer grows between two and three crops in the rainfed seasons. Labour for agricultural production mostly comes from within the household, with some hiring of external labour. The distribution of household labour across different agricultural tasks (such as land preparation, application of fertilizer, harvesting, etc.) is relatively similar by gender.[6] Women exercise the greatest decisionmaking power over household tasks, where nearly 90% of women were involved in decisionmaking. Approximately 80% of women had joint or sole decisionmaking power over plot management.[7] Women also were heavily involved in agriculture, and in approximately 38% of households women provided more time on rainfed crops than men in the household.

In the sample of households in this experiment, only one in five has a female head of household and approximately one third of household heads have at least a secondary education. Households include on average five members, with two adults and three children. The context is fairly rural, with households being on average three kilometers from the nearest paved road and eight kilometers from the nearest town.

3. Experiment Design

3.1. Sampling Strategy & Randomization

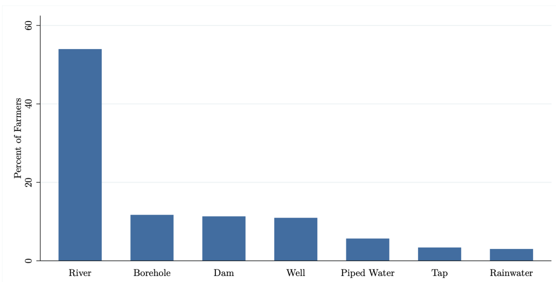
The participants recruited for this study were respondents who were at least eighteen years old and living in areas where local partner ChildFund

[5]For further detail, see Table C.8 where we show the frequency of crop production at baseline across the three types of crop production.

[6]See Table C.9 for more detailed summary statistics on the breakdown of agricultural labour across types of agricultural production and by gender.

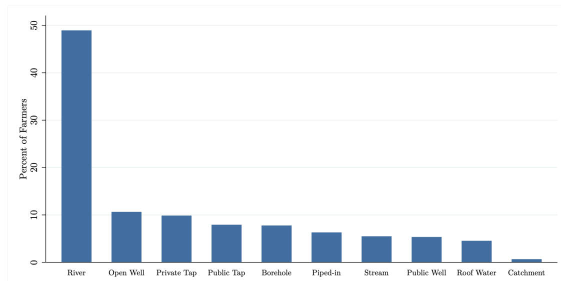
[7]See Figure E.4 for more detail on women's decisionmaking by category.

Figure 1: Household Water Sources



(a) Sources of Irrigation Water

Description: This figure shows the sources of water for irrigation.
Data Source: Baseline survey.



(b) Sources of Drinking Water

Description: This figure shows the sources used by the household for drinking water.
Data Source: Baseline survey.

was operating. Participant households were selected among households identified as poor or needy by ChildFund, who had some access to farmland (i.e, excluding landless households) and who have some access to a water source, making irrigation feasible. A total of one thousand households were recruited for this study.

In this project we implemented a randomized controlled trial (RCT) in order to evaluate the impact of irrigation pumps. Five hundred households, half the sample, were chosen to receive the manual-powered irrigation pump free of charge. This stratified randomization was conducted by public lottery within each county with respondents drawing either red or green cards from a bin at public meetings.

3.2. Intervention

The intervention in this experiment is relatively straightforward. Manual irrigation pumps including hosepipes, with a purchase price of approximately 100 USD, or 10,000 Kenya Shillings, were given to treatment households after information sessions in which both treatment and control received the same information about the capability of, and how to use and maintain, the irrigation pumps. This ease of installation and setup, requiring only a short introductory training session, is one advantage of small, manually powered irrigation pumps. As these pumps weight approximately ten pounds, they are fairly mobile. This type of pump can typically irrigate up to one and a quarter acres of land per day, spraying up to ten gallons of water per minute. These irrigation pumps can draw water from water sources with a depth of up to twenty-three feet, and can pump water a further twenty-three feet above this level for a maximum pumping height of forty-six feet. The maximum water pushing distance along flat ground from water source to target is approximately six hundred and fifty feet.[8] The pumps used in this intervention are hip pumps, meaning that they are manually driven with one person operating the pump itself, and another person holding the outlet hosepipe to direct the water flow. The pump consists of a single upright cylinder with a handle depressed by the user to spray water. To make it easier to use, the cylinder is attached to a foot plate by a rotating joint, allowing the user to rock back and forth while operating the pump in order to make use of their momentum and and bodyweight to power the pump, meaning that it does not rely on significant upper-body strength.[9] The output from the pump can be directly sprayed onto crops, or used to fill a water tank supplying drip irrigation systems or other water uses including as a source of water for the household. Hip pumps of this type are not common in this setting, and were owned by less than 1% of farmers in the sample at baseline, and about 1.8% of farmers in the sample owned to a more powerful motorized water pump. By the endline survey, more farmers in the control group had also adopted the technology and 4.5% owned a hip pump.

Special care was taken to ensure that pumps were allocated to the primary female head of the household. Where the female head of treated households were unable to participate in the initial meeting, another household member participated in the lottery and local mobilizers followed up by telephone with the female head of household in order to confirm that she received the pump and that it was her asset, not her husband's. Households kept the pump and had full discretion over how they would use it, and received limited assistance in use or help with maintenance during the treatment period. In this regard it was a fairly 'light-touch' intervention as the only support and maintenance was the short training session conducted when pumps were distributed. Beyond the initial clarification that the pump was owned by the female head of household, there was no follow-up to check whether she

[8] See http://kickstart.org/how-we-work/ or http://moneymakerpumps.org/wp-content/uploads/2015/09/Kickstart-GIP-Brochure.pdf for a description of an irrigation pump.

[9] See https://www.engineeringforchange.org/solutions/product/moneymaker-hip-pump/ for more details on the use and operation of hip pumps.

maintained control of the asset and farmers were given no indication that pumps would be confiscated if the husband usurped control of the asset.

4. Research Questions

The primary research question is to understand how ownership of an irrigation pump impacts household welfare, through agricultural income and food security.

Secondly, if pump ownership increases the returns to agricultural production relative to other forms of work, it may lead to reallocation of inputs and time use by the household towards agriculture. This will be especially true during the non-rainfed seasons if crops receive higher prices when supply is lower or if off-farm work is unproductive work, only done because there is no possibility of doing agricultural work during the dry season. We therefore explore effects on land and time inputs into agriculture.

Finally, as control of household assets influences household power and decisionmaking and household power, our final research question is to explore how pump ownership influences female decisionmaking and experience of domestic violence.

5. Data Sources

To answer these research questions, we collected detailed survey data at baseline (prior to finding out treatment status) and at endline. The survey included detailed modules collecting data on the main outcomes of interest, including land usage and the crops farmers chose to plant in the long rains and short rains, as well as crops grown under irrigation. For the major crops in each of the types of agricultural production (the top three by land use) we also collected detailed information on yields and how harvests were used, including marketing decisions and sale prices. We also collected information on input spending by crop across a number of categories, including inorganic and organic fertilizer, seeds and planting materials, as well as hired labour and other chemicals. To understand time use, the survey included self-reported time use of different members of the household on a number of agricultural and non-agricultural economic activity as well as household work and leisure. We use this detailed information on agricultural production to generate measures of agricultural profits after cleaning output by removing outliers in input intensity, yields per hectare, and plot size, and using median prices by crop. We restrict to crops with more than ten observations in order to facilitate this cleaning procedure.[10] The identical procedure is used for results on net farm revenue, as well as the net value of output per hectare.

We construct information on income from rainfed crops grown in the long rains season, income from rainfed crops grown during the short rains season, and irrigated crops that do not fall into the prior two categories. To understand more about the timing of irrigation, and whether any impact is coming through intensification or through additional harvest cycles, we also ask in what months each irrigated crop was harvested.

In order to assess impacts on food security, we also collected self-reported data on a number of indicators of insecurity, such as household members skipping meals, having to borrow to buy food and whether there is enough food in the house for the next day. The survey also included four standard, validated measures of psychological health.[11]

The survey also included questions that were asked in private to the primary female member of the household - without the male head of household present - on whether women in the household had a say in decisionmaking, including agricultural decisions as well as other non-agricultural decisions regarding household finances, fertility decisions and allocation of household tasks. To understand the effect on domestic violence, we also asked about the number of incidents of various types types of emotional, physical or sexual violence in the last six months.

This data was used to create the following indices: *Total Value of Assets*, *Annual Net Farm Revenue*, *Monthly Consumption*, *Food Security*, *Physchological Health*, and a combined index of *Domestic Violence and Female Empowerment* with the details of the exact construction of outcome indices listed in Appendix A.[12]

5.1. Data Collection Method

Data collection was conducted using the SurveyCTO platform on Android tablets used by survey enumerators. The exact survey instrument text was uploaded as a supporting document with the study Pre-Analysis Plan.

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[10] See Section Appendix A.2 for details on the cleaning procedure.

[11] Specifically, we included the Perceived Stress Scale (PSS), the Scheier-Rosenberg Optimism Scale, the Scheier-Rosenberg Self-Esteem Scale and the CESD Depression Score.

[12] These indices were pre-registered. See the Pre-Analysis Plan at: AEARCTR-0002313

Baseline data was collected prior to the pump assignment lottery in May-June 2015. Endline data was collected after the long rains in August-September 2017. Respondents came to central locations in each of the three study districts where the surveys were conducted privately by trained and experienced enumerators. Backchecks were implemented for a subset of this sample to check the accuracy of the data.

6. Empirical Specification

The empirical specification for our main results estimates Intent To Treat (ITT) effects of the intervention, comparing pump recipients to non-recipients. The specification is as follows:

$$y_{i,r}^{\mathrm{EL}} = \beta_1 \mathrm{treat}_{i,r} + \beta_2 y_{i,r}^{\mathrm{BL}} + \theta_r + \epsilon_{i,r} \tag{1}$$

where $y_{i,r}^{\mathrm{EL}}$ is the outcome variable for household i in region r at endline, treat_i is a dummy variable recording if household i received a pump, and θ_r is a set of fixed effects for the three regions where pumps were distributed. As randomization into treatment was done at the individual level, the errors in this specification, $\epsilon_{i,r}$, are not clustered.[13] We account for multiple hypotheses by combining individual outcome variables into indices and report adjusted p-values accounting for multiple hypothesis testing using the Family-Wise Error Rate (FWER) and the False Discovery Rate (FDR).[14]

Finally, $y_{i,r}^{\mathrm{BL}}$ is the closest analogue to the outcome variable available in the baseline data. In most cases, this will simply be the exact same as the outcome variable. There were, however, some modifications to the survey instrument between surveys, and so this choice of notation makes it explicit that for some outcomes, the baseline measure is not the exact same as that used at endline. The two primary outcome indices where the endline index cannot be identically constructed using the baseline survey instrument are Total Annual Revenue, and the Food Security Index. [15]

[13] For robustness, we also report results in Table C.10 using a differences-in-differences specification $y_{i,r,p} = \beta_0 + \beta_1 \mathrm{treat}_{i,r} + \beta_2 \mathrm{endline}_{i,r,p} + \beta_3 \mathrm{treat}_{i,r} \cdot \mathrm{endline}_{i,r,p} + \theta_r + \epsilon_{i,r}$.

[14] See Appendix A for more details on the construction of outcome indices and the method for computing adjusted errors.

[15] For this reason, secondary analysis of the components of each of the main indices uses only the endline data.

The index for Total Annual Revenue was updated for the endline survey to improve our ability to identify the income received for each crop. Baseline data collected on agricultural revenue was not as detailed in terms of price per crop and exact amounts produced by crops, so extrapolating sale prices to the generate a monetary value of all crop production (including unsold crops) is somewhat more noisy than in the endline data. For this reason, these two indices are not constructed identically, so the difference between the two shouldn't be interpreted directly as an increase in farm revenue. Including the baseline index does, however, capture differences across households in baseline agricultural revenue which will make our estimation of treatment effects more precise. The Food Security Index was also updated after baseline to include two additional components in the endline index of food security, to capture potential seasonal aspects of food security.[16]

7. Results

In Table 1 we first show that randomization successfully created balanced treatment and control groups on a number of baseline characteristics where a joint test of differences is not significant.

7.1. Manipulation Check

In order to establish that the intervention of free pump distribution had the expected effect on use of irrigation, we first show a manipulation check in Table 2 testing whether treated households increased their use of irrigation under a range of measures. First, we check whether the households still own the pumps they were given, and did not re-sell them. We find that the treatment households owned approximately 8,000 Kenya Shillings more of irrigation assets, which roughly corresponds to the depreciated value of the pumps they were given. We also find that treated households spend significantly more time on irrigation. On the intensive margin, treated households spend approximately twice as much time as the control group households on

[16] These new components of the food security index were *Food security in worst month relative to last month*, and *Length of hungry season*. The first outcome captures the range in food security over the agricultural calendar, and whether the gap between best and worst month has narrowed. By including the length of the hungry season, we further capture whether food security has improved during the hungriest parts of the year, and not just the season in which surveys happened to be conducted.

irrigation, measured as the mean minutes per day the household as a whole spends on irrigation. On the extensive margin, we find that seventy-seven percent of treated households report spending any time on irrigation. which is thirty-four percentage points higher than in the control group, a statistically and economically significant difference. Taken together, these results show that two years after receiving a pump, households still own them and continue to use them in irrigation.

7.2. Main Outcomes

We first present main results on indices covering the primary mechanisms by which we hypothesised irrigation pumps might impact household wellbeing, before exploring these results in greater detail. Table 3 presents Intent-to-Treat results for our six main pre-registered outcome indices, including p-values corrected for multiple hypothesis testing.[17] We find positive effects, significant at the 5% level after multiple hypothesis testing, on the outcome indices for Asset Ownership (though this is primarily mechanical, driven by the ownership of the irrigation pump itself) and Female Empowerment & Domestic Violence. We find significant effects on Annual Net Farm Revenue and Psychological Wellbeing that are not significant after adjust for multiple hypothesis testing.[18]

These results suggest that the intervention improved economic and non-economic dimensions of household wellbeing. Given the nature of these combined indices, further analysis is required to interpret what exactly is driving these results, and so we next analyse each of the indices with significant results in greater detail.

7.3. Asset Ownership

To understand the above effect on asset ownership, in Table 4 we break the result down and look at the total value of assets grouped into the following categories: Productive Assets, Vehicles, Household Durables and Livestock. As the intervention involved giving households an irrigation pump, we split

[17] Unfortunately, some of these outcomes in the Food Security category are missing at baseline, which is why the number of observations is lower in column 4 of Table 3.

[18] In Appendix F we explore spillovers, looking at the effect of village-level treatment intensity on control households in terms of main outcomes and on access to different water sources. We find no significant evidence of spillovers, consistent with what we expect from small-scale irrigation technology.

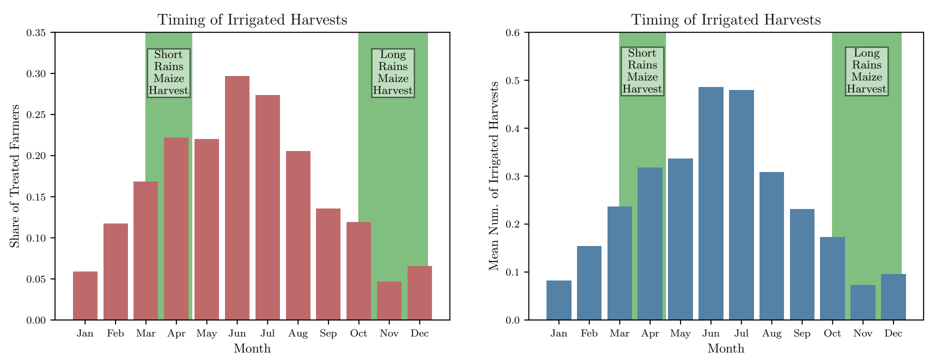
Productive Assets and look at ownership of productive assets other than pumps. We find that a large share of the effect on the asset index was a mechanical effect driven by the pumps category of productive assets. The effect on other productive assets, excluding pumps, is large but insignificant, and we find no economically or statistically significant effects on other types of asset ownership.

7.4. Agricultural Income

To understand the effect on agricultural income, we first disaggregate this into the categories of interest: agricultural net revenue across the three categories of interest as well as income from livestock. In Table 5 we show that this net revenue effect is overwhelmingly driven by the irrigated crops, where net income increased by approximately 4,300 Kenya Shillings, with the effects in rainfed seasons much smaller and not statistically significant.

The category of irrigated crops includes crops grown under irrigation that overlap with rainfed seasons as well as additional harvest cycles, with the average treatment household harvesting irrigated crops in two months. To clarify the timing, in Figure 2 we present a plot of the distribution of irrigated harvests by month. We show that the bulk of irrigated harvests do not occur at the same time as the main rainfed maize harvests, suggesting that irrigation primarily acts through additional seasons.

Figure 2: Timing of Irrigated Harvests



Description: These figures show the timing of irrigated crop harvests relative to the major rainfed harvests. The left panel shows the share of farmers in the treatment group who harvested any irrigated crops during a given month at endline. The right panel shows the mean number of irrigated crops harvested in a month by farmers in the treatment group at endline. This plot shows that most of the irrigated harvests come at a different time than the main rainfed season.

These effect magnitudes are smaller than other effects found from surface water irrigation such as Duflo and Pande (2007) who find an increase of between 34 to 53 percent on crop production and Jones et al. (2022) who find a treatment on the treated increase in annual cash profits of between 43 to 62 percent. This is not surprising given the relative scale of the irrigation technology, and the fact that this intervention changes the cost of accessing water for irrigation while leaving the source of water as given. However, these small scale irrigation pumps have much lower up-front and maintenance costs and are an individual investment which do not require large rates of adoption to be sustainable, or create negative spillovers to those who live near where dams are constructed. In addition, small-scale irrigation pumps primarily draw on rivers as a source of water, and are therefore subject to fluctuations from extreme weather events. In 2016-2017 Kenya experienced a severe drought and unusually high temperatures that were ongoing during the study period (World Food Programme, 2017; Uhe et al., 2017) meaning these results may be an underestimate.

Irrigation may influence the income of farmers by a number of different mechanisms, and so these estimates may be capturing both intensive and extensive margins of production. We examine total land use, crop allocation, yields, inputs and prices in turn to identify the mechanisms by which irrigation technology impacts smallholder farm income.[19]

We first explore the extensive margin by looking at total farmed area as well as the number of crops grown in each rainfed season and under irrigation. In Table 6 we present these outcomes and show the treatment led to large increases in the area farmed on major crops under irrigation and the number of irrigated crops grown.[20] The effects on area of rainfed crops in the long rains and short rains seasons are not statistically significant. The intervention therefore had a significant effect on agricultural income by increasing the number of crops grown and the area cultivated under irrigation.

We next explore the way land is allocated across crops and whether irrigation allows farmers to adjust cropping decisions. In Tables C.13-C.16 we find few significant effects on the share of cultivated land allocated to different

[19]Here we focus on mechanisms behind the income effect, while in Table C.11 we focus on the potential mechanisms by which the intervention impacts women empowerment and decisionmaking.

[20]In Table C.12 we show this the crop-level outcomes to show which crops farmers chose to grow under irrigation.

crops or different groups of crops by farmers for a given type of cultivation, suggesting that most effects of the treatment were on the extensive margin, increasing cultivated area and whether farmers chose to farm in the more marginal seasons, rather than from treated farmers adapting their cropping profile for rainfed or irrigated crops.[21]

Now we test whether irrigation impacted output through changes in spending on inputs or time inputs, or directly impacted yields for a given level of inputs. In Table C.17 we look at aggregate levels and intensity of agricultural inputs, including spending on inputs as well as time used in agricultural work. We find no significant effect on total spending on inputs in the short and long rains, but find a large and significant increase to total input spending on the irrigated crops. When we look at intensity of input spending, however, we find negative and insignificant effects for both rainfed seasons and irrigated crops. The results on time spent in agriculture are similar, with very small and insignificant effects on total input spending or input intensity in the rainfed seasons. For the irrigated crops, we see a large increase in total time inputs, but the time spent per cultivated acre is negative and significant at the 10% level. These results are broadly consistent with the argument that irrigation mostly improved income through the extensive margin, with greater total spending on inputs and total time spent in agriculture, but the effect on intensity of inputs into agriculture per cultivated hectare is small or negative and if anything suggests the intervention resulted in lower intensity of inputs.

In Table C.18 we look directly at the value of agricultural output per-hectare, using median crop prices to focus on the impact on production, and find no significant effect, with or without controlling for spending on inputs per acre, which significantly increase the value of agricultural output.[22] This suggests that the negative treatment effect on value of production per hectare is not mediated by the endogenously chosen level of inputs, and is consistent with the argument that pumps primarily increase net income by allowing farmers to expand irrigated production.

In Appendix D, we use data from a long-run panel of farmers who pur-

[21] It should be noted, however, that changes to cropping patterns or crop diversification can be considered extensive margin if they result from additional area being brought into cultivation.

[22] In Appendix Table C.19 we show that this pattern is consistent with results at the crop-level, with few strong effects on output per acre.

chased similar irrigation pumps to estimate how the effectiveness of these irrigation pumps depreciates over the first five years of ownership.[23] Given the retail cost of approximately 10,000 Kenya Shillings, and the Intent-To-Treat estimate of additional net farm revenue of 4,300 ksh from irrigated crops, we estimate that the pump would pay for itself in less than three years, and using a back-of-the-envelope calculation (see Equation D.2 in Appendix D) the cumulative additional agricultural net income over the first five years are approximately 16,725 Kenya Shillings, after accounting for depreciation.

7.5. Non-Agricultural Income

Given the results above showing that the irrigation intervention led to increased agricultural income through expanded production, we then look at non-agricultural income to understand whether households are substituting away from non-agricultural work. In Table C.20 we show that treated households were significantly less likely to have done any casual or wage labour, and that average income from casual cash labour or wage work was also significantly lower. We find no effect on household supply of labour compensated in-kind, which is unsurprising given that only 15% of control households had in-kind earnings for labour. We also find no effect on the extensive margin of non-farm enterprises but find that monthly off-farm enterprise earnings were significantly lower for treated households.[24]

7.5.1. Overall Income Effect

In order to properly evaluate the overall effect of irrigation pumps on household income, foregone earnings from non-farm labour and enterprises need to be taken into account. To do this, we use the monthly non-farm income results above, combined with the number of months when farmers were active in irrigation.[25] The average impact on monetary earnings from

[23] We look only at how the perceived current value of their irrigation hip pump varies with the number of years they have owned it to approximate depreciation. In Table D.23 we find that pump value depreciates by approximately 6.5% per year owned. It should be noted, however, that farmers selecting into buying pumps may take greater care of them leading to lower depreciation, but this is the best available benchmark for estimating long-run sustainability.

[24] This is, however, largely driven by outliers and is not significant after accounting for this.

[25] For this reason our calculation uses 2 × monthly non-farm income effect, rather than 12 × monthly non-farm income effect, as this seemed a more reasonable approximation

casual/wage labour is approximately 780 Kenya Shillings. The average impact on off farm enterprise earnings is approximately 350 Kenya Shillings.[26] Together, this equals a total of 1,130 Kenya Shillings lost earnings per month. The average treatment household harvests irrigated crops in two months, so a simple back of the envelope calculation suggests that even after accounting for non-farm income the additional net farm revenue of 4,300 Kenya Shillings means irrigation pumps are profitable.[27]

7.6. Psychological Wellbeing

We now explore the non-economic impacts of irrigation pumps and show, in Table C.21 that the intervention significantly improved mental health.[28] It is not possible, however, to determine if this effect is a simple income effect from increased agricultural production or whether this reflects reduced worry about crops failing due to negative rainfall shocks.

7.7. Decisionmaking & Domestic Violence

One important aspect of the intervention was that irrigation pumps were given directly to the primary woman in the household. We show in Table 7a that this right of ownership was persistent, with eighty percent of treated households reporting that women in the household are involved in decisions over use of irrigation equipment. This increased decisionmaking is also not limited to decisions directly over control of irrigation pumps. We also show that, on an index of ten household decisions, in treated households women are involved in approximately 0.5 more decisions, significant at the 5% level. When we look at these decision making outcomes individually, in Table C.22,

than assuming irrigation impacted non-farm income generation in every month, even when irrigation was not heavily used.

[26]This is potentially an overestimate of the impact on *profits* as the responses may reflect gross earnings rather than profits, given the wording of the question: *"In a usual month how much do they take in altogether? After costs, how much is left over in a usual month?"*

[27]In addition, the cash earnings may not accurately reflect the utility gain, if there is any relative disutility to working off-farm or if the hours spent on irrigation are fewer than the hours spent wage labour and leisure hours increase. These effects on displaced off-farm labour may also be an overestimate of the year-round effects since the survey occurred in August-September, shortly after the bulk of irrigated crops were harvested when labour diversion would likely have been highest. At this level of return, lack of adoption by the control group may be consistent with credit constraints (Berkouwer and Dean, 2022).

[28]Specifically, the Self-Esteem and CESD Depression scores showed improvement.

we find strong effects on the expected decisions relating to irrigated farming, but we also see strong positive effects where women have greater decision making power over fertility decisions and how to allocate household tasks. On the other measure of female empowerment we consider, instances of domestic violence, we find a significant negative effect on instances of physical violence, with women in treated households experiencing approximately one fewer instance of physical violence over the past six months.

We also explore in Table 7b the impact of the intervention on attitudes held by female members of the household. On a module of ten questions where women were asked whether they agree or disagree with statements regarding gender relations within the household and the acceptability of domestic violence, women in treated households gave 0.3 more responses consistent with women having greater power within the household. This is mostly driven by attitudes towards female decisionmaking, rather than attitudes towards the acceptability of domestic violence by men towards women and children. In Table 7c we also show weakly significant treatment effects where women control a greater share of the harvests of, and contribute an increased share of the household's time spent on, irrigated crops. We see no significant effects on these outcomes for rainfed crops. While some of these results are a mechanical effect of allocating pumps to women in the household, the impacts appear to go beyond this and suggest broader empowerment of women.

7.8. Understanding Mechanisms

To try and understand the mechanisms driving these results, we also conduct heterogeneity analysis by baseline non-experimental variation. In Table C.11 we find positive but insignificant heterogeneity in effects on main outcome indices by whether there was a woman head of household. We also find no significant heterogeneity in treatment effect depending on the household size. We do, however, find strong heterogeneity in the treatment effect depending on the role of women in agriculture at baseline. We find that the treatment effects on net farm revenue, food security, and psychological wellbeing are driven almost entirely by households where women contributed more time than men to rainfed agriculture during the rainy season at baseline. The treatment effects on these outcomes are not statistically significant for households where women did not contribute more time than men. This suggests that women maintained control of the asset, and that the effect on net farm income is likely driven by improving the productivity of women in agriculture. There is no similar heterogeneous effect on empowerment and domestic violence. The fact that the impact on food security and psychological wellbeing are small and not significant for households with no effect on agricultural income suggests that the income mechanism drives these other outcomes. We cannot separate whether this is specific to women's income, or overall agricultural income. The effect on women empowerment is similar for households with an income effect and for those without, which suggests that the transfer of assets is the mechanism driving the empowerment effect.

8. Conclusion

In this project we find that manually powered irrigation pumps have significant benefits for smallholder farmers in Kenya. Using a field experiment where pumps were distributed for free to the primary women in small-scale farming households, we find that the intervention increased net farm revenues, driven primarily by an additional 4,300 Kenya Shillings of annual net income from irrigated crops. We find that this effect primarily operates on the extensive margin, increasing the number of crops grown under irrigation and the area cultivated under irrigation. We find insignificant effects on the value of output per hectare under rainfed seasons or irrigated crops, and no significant effect on intensity of input spending or time use per cultivated hectare. This is consistent with small-scale, manually powered, irrigation pumps primarily acting to enable the cultivation of more marginal plots or in more marginal seasons. We find that this intervention also had non-economic benefits, with improved self-esteem and reduced depression. We also find increased female participation in household decisionmaking, including fertility decisions, and a marginal reduction in physical violence experienced by women in the household, though we cannot disentangle the effect of female control over productive assets from the income effect. This evidence suggests that small-scale irrigation technology is an effective way to improve economic and non-economic outcomes of smallholding farming households using an intervention requiring minimal training or institutional capacity, thus avoiding many of the challenges that have constrained the adoption of large-scale irrigation technology in Sub-Saharan Africa.

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9. Tables

Table 1: Summary Statistics & Baseline Balance

			Treatment	
Category	Variable	Mean	Diff	Std.Err
Demographics	Female Head of Household†	.170	-0.043	.034
	Head of H'hold Education Years	3.239	-0.018	.084
	Household Size	5.208	0.046	.132
	Num. Male Children	1.574	-.171*	.096
	Num. Female Children	1.495	0..060	.082
Agricultural Inputs	Total Time Spent Rainfed Ag.	1117	26	51
	Total Time Spent Irrigated Ag.	479	30	44
	Long Rains Cultivated Land	1.529	.590	.418
	Irrigated Cultivated Land	.439	.010	.109
Income & Assets	Net Farm Revenue	16073	-775	1815
	Total Household Assets	36948	-434	2977
Wellbeing	Food Security Index	-.000	-.077	.084
	Psych. Wellbeing Index	-.018	.058	.071
	Female Empowerment Index	.275	-.059	.070

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. 1 of 17 variables ($\sim 5.8\%$) is significant at the 5% level, roughly consistent with random chance.
† Binary variable, equal to 1 if true, 0 if not.

Table 2: Intervention Effect on Irrigation Adoption

Outcome Var	(1) Total Value Irrigation Assets	(2) Total Time Spent on Irrigation	(3) Any Time Spent on Irrigation
Treatment	8,051	224.364	0.344
	(346)***	(30.399)***	(0.030)***
Naive P-Value	[0.00]	[0.00]	[0.00]
FWER p-value	0.00	0.00	0.00
FDR p-value	0.00	0.00	0.00
Control Mean	645	236.52	0.43
Control Std. Err.	3,364.86	406.38	0.50
Num. Observations	876	876	876

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Standard Error in parentheses below estimate. Controls for all specifications: District Fixed Effects.

This table presents a manipulation check to test whether the intervention of free pumps had the intended effect, and that pumps were not resold, and are still in use. We show this through asset ownership as well as intensive and extensive margins of time use. Total Value Irrigation Assets is the sum of self-reported value of assets (in Kenya Shillings) owned in the categories Hip pump, Moneymaker Plus Pump (MMP), Super Moneymaker Plus Pump (SMMP) and Motorized pump. Total Time Spent on Irrigation is the sum of self-reported time (minutes per typical day) spent by the household on irrigation activities for purely irrigated crops, as well as for long rains and short rains seasons. Any Time Spent on Irrigation is a dummy variable for Total Time Spent on Irrigation being greater than zero.

Table 3: Main Outcome Indices with Baseline Controls

Outcome Var	(1) Asset Ownership Index†	(2) Annual Net Farm Revenue†	(3) Monthly Food Consumption†	(4) Household Food Security	(5) Psychological Wellbeing	(6) Female Empower-ment & Domestic Violence
Treatment	11,880	4,453	-181	0.014	0.111	0.253
	(2,517)***	(2,687)*	(200)	(0.081)	(0.066)*	(0.065)***
P-Value	[0.00]	[0.10]	[0.37]	[0.86]	[0.09]	[0.00]
FWER p-value	0.00	0.32	0.61	0.87	0.32	0.00
FDR p-value	0.00	0.32	0.58	0.86	0.32	0.00
Num. Observations	871	871	871	553	871	871
Control Mean	36,379	35,145	4,352	0.00	-0.00	0.00
Control Std. Err.	42,226.42	40,891.54	3,112.93	1.00	1.00	0.99

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

† Variables measured in Kenya Shillings Winsored at 5%.

Standard Error in parentheses below estimate. Controls for all specifications: District Fixed Effects and Baseline Proxy of Outcome. We also report the same outcomes with differences-in-differences specification in Table C.10. Asset Index is the sum of self-reported values (in Kenya Shillings) for assets classified as being Productive Assets, Vehicles, Durable Assets and Livestock, where livestock prices are generated as the average sale price for each livestock category reported in the sample. Annual Net Farm Revenue is income (in Kenya Shillings) from Long Rains, Short Rains, and Irrigated agriculture as well as livestock, minus input spending, as described in Appendix Appendix A.2. Monthly Food Consumption is the sum of spending and self-reported value (in Kenya Shillings) of own-consumption over twelve categories of food. Household Food Security is the weighted average of self-reported behaviours indicating food insecurity, along with self-reported length and relative severity of the hungry season, where a higher value indicates improved food security. Psychological Wellbeing index is the weighted average of modules measuring the Optimism, Self-Esteem, Depression and Perceived Stress Scales. Empowerment and Domestic Violence is the weighted average of an Empowerment Index, which is the weighted average of self-reported female decisionmaking, and a Domestic Violence Index, which is the negative count of self-reported instances of domestic violence across a number of categories.

Table 4: Intervention Effect on Asset Ownership

Outcome Var	Productive Assets (1) Only Pumps[1]	Productive Assets (2) Pumps Excluded	(3) Vehicles	(4) Durable Assets	(5) Livestock
Treatment	8,051	2,262	-38	66	34
	(352)***	(1,563)	(1,112)	(554)	(856)
p-value	[0.00]	[0.15]	[0.97]	[0.91]	[0.97]
Control Mean	651	14,886	6,868	7,191	6,208
Control Std. Err.	3,379	24,435	16,543	7,998	13,169
Num. Observations	876	876	876	876	876

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

All variables in this table measured in Kenya Shillings, Winsored at 5%. Robust Standard Error in parentheses below estimate. Controls for all specifications: District Fixed Effects.

This table reports the impact of the intervention on ownership of assets. We find that the overall effect is largely driven by ownership of irrigation pumps, which is largely a mechanical result from the intervention distributing pumps. We do, however, still find a smaller, though insignificant, effect on productive assets when we exclude irrigation pumps. Only Pumps includes the sum of current value of manually-powered irrigation pumps owned by the household. Pumps Excluded includes the sum of current value of all productive assets owned by the household, *excluding* manually-powered irrigation pumps. These assets are: Ox-Ploughs, Oxen/work bulls, Knapsack Sprayers, Wheelbarrows, Motorized Pump, Hose Pipes, Ox-carts/donkey carts, Hand carts, Zero grazing unit, Fishing Equipment, Sewing Machine, and Water tanks. Vehicles includes Motor Vehicle/pickup truck, Bicycles, and Motorcycles.

Table 5: Components of Net Farm Revenue

Outcome Var	(1) Long Rains	(2) Short Rains	(3) Irrigated	(4) Livestock
Treatment	-843	546	4,302	34
	(905)	(795)	(2,106)**	(856)
p-value	[0.35]	[0.49]	[0.04]	[0.97]
Control Mean	12,381	7,409	10,522	6,164
Control Std. Err.	14,493	12,772	29,208	13,169
Num. Observations	876	876	876	876

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$
Variables measured in Kenya Shillings, Winsored at 5%. Robust Standard Error in parentheses below estimate. Controls for all specifications: District Fixed Effects.
In this table we report the intervention effect on the components of net farm annual income, including the three types of agricultural production we consider as well as income from livestock. We use median prices by crop to compute value of farm output in order to isolate the effect of treatment on agricultural production. Here we show that the overall effect on net farm income is driven overwhelmingly by the income from irrigated agriculture.

Table 6: Effect on Extensive Margin of Agricultural Production

	Long Rains		Short Rains		Irrigated Crops	
	(1)	(2)	(3)	(4)	(5)	(6)
Outcome Var	Crop Count	Cropped Area†	Crop Count	Cropped Area†	Crop Count	Cropped Area†
Treatment	0.085	0.048	0.044	0.049	0.886	0.068
	(0.137)	(0.062)	(0.096)	(0.049)	(0.092)***	(0.010)***
p-value	[0.54]	[0.44]	[0.65]	[0.32]	[0.00]	[0.00]
Control Mean	4.4	1.17	3.01	.88	1.02	.08
Control Std. Err.	2.09	.99	1.33	.79	1.34	.14
Num. Observations	876	876	876	876	876	876

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Robust Standard Error in parentheses below estimate. Controls for all specifications: District Fixed Effects. For crop-level results on planting decisions, see Tables C.12-C.16. Crop Count is the integer count of the number of rainfed crops grown in each rainfed season and crops grown under irrigation.

† Cropped area measured in hectares, Winsored top at 5%.

In this table we report effects on the extensive margin of agricultural production, both in terms of number of crops grown and how much land is cultivated across the three types of agricultural production. We find the intervention had a strong effect on expanding irrigated production, growing more crops on more land under irrigation.

Table 7: Intervention Effect on Female Empowerment

(a) Actual Outcomes for Women

Outcome Var	Decisionmaking: Control Over Pump	Decisionmaking: Other Household Decisions[1]	Domestic Violence Experienced: Emotional Violence	Domestic Violence Experienced: Physical Violence	Domestic Violence Experienced: Sexual Violence	Domestic Violence Experienced: Violence Against Children
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment	0.444	0.482	-1.678	-1.039	-0.089	0.053
	(0.029)***	(0.196)**	(1.911)	(0.553)*	(0.306)	(0.161)
Naive P-Value	[0.00]	[0.01]	[0.38]	[0.06]	[0.77]	[0.74]
Num. Observations	876	876	522	522	521	522
Control Mean	0.37	7.43	7.78	1.80	0.68	0.49
Control Std. Err.	0.48	2.95	25.18	8.93	3.81	1.90

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

In this table we report effects on female empowerment and domestic violence. Empowerment is measured by self-reported responses, taking the count of the number of household decisions women participate in (either jointly or by themselves). Domestic violence is measured by count of incidents of violence in the last six months, broken down into different categories.

[1] This group of questions includes decisionmaking over household expenditures, as well as decisionmaking and control of incomes from agriculture. For the full list of questions, see Section Appendix A.7. For effects broken down by individual household decisions, see Table C.22.

(b) Female Empowerment Attitudes

Outcome Var	(1) Combined	Disaggregated: (2) Attitudes Towards Domestic Decisionmaking	Disaggregated: (3) Attitudes Towards Tolerance of Domestic Violence
Treatment	0.310	0.093	0.217
	(0.178)*	(0.055)*	(0.154)
p-value	[0.08]	[0.09]	[0.16]
Num. Observations	522	522	522
Control Mean	8.01	2.52	5.49
Control Std. Err.	2.15	0.67	1.86

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

In this table we report effects on female empowerment as measured by attitudes towards different aspects of household decisionmaking, asking whether women should be able to participate in different decisions or the rights of women and children, as well as whether domestic violence is acceptable under certain conditions. We show the intervention had a marginal effect shifting attitudes towards a greater place for women and children in rights and household decisionmaking. The outcome is the count of responses that indicate greater empowerment of women. For the list of questions used to construct the measures of attitudes, see Section Appendix A.8.

(c) Women Role in Agriculture

Outcome Var	Share of Harvests Controlled: (1) Rainfed Crops	Share of Harvests Controlled: (2) Irrigated Crops	Household Labour Share: (3) Rainfed Crops	Household Labour Share: (4) Irrigated Crops
Treatment	0.03	0.05	-0.02	0.04
	(0.03)	(0.03)*	(0.01)	(0.02)*
p-value	[0.20]	[0.06]	[0.24]	[0.07]
Num. Observations	804.00	731.00	867.00	527.00
Control Mean	0.82	0.82	0.60	0.56
Control Std. Err.	0.37	0.38	0.22	0.23

* $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

In this table we report effects on empowerment of women by looking at the share of crops where they have sole or joint control over the harvest procedures. The exact question text is *Who mainly controls the harvest procedures of this crop?*. We code a crop as being controlled by women if they select the options *"entire family"* or *"female family members"* if they select *"head of household"* where the head of household is a woman, or *"spouse"* where the spouse is a woman, or if they select *"household head and spouse"* Given this coding, most crops are listed as being jointly managed, which diminishes the effect size. The Share of Household Labour was computed by taking the sum of time used by women on the categories *land preparation, planting, weeding, crop protection, fertilizer application, irrigation, harvesting,* or *other,* divided by the total time contributed by men and women in the household for that type of crop.