A Main variable appendix

Household variables: All household variables are constructed from the baseline.

- *HHH female*: Indicator that the household head is female.
- *HHH age*: Age of the household head.
- *HHH completed primary*: Indicator that the household head completed primary.
- *HHH worked off farm*: Indicator that the household head worked off farm.
- *# of plots*: Number of plots reported as managed by the household. Includes plots rented in, plots owned and cultivated in the past year, and plots rented out.
- *# of HH members*: Number of members of the household.
- *# of HH members who worked off farm*: Number of members of the household who worked off farm.
- *Housing expenditures*: Expenditures over the past year on housing and furnishing. Winsorized at the 99th percentile.
- *Asset index*: First principal component of log number of assets-by-category owned and an indicator for positive number of assets-by-category owned, where the categories are cows, goats, pigs, chickens, radios, mobile phones, pieces of furniture, bicycles, and shovels. Standardized to be mean 0 and standard deviation 1, with positive values indicating more assets.
- *Food security index*: First principal component of log days in the past week of consumption of food item-by-category and an indicator for any consumption of food item-by-category. In baseline, categories are flour, bread, rice, meat and fish, poultry and eggs, dairy products, cooking oil, fruits, beans, vegetables, plantains and cassava and potatoes, juice and soda, sugar and honey, salt and spices, meals prepared outside

home, and groundnut and other oilseed flour. In follow up surveys, categories are flour, bread, cakes and chapati and mandazi, rice, small fish, meats and other fish, poultry and eggs, dairy products, peanut oil, palm oil and other cooking oil, avocados, other fruits, beans, tomato, onion, other vegetables, plantains, Irish potatoes, sweet potatoes, sugar, salt, local banana beer at home, groundnut flour. Standardized to be mean 0 and standard deviation 1, with positive values indicating more consumption.

- *Overall index*: Index constructed following Anderson (2008) using housing expenditures, asset index, and food security index.

Plot variables: All plot variables are constructed from the baseline.

- *Command area*: Indicator that plot located in command area, equal 1 if any share of the plot is inside of the command area. Calculated from plot map.

- *Distance to boundary*: Distance from plot boundary to command area boundary, 0 for plots whose plot map intersects the boundary. Positive for plots that are inside the command area, negative for plots that are outside the command area. Calculated from plot map.

- *Area*: Area in hectares. Calculated from plot map.

- *Water user group*: Water user groups that the plot is located in, calculated from plot map. If the plot intersects multiple water user group boundaries, the water user group in which the largest share of the plot's area is contained. Missing for plots that are outside the command area.

- *Nearest water user group*: For plots inside the command area, the water user group. For plots outside the command area, the water user group whose boundary the boundary of the plot is the shortest distance from. Calculated from plot map.

- *Terraced*: Indicator that the plot was terraced.

Plot-season variables: All plot-season variables are constructed from the baseline when used in balance tables. Variables related to attrition are observed at plot-season level when used as outcomes in regressions testing for differential attrition.

- *Own plot*: Indicator that the surveyed cultivator owns the plot. 0 when the surveyed cultivator rents in the plot.
- *Owned plot >5 years*: Indicator that the surveyed cultivator had owned the plot for at least 5 years.
- *Rented out to farmer*: Indicator that the surveyed cultivator rented out the plot to another farmer.
- *Rented out to commercial farmer*: Indicator that the plot was rented out to a commercial farmer.
- *HH attrition*: Plot-season indicator that the household associated with the plot was not reached for the survey.
- *Transaction (not tracked)*: Plot-season indicator that the plot was sold, rented out, or no longer rented in, and the new household responsible for the plot was not successfully followed up with.
- *Tracked*: Plot-season indicator that the plot was sold, rented out, or no longer rented in, and the new household responsible for the plot was successfully followed up with and asked questions on agricultural production on the plot.
- *Missing*: Plot-season indicator that agricultural production data is missing for that plot. Sum of variables HH attrition, Rented out to commercial farmer, and Transaction (not tracked).

Agricultural variables

- *Cultivated*: Plot-season indicator for any cultivation. All other agricultural variables are set to 0 when no cultivation takes place.

- *Irrigated*: Plot-season indicator for any irrigation use.

- *Horticulture*: Plot-season indicator for any horticulture cultivated. As horticultural crops are annuals, this will include activities associated with planting, growing, and harvesting.[53]

- *Banana*: Plot-season indicator for any bananas cultivated. As bananas are perennials, this refers to any activities associated with planting, growing, or harvesting, and need not include all three.

- *HH labor/ha*: Plot-season sum of household labor use, divided by plot area. Winsorized at the 99th percentile.

- *Input expenditures/ha*: Plot-season sum of expenditures on non-labor inputs, divided by plot area. Winsorized at the 99th percentile.

- *Hired labor expenditures/ha*: Plot-season sum of expenditures on hired labor, divided by plot area. Winsorized at the 99th percentile.

- *Hired labor (days)/ha*: Plot-season sum of hired labor use, divided by plot area. Winsorized at the 99th percentile.

- *Price*: Prices are calculated at the District-crop-season level, as the median of plot-crop-season reported sales divided by reported kilograms sold. Prices are set to missing when there are less than 10 observations that District-crop-season and either more than two District-crop-seasons with at least 10 observations that District-crop-survey or at least 30 observations that District-crop-survey; these cut-off points were chosen

[53]In Figure 3 and Table 1, an alternative definition of crop choice is used, where a crop indicator indicates that crop is the primary crop cultivated that plot-season.

to maximize inclusion of prices judged subjectively to be reasonable, and maximize exclusion of prices judged subjectively to be not reasonable.

- *Yield*: Plot-season sum of prices times harvested quantities. Yields are missing when all crops cultivated that plot-season have missing prices or missing harvested quantities. When multiple crops are grown on a plot-season and some have observed prices and harvested quantities, those with missing prices or quantities are treated as 0 production. After this procedure 3.6% of rainy season observations and 5.3% of dry season observations in our discontinuity sample have missing yields. Winsorized at the 99th percentile.

- *Sales/ha*: Plot-season total reported sales, divided by area. Winsorized at the 99th percentile.

- *Sales share*: Sales/ha divided by yield, equal to 1 when reported sales/ha is greater than yield.

- *Profits/ha (Shadow wage = 0 RwF/day)*: Yield minus hired labor expenditures/ha minus input expenditures/ha.

- *Profits/ha (Shadow wage = 800 RwF/day)*: Yield minus hired labor expenditures/ha minus input expenditures/ha minus 800 times HH labor/ha.

Experimental variables: Additional details on these variables are in Appendix E.

- *Assigned minikit*: Indicator that household was assigned to receive a minikit.

- *Minikit saturation*: Saturation of minikits assigned for the Water User Group of the plot.

- *Minikit takeup*: Indicator that the household reported using a minikit.

- *Zone*: The Zone in which the plot's Water User Group is located in. The plots in our survey are located in 239 Water User Groups grouped into 33 Zones.

- *O&M treatment*: O&M treatment status of the Water User Group of the plot.
- *# of lotteries entered, minikits*: Number of lotteries for minikits the household was entered into.

B Household results

We present results of the impacts of access to irrigation on household welfare outcomes in Table A1. We estimate specifications similar to Equations (1), (2), and (3), but now use annual outcomes at the household level (instead of outcomes on sample plots).

We find suggestive evidence of positive impacts on household welfare. All point estimates are positive, and impacts on housing expenditures and an Anderson (2008) index of household welfare are each significantly different from zero in two specifications. The implied treatment on the treated estimates are large. However, as impacts on household are imprecisely estimated, we interpret these results with caution.

C Prices and wages

We present figures showing the evolution of wages (Figure A1) and sale prices (Figure A2) across the 3 hillside irrigation schemes. In Figure A1, average wages do not appear to change after the hillside irrigation schemes became fully operational.[54] In Figure A2, median sale prices appear to display more meaningful trends. In Karongi, there do not appear to be any trends in sale prices of horticultural crops. However, in Nyanza, sale prices of both tomatoes and eggplants appear lower after the hillside irrigation schemes became fully operational than before. We discuss the interpretation of these changes, if one believes they are causal, in Section 3.2.3.

[54] Median wages (not presented here) remain constant within both of the sites used for the regression discontinuity analysis, and are slightly higher in the third site after the hillside irrigation schemes became fully operational.

D Model appendix

Derivation of first order conditions. Substitute for L^O using the household labor constraint, $L_1 + L_2 + \ell + L^O = \overline{L}$, and substitute for c in the household's maximization problem. This leaves two constraints, $M_1 + M_2 \leq \overline{M}$, and $\overline{L} - L_1 - L_2 - \ell \leq \overline{L^O}$; call the multipliers on these constraints $\widetilde{\lambda_M}$ and $\widetilde{\lambda_L}$, respectively. Taking first order conditions yields

$$\begin{aligned}
(M_k) \quad & \mathbf{E}[u_c\sigma]A_kF_{kM} - \mathbf{E}[u_c]r && = \widetilde{\lambda_M} \\
(L_k) \quad & \mathbf{E}[u_c\sigma]A_kF_{kL} - \mathbf{E}[u_c]w && = -\widetilde{\lambda_L} \\
(\ell) \quad & \mathbf{E}[u_\ell] - \mathbf{E}[u_c]w && = -\widetilde{\lambda_L}
\end{aligned}$$

To ease interpretation, normalize $\lambda_M \equiv \widetilde{\lambda_M}/r\mathbf{E}[u_c]$ and $\lambda_L \equiv \widetilde{\lambda_L}/w\mathbf{E}[u_c]$, and substitute $\text{cov}(\sigma, u_c) = \mathbf{E}[u_c\sigma] - \mathbf{E}[u_c]\mathbf{E}[\sigma] = \mathbf{E}[u_c\sigma] - \mathbf{E}[u_c]$. This yields

$$\begin{aligned}
(M_k) \quad & \left(1 + \tfrac{\text{cov}(\sigma,u_c)}{\mathbf{E}[u_c]}\right) A_kF_{kM} && = (1 + \lambda_M)r \\
(L_k) \quad & \left(1 + \tfrac{\text{cov}(\sigma,u_c)}{\mathbf{E}[u_c]}\right) A_kF_{kL} && = (1 - \lambda_L)w \\
(\ell) \quad & \tfrac{\mathbf{E}[u_\ell]}{\mathbf{E}[u_c]} && = (1 - \lambda_L)w
\end{aligned}$$

No constraints. When no constraints bind, as discussed the first order conditions simplify to

$$\begin{aligned}
(M_k) \quad & A_kF_{kM} && = r \\
(L_k) \quad & A_kF_{kL} && = w \\
(\ell) \quad & \tfrac{u_\ell}{u_c} && = w
\end{aligned}$$

Note that the first order conditions for M_2 and L_2 are functions only of (M_2, L_2), and exogenous (A_2, r, w). Therefore, $\frac{dM_2}{dA_1} = \frac{dL_2}{dA_1} = 0$.

Insurance market failure. Consider the case when insurance markets fail. To abstract fully from labor supply, we temporarily remove leisure from the model. To further simplify, we drop other inputs from the production function; when the production function is homogeneous in labor and other inputs, this is without loss of generality. Households solve

$$\max_{L_1,L_2} \mathbf{E}[u(c)]$$
$$\sigma(A_1F_1(L_1) + A_2F_2(L_2)) - w(L_1 + L_2) + w\overline{L} + r\overline{M} = c$$

To simplify the analysis, this can be rewritten as the two step optimization problem

$$\max_{L} \mathbf{E}[u(c)]$$
$$\sigma G(L; A_1) - wL + w\overline{L} + r\overline{M} = c$$
$$\max_{L_2} aF_1(L - L_2) + A_2F_2(L_2) = G(L; a)$$

Next, let $\gamma(g, c) = \frac{\mathbf{E}[u_c(\sigma g+c)]}{\mathbf{E}[\sigma u_c(\sigma g+c)]}$; $\gamma \geq 1$ is the ratio of the marginal utility from consumption to the marginal utility from agricultural production. As above, to represent derivatives of G and γ we use subscripts to indicate partial derivatives and subsume arguments. This yields the first order condition

$$(L) \quad G_L - \gamma(G(L; A_1), w(\overline{L} - L) + r\overline{M})w \quad = 0$$

The central intuition for this case can be captured from just the first order condition: $\overline{L}$ and $\overline{M}$ enter symmetrically into the model, so larger households should respond similarly to richer households. If absolute risk aversion decreases sufficiently quickly (e.g., with CRRA preferences), then for sufficiently high levels of consumption $\mathbf{E}[\sigma u_c] = \mathbf{E}[\sigma]\mathbf{E}[u_c] = \mathbf{E}[u_c] \Rightarrow \gamma = 1$. Therefore, sufficiently wealthy or sufficiently large households should not respond to the sample plot shock. Below, we will maintain the assumption that preferences exhibit decreasing absolute risk aversion, and that $\lim_{c\to\infty} \gamma(g, c) = 1$.

Let FOC_L be the left hand side of the first order condition for the utility maximization problem. Then, an application of the implicit function theorem yields $\frac{dL}{dA_1} = -\frac{d\text{FOC}_L/dA_1}{d\text{FOC}_L/dL}$. Evaluating these derivatives yields

$$\frac{d\text{FOC}_L}{dL} = G_{LL} + \gamma_c w^2 - \gamma_g G_L w$$
$$\frac{d\text{FOC}_L}{dA_1} = G_{La} - \gamma_G G_a$$
$$\frac{dL}{dA_1} = -\frac{G_{La} - \gamma_g G_a}{G_{LL} + \gamma_c w^2 - \gamma_g G_L w}$$

Next, we use the first order condition for constrained production maximization. Some applications of the envelope theorem and taking derivatives yields

$$G_L = A_1 F_{1L}$$
$$G_a = F_1$$
$$G_{La} = F_{1L}(1 - dL_2/dL)$$
$$G_{LL} = A_1 F_{1LL}(1 - dL_2/dL)$$

Lastly, note that $\frac{dL_2}{dA_1} = \frac{dL_2}{dL}\frac{dL}{dA_1} + \frac{dL_2}{da}$, as the increase in A_1 shifts both arguments to G. Let FOC_{L_2} denote the left hand side of the first order condition for constrained production maximization. Then, applications of the implicit function theorem yield $\frac{dL_2}{dL} = -\frac{d\text{FOC}_{L_2}/dL}{d\text{FOC}_{L_2}/dL_2}$

and $\frac{dL_2}{da} = -\frac{d\text{FOC}_{L_2}/da}{d\text{FOC}_{L_2}/dL_2}$. Additional math yields

$$\begin{aligned}
\text{FOC}_{L_2} &= -aF_{1L} + A_2 F_{2L} \\
\frac{d\text{FOC}_{L_2}}{da} &= F_{1L} \\
\frac{d\text{FOC}_{L_2}}{dL} &= -aF_{1LL} \\
\frac{d\text{FOC}_{L_2}}{dL_2} &= aF_{1LL} + A_2 F_{2LL} \\
\frac{dL_2}{dL} &= \frac{aF_{1LL}}{aF_{1LL} + A_2 F_{2LL}} \\
\frac{dL_2}{da} &= -\frac{F_{1L}}{aF_{1LL} + A_2 F_{2LL}}
\end{aligned}$$

substituting these into our expression for $\frac{dL_2}{dA_1}$, and in turn our expressions for derivatives of G (in the numerator), yields

$$\begin{aligned}
\frac{dL_2}{dA_1} &= \frac{-A_1 F_{1LL}(G_{La} - \gamma_g G_a) + F_{1L}(G_{LL} + \gamma_c w^2 - \gamma_g G_L w)}{(A_1 F_{1LL} + A_2 F_{2LL})(G_{LL} + \gamma_c w^2 - \gamma_g G_L w)} \\
&= \frac{(F_{1L} w^2)\gamma_c - (F_{1L} w - F_{1LL} F_1) A_1 \gamma_g}{(A_1 F_{1LL} + A_2 F_{2LL})(G_{LL} + \gamma_c w^2 - \gamma_g G_L w)}
\end{aligned}$$

To sign this expression, note that the denominator is the product of two second order conditions, for utility maximization and for maximization of production subject to $L_1 = L - L_2$; each of these is negative, so the product is positive. Therefore $\text{sign}(dL_2/dA_1) = \text{sign}((F_{1L}w^2)\gamma_c - (F_{1L}w - F_{1LL}F_1)A_1\gamma_g)$. Next, note that $F_{1L}w^2 > 0$ and $-(F_{1L}w - F_{1LL}F_1)A_1 < 0$; therefore one sufficient condition for this derivative to be negative is that $\gamma_c < 0$ and $\gamma_g > 0$; in other words, increasing consumption reduces the marginal utility from consumption relative to the marginal utility from agricultural production, and increasing agricultural production increases the marginal utility from consumption relative to the marginal utility from agricultural production. The former generically holds under decreasing absolute risk aversion, while the latter holds under some restrictions; under these restrictions, $\frac{dL_2}{dA_1} < 0$.

For one sufficient restriction, we follow Karlan et al. (2014) and make restrictions on the distribution of σ. We assume that, for some $k > 1$, $\sigma = k$ with probability $\frac{1}{k}$ ("the good state") and $\sigma = 0$ with probability $\frac{k-1}{k}$ ("the bad state"); i.e., there is a crop failure with probability $\frac{k-1}{k}$. Under this assumption. Next, define $\overline{R} = -\frac{\mathbf{E}[u_c \frac{u_{cc}}{u_c}]}{\mathbf{E}[u_c]}$ to be the household's average risk aversion, and $R_k = -\mathbf{E}[\frac{u_{cc}}{u_c}|\sigma = k]$ to be the household's risk aversion in the good state. Note that by decreasing absolute risk aversion, $R_k < \overline{R}$. From this, it follows that

$$\gamma_c = \frac{\mathbf{E}[u_{cc}]}{\mathbf{E}[\sigma u_c]} - \frac{\mathbf{E}[\sigma u_{cc}]\mathbf{E}[u_c]}{\mathbf{E}[\sigma u_c]^2} = \gamma(R_k - \overline{R}) < 0$$
$$\gamma_g = \frac{\mathbf{E}[\sigma u_{cc}]}{\mathbf{E}[\sigma u_c]} - \frac{\mathbf{E}[\sigma^2 u_{cc}]\mathbf{E}[u_c]}{\mathbf{E}[\sigma u_c]^2} = (k-1)\frac{\mathbf{E}[u_c|\sigma = 0]}{\mathbf{E}[u_c|\sigma = k]} R_k = (k\gamma - 1)R_k > 0$$

Finally, consider the limit as household wealth increases, and assume that agricultural production will not grow infinitely with household wealth; this holds when the marginal product of labor on each plot falls sufficiently quickly and is true of typical decreasing returns to scale production functions. Then, $\lim_{\overline{M}\to\infty} \gamma = 1$ and $\lim_{\overline{M}\to\infty} \gamma_c = \lim_{\overline{M}\to\infty} \gamma_g = 0$, and therefore $\lim_{\overline{M}\to\infty} \frac{dL_2}{dA_1} = 0$. We therefore expect that, heuristically on average, $\frac{d^2 L_2}{dA_1 d\overline{M}} > 0$, as $\frac{dL_2}{dA_1} < 0$ and $\frac{dL_2}{dA_1}$ approaches 0 for large $\overline{M}$. As $\overline{L}$ and $\overline{M}$ enter symmetrically, the same results hold for $\overline{L}$.

Input constraint. When only the input constraint binds, the first order conditions simplify to

$$\begin{aligned}
(M_k) \quad & A_k F_{kM} && = (1 + \lambda_M) r \\
(L_k) \quad & A_k F_{kL} && = w \\
(\ell) \quad & \frac{\mathbf{E}[u_\ell]}{\mathbf{E}[u_c]} && = w
\end{aligned}$$

Note that the choice of leisure does not enter into the first order conditions for M_k or L_k.

Substituting $M_2 = \overline{M} - M_1$ yields the following system of equations

$$\begin{aligned} A_1 F_{1M}(M_1, L_1) - (1+\lambda_M)r = 0 \\ A_1 F_{1L}(M_1, L_1) - w = 0 \\ A_2 F_{2M}(\overline{M} - M_1, L_2) - (1+\lambda_M)r = 0 \\ A_2 F_{2L}(\overline{M} - M_1, L_2) - w = 0 \end{aligned}$$

Stack the left hand sides into the vector FOC_M. Define the Jacobian $J_M \equiv D_{(M_1,L_1,\lambda_M,L_2)}\mathrm{FOC}_M$. Applying the implicit function theorem yields $D_{(A_1)}(M_1, L_1, \lambda_M, L_2)' = -J_M^{-1} D_{(A_1)}\mathrm{FOC}_M$. Some algebra yields

$$J_M = \begin{pmatrix} A_1 F_{1MM} & A_1 F_{1ML} & -r & 0 \\ A_1 F_{1ML} & A_1 F_{1LL} & 0 & 0 \\ -A_2 F_{2MM} & 0 & -r & A_2 F_{2ML} \\ -A_2 F_{2ML} & 0 & 0 & A_2 F_{2LL} \end{pmatrix}$$

$$\begin{aligned} D_{(A_1)}\mathrm{FOC}_M &= (F_{1M}, F_{1L}, 0, 0)' \\ \frac{dM_2}{dA_1} &= k_M A_2 F_{2LL} A_1 (F_{1L}F_{1ML} - F_{1M}F_{1LL}) \\ \frac{dL_2}{dA_1} &= -k_M A_2 F_{2ML} A_1 (F_{1L}F_{1ML} - F_{1M}F_{1LL}) \end{aligned}$$

where k_M is positive.[55] As $F_{2LL} < 0$, $\mathrm{sign}\left(\frac{dM_2}{dA_1}\right) = -\mathrm{sign}\left(F_{1L}F_{1ML} - F_{1M}F_{1LL}\right)$. This is negative whenever productivity growth on plot 1 would cause optimal input allocations, holding fixed the shadow price of inputs, to increase on plot 1. Similarly, $\mathrm{sign}\left(\frac{dL_2}{dA_1}\right) = \mathrm{sign}(F_{2LM})\mathrm{sign}\left(\frac{dM_2}{dA_1}\right)$. The labor response and input response on the second plot have the same sign whenever labor and inputs are complements on the second plot.

[55] $k_M = -\frac{1}{(A_1 F_{1LL}) A_2^2 (F_{2MM}F_{2LL} - F_{2ML}^2) + (A_2 F_{2LL}) A_1^2 (F_{1MM}F_{1LL} - F_{1ML}^2)}$. We make standard assumptions required for unconstrained optimization; second order conditions for unconstrained optimization imply k_M is positive.

Labor constraint. When only the labor constraint binds, the first order conditions simplify to

$$\begin{aligned} (M_k) \quad & A_k F_{kM} && = r \\ (L_k) \quad & A_k F_{kL} && = (1-\lambda_L)w \\ (\ell) \quad & \tfrac{u_\ell}{u_c} && = (1-\lambda_L)w \end{aligned}$$

Substituting $\ell = \overline{L} - L^O - L_1 - L_2$ and $L^O = \overline{L^O}$, and some rearranging yields

$$\begin{aligned} A_1 F_{1M}(M_1, L_1) - r = 0 \\ A_1 F_{1L}(M_1, L_1) - (1+\lambda_L)w = 0 \\ A_2 F_{2M}(M_2, L_2) - r = 0 \\ A_2 F_{2L}(M_2, L_2) - (1+\lambda_L)w = 0 \end{aligned}$$

$$u_\ell\left(\sum_{k\in\{1,2\}} A_k F_k(M_k, L_k) + r(\overline{M} - M_1 - M_2) + w\overline{L^O}, \overline{L} - \overline{L^O} - L_1 - L_2\right) -$$
$$(1+\lambda_L)wu_c\left(\sum_{k\in\{1,2\}} A_k F_k(M_k, L_k) + r(\overline{M} - M_1 - M_2) + w\overline{L^O}, \overline{L} - \overline{L^O} - L_1 - L_2\right) = 0$$

Stack the left hand sides into the vector FOC_L.

Additionally, it will be convenient to define the following derivatives of on farm labor demand on plot k, LD_k, with respect to the shadow wage w^* and productivity A_k, on farm input demand on plot k, MD_k, with respect to productivity A_k, and on farm labor supply, LS, with respect to the shadow wage w^* and consumption (through shifts to wealth) c. Let

$$\begin{aligned}
\text{LD}_{kw^*} &= \frac{A_k F_{kMM}}{A_k^2(F_{kMM}F_{kLL} - F_{kML}^2)} \\
\text{LD}_{kA_k} &= \frac{A_k F_{kM}F_{kML} - A_k F_{kL}F_{kMM}}{A_k^2(F_{kMM}F_{kLL} - F_{kML}^2)} \\
\text{MD}_{kA_k} &= \frac{A_k F_{kL}F_{kML} - A_k F_{kM}F_{kLL}}{A_k^2(F_{kMM}F_{kLL} - F_{kML}^2)} \\
\text{LS}_{w^*} &= -\frac{u_c}{u_{\ell\ell} - (1+\lambda_L)wu_{c\ell}} \\
\text{LS}_c &= -\frac{u_{c\ell} - (1+\lambda_L)wu_{cc}}{u_{\ell\ell} - (1+\lambda_L)wu_{c\ell}}
\end{aligned}$$

We make standard assumptions required for unconstrained optimization; these imply LD_{kw^*} is negative (labor demand decreasing in shadow wage), and LS_{w^*} is positive (labor supply increasing in shadow wage). We further assume LD_{kA_k} and MD_{kA_k} are positive (labor demand and input demand are increasing in productivity); an additional sufficient assumption for this is that F is homogeneous. We further assume LS_c is negative (labor supply is decreasing in wealth); an additional sufficient assumption for this is that u is additively separable in c and ℓ.

Next, define the Jacobian $J_L \equiv D_{(M_1,L_1,M_2,L_2,\lambda_L)}\text{FOC}_L$. Some algebra yields

$$J_L = \begin{pmatrix} A_1F_{1MM} & A_1F_{1ML} & 0 & 0 & 0 \\ A_1F_{1ML} & A_1F_{1LL} & 0 & 0 & -w \\ 0 & 0 & A_2F_{2MM} & A_2F_{2ML} & 0 \\ 0 & 0 & A_2F_{2ML} & A_2F_{2LL} & -w \\ \frac{d\text{FOC}_{L,\ell}}{dM_1} & \frac{d\text{FOC}_{L,\ell}}{dL_1} & \frac{d\text{FOC}_{L,\ell}}{dM_2} & \frac{d\text{FOC}_{L,\ell}}{dL_2} & -wu_c \end{pmatrix}$$

$$\frac{d\text{FOC}_{L,\ell}}{dM_1} = A_1F_{1M}(u_{c\ell} - (1+\lambda_L)wu_{cc})$$

$$\frac{d\text{FOC}_{L,\ell}}{dL_1} = A_1F_{1L}(u_{c\ell} - (1+\lambda_L)wu_{cc}) - (u_{\ell\ell} - (1+\lambda_L)wu_{c\ell})$$

$$\frac{d\text{FOC}_{L,\ell}}{dM_2} = A_2F_{2M}(u_{c\ell} - (1+\lambda_L)wu_{cc})$$

$$\frac{d\text{FOC}_{L,\ell}}{dL_2} = A_2F_{2L}(u_{c\ell} - (1+\lambda_L)wu_{cc}) - (u_{\ell\ell} - (1+\lambda_L)wu_{c\ell})$$

Applying the implicit function theorem yields $D_{(A_1)}(M_1, L_1, M_2, L_2, \lambda_L)' = -J_L^{-1}D_{(A_1)}\text{FOC}_L$. Some further algebra, and substitution, yields

$$D_{(A_1)}\text{FOC}_L = (F_{1M}, F_{1L}, 0, 0, (u_{c\ell} - (1+\lambda_L)wu_{cc})F_1)'$$

$$\frac{dL_2}{dA_1} = \text{LD}_{2w^*}\frac{\text{LD}_{1A_1} - \text{LS}_c(F_{1M}\text{MD}_{1A_1} + F_{1L}\text{LD}_{1A_1} + F_1)}{\text{LS}_{w^*} - (\text{LD}_{1w^*} + \text{LD}_{2w^*}) - \text{LS}_c(\text{LD}_{1A_1} + \text{LD}_{2A_2})}$$

$$\frac{dL_2}{d\overline{L}} = \text{LD}_{2w^*}\frac{1}{\text{LS}_{w^*} - (\text{LD}_{1w^*} + \text{LD}_{2w^*}) - \text{LS}_c(\text{LD}_{1A_1} + \text{LD}_{2A_2})}$$

$$\frac{dL_2}{d\overline{M}} = \text{LD}_{2w^*}\frac{r\text{LS}_c}{\text{LS}_{w^*} - (\text{LD}_{1w^*} + \text{LD}_{2w^*}) - \text{LS}_c(\text{LD}_{1A_1} + \text{LD}_{2A_2})}$$

$\frac{dL_2}{dA_1} < 0$; for interpretation, note that this expression is the derivative of labor demand on plot 2 with respect to the shadow wage, times the effect of the shock to A_1 on the shadow wage. The numerator of the latter is the effect the shock on negative residual labor supply through direct effects (LD_{1A_1}) and wealth effects, including through adjustments of labor and inputs ($-\text{LS}_c(F_{1M}\text{MD}_{1A_1} + F_{1L}\text{LD}_{1A_1} + F_1)$). The denominator of the latter is the derivative of residual labor supply with respect to the shadow wage, adjusted for wealth effects ($\text{LS}_{w^*} - (\text{LD}_{1w^*} + \text{LD}_{2w^*}) - \text{LS}_c(\text{LD}_{1A_1} + \text{LD}_{2A_2})$).

The signs of $\frac{d^2 L_2}{d\bar{L}dA_1}$ and $\frac{d^2 L_2}{d\bar{M}dA_1}$ are ambiguous. However, unlike the cases of input market failures or insurance market failures, here these second derivatives may have opposite signs. To see one example of this, consider a case where on farm labor and input demands are approximately linear in the shadow wage and productivity, and on farm labor supply is approximately linear in consumption, but exhibits meaningful curvature with respect to the shadow wage. In this case, $\text{sign}(\frac{d^2 L_2}{d\bar{L}dA_1}) = \text{sign}\left(\frac{d}{d\bar{L}}\text{LS}_{w^*}\right)$ and $\text{sign}(\frac{d^2 L_2}{d\bar{L}dA_1}) = \text{sign}\left(\frac{d}{d\bar{M}}\text{LS}_{w^*}\right)$. To focus on one case, larger households are less responsive to the A_1 shock ($\frac{d^2 L_2}{d\bar{L}dA_1} > 0$) if and only if they are on a more elastic portion of their labor supply curve ($\frac{d}{d\bar{L}}\text{LS}_{w^*} > 0$). That larger households, with more labor available for agriculture, or poorer households, who likely have fewer productive opportunities outside agriculture, would be on a more elastic portion of their labor supply curve is consistent with proposed models of household labor supply dating back to Lewis (1954). This motivates the prediction we focus on: that larger households should be less responsive to the A_1 shock, and richer households should be more responsive to the A_1 shock.

E Experimental Appendix

E.1 Experimental design

We conducted three randomized controlled trials in these hillside irrigation schemes. First, we manipulated operations and maintenance (O&M) in the hillside irrigation schemes, by randomly assigning water user groups to different approaches to monitoring. Qualitative work raised concerns that the water user groups as established would not be sufficient to enforce water usage schedules and that routine maintenance tasks would not be performed adequately, as has been documented by Ostrom (1990). Second, we subsidized water usage fees the government had planned to collect from farmers, which were as high as 77,000 RwF/ha/year. For reference, this is roughly 20% of our dry season treatment on the treated estimates, and roughly 50% of median land rental prices. If farmers believed that they were more likely to be required to pay the fees if they used the irrigation infrastructure, then these fees had the potential to influence farmers production decisions, (even though they are small relative to potential yield gains from irrigation use). Third, we provided agricultural minikits, which included 0.02 ha of seeds, chemical fertilizer, and insecticide, which could be used for horticulture cultivation. In other contexts, minikits of similar size relative to median landholdings have been shown to increase adoption of new crop varieties or varieties with low levels of adoption (Emerick et al., 2016; Jones et al., 2018). Although horticulture is not unfamiliar in these areas, at baseline 3.2% of plots outside the command area were planted with at least some horticulture, and primarily during the rainy seasons.

Assignment to experimental arms for O&M, minikits, and subsidies were as follows. First, for the O&M intervention, 251 water user groups across three irrigation sites were randomized, stratified across the 33 Zones these irrigation sites are divided into, into three arms.[56] Second, for the minikit intervention, water user groups were randomly assigned to 20%, 60% or 100% saturation, with rerandomization for balance on Zone and O&M treatment status. Following this assignment, individuals on the lists of water user group members provided to us by the sites were randomly assigned to receive minikits with probabilities equal to that water user group's saturation. Minikits were offered to assigned individuals prior to 2017 Rainy 1 and 2017 Dry. Third, for the subsidy intervention, our implementing partner was concerned with the perception of an assignment rule that might be perceived as hidden, so public lotteries for subsidies were conducted at the Zone level.[57]

[56] 40% were assigned to a status quo arm where the irrigator/operators employed by the site were responsible for enforcing water usage schedules and reporting O&M problems to the local Water User Association. 30% were assigned to an arm where the water user group elected a monitor who was tasked with these responsibilities, trained in implementing them, and given worksheets to fill and return to the Water User Association reporting challenges with enforcement of the water usage schedule and any O&M concerns. In an additional 30%, the elected monitor was required to have a plot near the top of the water user group, where the flow of water is most negatively impacted when too many farmers try to irrigate at once. Monitors were trained just before the 2016 Dry season, with refresher trainings during 2016 Dry and 2017 Rainy 1.

[57] At these public lotteries, 40% of farmers received no subsidy, 20% received a 50% subsidy for one season, 20% received a 100% subsidy for one season, and 20% received a 100% subsidy for two seasons. The lotteries took place at the start of the 2017 Rainy 1, and subsidies were for 2017 Rainy 1 and 2017 Rainy 2; at the time the Water User Associations did not plan to collect fees during the Dry season.

E.2 O&M and Fee Subsidies

We find no effects of empowering monitors and fee subsidies on agricultural decisions in our context; we offer some qualitative evidence and simple descriptives from our data that explain these null effects.[58]

First, we find no impact of empowering monitors. This is because O&M was highly effective in these irrigation schemes, and empowering monitors therefore had limited scope for changing O&M practices. Farmers reported 14% as many days without enough water during the dry seasons as they reported days using irrigation. Any event where conflict among water user group members caused insufficient water at some point during the dry season was reported for 3% of irrigated plots.[59] This success was far from guaranteed in the early years of the schemes; site engineers have suggested that the combination of lower adoption of irrigation than the schemes are designed for and high compliance with water usage schedules among farmers have been the cause of this. Moreover, during the 2018 Dry season we found evidence that control water user groups adopted the intervention, as some members of control water user groups adopted the roles that were assigned to monitors.

Second, we find no impact of fee subsidies. The reason for this is clear – although we have a strong and large first stage on fees owed by farmers in administrative data, the impacts of subsidies on feed paid by farmers were 10% of the size of the impacts on fees owed, both in administrative data and self reports. Moreover, the fees were implemented as land taxes and not charged based on irrigation use so as not to discourage adoption. In sum, at the low levels of enforcement observed during the 2017 Rainy seasons, they should not have affected farmers' production decisions, consistent with the results we find.

[58] Results are available upon request.

[59] This magnitude is small; as reference, Sekhri (2014) finds the share of farmers reporting disputes over ground water in India increases by 29pp when water tables become sufficiently low.

F Baseline results

We present results from 2014 Dry, when the hillside irrigation systems were online in only a small part of the sites, and from 2015 Rainy 1 and Rainy 2, when hillside irrigation was just beginning to come online. These surveys were just a few years after terracing occurred, and shortly after the construction of the hillside irrigation schemes was completed.

To begin, we estimate specifications (1), (2), and (3) in Tables A2, A3, A4, and A5.

First, in Table A2, we consider two additional impacts of command area construction. First, terracing occurred jointly with hillside irrigation. Although there was also meaningful terracing outside the command area to protect against erosion, there was much more terracing inside the command area, as it is impossible to have hillside irrigation without terracing (as water would run off the sloped hillsides). We therefore note that our effects are the combined effect of terracing and access to irrigation. However, we also note that irrigation is used almost exclusively for dry season horticulture, and our results in Section 3 are fully explained by crop fixed effects, providing suggestive evidence that the transition to dry season horticulture enabled by access to irrigation, as opposed to any direct productivity effects conditional on crop choice caused by terracing, drives our results. Second, rentals out to commercial farmers occurred inside the command area, as these commercial farmers were keen to take advantage of access to irrigation. These commercial farmers were private businesses exporting vegetables and they had negotiated land lease rates with the government, and as such they were not willing to share detailed data on their profitability. We discuss the implications of this differential attrition for our results in Section G.

In addition, while our primarily agricultural outcomes for analysis are from recall over the past three agricultural seasons, our measure of food security comes from the past week of food consumption. Our baseline survey was conducted from August - October 2015, so most irrigating households would have just recently harvested and sold any 2015 Dry horticultural production. Consistent with this, in Table A2 we find significant impacts of the command area on food security at baseline.

Second, in Table A3, we estimate impacts on cultivation, irrigation, and crop choice decisions; consistent with irrigation not having come fully online, we observe limited adoption of irrigation. In contrast to our main results from follow up surveys, at baseline cultivation is lower in the dry season inside the command area. This is driven by a combination of low adoption of irrigation and horticulture (only 2 - 5pp higher in the command area than outside the command area), and lower cultivation of bananas (8 - 10pp lower). These banana effects are partially explained by terracing, during which bananas were torn up to construct the terraces. These banana effects are smaller than in follow up surveys, and the share of plots cultivated with bananas is also lower outside the command area than in follow up surveys. Together, we interpret these results as farmers beginning to replant bananas following terracing, but less replanting occurring inside the command area than outside. As irrigation had come online by 2015 Rainy 1 and 2, rainy season results look similar to rainy season results in subsequent seasons – modestly lower cultivation, and significant but modest increases in adoption of irrigation and horticulture, and reduced banana cultivation.

Third, we estimate impacts on inputs in Table A4, and output in Table A5. Consistent with the small increases in horticulture and modestly larger decreases in low input intensive bananas, we do not find consistent significant effects on input use, yields, sales, or measures of profits in the dry season or rainy season.

Lastly, as the command area, as of the baseline, had not yet caused a large increase in demand for labor or inputs, or caused large increases in agricultural production, we do not anticipate any MIP effects. As a placebo check, we present MIP results, estimating specifications (7), (8), and (9), and specifications with heterogeneity following Equation (10). We present these results in Tables A6, A7, A8, A9, and A10. In line with our prediction, we fail to find any consistent significant effects on MIPs, either in our main specifications or for heterogeneity.

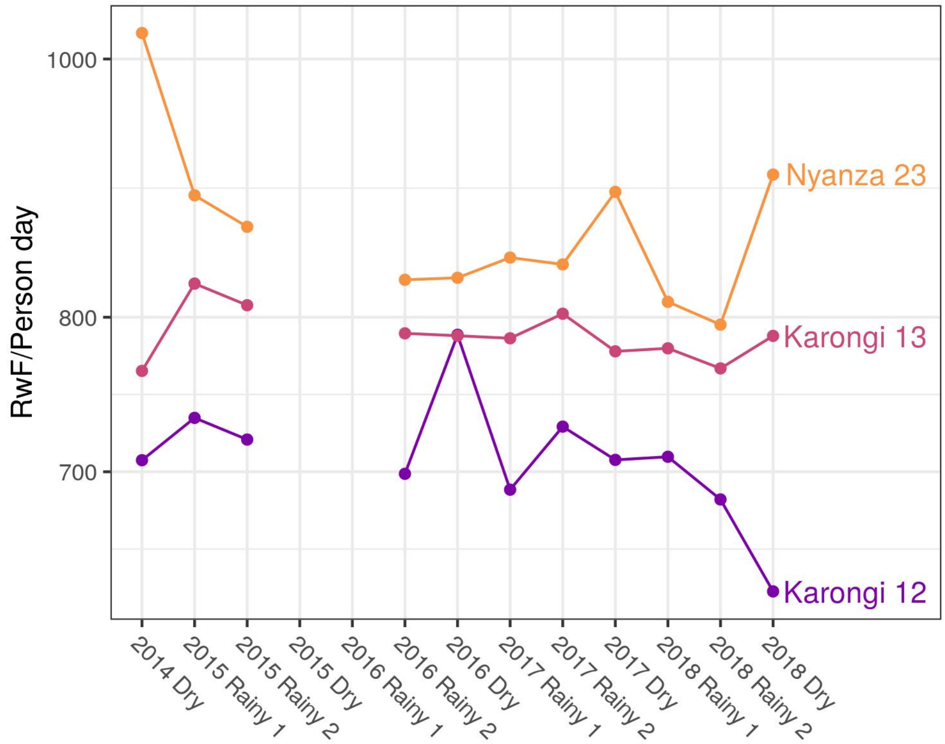
G Attrition

We present results on attrition for our sample plot regressions for specifications (1), (2), and (3) in Table A11; we do not find significant differential attrition on the MIP. Additionally, we break attrition down into three causes: household attrition (typically caused by the household having moved), transactions to other local farmers where we failed to track the plot across the transaction, and rentals out to commercial farmers.

We find significant differential attrition, but this differential attrition is driven almost entirely by rentals out to commercial farmers in one of the two sites. These were private businesses exporting vegetables and they had negotiated land lease rates with the government, and as such they were not willing to share detailed data on their profitability. Because they were producing chillies and stevia for export, land rented out to commercial farmers is likely to have much higher production and to be farmed more intensively, and therefore not having it in our data biases our main estimates downwards. Additionally, the commercial farmers preferred to rent land in the most productive areas of the sites, and therefore our estimates are if anything biased downward relative to the effect of access to irrigation on production for local farmers.

Some discussion of the two other sources of attrition is potentially warranted. First, excluding rentals out to commercial farmers, attrition is low, at 4.8% outside the command area, and is a non statistically significant 0.9 - 3.5pp higher inside the command area. However, in one specification we do find 3.2pp higher household attrition statistically significant at the 10% level. Lastly, tracking plots was important to correct for differential attrition – although command area plots were not differentially likely to be transacted to other farmers and not tracked, they were significantly more likely to be transacted to other farmers and tracked during the dry season (1.8 - 3.5pp).

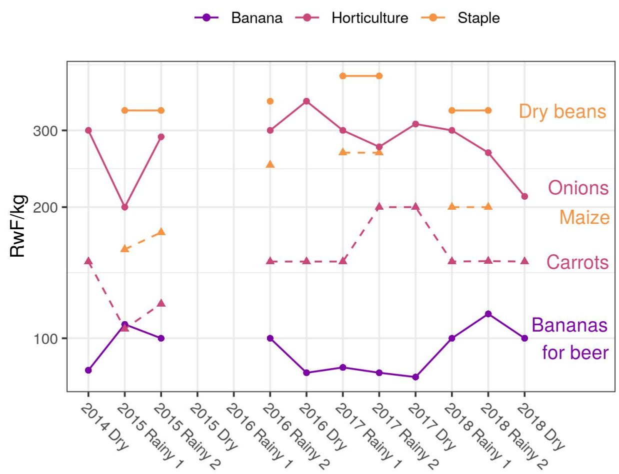
Figure A1: Wages



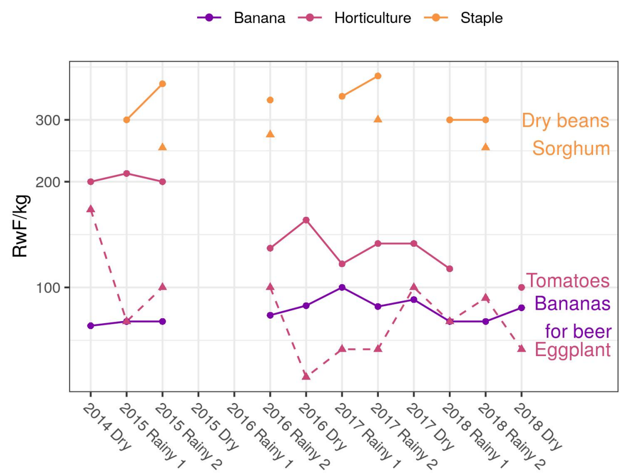
Notes: Average wages by season across the three hillside irrigation schemes are presented in this figure. Average wages are calculated across household-by-plot-by-season observations within site-by-season and are weighted by person days of hired labor.

Figure A2: Prices

(a) Karongi



(b) Nyanza



Notes: Median sale prices by season are presented in this figure. Prices are calculated separately for Karongi district (Karongi 12 and Karongi 13) and for Nyanza district (Nyanza 23). For each district, prices are calculated for the most commonly sold banana crop, the two most commonly sold staple crops, and the two most commonly sold horticultural crops.

Table A1: Household welfare

	RD sample			
	Dep. var.	Coef. (SE) [p]		
	(1)	(2)	(3)	(4)
Housing expenditures	28.03	6.35	12.10	13.91
	(86.45)	(5.00)	(6.73)	(8.25)
	2,771	[0.204]	[0.072]	[0.092]
Asset index	-0.14	0.11	0.13	0.05
	(0.95)	(0.07)	(0.11)	(0.12)
	2,776	[0.104]	[0.224]	[0.668]
Food security index	-0.12	0.08	0.07	0.07
	(0.98)	(0.06)	(0.08)	(0.10)
	2,772	[0.167]	[0.372]	[0.509]
Overall index	-0.08	0.08	0.12	0.11
	(0.68)	(0.05)	(0.07)	(0.08)
	2,764	[0.071]	[0.077]	[0.191]
Site-by-survey FE		X	X	
Distance to boundary			X	X
log area			X	X
Spatial FE				X

Notes: Regression analysis is presented in this table. Column 1 presents, for sample plots in the main discontinuity sample that are outside the command area, the mean of the dependent variable, the standard deviation of the dependent variable in parentheses, and the total number of observations. Columns 2 through 4 present regression coefficients on a command area indicator, with standard errors in parentheses, and p-values in brackets. Robust standard errors are clustered at the nearest water user group level in specifications without Spatial FE, and Conley (1999) standard errors are used in specifications with Spatial FE. Column 2 uses the specification in Equation (1). Column 3 uses the regression discontinuity specification in Equation (2). Column 4 uses the spatial fixed effects specification in Equation (3).

Table A2: Terracing, baseline rentals to commercial farmer, and baseline food security in command area

	RD sample			
	Dep. var.	Coef. (SE) [p]		
	(1)	(2)	(3)	(4)
Terraced	0.484	0.428	0.407	0.450
	(0.500)	(0.034)	(0.055)	(0.053)
	969	[0.000]	[0.000]	[0.000]
Rented out, comm. farmer	0.018	0.183	0.173	0.168
	(0.132)	(0.029)	(0.031)	(0.044)
	969	[0.000]	[0.000]	[0.000]
Omnibus F-stat [p]		84.6	37.7	37.3
		[0.000]	[0.000]	[0.000]
Site FE		X	X	
Distance to boundary			X	X
log area			X	X
Spatial FE				X

	RD sample			
	Dep. var.	Coef. (SE) [p]		
	(1)	(2)	(3)	(4)
Food security index	-0.13	0.16	0.19	0.15
	(0.98)	(0.06)	(0.10)	(0.10)
	968	[0.008]	[0.053]	[0.122]
Site-by-survey FE		X	X	
Distance to boundary			X	X
log area			X	X
Spatial FE				X

Notes: Regression analysis is presented in this table. Column 1 presents, for sample plots in the main discontinuity sample that are outside the command area, the mean of the dependent variable, the standard deviation of the dependent variable in parentheses, and the total number of observations. Columns 2 through 4 present regression coefficients on a command area indicator, with standard errors in parentheses, and p-values in brackets. Robust standard errors are clustered at the nearest water user group level in specifications without Spatial FE, and Conley (1999) standard errors are used in specifications with Spatial FE. Column 2 uses the specification in Equation (1). Column 3 uses the regression discontinuity specification in Equation (2). Column 4 uses the spatial fixed effects specification in Equation (3).

Table A3: Sample plots (baseline)

	Dry season				Rainy seasons			
	Dep. var.	Coef. (SE) [p]			Dep. var.	Coef. (SE) [p]		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cultivated	0.211	-0.099	-0.128	-0.120	0.756	-0.049	-0.067	-0.048
	(0.409)	(0.030)	(0.046)	(0.051)	(0.430)	(0.027)	(0.038)	(0.042)
	894	[0.001]	[0.005]	[0.020]	1,632	[0.074]	[0.076]	[0.261]
Irrigated	0.009	0.045	0.029	0.029	0.011	0.044	0.043	0.041
	(0.095)	(0.012)	(0.016)	(0.016)	(0.103)	(0.009)	(0.011)	(0.015)
	894	[0.000]	[0.068]	[0.067]	1,632	[0.000]	[0.000]	[0.006]
Horticulture	0.012	0.044	0.019	0.014	0.042	0.080	0.057	0.064
	(0.109)	(0.014)	(0.019)	(0.018)	(0.200)	(0.015)	(0.022)	(0.029)
	894	[0.001]	[0.304]	[0.454]	1,632	[0.000]	[0.008]	[0.029]
Banana	0.145	-0.097	-0.103	-0.077	0.162	-0.101	-0.104	-0.093
	(0.352)	(0.022)	(0.036)	(0.041)	(0.369)	(0.022)	(0.037)	(0.038)
	894	[0.000]	[0.005]	[0.060]	1,632	[0.000]	[0.005]	[0.015]
Site-by-season FE		X	X			X	X	
Distance to boundary			X	X			X	X
log area			X	X			X	X
Spatial FE				X				X

Notes: Regression analysis is presented in this table. Columns 1 through 4 restrict to observations during the dry season, while columns 5 through 8 restrict to observations during the rainy season. Columns 1 and 5 present, for sample plots in the main discontinuity sample that are outside the command area, the mean of the dependent variable, the standard deviation of the dependent variable in parentheses, and the total number of observations. Columns 2 through 4 and 6 through 8 present regression coefficients on a command area indicator, with standard errors in parentheses, and p-values in brackets. Robust standard errors are clustered at the nearest water user group level in specifications without Spatial FE, and Conley (1999) standard errors are used in specifications with Spatial FE. Columns 2 and 6 use the specification in Equation (1). Columns 3 and 7 use the regression discontinuity specification in Equation (2). Columns 4 and 8 use the spatial fixed effects specification in Equation (3).

Table A4: Sample plots (baseline)

	Dry season				Rainy seasons			
	Dep. var.	Coef. (SE) [p]			Dep. var.	Coef. (SE) [p]		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
HH labor/ha	41.3	-7.7	-26.9	-39.5	225.4	-13.6	-5.5	-7.3
	(180.0)	(14.6)	(23.6)	(28.2)	(321.7)	(20.6)	(23.5)	(34.4)
	890	[0.598]	[0.255]	[0.162]	1,621	[0.508]	[0.815]	[0.831]
Input exp./ha	1.9	2.2	1.6	1.5	12.5	1.3	2.3	4.4
	(18.3)	(1.5)	(2.1)	(2.0)	(34.8)	(2.2)	(3.4)	(3.9)
	894	[0.133]	[0.437]	[0.458]	1,632	[0.560]	[0.492]	[0.265]
Hired labor exp./ha	0.8	2.2	0.7	-0.1	12.8	6.5	3.0	3.9
	(5.7)	(1.2)	(1.4)	(1.6)	(42.8)	(2.9)	(4.2)	(6.0)
	894	[0.060]	[0.623]	[0.930]	1,632	[0.025]	[0.480]	[0.518]
Site-by-season FE		X	X			X	X	
Distance to boundary			X	X			X	X
log area			X	X			X	X
Spatial FE				X				X

Notes: Regression analysis is presented in this table. Columns 1 through 4 restrict to observations during the dry season, while columns 5 through 8 restrict to observations during the rainy season. Columns 1 and 5 present, for sample plots in the main discontinuity sample that are outside the command area, the mean of the dependent variable, the standard deviation of the dependent variable in parentheses, and the total number of observations. Columns 2 through 4 and 6 through 8 present regression coefficients on a command area indicator, with standard errors in parentheses, and p-values in brackets. Robust standard errors are clustered at the nearest water user group level in specifications without Spatial FE, and Conley (1999) standard errors are used in specifications with Spatial FE. Columns 2 and 6 use the specification in Equation (1). Columns 3 and 7 use the regression discontinuity specification in Equation (2). Columns 4 and 8 use the spatial fixed effects specification in Equation (3).

Table A5: Sample plots (baseline)

	Dry season				Rainy seasons			
	Dep. var.	Coef. (SE) [p]			Dep. var.	Coef. (SE) [p]		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Yield	46.5	-20.0	-30.4	-31.4	171.2	11.4	5.7	-1.6
	(216.3)	(17.3)	(23.5)	(30.4)	(307.4)	(19.0)	(22.8)	(29.0)
	868	[0.249]	[0.197]	[0.302]	1,585	[0.548]	[0.804]	[0.957]
Sales/ha	27.1	-2.4	-26.2	-37.2	45.0	26.1	9.5	24.5
	(148.7)	(11.3)	(21.7)	(28.7)	(144.7)	(9.7)	(13.8)	(17.9)
	894	[0.829]	[0.227]	[0.194]	1,632	[0.007]	[0.491]	[0.170]
Profits/ha								
Shadow wage = 0	45.0	-22.8	-31.7	-32.6	146.2	5.8	0.5	-9.6
	(208.5)	(16.6)	(22.1)	(29.2)	(302.9)	(18.7)	(23.2)	(28.9)
	868	[0.169]	[0.153]	[0.264]	1,585	[0.757]	[0.984]	[0.739]
Shadow wage = 800	13.4	-11.5	-16.4	-7.9	-30.0	13.9	2.8	-6.5
	(108.7)	(7.2)	(13.9)	(19.2)	(266.1)	(15.4)	(24.0)	(35.0)
	864	[0.113]	[0.240]	[0.682]	1,575	[0.369]	[0.906]	[0.853]
Site-by-season FE		X	X			X	X	
Distance to boundary			X	X			X	X
log area			X	X			X	X
Spatial FE				X				X

Notes: Regression analysis is presented in this table. Columns 1 through 4 restrict to observations during the dry season, while columns 5 through 8 restrict to observations during the rainy season. Columns 1 and 5 present, for sample plots in the main discontinuity sample that are outside the command area, the mean of the dependent variable, the standard deviation of the dependent variable in parentheses, and the total number of observations. Columns 2 through 4 and 6 through 8 present regression coefficients on a command area indicator, with standard errors in parentheses, and p-values in brackets. Robust standard errors are clustered at the nearest water user group level in specifications without Spatial FE, and Conley (1999) standard errors are used in specifications with Spatial FE. Columns 2 and 6 use the specification in Equation (1). Columns 3 and 7 use the regression discontinuity specification in Equation (2). Columns 4 and 8 use the spatial fixed effects specification in Equation (3).

Table A6: Most important plot (baseline)

	Sample plot	MIP						
	Coef. (SE) [p]	Dep. var.	Coef. (SE) [p]					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Cultivated								
CA	-0.099	0.186	0.041	0.034	0.018	0.025	0.015	0.039
	(0.030)	(0.390)	(0.029)	(0.048)	(0.058)	(0.040)	(0.058)	(0.068)
	[0.001]	751	[0.160]	[0.476]	[0.750]	[0.528]	[0.800]	[0.566]
CA * MIP CA						0.043	0.046	-0.046
						(0.062)	(0.062)	(0.069)
						[0.492]	[0.461]	[0.512]
Joint F-stat [p]						1.4	0.6	0.2
						[0.240]	[0.541]	[0.779]
Irrigated								
CA	0.045	0.030	-0.000	0.018	0.004	-0.001	0.020	0.009
	(0.012)	(0.172)	(0.014)	(0.018)	(0.019)	(0.011)	(0.016)	(0.017)
	[0.000]	751	[0.973]	[0.308]	[0.853]	[0.920]	[0.196]	[0.624]
CA * MIP CA						-0.002	-0.005	-0.011
						(0.031)	(0.030)	(0.029)
						[0.936]	[0.869]	[0.700]
Joint F-stat [p]						0.0	0.8	0.2
						[0.988]	[0.430]	[0.854]
Site-by-season FE	X		X	X		X	X	
Distance to boundary				X	X		X	X
log area				X	X		X	X
Spatial FE					X			X
MIP log area				X	X		X	X
MIP CA				X	X	X	X	X

Notes: Regression analysis is presented in this table. Column 1 uses outcomes on the sample plot (and replicates analysis in Table A3), while Columns 3 through 8 use outcomes on the associated most important plot. All columns restrict to observations during the dry season. Column 2 presents, for the most important plot associated with sample plots in the main discontinuity sample that are outside the command area, the mean of the dependent variable, the standard deviation of the dependent variable in parentheses, and the total number of observations. For Columns 1 and 3 through 8, Rows "CA" present coefficients on a command area indicator for the sample plot, while Rows "CA * MIP in CA" present coefficients on the interaction of a command area indicator for the sample plot with a command area indicator for the most important plot; standard errors are in parentheses, and p-values are in brackets. Robust standard errors are clustered at the nearest water user group level in specifications without Spatial FE, and Conley (1999) standard errors are used in specifications with Spatial FE. Column 3 uses the specification in Equation (7), Column 4 uses the specification in Equation (8), and Column 5 uses the specification in Equation (9). Columns 6 though 8 uses analogous specifications building on Equation (10).

Table A7: Most important plot (baseline)

	Sample plot	MIP						
	Coef. (SE) [p]	Dep. var.	Coef. (SE) [p]					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Horticulture								
CA	0.044	0.027	0.004	0.017	0.014	0.005	0.021	0.022
	(0.014)	(0.161)	(0.013)	(0.017)	(0.016)	(0.009)	(0.016)	(0.015)
	[0.001]	751	[0.738]	[0.309]	[0.367]	[0.583]	[0.195]	[0.140]
CA * MIP CA						-0.006	-0.009	-0.018
						(0.030)	(0.030)	(0.031)
						[0.852]	[0.773]	[0.549]
Joint F-stat [p]						0.2	0.9	1.1
						[0.858]	[0.429]	[0.337]
Banana								
CA	-0.097	0.129	0.054	0.037	0.048	0.040	0.016	0.056
	(0.022)	(0.336)	(0.025)	(0.038)	(0.046)	(0.038)	(0.050)	(0.057)
	[0.000]	751	[0.031]	[0.327]	[0.293]	[0.291]	[0.752]	[0.325]
CA * MIP CA						0.043	0.051	-0.018
						(0.050)	(0.050)	(0.058)
						[0.388]	[0.311]	[0.759]
Joint F-stat [p]						4.6	1.6	0.6
						[0.011]	[0.214]	[0.572]
Site-by-season FE	X		X	X		X	X	
Distance to boundary				X	X		X	X
log area				X	X		X	X
Spatial FE					X			X
MIP log area				X	X		X	X
MIP CA				X	X	X	X	X

Notes: Regression analysis is presented in this table. Column 1 uses outcomes on the sample plot (and replicates analysis in Table A3), while Columns 3 through 8 use outcomes on the associated most important plot. All columns restrict to observations during the dry season. Column 2 presents, for the most important plot associated with sample plots in the main discontinuity sample that are outside the command area, the mean of the dependent variable, the standard deviation of the dependent variable in parentheses, and the total number of observations. For Columns 1 and 3 through 8, Rows "CA" present coefficients on a command area indicator for the sample plot, while Rows "CA * MIP in CA" present coefficients on the interaction of a command area indicator for the sample plot with a command area indicator for the most important plot; standard errors are in parentheses, and p-values are in brackets. Robust standard errors are clustered at the nearest water user group level in specifications without Spatial FE, and Conley (1999) standard errors are used in specifications with Spatial FE. Column 3 uses the specification in Equation (7), Column 4 uses the specification in Equation (8), and Column 5 uses the specification in Equation (9). Columns 6 though 8 uses analogous specifications building on Equation (10).

Table A8: Most important plot (baseline)

	Sample plot	MIP						
	Coef. (SE) [p]	Dep. var.	Coef. (SE) [p]					
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
HH labor/ha								
CA	-7.7	40.6	-15.0	-9.5	-37.5	-9.6	-2.4	-23.5
	(14.6)	(184.3)	(12.2)	(20.5)	(27.0)	(11.9)	(26.2)	(31.2)
	[0.598]	747	[0.222]	[0.642]	[0.165]	[0.420]	[0.927]	[0.452]
CA * MIP CA						-14.8	-16.9	-31.0
						(27.0)	(27.4)	(28.8)
						[0.586]	[0.538]	[0.281]
Joint F-stat [p]						0.8	0.4	1.7
						[0.449]	[0.663]	[0.177]
Input exp./ha								
CA	2.2	1.4	1.7	3.6	0.1	1.9	3.8	1.2
	(1.5)	(14.7)	(1.5)	(1.5)	(1.3)	(1.2)	(1.9)	(1.2)
	[0.133]	751	[0.262]	[0.017]	[0.965]	[0.121]	[0.039]	[0.292]
CA * MIP CA						-0.6	-0.6	-2.6
						(3.1)	(3.2)	(3.7)
						[0.846]	[0.859]	[0.478]
Joint F-stat [p]						1.2	3.0	0.6
						[0.298]	[0.053]	[0.573]
Hired labor exp./ha								
CA	2.2	5.1	-4.0	-7.5	-11.6	-2.9	-6.3	-10.0
	(1.2)	(32.8)	(2.2)	(4.2)	(5.7)	(2.4)	(5.4)	(6.8)
	[0.060]	751	[0.061]	[0.078]	[0.041]	[0.227]	[0.240]	[0.142]
CA * MIP CA						-2.9	-2.8	-3.6
						(4.5)	(4.7)	(5.6)
						[0.522]	[0.554]	[0.524]
Joint F-stat [p]						1.8	2.6	2.8
						[0.168]	[0.079]	[0.059]
Site-by-season FE	X		X	X		X	X	
Distance to boundary				X	X		X	X
log area				X	X		X	X
Spatial FE					X			X
MIP log area				X	X		X	X
MIP CA				X	X	X	X	X

Notes: Regression analysis is presented in this table. Column 1 uses outcomes on the sample plot (and replicates analysis in Table A4), while Columns 3 through 8 use outcomes on the associated most important plot. All columns restrict to observations during the dry season. Column 2 presents, for the most important plot associated with sample plots in the main discontinuity sample that are outside the command area, the mean of the dependent variable, the standard deviation of the dependent variable in parentheses, and the total number of observations. For Columns 1 and 3 through 8, Rows "CA" present coefficients on a command area indicator for the sample plot, while Rows "CA * MIP in CA" present coefficients on the interaction of a command area indicator for the sample plot with a command area indicator for the most important plot; standard errors are in parentheses, and p-values are in brackets. Robust standard errors are clustered at the nearest water user group level in specifications without Spatial FE, and Conley (1999) standard errors are used in specifications with Spatial FE. Column 3 uses the specification in Equation (7), Column 4 uses the specification in Equation (8), and Column 5 uses the specification in Equation (9). Columns 6 though 8 uses analogous specifications building on Equation (10).

Table A9: Heterogeneity with respect to household size and wealth (baseline)

	MIP		
	Coef. (SE) [p]		
	(1)	(2)	(3)
Cultivated			
CA	0.150	0.135	0.079
	(0.086)	(0.085)	(0.104)
	[0.080]	[0.113]	[0.446]
CA * # of HH members	-0.023	-0.021	-0.013
	(0.016)	(0.016)	(0.019)
	[0.160]	[0.185]	[0.507]
CA * Asset index	0.005	-0.003	0.033
	(0.037)	(0.037)	(0.047)
	[0.891]	[0.940]	[0.482]
Joint F-stat [p]	1.5	1.2	0.2
	[0.217]	[0.306]	[0.867]
Irrigated			
CA	0.027	0.045	0.013
	(0.042)	(0.046)	(0.045)
	[0.518]	[0.333]	[0.776]
CA * # of HH members	-0.006	-0.005	-0.002
	(0.008)	(0.008)	(0.008)
	[0.475]	[0.498]	[0.811]
CA * Asset index	0.008	0.008	0.010
	(0.017)	(0.017)	(0.018)
	[0.652]	[0.656]	[0.587]
Joint F-stat [p]	0.2	0.4	0.1
	[0.915]	[0.736]	[0.933]
# of HH members	X	X	X
Asset index	X	X	X
Site-by-season FE	X	X	
Distance to boundary		X	X
log area		X	X
MIP log area		X	X
MIP CA		X	X
Spatial FE			X

	MIP		
	Coef. (SE) [p]		
	(1)	(2)	(3)
Horticulture			
CA	0.002	0.013	-0.002
	(0.039)	(0.040)	(0.037)
	[0.952]	[0.741]	[0.957]
CA * # of HH members	0.000	0.001	0.003
	(0.007)	(0.007)	(0.008)
	[0.968]	[0.940]	[0.687]
CA * Asset index	-0.003	-0.003	0.000
	(0.017)	(0.016)	(0.018)
	[0.860]	[0.857]	[0.992]
Joint F-stat [p]	0.0	0.3	0.3
	[0.986]	[0.810]	[0.852]
Banana			
CA	0.093	0.067	0.051
	(0.071)	(0.065)	(0.082)
	[0.191]	[0.300]	[0.531]
CA * # of HH members	-0.008	-0.007	-0.000
	(0.013)	(0.013)	(0.015)
	[0.535]	[0.611]	[0.988]
CA * Asset index	0.011	0.002	0.043
	(0.031)	(0.030)	(0.041)
	[0.725]	[0.959]	[0.284]
Joint F-stat [p]	1.7	0.5	0.7
	[0.175]	[0.658]	[0.527]
# of HH members	X	X	X
Asset index	X	X	X
Site-by-season FE	X	X	
Distance to boundary		X	X
log area		X	X
MIP log area		X	X
MIP CA		X	X
Spatial FE			X

Notes: Regression analysis is presented in this table. All columns use outcomes on most important plots and restrict to observations during the dry season.. Rows "CA" present coefficients on a command area indicator for the sample plot, while Rows "CA * W" present coefficients on the interaction of a command area indicator for the sample plot with a household characteristic W; standard errors are in parentheses, and p-values are in brackets. Robust standard errors are clustered at the nearest water user group level in specifications without Spatial FE, and Conley (1999) standard errors are used in specifications with Spatial FE. The Row "Joint F-stat [p]" presents F-statistics for the null that all 3 coefficients are 0, with the p-value for the associated test in brackets. Columns 1, 2, and 3 use regression specifications building on Equation (10) following Equations (7), (8), and (9), respectively.

Table A10: Heterogeneity with respect to household size and wealth (baseline)

	MIP		
	Coef. (SE) [p]		
	(1)	(2)	(3)
HH labor/ha			
CA	8.3	19.3	-20.7
	(32.3)	(29.8)	(31.6)
	[0.797]	[0.518]	[0.512]
CA * # of HH members	-5.0	-6.3	-3.8
	(5.6)	(5.5)	(6.1)
	[0.378]	[0.255]	[0.532]
CA * Asset index	-13.6	-10.8	-11.9
	(17.3)	(16.4)	(15.9)
	[0.430]	[0.507]	[0.454]
Joint F-stat [p]	1.1	1.2	0.7
	[0.331]	[0.311]	[0.541]
Input exp./ha			
CA	-1.7	0.3	-3.0
	(4.7)	(3.8)	(3.5)
	[0.715]	[0.935]	[0.386]
CA * # of HH members	0.7	0.6	0.6
	(0.8)	(0.8)	(0.6)
	[0.432]	[0.426]	[0.325]
CA * Asset index	-2.8	-2.7	-1.9
	(2.3)	(2.2)	(2.0)
	[0.236]	[0.222]	[0.343]
Joint F-stat [p]	2.0	2.5	0.7
	[0.121]	[0.057]	[0.575]
# of HH members	X	X	X
Asset index	X	X	X
Site-by-season FE	X	X	
Distance to boundary		X	X
log area		X	X
MIP log area		X	X
MIP CA		X	X
Spatial FE			X

	MIP		
	Coef. (SE) [p]		
	(1)	(2)	(3)
Hired labor exp./ha			
CA	-6.6	-9.8	-12.4
	(5.8)	(6.0)	(6.1)
	[0.256]	[0.099]	[0.044]
CA * # of HH members	0.4	0.3	0.0
	(0.9)	(0.9)	(0.9)
	[0.674]	[0.750]	[0.977]
CA * Asset index	-6.4	-6.4	-6.8
	(3.9)	(3.8)	(3.3)
	[0.097]	[0.093]	[0.039]
Joint F-stat [p]	1.3	1.5	1.9
	[0.274]	[0.224]	[0.133]
# of HH members	X	X	X
Asset index	X	X	X
Site-by-season FE	X	X	
Distance to boundary		X	X
log area		X	X
MIP log area		X	X
MIP CA		X	X
Spatial FE			X

Notes: Regression analysis is presented in this table. All columns use outcomes on most important plots and restrict to observations during the dry season.. Rows "CA" present coefficients on a command area indicator for the sample plot, while Rows "CA * W" present coefficients on the interaction of a command area indicator for the sample plot with a household characteristic W; standard errors are in parentheses, and p-values are in brackets. Robust standard errors are clustered at the nearest water user group level in specifications without Spatial FE, and Conley (1999) standard errors are used in specifications with Spatial FE. The Row "Joint F-stat [p]" presents F-statistics for the null that all 3 coefficients are 0, with the p-value for the associated test in brackets. Columns 1, 2, and 3 use regression specifications building on Equation (10) following Equations (7), (8), and (9), respectively.

Table A11: Sample plots

	Dry season				Rainy seasons			
	Dep. var.	Coef. (SE) [p]			Dep. var.	Coef. (SE) [p]		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Tracked	0.032	0.018	0.023	0.035	0.047	0.011	0.019	0.036
	(0.177)	(0.010)	(0.014)	(0.019)	(0.211)	(0.011)	(0.016)	(0.023)
	2,907	[0.056]	[0.083]	[0.069]	4,845	[0.306]	[0.224]	[0.114]
Missing	0.060	0.111	0.127	0.103	0.064	0.102	0.121	0.094
	(0.238)	(0.020)	(0.025)	(0.028)	(0.244)	(0.020)	(0.026)	(0.028)
	2,907	[0.000]	[0.000]	[0.000]	4,845	[0.000]	[0.000]	[0.001]
Reason data is missing								
HH attrition	0.038	0.007	0.032	0.034	0.039	0.007	0.032	0.035
	(0.192)	(0.014)	(0.019)	(0.022)	(0.194)	(0.014)	(0.019)	(0.022)
	2,907	[0.590]	[0.096]	[0.129]	4,845	[0.601]	[0.096]	[0.121]
Rented out comm. farmer	0.012	0.102	0.092	0.069	0.011	0.099	0.089	0.064
	(0.108)	(0.017)	(0.019)	(0.015)	(0.105)	(0.016)	(0.019)	(0.015)
	2,907	[0.000]	[0.000]	[0.000]	4,845	[0.000]	[0.000]	[0.000]
Transaction (not tracked)	0.010	0.002	0.003	0.001	0.014	-0.004	0.000	-0.005
	(0.099)	(0.005)	(0.005)	(0.007)	(0.116)	(0.005)	(0.006)	(0.008)
	2,907	[0.681]	[0.539]	[0.921]	4,845	[0.465]	[0.945]	[0.542]
Site-by-season FE		X	X			X	X	
Distance to boundary			X	X			X	X
log area			X	X			X	X
Spatial FE				X				X

Notes: Regression analysis is presented in this table. Columns 1 through 4 restrict to observations during the dry season, while columns 5 through 8 restrict to observations during the rainy season. Columns 1 and 5 present, for sample plots in the main discontinuity sample that are outside the command area, the mean of the dependent variable, the standard deviation of the dependent variable in parentheses, and the total number of observations. Columns 2 through 4 and 6 through 8 present regression coefficients on a command area indicator, with standard errors in parentheses, and p-values in brackets. Robust standard errors are clustered at the nearest water user group level in specifications without Spatial FE, and Conley (1999) standard errors are used in specifications with Spatial FE. Columns 2 and 6 use the specification in Equation (1). Columns 3 and 7 use the regression discontinuity specification in Equation (2). Columns 4 and 8 use the spatial fixed effects specification in Equation (3).