(In)Efficiency in Intrahousehold Allocations *

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Abstract

Previous research using plot-level agricultural data from Burkina Faso found that the allocation of resources within African households was Pareto inefficient, contradicting most collective models of intrahousehold bargaining. I provide an explanation for these households' Pareto inefficient behavior and I test its robustness using an alternative dataset also collected in Burkina Faso. Households experiencing exogenous negative rainfall shocks are less likely in that year to exhibit Pareto inefficient intrahousehold allocations. These negative rainfall shocks are correlated with increases in labor resources allocated to the wife's plots, further confirming that in bad years, households try to avoid losses from Pareto inefficiency.

Keywords: Household bargaining models, Rainfall shocks, Pareto efficiency, Africa
JEL classification: D13, O12, J12, O15

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1. Introduction

Extensive evidence refuting the unitary model of household decision making, which treats the members of a family as if they behave as a single individual, has led economists to consider more general models that emphasize the role of individual actors and allow for intrahousehold bargaining among family members.[1] The most general collective model of the household (Chiappori, 1988; Browning and Chiappori, 1998) argues that, although individuals may bargain over the allocation of household resources, the outcome is assumed to be Pareto efficient. Using data from France (Bourguignon, Browning, Chiappori, and Lechène, 1993), Canada (Browning, Bourguignon, Chiappori, and Lechène, 1994), Taiwan (Thomas and Chen, 1994), Côte d'Ivoire (Hoddinott and Haddad, 1995), Indonesia (Thomas, Contreras, and Frankenberg, 2002), Bangladesh, Ethiopia, South Africa (Quisumbing and Maluccio, 2003), Ghana and Senegal (Rangel and Thomas, 2005), and Mexico (Bobonis, 2007) researchers empirically reject the unitary model, but the results remain consistent with Pareto efficiency.

However, an influential paper by Udry (1996) using plot-level agricultural data from households in Burkina Faso finds that the allocation of resources within these African households is Pareto inefficient.[2] Udry estimates household-year-crop fixed effects regressions and finds that within a given household, among similar plots planted with the same crop in the same year, plots controlled by women produce lower yields than the men's plots. This evidence

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[1] Seminal theoretical papers by Manser and Brown (1980), McElroy and Horney (1981), and Lundberg and Pollak (1993) develop cooperative bargaining models. Influential empirical papers by Schultz (1990), Thomas (1990), and Lundberg, Pollak, and Wales (1997) reject the unitary model. For a more recent review of the intrahousehold bargaining literature see Strauss and Thomas (1995), Lundberg and Pollak (1996), Behrman (1997), Haddad, Hoddinott, and Alderman (1997), and Strauss, Mwabu, and Beegle (2000).

[2] Anthropologists have also argued that in the African context there is a broad division between the economic spheres of men and women and that husbands and wives separately control their productive resources, have different constraints on their choices, have different responsibilities to satisfy with their personal incomes, and have different prospects for risk diversification (Hill, 1975; Guyer, 1986). Research using data from Cameroon (Jones, 1986), Ethiopia (Dercon and Krishnan, 2000), and Côte d'Ivoire (Duflo and Udry, 2004) finds evidence of Pareto inefficiencies in intrahousehold allocations, although the Ethiopian results hold only for poor households in certain regions of the country. All the evidence of Pareto inefficient intrahousehold allocations is based on African surveys with the exception of Djebbari (2005) who finds similar results using Mexican Progresa data.

implies that productive resources (labor, land, or fertilizer) reallocated within a household from husband to wife would yield a larger output for the family, but since this does not occur, the household is being inefficient.

In this paper, I reexamine the behavior of these same households in Burkina Faso and provide an explanation for their Pareto inefficiency. I am able to test the robustness of this explanation using an alternative dataset collected in Burkina Faso several years later. The data used to show Pareto inefficiency were collected from 1981 to 1983 by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and are from 150 households in six villages in three Burkina Faso provinces. I compare the ICRISAT data with an alternative household survey that is nationally representative and was collected in 1990 by the World Bank's Technical Department for Africa in conjunction with the Burkina Faso National Directorate for Studies and Planning (DEP is the French acronym used throughout the paper). This nationally representative survey interviewed 2406 households in 401 villages in all thirty Burkina Faso provinces.[3]

These two datasets vary in a number of dimensions, including being collected in different years and having different geographic coverage. Despite these differences, when I restrict the regressions examining intrahousehold Pareto inefficiency using the DEP data to include only provinces located geographically close to the three ICRISAT provinces, there is a significant, negative effect on yields for women, confirming Udry's findings. However, when I estimate the fixed effects regressions using the other Burkina Faso provinces (those not located near the three ICRISAT provinces), the results indicate no evidence of Pareto inefficient intrahousehold allocations. Given this within country heterogeneity regarding which regions exhibit Pareto inefficiency, conclusions based on data from only six villages should be drawn with caution.

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[3] The six villages interviewed in the ICRISAT data were not included in the 401 villages selected by DEP.

Within the Pareto inefficient households, women have less access than men to household fertilizer and labor resources (male, child, and non-household labor). While it is feasible there could be a Pareto efficient allocation of household resources that yields a larger output for both husband and wife, in practice there might be costs involved in achieving this or barriers that prevent its implementation. These costs and barriers could include monitoring labor inputs over geographically dispersed plots, transaction costs and asymmetric information involved in trading labor and resources between household members, weak property rights for women that prevent temporary land exchanges, or social norms that discourage such exchanges. Recent theoretical work argues that intrahousehold allocation decisions may be non-cooperative, leading to Pareto inefficient allocations, due to the difficulty of enforcing binding commitments within marriage (Ligon, 2002; Lundberg and Pollak, 2003). If these costs are greater than the loss due to the Pareto inefficiency, husbands and wives will not modify their behavior.

However, these costs may not be constant over time. In certain years, a household might have larger incentives to overcome these barriers because the consequences of being inefficient in that year are greater. Since these Burkinabé households are predominantly rural subsistence farmers that rely on rain-fed agriculture, in years when rainfall is lower than normal, being inefficient can be particularly costly. I present evidence that in years when there is a negative exogenous rainfall shock in a household's region (rainfall below the long-run historical average), households are less likely to exhibit Pareto inefficiencies, and this result is stronger for the poorest households. The result holds using both the DEP data, which are cross-sectional and cover only one agricultural season, and the ICRISAT data, which are panel data covering three years. Additional evidence shows that these negative rainfall shocks are correlated with increases in labor resources allocated to the wife's plots in the household, further confirming that, in bad years, households try to avoid the losses due to Pareto inefficiency.

The remainder of the paper is organized as follows. In Section 2, I describe the ICRISAT and DEP data and the empirical setting in Burkina Faso. Section 3 describes the empirical identification strategy and the relevant test of Pareto efficiency, followed by an extension of that test to examine the role of rainfall shocks in intrahousehold resource allocation. Section 4 presents the empirical results and Section 5 concludes.

2. Data and Empirical Setting

Farm production in Burkina Faso is primarily at the subsistence level and is based on rain-fed agriculture in which each household cultivates multiple plots growing different crops (see Matlon (1988) or Fafchamps (1993) for a more detailed description of the farming system). An individual within a household has substantial control over which crops are planted on his or her plots, the timing of sowing, weeding, and harvesting, the quantity of inputs used on the plot, and the rights to the output from that plot (Guyer, 1986; Berry, 1993; Saul, 1993). This individual control over inputs and outputs often leads husbands and wives, who face the same environmental conditions, to plant the same crop in the same year.

2.1 ICRISAT Data

There are several differences between the ICRISAT and DEP datasets which may confound comparisons. ICRISAT collected data between 1981 and 1985 in three provinces of Burkina Faso, but only the data collected from 1981 to 1983 contain detailed plot-level agricultural information, so I restrict the analysis to those years.[4] The survey period comprises both good and poor harvests, with 1984 and 1985 being particularly bad drought years (Reardon, Delgado, and Matlon, 1992; Reardon, Kelly, Crawford, Jayne, Savadogo, Clay, 1996).

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[4] Udry (1996) also restricts his analysis to the 1981 to 1983 data.

In 1980, prior to the survey, ICRISAT conducted qualitative interviews with small groups of farmers in 30 villages in western Burkina Faso (between Dori and Bobo-Dioulasso) to determine which provinces and villages should be selected. ICRISAT combined the data from these qualitative interviews with secondary data to select provinces that met their program objectives, and the three provinces were chosen to be representative of the different agroecological zones of Burkina Faso (Matlon, 1988).[5] Within each province, ICRISAT used a number of criteria to select one village situated on a main road and one more remotely located village. Villages had to be cooperative during the initial 1980 qualitative survey, accessible year-round, not have unusual soils or crops, not have been involved in a major development project, have the modal soil type for villages in that study zone, and have the modal village population for that study zone. In addition, ICRISAT tried to select at least one village in each province which satisfied all of the above criteria and also had a significant fraction of farmers using animal traction (Matlon, 1988). Within each selected village, households were stratified based on animal traction use and then randomly selected. Approximately every ten days, survey enumerators living in the six villages collected information on farm operations, inputs, and outputs on each of the households' plots.

2.2 DEP Data

DEP collected the data during the 1990 agricultural season to examine the implementation of a training and visit-based agricultural extension program. DEP selected a random, nationally representative sample of 2406 households from all 30 provinces of Burkina Faso. Household

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[5] The northern province, Soum, represents the agroclimatic zone of the Sahel. This region is characterized by low rainfall and sandy soils. Because of the land's low productivity potential and because large parts of the Sahel are suitable only for livestock grazing, there are significant population pressures on the remaining arable land. The central province, Passore, represents the Sudan-Savanna climatic zone. Rainfall is higher than in the Sahel but still low. Soils have a low natural fertility, but production yields tend to be higher than in the Sahel. This region is also more densely populated than the northern province. The southern province, Mouhan, represents the northern Guinea-Savanna climatic zone. It has relatively high annual rainfall, good agricultural potential with soils of intermediate depth and fertility, and low population pressures.

sampling was done in two steps. First, in each province, villages were randomly selected with the selection probability proportional to the village's size. Second, in each of the 401 villages, six households were randomly chosen and interviewed. To minimize potential bias, the Burkina Faso government agency that provided training and visit-based extension did not participate in the sampling or questionnaire design phases and did not collect the data (Bindlish, Evenson, and Gbetibouo, 1993). Summarizing the dataset differences, the DEP data are nationally representative with a larger sample of interviewed households, but the data are from only one year and there is less detailed information about production inputs and less plot-level information about soil quality and plot topography.

2.3 Preliminary Observations

In the DEP data, there is also significant regional variation, in particular when comparing provinces located near the three ICRISAT provinces (I label these provinces near-ICRISAT) and the rest of the country.[6] Table 1 presents summary statistics comparing the ICRISAT and DEP data, as well as within the DEP data, comparing the near-ICRISAT region with the rest of the country. The near-ICRISAT provinces contain households with larger average plot sizes, a larger fraction of plots planted with cash crops or crops requiring significant fertilizer or labor inputs, and a higher percentage of households experiencing rainfall above the historical average.

For the DEP data, I measure current rainfall and the long-run historical rainfall average at the province level using 1977 to 1990 annual rainfall data from the Burkina Faso National Meteorological Service collected from weather stations in each province. I define a positive rainfall shock to be current year rainfall in 1990 being greater than the historical province average (calculated from 1977 to 1989). Relative to the long-run historical rainfall pattern, 1990

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[6] The near-ICRISAT provinces include the three provinces surveyed by ICRISAT (Soum, Passore, and Mouhoun) as well as Bam, Namentenga, and Oudalan in the northern zone, Oubritenga, and Sourou in the central zone, and Kossi and Komoe in the southern zone. Regression results are robust to using alternative near-ICRISAT definitions.

was a bad rainfall year for many provinces in Burkina Faso. In 1990 for the DEP data, only 13.75 percent of household plots are in provinces that experience a positive rainfall shock. However, the near-ICRISAT provinces experience significantly better rainfall relative to the long-run historical average in those provinces. In the near-ICRISAT region, 25.33 percent of plots are in provinces that had rainfall in 1990 above the long-run historical province average. This contrasts with the other provinces in Burkina Faso in which only 7.05 percent of plots are in provinces that experience a positive rainfall shock, and the difference across regions is significant at the 1 percent level.

For the ICRISAT data, I take advantage of rainfall data collected by ICRISAT in each of the six surveyed villages for 1981 to 1983. Using this village-level data, I calculate a three year long-run average rainfall for each village. I define a positive rainfall shock as current year rainfall in a given village being greater than the long-run average rainfall for that same village. For these six villages, 1982 was the worst of the three years, but over this time period, 54.99 percent of household plots are in villages that experience a positive rainfall shock. Relative to the DEP data and the rainfall in 1990, a larger share of households in the ICRISAT data experienced positive rainfall.

While it is advantageous to have rainfall data at the village level as opposed to the province level, the disadvantage of using the village level ICRISAT rainfall data is that I only have rainfall information for the same years as the survey data. To test the robustness of using these three years to calculate the village long-run rainfall average, I use the Burkina Faso National Meteorological Service data from 1977 to 1980 to calculate an alternative historical long-run average for these provinces. These province level rainfall data were collected prior to the ICRISAT surveys, so the long-run rainfall average is a true historical average, but the data are only at the province level. All subsequent regression results using the ICRISAT data are similar using either measure of long-run average rainfall (ICRISAT village rainfall or National Meteorological Service data).

In addition to these rainfall differences across regions and datasets, there are significant differences in terms of plot size and which crops are planted. Panel A of Table 1 shows that for the DEP data average plot size is 0.70 hectares in the near-ICRISAT region but only 0.64 hectares in the rest of the country, a difference that is significant at the 1 percent level. Panel B of Table 1 shows that using the DEP data, households in the near-ICRISAT region plant a higher percentage of plots with cash crops (cotton) or crops that require large inputs of fertilizer (maize) or labor (rice, fonio, and earthpeas) and fewer plots are planted with the traditional crops of sorghum or groundnuts. The differences across regions are all significant at the one percent level (except for the difference in plots planted with rice which is significant at the five percent level). Despite being from a different time period, the ICRISAT data show a similar pattern to the near-ICRISAT provinces in the DEP data, with an even larger percentage of plots planted to cotton and rice and fewer plots planted to sorghum or groundnuts.

3. Empirical Identification Strategy and Pareto Efficiency Test

Based on the model of household behavior developed by Udry (1996), if a household allocates the factors of production efficiently, then within a given household, in the same year, similar plots planted to the same crop should have the same yield regardless of whether the plot is controlled by the husband or the wife. To empirically estimate this test for Pareto efficiency in the allocation of productive resources within a household, I run the following household-year-crop fixed effects regression to examine whether the gender of the individual who controls the plot influences the plot yield:

$$Q_{htci} = \beta X_{htci} + \gamma G_{htci} + \lambda_{htc} + \varepsilon_{htci} \tag{1}$$

where Q_{htci} is the yield on plot i planted with crop c at time t by a member of household h, X_{htci} is a vector of characteristics for the plot (that includes plot area), G_{htci} is the gender of the person who controls the plot, λ_{htc} is a household-year-crop fixed effect, and ε_{htci} is an error term that captures any unobserved plot quality variation and plot-specific production shocks on yields. Including a household-year-crop fixed effect means that identification is based on comparing plots within a given household, in the same year, and growing the same crop. The Pareto efficiency test yields an exclusion restriction that the gender of the individual controlling the plot should not have any impact on plot output, which is a test of whether $\gamma=0$.

Within this framework, a household facing an exogenous change should still allocate factors of production efficiently. To examine how an exogenous shock influences the intrahousehold allocation of resources, I modify the previous Pareto efficiency test to include an interaction of rainfall shocks with the gender of the person who controls the plot, as in the following household-year-crop fixed effects regression:

$$Q_{htci} = \beta X_{htci} + \gamma_1 G_{htci} + \gamma_2 (G_{htci} * PositiveRainShock_{ht}) + \lambda_{htc} + \psi_{htci} \tag{2}$$

where Q_{htci}, X_{htci}, G_{htci}, and λ_{htc} are as previously defined, *Positive Rain Shock*$_{ht}$ is an indicator for whether household h experiences a positive rainfall shock at time t (current year rainfall above the long-run historical average), and ψ_{htci} is a random, idiosyncratic error term.[7] The coefficient, $\gamma_{1,}$ indicates the impact of gender on plot yields for a household in a region that experiences a negative rainfall shock, while γ_2 measure the additional impact of gender on plot yields for a household in a region that experiences a positive rainfall shock.

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[7] In Equation 2, I do not include a *Positive Rain Shock*$_{ht}$ main effect because it will be absorbed by the household-year-crop fixed effect, λ_{htc}.

4. Empirical Results

4.1 Baseline Household-Year-Crop Fixed Effects Regressions

I estimate the household-year-crop fixed effects regression from Equation 1 to examine the impact on yields of the gender of the person who controls the plot, and in Table 2, I present these results.[8] In column 1, I present results using the ICRISAT data.[9] I find that if a woman manages a plot, then yields are significantly lower than other plots within the household planted to the same crop in the same year but controlled by men. The mean yield across plots is 88.99 (measured in local currency units of 1000 FCFA), so the negative gender effect results in a drop in yields of 32.1 percent of the average yield.[10] The gender result holds even after controlling for observable characteristics of the plot, such as plot size.[11] The results show a strong pattern in which smaller plots are farmed more intensively and have higher yields than larger plot sizes.

The ICRISAT data also measure additional observable plot characteristics, such as soil type, topography, and distance from the compound, and in Appendix Table 1 column 1, I replicate the Table 2 ICRISAT regression and include these additional variables.[12] With the inclusion of these variables, results are quantitatively similar and statistically robust to those in Table 2. The DEP data do not contain these additional plot characteristics, so in the main tables, I restrict the ICRISAT regressions to only control for plot size. However, all the ICRISAT regression results in the paper (including those with rainfall shocks) are replicated in Appendix

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[8] Since the DEP data are only from one agricultural season, I cannot include year fixed effects, so the estimated regressions using DEP data are household-crop fixed effects regressions.

[9] Results are consistent with Udry's (1996) findings (see Table 7, Column 2).

[10] The exchange rate in 1982 was $1 USD = 325 FCFA.

[11] To remain consistent with the Udry (1996) analysis, for the ICRISAT data, I omit the 5th decile of plot size and for the DEP data, I omit the plot size category Size 4.

[12] To control for unobservable plot characteristics, I would want to include plot fixed effects, but while the ICRISAT data are panel data following households over three years, it is not possible to link individual plots across survey rounds.

Table 1 with the addition of controls for soil type, topography, and plot location and all results remain consistent.

In columns 2 and 3 of Table 2, I estimate the fixed effects regressions using the DEP data restricted to the near-ICRISAT provinces (column 2) and all other provinces in Burkina Faso (column 3). When the data are restricted to the near-ICRISAT provinces, there is a negative impact of gender on plot yields and the result is significant at the five percent level. The mean yield across all plots in the DEP data is 643.51, so a female plot manager has crop yields reduced by 6.8 percent of the average yield. However, in the other provinces of Burkina Faso, there is no negative relationship between the gender of the plot manager and yields. For households outside of the near-ICRISAT regions, men and women, within a given household, growing the same crop in the same year, show no statistical difference in plot yields based on the gender of the plot manager. The DEP data show similar results to the ICRISAT data regarding the coefficients on plot size, with smaller plots having larger yields, although the coefficients for the largest plot size variables are not precisely measured.[13]

As the ICRISAT data contain crop price information from the six surveyed villages, I use the value of plot output per hectare as the dependent variable. However, the DEP data do not contain local price information and so I estimate the regressions using plot output per hectare as the dependent variable. To test this approach's robustness, I re-estimate the fixed effects regressions with the DEP data in two alternative ways. First, I use 1990 Burkina Faso Ministry

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[13] Unlike the ICRISAT data, which measures plot size in a continuous manner, in the DEP data, plot size is coded in 0.1 hectare increments, and 27.1 percent of all plots are coded as 0.1 hectares. Due to this, I code the first three deciles of plot size into one plot size variable called Size 1. The other plot size variables (Size 2 to Size 8) roughly correspond to the fourth to tenth deciles as shown in the table, although there is rounding due to plot size not being continuous. Size 2 is for plots that are 0.2 hectares and contains 15.6 percent of all plots. Size 3 is for 0.3 hectare plots and contains 10.0 percent of all plots. Size 4 is for 0.4 and 0.5 hectare plots and contains 12.8 percent of plots while Size 5 is for plots 0.6 and 0.7 hectares and represents 8.0 percent of all plots. Size 6 is for plots between 0.8 and 1.1 hectares inclusive and represents 9.7 percent of all plots. Size 7 is for plots between 1.2 and 2.1 hectares and contains 10.7 percent of all plots, while Size 8 is for plots larger than 2.2 hectares and contains 6.1 percent of all plots. Results are robust to alternative plot size category codings.

of Agriculture and Animal Resources data on national crop prices to calculate the value of plot output per hectare for the DEP households. In 1990, minimum producer prices for crops were still fixed by the Burkina Faso government, meaning local price variation was minimized, and only in 1991 (the year following the DEP data collection) were prices of local products freed (IMF, 1998). There is little variation in the per kilogram price of most traditional crops (sorghum, millet, maize, and groundnuts), and this tends to be lower than the per kilogram price of rice, fonio, and cotton. Results with the DEP data using the value of plot output per hectare as the dependent variable are consistent with the Table 2 regressions. Second, using the DEP data, I estimate the fixed effects regressions and focus only on a specific crop, such as millet or sorghum, so problems in aggregating yields across crops are removed. Results show that in the near-ICRISAT provinces, women planting millet or sorghum still experience a significantly reduced yield compared to men in the same household planting the same crop.

Despite the differences between the two datasets, when the regressions using the DEP data are restricted to provinces near the ICRISAT villages, results indicate that households are Pareto inefficient, confirming Udry's findings. However, extending the analysis to the other Burkina Faso provinces shows that within a household in a given year, for plots planted to the same crop, women's yields are not significantly different from men's yields.

4.2 Impact of Rainfall Shocks

Having analyzed the regional heterogeneity related to which households exhibit Pareto inefficient intrahousehold allocations, I explore possible explanations for this variation. I begin by exploring static characteristics (ethnicity, religion, polygamy, and household structure), but these factors are unable to explain the year to year variation in which households exhibit Pareto inefficient behavior. Based on the ICRISAT data, the same household is not Pareto inefficient every year and so static factors will be unable to explain changes in behavior. I instead focus on rainfall shocks as these vary over time and are important for subsistence farmers who rely on rain-fed agriculture. In years when rainfall is lower than normal and households might not be able to produce enough food to survive, being inefficient is a luxury.

In Table 3, I present household-year-crop fixed effects regressions that estimate Equation 2 and include two alternative measures of rainfall shocks interacted with the plot manager's gender to determine if Pareto inefficient outcomes differ in the presence of rainfall shocks. The first rainfall shock measure is a dummy variable indicating a positive rainfall shock and is defined as current year rainfall being greater than the long-run historical average. The second rainfall shock measure captures extreme positive rainfall variations (in which rainfall is more than 0.5 standard deviations above the long-run historical average) and extreme negative rainfall variations (in which rainfall is more than 0.5 standard deviations below the long-run average). The omitted category is average rainfall (in which rainfall falls between 0.5 standard deviations below long-run average rainfall and 0.5 standard deviations above long-run average rainfall).[14]

In column 1 of Table 3, using the ICRISAT data, I find that during a year that a village experiences a positive rainfall shock, women's yields on plots planted with the same crop in the same year in the same household are an additional 27.4 percent of the average yield lower than men's yields, and the result is significant at the one percent level. The net impact of gender for a year in which the household had a positive rainfall shock is 44.9 percent lower yields (relative to the mean yield) for women, compared with only 17.5 percent lower yields for a year in which the

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[14] For the DEP data, both rainfall shock measures are calculated at the province level, and 58.1 percent of plots had extreme negative rainfall shocks, while only 6.7 percent of plots had extreme positive rainfall shocks. For the ICRISAT data, the measures are calculated at the village level, and only 28.7 percent of plots had extreme negative rainfall shocks, while 27.7 percent of plots had extreme positive rainfall shocks.

household experienced a negative rainfall shock. This is the strongest evidence that households reduce intrahousehold inefficiency when faced with exogenous negative rainfall shocks.[15]

As a robustness check in column 2, I present results using a second alternative rainfall shock measure which incorporates extreme variations in rainfall. Compared to a household that had average rainfall, for a household in a village during a year when the village experiences an extreme positive rainfall shock, women had (relative to the mean yield) an additional 35.7 percent lower yields than men, and the coefficient is significant at the 10 percent level. In those households in villages that experience a year of extreme negative rainfall shocks, there is no additional negative impact for women's yields.[16]

Using the DEP data (in column 3), for households in provinces that experience either a positive or negative rainfall shock, there is no statistically significant difference between men's and women's yields. However, this overall result hides significant heterogeneity by crop and wealth levels that I explore in subsequent tables. Using the extreme rainfall shock measure (in column 4) shows that women's yields are an additional 32.4 percent of the mean yield lower than men's yields in households that experience an extreme positive rainfall shock, and the coefficient is significant at the 10 percent level. In addition, for households in provinces that experience an extreme negative rainfall shock, the net impact of gender on crop yields shows no statistically significant difference between men's and women's yields.

To further examine the link between rainfall shocks and inefficiency, in Table 4, I estimate household-year-crop fixed effects regressions comparing the staple crops, millet and sorghum, with the cash and labor intensive crops, cotton, rice, and fonio. The results indicate

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[15] In Appendix Table 1, columns 2 and 3, results are consistent when I re-estimate these ICRISAT regressions and include additional controls for topography, soil type, and plot location.

[16] Results (not shown) are quantitatively similar using two alternative rainfall shock measures. The first measure calculates the actual deviation in millimeters of current year rainfall from the long-run historical average. The second measure normalizes this deviation by the long-run standard deviation of rainfall.

that rainfall shocks and gender have significantly different impacts on yields for the two types of crops. With the ICRISAT data, for staple crops in the years in which a household experiences a positive rainfall shock (rainfall above the long-run average), women's yields are an additional 39.5 percent (relative to the mean staple crop yield) lower than men's yields. However, for the cash and labor intensive crops, the effect of a female plot manager in a household experiencing a positive rainfall shock is to reduce yields by 1.5 times the average yield.[17] A similar pattern is seen in the DEP data. Women's yields on staple crops are not significantly different than men's yields in households that either experienced positive or negative rainfall shocks. However, for cotton, rice, and fonio, in households that had positive rainfall shocks, women's yields are reduced by 71.6 percent of the average yield relative to men's yields.

Since the DEP data are cross-sectional, it is possible that provinces that experience negative rainfall shocks are systematically different from provinces that had good rainfall in that year, and these differences might be correlated with household inefficiency. However, using the three years of ICRISAT data, I find the same result. Households in villages that had a negative rainfall shock in a given year (current year rainfall below the historical average for that village) are less inefficient than either households in villages that had positive rainfall shocks (using variation in the cross-section) or households in the same village in a different year with different rainfall (using variation in the time dimension). These results indicate that in years in which a household experiences a negative rainfall shock in which the cost of being inefficient is larger, the negative impact of gender on yields is greatly reduced. This contrasts with years in which a household has a positive rainfall shock and Pareto inefficiency is seen as a luxury good, with

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[17] In Appendix Table 1, columns 4 and 5, results for the fixed effects regressions by crop are consistent if I include additional controls for topography, soil type, and plot location.

women's yields being significantly lower than men's for the same crop planted in the same household in the same year.

4.3 Impact of Rainfall Shocks by Wealth Levels

In Table 5, I analyze the role wealth plays in the intrahousehold allocation of resources and the link between wealth and rainfall shocks. I develop a measure of wealth based on whether, in a given year, a household hires more than the average number of non-family workers in that region.[18] In columns 1 and 4, I present baseline specifications interacting this measure of household wealth with the plot manager's gender.[19] There is some evidence that women in non-poor households (those hiring above the average number of non-family workers) have even lower yields, although the coefficient on the interaction term is significant only for the DEP data.

However, this result is magnified when the sample is divided into poor and non-poor households (based on the number of workers hired by the household) and the plot manager's gender is interacted with rainfall shocks. For non-poor households, the net impact of gender on yields is significantly more negative in years when a household experiences a positive rainfall shock. Conversely, in years when a poor household experiences a negative rainfall shock, the negative net impact of gender on yields is greatly reduced. Using the ICRISAT data, female plot managers in non-poor households with a positive rainfall shock have a drop in yields of 60.9 percent of the average yield. However, female plot managers in non-poor households with a negative rainfall shock only have a drop in yields of 25.5 percent of the mean yield. Both coefficients are significant at the ten percent level. In contrast, female plot managers in poor households facing a positive rainfall shock have a reduction in yields of 33.4 percent of the

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[18] To account for regional differences in hiring patterns, with the ICRISAT data, the mean number of hired workers is calculated separately for each village, while with the DEP data, the mean number of hired workers is calculated separately for each province.

[19] All results in the table are robust to using alternative wealth measures, including livestock holdings, use of animal traction, or household landholdings.

average yield (significant at the ten percent level), while female plot managers in poor households with a negative rainfall shock only experience a drop of 13.7 percent of the average yield (significant at the five percent level).[20] The worse-off households, those who are poor and facing a year with a negative rainfall shock, reduce their inefficiency the most.

The results using the DEP data are similar. Females in non-poor households with positive rainfall shocks have an additional drop of 50.1 percent of the average yield (significant at the five percent level), while yields of females in non-poor households with negative rainfall shocks have no statistically significant difference from men. For females in poor households experiencing either a positive or negative rainfall shock, yields are not significantly different from men's yields.

4.4 Impact of Rainfall Shocks On Productive Inputs

Having analyzed the impact of rainfall shocks on Pareto inefficient outcomes within the household, in Table 6, I use the ICRISAT data to estimate household-year-crop fixed effects Tobit regressions to consider the mechanisms a household uses to adjust its behavior in response to rainfall shocks, particularly focusing on adjustments to labor and fertilizer inputs (male labor, female labor, child labor, non-family labor, and fertilizer).[21] I estimate the regressions using Honoré's (1992) fixed effects Tobit estimator, and in the baseline specifications (columns 1, 3, 5, 7, and 9) I control for the plot manager's gender.[22] Results indicate plots managed by women have 632 hours less male labor, 248 hours less child labor, 356 hours less non-family labor, and 15.07 metric tons less manure. The male labor result is significant at the 1 percent level, while

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[20] Results (presented in Appendix Table 1, columns 6 and 7) for the fixed effects regressions broken down by household wealth are consistent if I include additional controls for topography, soil type, and plot location.

[21] The DEP data do not contain information about productive inputs, so I cannot replicate this analysis with those data.

[22] I use the Broyden-Fletcher-Goldfarb-Shanno optimization method, but similar results are obtained using the Polak-Ribiere Conjugate Gradient Method, the Simplex Method, or Powell's Method.

the child labor and fertilizer results are significant at the 5 percent level. The non-family labor result is not significant at standard levels. However, in years that a household faces a negative rainfall shock, plots managed by women garner an extra 205 hours of child labor, an amount that significantly differs from zero at the five percent level. Women in these households also receive an additional 113 hours of non-family labor and 37 hours of male labor in years with a negative shock, although the coefficients are not statistically significant at standard levels. In addition, in households facing negative rainfall shocks, women work 144 fewer hours on their plots, presumably switching labor to other tasks that are more productive such as home production or marketing. These labor input results further confirm that in bad years, households attempt to avoid the losses due to Pareto inefficiency by reallocating variable factors of production.

5. Conclusion

Previous research using plot-level agricultural data from Burkina Faso found that the allocation of resources within these African households was Pareto inefficient, contradicting the main assumption of most collective models of intrahousehold bargaining. Udry (1996) develops a test of Pareto inefficiency and estimates household-year-crop fixed effects regressions and finds that among similar plots within a given household planted with the same crop in the same year, those plots managed by a woman have lower yields than men’s plots. I provide an explanation for the Pareto inefficient behavior of these same households in Burkina Faso, and I test the explanation’s robustness using an alternative dataset collected in Burkina Faso in a more recent year. Despite the differences in the these two datasets, using the more recent dataset, I find that only households in regions geographically proximate to those in the original sample exhibit Pareto inefficient intrahousehold allocations, while the rest of the country reveals no evidence of Pareto inefficiencies.

However, this household inefficiency is not constant over time and in certain years the consequences of being inefficient are greater. In particular, for African rural subsistence farmers that depend on rain-fed agriculture, in years when rainfall is lower than normal and households might not be able to produce enough food to survive, being inefficient is a luxury they cannot afford. I find that households are less likely to exhibit Pareto inefficiency in years when there is an exogenous negative rainfall shock in the household's region and this result is stronger for the poorest households. Households facing a negative rainfall shock are also more likely to allocate additional labor resources to the wife's plots in the household, further verifying that, in bad years, household members try to avoid income losses due to being inefficient.

These results describe how households are efficiently responding to changes in relative productivity shocks. In the years when a household experiences a positive rainfall shock, labor and resources are shifted to crops that are predominantly controlled by men (cotton, rice, and fonio) and for which prices are determined at a national or international level. However, for women, who are growing primarily staple crops (millet and sorghum) for which the price is determined locally, if their household experiences a positive rainfall shock, they do not receive an increase in resources allocated to them. There is also evidence that in bad rainfall years, husbands shift resources to growing staple crops to ensure household consumption.

Households respond to changes in incentives and accounting for the role of rainfall shocks is critical for understanding household behavior. Understanding the implications of this decision-making process merits additional future research, both to measure whether similar patterns are found in other countries and to measure the impact of the decision on labor supply, health, and human capital investment outcomes. The data requirements to test the hypothesis that rainfall shocks are correlated with the household Pareto efficiency decision are quite high.

Data must include plot-level information, including yields, and knowledge of who managed the plot. There also must be enough geographical variation (multiple regions) or time variation in the data to have differential rainfall shocks across regions or over time. Few datasets satisfy these requirements suggesting additional data collection may be necessary to adequately test these hypotheses of whether or not households are behaving efficiently.

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Table 1: Summary Statistics Comparing ICRISAT and DEP Data

	ICRISAT Data	DEP Data		
	(1)	Near-ICRISAT Provinces (2)	All Other Provinces in Burkina Faso (3)	Difference (3) – (2)
Panel A:				
Percentage of Plots with Positive Rainfall Shock	54.99	25.33 [0.66]	7.05 [0.29]	-18.28*** [0.63]
Average Plot Size (hectares)	0.51	0.70 [0.02]	0.64 [0.01]	-0.06*** [0.02]
Panel B:				
Percentage of Plots Planted to a Given Crop [column percent]				
Sorghum	29.52	29.36 [0.69]	35.25 [0.55]	5.89*** [0.89]
Groundnuts	8.85	12.53 [0.50]	16.20 [0.42]	3.67*** [0.68]
Millet	17.64	25.81 [0.66]	25.72 [0.50]	-0.09 [0.83]
Cotton	7.37	3.96 [0.30]	2.69 [0.19]	-1.27*** [0.33]
Maize	13.02	15.09 [0.54]	12.36 [0.38]	-2.73*** [0.65]
Fonio/ Earthpeas	10.59	11.31 [0.48]	6.37 [0.28]	-4.94*** [0.52]
Rice	3.39	1.95 [0.21]	1.42 [0.14]	-0.53** [0.24]
Other	9.62			
Observations	4655	4367	7555	

Note: Standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. ICRISAT data are from 3 provinces in Burkina Faso. DEP data are from all 30 provinces in Burkina Faso. Column 2 uses DEP data and is restricted to 10 provinces (including the 3 ICRISAT provinces) that are geographically proximate to the 3 ICRISAT provinces. Column 3 uses DEP data restricted to the other 20 provinces of Burkina Faso. For the ICRISAT data, long-run historical average rainfall is calculated at the village level and a positive rainfall shock is defined as current year rainfall being greater than the historical village average. For the DEP data, long-run historical average rainfall is calculated at the province level and a positive rainfall shock is defined as current year rainfall being greater than the historical province average (see text for additional details on the rainfall shock measure).

Table 2: Household-Year-Crop Fixed Effects Regressions of the Determinants of Plot Yield

	ICRISAT Data	DEP Data	
		Near-ICRISAT Provinces	All Other Burkina Faso Provinces
	(1)	(2)	(3)
Female	-28.53*** [6.58]	-44.02** [20.09]	28.26 [17.42]
Plot Size:			
1st decile/Size 1	133.31*** [41.12]	168.81*** [38.24]	99.98*** [26.32]
2nd decile	69.61*** [20.36]		
3rd decile	64.09*** [13.74]		
4th decile/Size 2	34.18** [13.56]	74.68* [38.21]	32.94 [29.45]
6th decile/Size 3	-1.97 [8.91]	35.13 [43.12]	6.94 [31.08]
7th decile/Size 5	-13.48 [9.60]	-3.05 [40.50]	-33.42 [41.48]
8th decile/Size 6	-18.00** [8.67]	-44.69 [48.40]	-17.33 [38.25]
9th decile/Size 7	-26.89*** [8.52]	72.51* [43.71]	-10.95 [35.47]
10th decile/Size 8	-33.17*** [8.69]	49.86 [57.86]	55.18 [53.85]
Constant	78.44*** [8.22]	574.41*** [26.73]	607.59*** [21.82]
Observations	4655	4367	7555

Notes: Robust standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. The ICRISAT data are panel data so I estimate household-year-crop fixed effects regressions. The DEP data are from one agricultural season so I can only estimate household-crop fixed effects regressions. For the ICRISAT data, the dependent variable is value of plot output/hectare (mean equals 88.99) and for the DEP data, plot output/hectare (mean equals 643.51). ICRISAT data are from 3 provinces in Burkina Faso. DEP data are from all 30 provinces in Burkina Faso. Column 2 uses DEP data that are restricted to 10 provinces (including the 3 ICRISAT provinces) that are geographically proximate to the 3 ICRISAT provinces. Column 3 uses DEP data restricted to the other 20 provinces of Burkina Faso. The omitted land size category is the 5th decile for the ICRISAT data and Size 4 for the DEP data.

Table 3: Household-Year-Crop Fixed Effects Regressions of the Determinants of Plot Yield Including the Impact of Rainfall Shocks

	ICRISAT Data		DEP Data	
	(1)	(2)	(3)	(4)
Female	-15.61***	-21.99***	12.74	40.58
	[5.38]	[5.55]	[13.27]	[26.27]
Female * Positive Rainfall Shock	-24.34***		-34.58	
	[9.13]		[73.20]	
Female * Extreme Negative Rainfall Shock		3.16		-44.16
		[7.02]		[30.15]
Female * Extreme Positive Rainfall Shock		-31.73*		-208.58*
		[17.10]		[107.09]
Plot Size:				
1st decile/Size 1	130.95***	131.73***	126.14***	124.75***
	[41.10]	[41.12]	[21.85]	[21.82]
2nd decile	67.40***	68.53***		
	[20.58]	[20.43]		
3rd decile	62.90***	62.57***		
	[13.79]	[13.83]		
4th decile/Size 2	33.54**	33.32**	48.81**	48.54**
	[13.54]	[13.50]	[23.34]	[23.28]
6th decile/Size 3	-2.37	-3.21	17.99	18.22
	[8.91]	[9.02]	[25.19]	[25.17]
7th decile/Size 5	-14.44	-14.71	-21.07	-21.72
	[9.60]	[9.71]	[29.64]	[29.58]
8th decile/Size 6	-19.06**	-19.52**	-26.54	-28.03
	[8.71]	[8.89]	[30.06]	[30.05]
9th decile/Size 7	-27.47***	-27.35***	20.94	20.42
	[8.55]	[8.59]	[27.58]	[27.55]
10th decile/Size 8	-33.59***	-33.97***	52.77	50.30
	[8.72]	[8.83]	[39.72]	[39.58]
Constant	79.50***	80.02***	595.44***	595.75***
	[8.35]	[8.55]	[16.98]	[16.94]
Observations	4655	4655	11922	11922

Notes: Robust standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. The ICRISAT data are panel data so I estimate household-year-crop fixed effects regressions. The DEP data are from one agricultural season so I can only estimate household-crop fixed effects regressions. The dependent variable is value of plot output/hectare for the ICRISAT data and plot output/hectare for the DEP data. In columns 1 and 3, a positive rainfall shock is defined as current rainfall being greater than the long-run historical average. In columns 2 and 4, rainfall shocks are calculated to measure extreme positive shocks (rainfall more than 0.5 standard deviations above the long-run average) and extreme negative shocks (rainfall more 0.5 standard deviations below the long-run average). The omitted rainfall shock category in columns 2 and 4 is average rainfall with rainfall amounts that fall between 0.5 standard deviations below long-run average rainfall and 0.5 standard deviations above long-run average rainfall. The omitted land size category is the 5th decile for the ICRISAT data and Size 4 for the DEP data.

Table 4: Household-Year-Crop Fixed Effects Regressions of the Determinants of Plot Yield Broken Down by Crop

	ICRISAT Data		DEP Data	
	Millet-Sorghum (1)	Cotton-Rice-Fonio (2)	Millet-Sorghum (3)	Cotton-Rice-Fonio (4)
Female	-11.40***	27.59	20.41	38.73
	[3.40]	[23.67]	[12.85]	[101.40]
Female * Positive Rainfall Shock	-15.11***	-143.64*	16.65	-634.79**
	[4.32]	[73.69]	[69.94]	[289.51]
Plot Size:				
1st decile/Size 1	37.42	230.30**	129.19***	177.65
	[37.85]	[99.58]	[21.28]	[126.83]
2nd decile	35.99***	120.97***		
	[11.75]	[46.05]		
3rd decile	29.06***	128.49***		
	[6.84]	[43.71]		
4th decile/Size 2	17.82***	64.94*	35.80	58.30
	[5.50]	[35.10]	[23.79]	[131.08]
6th decile/Size 3	-2.85	3.61	18.93	47.23
	[4.37]	[43.25]	[24.05]	[151.45]
7th decile/Size 5	-12.10***	18.16	-39.48	76.59
	[4.56]	[30.96]	[24.44]	[207.62]
8th decile/Size 6	-23.66***	6.99	3.94	-202.34
	[5.07]	[31.20]	[25.44]	[220.43]
9th decile/Size 7	-27.87***	-6.12	24.76	109.79
	[4.58]	[29.93]	[24.12]	[198.63]
10th decile/Size 8	-32.56***	-15.23	35.11	177.68
	[4.87]	[32.53]	[33.79]	[271.77]
Constant	56.92***	44.41	521.35***	841.58***
	[3.96]	[37.88]	[15.79]	[104.95]
Mean of Dependent Variable	38.24	94.74	567.82	887.12
Observations	2195	994	7015	1543

Notes: Robust standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. The ICRISAT data are panel data so I estimate household-year-crop fixed effects regressions. The DEP data are from one agricultural season so I can only estimate household-crop fixed effects regressions. The dependent variable is value of plot output/hectare for the ICRISAT data and plot output/hectare for the DEP data. A positive rainfall shock is defined as current rainfall being greater than the long-run historical average. The omitted land size category is the 5th decile for the ICRISAT data and Size 4 for the DEP data.

Table 5: Household-Year-Crop Fixed Effects Regressions of the Determinants of Plot Yield Including the Impact of Rainfall Shocks and Wealth

	ICRISAT Data			DEP Data		
	All Households (1)	Below Mean Number Hired Workers (2)	Above Mean Number Hired Workers (3)	All Households (4)	Below Mean Number Hired Workers (5)	Above Mean Number Hired Workers (6)
Female	-23.20***	-12.20**	-22.72*	24.99	18.36	-5.44
	[5.75]	[5.94]	[11.87]	[15.54]	[15.03]	[27.88]
Female * Above Mean Number Hired Workers	-13.64			-63.45*		
	[10.48]			[32.88]		
Female * Positive Rainfall Shock		-17.52*	-31.48*		75.01	-322.35**
		[9.83]	[16.76]		[83.53]	[138.53]
Plot Size:						
1st decile/Size 1	133.46***	104.50**	178.66**	126.64***	124.51***	125.42***
	[41.12]	[48.93]	[72.88]	[21.85]	[24.49]	[47.69]
2nd decile	69.09***	71.85***	55.84			
	[20.44]	[23.68]	[38.85]			
3rd decile	63.49***	59.16***	65.74***			
	[13.76]	[17.60]	[22.48]			
4th decile/Size 2	33.64**	26.57	41.70*	49.63**	50.68*	41.78
	[13.52]	[16.21]	[23.47]	[23.33]	[26.42]	[49.37]
6th decile/Size 3	-2.31	-4.37	-0.17	18.29	-8.66	88.23
	[8.95]	[11.64]	[14.16]	[25.19]	[27.64]	[56.63]
7th decile/Size 5	-14.09	-12.47	-21.20	-18.76	-5.99	-49.54
	[9.67]	[10.59]	[19.13]	[29.59]	[30.04]	[76.03]
8th decile/Size 6	-18.47**	-16.17*	-26.66	-25.86	-18.61	-51.34
	[8.75]	[9.59]	[17.61]	[30.07]	[35.06]	[58.67]
9th decile/Size 7	-27.63***	-25.07***	-34.84*	21.45	-9.81	87.37
	[8.69]	[8.95]	[18.02]	[27.55]	[31.16]	[57.05]
10th decile/Size 8	-33.87***	-28.05***	-46.16**	52.14	57.63	41.99
	[8.85]	[8.99]	[18.72]	[39.58]	[47.39]	[71.90]
Constant	78.73***	73.90***	93.41***	594.52***	571.95***	669.48***
	[8.28]	[9.78]	[16.07]	[16.93]	[19.07]	[36.52]
Observations	4655	3032	1623	11922	8951	2971

Notes: Robust standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. The ICRISAT data are panel data so I estimate household-year-crop fixed effects regressions. The DEP data are from one agricultural season so I can only estimate household-crop fixed effects regressions. For the ICRISAT data, the mean number of hired workers is calculated separately for each village, while for the DEP data, the mean is calculated for each province. The dependent variable is value of plot output/hectare for the ICRISAT data and plot output/hectare for the DEP data. A positive rainfall shock is defined as current rainfall being greater than the long-run historical average. The omitted land size category is the 5th decile for the ICRISAT data and Size 4 for the DEP data.

Table 6: Household-Year-Crop Fixed Effects Tobit Estimates of the Determinants of Plot Input Intensities Including the Impact of Rainfall Shocks

Dependent Variables:	Male Labor Per Hectare		Female Labor Per Hectare		Child Labor Per Hectare		Non-Household Labor Per Hectare		Manure (1000kg) per Hectare	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Female	-631.80***	-607.20***	116.40***	42.57	-248.10**	-128.00	-355.70	-269.50	-15.07**	-20.90*
	[67.42]	[67.78]	[40.06]	[44.95]	[102.20]	[80.09]	[254.90]	[234.30]	[6.27]	[11.01]
Female * Positive Rainfall Shock		-37.16		144.30**		-204.70**		-112.80		8.84
		[82.38]		[67.36]		[92.82]		[94.63]		[10.66]
Plot Size										
1st decile/Size 1	1201.00***	1197.00***	1069.00***	1093.00***	835.40	794.70	121.10	111.90	23.53**	25.26**
	[460.2]	[463.10]	[231.30]	[238.50]	[534.20]	[539.70]	[325.80]	[302.30]	[11.29]	[11.85]
2nd decile	511.70***	506.50***	872.50***	898.50***	270.10*	231.60	397.50	408.50	1.44	3.29
	[149.1]	[147.80]	[194.20]	[196.70]	[149.60]	[141.80]	[413.10]	[415.20]	[7.33]	[8.91]
3rd decile	192.20**	190.50**	641.80***	651.10***	188.80**	164.40*	272.30	269.00	-2.52	-1.99
	[82.21]	[82.71]	[101.20]	[100.30]	[90.86]	[85.00]	[267.80]	[275.80]	[5.83]	[6.20]
4th decile/Size 2	69.04	68.26	354.00***	360.80***	98.06	86.78	409.30	419.10	-12.77*	-12.3
	[63.85]	[62.91]	[70.13]	[69.78]	[143.10]	[127.10]	[518.00]	[513.40]	[7.35]	[7.61]
6th decile/Size 3	-0.32	-0.57	-78.79	-73.71	-58.85	-61.03	-20.29	-20.23	-6.22	-6.07
	[51.58]	[51.26]	[48.40]	[48.16]	[81.05]	[79.84]	[87.29]	[90.89]	[9.53]	[9.93]
7th decile/Size 5	-164.10***	-164.60***	-279.40***	-272.00***	-82.21	-86.68	50.92	49.84	-15.68*	-14.58
	[58.66]	[58.87]	[51.27]	[51.64]	[99.75]	[92.75]	[90.95]	[96.15]	[9.02]	[9.09]
8th decile/Size 6	-372.70***	-372.80***	-358.80***	-354.30***	-290.00*	-306.60*	-71.39	-73.74	-14.46*	-13.28
	[61.99]	[62.20]	[59.80]	[60.87]	[155.10]	[165.50]	[158.80]	[160.90]	[7.87]	[9.22]
9th decile/Size 7	-408.40***	-408.50***	-369.20***	-366.10***	-342.00**	-367.10*	-290.00	-283.70	-18.33**	-17.32**
	[60.43]	[60.77]	[65.25]	[65.17]	[174.20]	[188.50]	[325.30]	[325.90]	[7.78]	[8.45]
10th decile/Size 8	-485.60***	-485.10***	-420.20***	-419.50***	-340.60**	-362.40**	-233.00	-223.40	-20.53***	-19.69**
	[61.96]	[61.91]	[66.68]	[66.58]	[153.60]	[164.70]	[257.90]	[248.00]	[7.62]	[8.26]
Mean dependent variable	427.39		466.18		85.55		84.88		2.20	
Observations	4655	4655	4655	4655	4655	4655	4655	4655	4655	4655

Note: Robust standard errors are in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. Only the ICRISAT data include information about plot inputs. Regressions are estimated using Honore's (1992) fixed effects Tobit estimator. I use the Broyden-Fletcher-Goldfarb-Shanno optimization method, but similar results are obtained using the Polak-Ribiere Conjugate Gradient Method, the Simplex Method, and Powell's Method. A positive rainfall shock is defined as current rainfall being greater than the long-run historical average. The omitted land size category is the 5th decile.

Appendix Table 1: Robustness Specification, Household-Year-Crop Fixed Effects Regressions of the Determinants of Plot Yield Including Soil Type, Topography, and Plot Location

	Baseline (1)	Rain Shock (2)	Extreme Rain Shock (3)	Millet-Sorghum (4)	Cotton-Rice-Fonio (5)	Below Mean Number Hired Workers (6)	Above Mean Number Hired Workers (7)
Female	-27.71***	-14.51***	-21.45***	-10.38***	35.60	-12.19**	-20.86*
	[6.76]	[5.54]	[5.75]	[3.45]	[24.23]	[6.18]	[12.12]
Female * Positive Rainfall Shock		-24.83***		-15.59***	-151.64**	-16.95	-31.80**
		[9.06]		[4.33]	[74.17]	[10.30]	[15.57]
Female * Extreme Negative Rainfall Shock			3.64				
			[7.20]				
Female * Extreme Positive Rainfall Shock			-31.14*				
			[16.84]				
Plot Size:							
1st decile/Size 1	133.99***	131.67***	132.47***	37.47	233.09**	104.86**	173.76**
	[41.57]	[41.52]	[41.56]	[38.53]	[100.53]	[49.38]	[75.16]
2nd decile	69.10***	66.92***	68.13***	35.27***	118.95***	71.73***	51.56
	[20.42]	[20.61]	[20.48]	[11.26]	[45.54]	[23.93]	[38.38]
3rd decile	63.45***	62.34***	62.00***	29.19***	124.04***	57.47***	64.75***
	[13.98]	[14.03]	[14.07]	[6.91]	[43.42]	[17.46]	[24.22]
4th decile/Size 2	34.09**	33.45**	33.23**	17.76***	67.68*	26.02	40.46*
	[13.96]	[13.93]	[13.90]	[5.53]	[34.96]	[16.36]	[24.41]
6th decile/Size 3	-2.05	-2.49	-3.28	-2.38	5.71	-4.57	-0.86
	[8.97]	[8.95]	[9.05]	[4.30]	[42.57]	[11.44]	[14.46]
7th decile/Size 5	-13.44	-14.45	-14.64	-11.47**	24.49	-12.83	-22.26
	[9.69]	[9.69]	[9.80]	[4.63]	[30.56]	[11.10]	[18.52]
8th decile/Size 6	-17.24**	-18.22**	-18.66**	-22.52***	10.26	-14.41	-26.50
	[8.75]	[8.79]	[8.97]	[4.97]	[30.41]	[9.68]	[17.41]
9th decile/Size 7	-26.68***	-27.18***	-27.01***	-26.20***	-2.81	-26.25***	-32.93*
	[8.83]	[8.85]	[8.89]	[4.65]	[28.60]	[9.33]	[17.63]
10th decile/Size 8	-31.52***	-31.94***	-32.25***	-31.10***	-8.30	-28.01***	-46.28**
	[8.89]	[8.92]	[9.01]	[4.95]	[30.36]	[9.29]	[18.02]
Constant	97.48***	97.61***	97.72***	50.62***	85.48*	94.59***	100.93*
	[27.54]	[27.55]	[27.56]	[7.30]	[49.57]	[28.87]	[60.98]
Topography	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Soil Type	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Plot Location	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	4655	4655	4655	2195	994	3032	1623

Notes: Robust standard errors in brackets. * significant at 10%; ** significant at 5%; *** significant at 1%. Only the ICRISAT data include information about topography, soil type, and plot location. Each regression is a replication of a household-year-crop fixed effects regression from a previous table in the paper but now the regressions also include variables measuring topography, soil quality, and plot location. Column 1 is from Table 2; columns 2 and 3 are from Table 3; columns 4 and 5 are from Table 4; columns 6 and 7 are from Table 5. The dependent variable is value of plot output/hectare. A positive rainfall shock is defined as current rainfall being greater than the long-run historical average. In column 3, rainfall shocks are calculated to measure extreme positive shocks (rainfall more than 0.5 standard deviations above the long-run average) and extreme negative shocks (rainfall more 0.5 standard deviations below the long-run average). The omitted rainfall shock category in column 3 is average rainfall with rainfall amounts that fall between 0.5 standard deviations below long-run average rainfall and 0.5 standard deviations above long-run average rainfall. The omitted land size category is the 5th decile for the ICRISAT data.