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Climate, women's resilience and mediating channels in rural Benin *

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Abstract

We investigate the gender gap in resilience to climate anomalies and the mediation channels between weather conditions and women's agricultural outcomes in Benin. We find that, compared to a man, agricultural production is lower and more vulnerable to adverse rainfall conditions when the parcel manager is a woman. We also show that the *Plans Fonciers Ruraux* (PFR), a land titling RCT reform that started in Benin in 2008, does not significantly mitigate the gendered effects of rainfall deviations. Moreover, we provide new suggestive evidence on the role of gender-based intra-household differences when climate variations occur. We find that adverse weather conditions would push female parcel managers to reduce cultivated land, agricultural investment and labour supply more than male managers. We argue that, in rain-fed agriculture, adverse climate events can increase household competition over resources; in such an environment, the differential in intra-household bargaining power may become relevant and result in larger gender gaps.

Keywords: Adverse climate events; Resilience; Gender gap in agriculture; Land tenure; Benin.

JEL codes: Q12; Q15; Q18; Q54; J16.

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1 Introduction

It is well established that climate change can have detrimental impacts on agricultural productivity (Holzkämper, 2017), especially in contexts where farm households predominantly rely on rain-fed agriculture (Dercon and Hoddinott, 2004). At the same time, resilience capacity to climate shocks may differ by socio-economic status. In particular, gender can play an important discriminatory role in climate change vulnerability (Dossou-Cadja, 2020; Wouterse et al., 2022). Gender disparities connected to market failures, institutional constraints, social norms, and endowments and command of assets and productive resources (World Bank, 2012) can result in different climate change impacts and resilience capacities across genders.

Improvements in land tenure security can positively affect the household's ability to cope with climate shocks (Ajefu and Abiona, 2020; Gebremedhin and Swinton, 2003; Lovo, 2016) and, hopefully, narrow the gender gaps in resilience strategies. Indeed, to cope with increasing weather abnormalities, smallholder farmers have developed different adaptation strategies such as irrigation and increasing water harvesting, mixed crop-livestock farming systems, income diversification, tree planting, soil and water conservation strategies (Bezabih et al., 2021; Di Falco et al., 2011; Mitchell and Herrera, 2011). However, most of them require significant investments for farm households. Secure property rights can improve farmers' incentives and capacity to adopt such strategies (Yegbemey et al., 2013) and land registration programs may be key policies in this direction (Bezabih et al., 2021). But, evidence on the gender effects of these programs (like land certification and demarcation) is mixed (Ali et al., 2014; Goldstein et al., 2018). At the same time, intra-household dynamics and negotiations within farm households can play a mediating role in the relationship between land programs, adverse climate events and agricultural production. For instance, the agricultural economics literature has emphasized the role of pro-men intra-household resource allocation on farming efficiency (Udry, 1996).

Based on this background, the objectives of this study are threefold. First, we provide new evidence on the gendered effects of rainfall deviations from long-term trends on agricultural production. Second, we study whether land tenure security interventions (in our case, land demarcation activities) can reduce gender gaps in resilience to rainfall anomalies. Indeed, gender disparity in rural areas is also mirrored in the sphere of land tenure security, land control and access. In several African countries, women often own less land or experience higher tenure insecurity and more limited land rights than men (Doss et al., 2015; Slavchevska et al., 2020; Hasanbasri et al., 2022; Quisumbing et al., 2019). Nonetheless, land tenure security via land formalization may improve women's and smallholder farmers' ability to implement adaptation strategies and increase resilience to shocks. To the extent that women's rights are recognised within the programs and in local customary land tenure systems, the potential benefits may be more relevant for them, who usually suffer a disadvantage in the initial level of tenure security (Ali et al., 2014). Third, we investigate the mediating role of intra-household reallocation of resources in the interaction between rainfall variability and agricultural production. The existing gender gap in decision-making over cultivation choices (inputs, types of crops, labour allocation etc.) may interact with unfavourable weather conditions (e.g., Yokying and Lambrecht (2019) for Northern Ghana, Pierotti et al. (2022) for Nigeria). The existing evidence shows that environmental shocks can alter the division of labour between genders by favouring men's time allocation for reproductive work (Akter, 2021) and disproportionately hit pastoralist women because they are excluded from decision-making on the purchase and sale of livestock (Grillos, 2018).

We explore these research issues in Benin for several reasons. Agriculture is a key component of the Beninese economy, is characterized by a significant women's involvement and is highly vulnerable to climate change effects. The agricultural system is predominantly rain-fed and characterized mainly by smallholders with low investment capacity. The ND-GAIN index (2017) ranked Benin 19^{th} in terms of vulnerability to climate change and 45^{th} for readiness to cope with climate impacts (Ministry of Foreign Affairs of the Netherlands, 2018). Benin is particularly vulnerable regarding cereals' crop yields and water capacity. The agricultural sector accounted for 44% of the total employed workforce in Benin in 2010, of which 37% were women[1]. In Benin, as in other sub-Saharan African countries, women farmers, despite their high engagement in agricultural activities, face gender discrimination such as low access to land rights and

[1]Source: https://data.worldbank.org/indicator/SL.AGR.EMPL.MA.ZS?locations=BJ

participation in household and community decision-making (Atozou et al., 2017).

Data availability is another factor of interest. To conduct our analysis, we focus on the *Plans Fonciers Ruraux* (PFR), a land titling reform that started in Benin in 2008. The design of the PFR program is based on a national-wide experiment on land formalization. Other countries have conducted similar land programs, but in the PFR the complete random treatment assignment at the village level minimizes the risk of endogenous land rights interventions (see also Goldstein et al. (2018)). In addition, the impact evaluation survey carried out by the World Bank in 2011 collected data at the plot level, allowing the analysis of gender-related intra-household differences.

The PFR program has two components: parcels demarcation and delimitation, and delivery of land registration certificates. At the time of the collection of the latest publicly available data, the program had completed the first stage, so we estimated the gender gap in vulnerability to rainfall variability and its interaction with the land demarcation activities of the PFR program. We do so by estimating a simple ordinary least squares (OLS) model, controlling for various households, parcels and community variables. Our analysis shows that, compared to a man, agricultural production is lower and more vulnerable to adverse rainfall conditions when the parcel manager is a woman. Land demarcation interventions do not mitigate such a gender gap. In addition, our results are consistent with the hypothesis supported by some suggestive evidence that adverse weather events can trigger husbands' use of women's resources by further impacting women's production. We argue that, in rain-fed agriculture, adverse climate events can increase household competition over resources; in such an environment, the differential in intra-household bargaining power may become relevant and result in larger gender gaps.

The paper has various policy take-aways. First, land programs alone might not be able to effectively improve farmers' resilience to climate anomalies, at least in the short run. Henceforth, they should be integrated with other measures (like irrigation systems, extension services, improved seeds, etc.) before or during their rolling. In addition, both these lines of interventions should target women as beneficiaries as they have lower access to farming inputs and are less resilient to adverse climate events. Furthermore, making women more empowered is key to preventing pro-men reallocation. Indeed, it has been observed that deep-rooted social norms and values may hamper the effective implementation of land programs for women (Mengesha et al., 2021; Bayisenge, 2018). In Benin, it has also been reported that measures for water and soil conservation and agricultural productivity in women's fields have sometimes induced men to take the lands back (FriEnt, 2019). Investing in girls' education, family planning, and formal old age systems should be therefore viewed as ways to increase women's decision-making power within the household (Klugman et al., 2014) and, indirectly, to improve the overall outcomes of land security programs.

The paper is structured as follows. Section 2 discusses the main strands of literature related to this work. Section 3 presents the *Plans Fonciers Ruraux* policy, its design and implementation. Section 4 introduces the data used for the analysis and presents some summary statistics. Sections 5 and 6 are devoted to the empirical strategy and the discussion of the results. Section 7 concludes with some final remarks and policy implications.

2 Contribution to the existing literature

This paper contributes to the broad literature on the economic impacts of adverse climate events, particularly concerning gender gaps in agriculture, agricultural production, and farmers' livelihoods.

Climate variability and gender-based vulnerabilities. Existing evidence finds that female farmers are likely to be more vulnerable to climate change than their male counterparts (see, e.g., Dossou-Cadja (2020) for the case of Benin). Earlier research on South Africa, Niger and Ethiopia found that female-headed households are more affected by climate variability (Flatø et al., 2017) and are less likely to engage in on-farm adaptive production strategies (Wouterse et al., 2022) than male-headed households. Most past studies define gender-related climate vulnerabilities in agriculture based on the gender of the household head (Flatø et al., 2017). Differently from this research, our paper uses the gender of the parcel manager. Measuring gender at the plot manager level improves the estimation of gender gaps in agriculture as it allows to capture any gender-related intra-household differences and dynamics, not just across-household heterogeneity. Peterman et al. (2011), for instance, found that gender differences at the plot level are likely to be overlooked in analyses performed at the household-head level. This may also be the case in Benin, where most female parcel managers are not household heads. In our sample, 63% of female-managed plots are located in men-headed households. In this way, we uncover heterogeneous impacts of weather anomalies and land demarcation on household members' agricultural production, likely to translate into differentiated well-being effects within the household. Indeed, earlier studies have documented that weather shocks can have differentiated impacts on household consumption choices depending on the type of crops (that is gender-based) that are mainly hit (Doss, 1996a; Duflo and Udry, 2004). In the case of Malawi, Asfaw and Maggio (2018) show that temperature shocks hit more severely household consumption when the plot's decision-maker is a woman, but not in districts where matrilineage inheritance practice is prevalent. Indeed, women are likely to have stronger land tenure security and higher control over resources in matrilineal contexts, so their incentives and capacity to adopt climate-resilient technologies are larger. Relative to the existing evidence, we contribute by investigating the role of land security programs in reducing the gender gap in resilience to weather anomalies and the mediation channels between weather conditions and women's agricultural outcomes.

Land tenure reforms and climate change adaptation. This paper also contributes to the literature on the role of land security reforms in enhancing resilience to adverse climate events. Several studies find that land certification and formalization programs can promote soil conservation and sustainable land use practices or long-term agricultural investments[2] (Ali et al., 2014; Holden et al., 2009; Melesse and Bulte, 2015) as well as the participation in agricultural extension programs and sustainable resource management interventions (Adamie, 2021). All these effects can improve farmers' resilience to climatic shocks, but existing evidence is still incipient. In Benin, Yegbemey et al. (2013) finds that land ownership positively impacts the decision to implement adaptation strategies to climate change. Ajefu and Abiona (2020) shows that land tenure security reduces drought-induced food insecurity in rural Malawi. A positive role of land ownership and

[2]For a literature review on land tenure security impact, see Higgins et al. (2018).

land tenure security in reducing adaptation barriers is also found in Burkina Faso and Bangladesh (Alam, 2015; Kpadonou et al., 2017). However, modalities of land policies and tenure reforms to reach the above-mentioned results are still far from being well understood (IPCC, 2019). Bezabih et al. (2021) find that land certification alleviates the impact of excess rainfall on farm revenues in Ethiopia. Rampa and Lovo (2023) confirm that, in Ethiopia, the Land Registration and Certification Program increased both climate change mitigation and adaptation. There is, instead, little evidence from other countries. In Benin, for instance, the available evidence is indirect and not conclusive. Wren-Lewis et al. (2020) estimate that the *Plans Fonciers Ruraux* has reduced the area of forest loss and fires probably due to better forest community management and lower incentives for land clearing. Results reported by Goldstein et al. (2018) and by World Bank (2019) suggest that land demarcation activities promote long-term agricultural investment in tree planting and perennial crops, but they have not been effective in enhancing agricultural output or farm yields. Therefore, the role of land demarcation initiatives in enhancing resilience to climate anomalies is not clearly understood. We aim to narrow this gap by testing if the PFR has reduced agricultural production losses due to adverse rainfall conditions.

Land tenure security programs and gender-based heterogeneity. We also intend to contribute to the literature assessing whether land tenure programs are gender-neutral or not in adverse weather environments. Ali et al. (2014) find that the pilot of a land tenure regularisation program in Rwanda led to better land access for legally married women and a larger impact on land investment and soil conservation among female-headed households compared to male-headed households. Muchomba (2017) show that in Ethiopia, land certification, which issues joint certificates to household heads and spouses, can improve women's decision-making power compared to the land certification issued to household heads only (usually men). According to the qualitative study by Mengesha et al. (2021), joint land titling in Ethiopia improved women's access, control and decision-making over agricultural resources. Other studies provide more nuanced results. Although the land demarcation program in Benin, for instance, increased fallowing among female-headed households, it also widened the gender gap in agricultural yields (Goldstein et al., 2018). Our study aims to contribute to the empirical evidence on the gendered effects of land tenure programs at the occurrence of negative weather conditions.

Climate variability and intra-household allocation of agricultural resources. Finally, this paper adds to the literature on the intra-household allocation of farming resources. Our analysis disaggregates parcels by their manager's gender, allowing us to shed some light on within-household dynamics, which may have important implications for production efficiency and risk management. In his influential work, Udry (1996) discusses that transaction and monitoring costs, asymmetric information, and social norms can prevent the efficient intra-household allocation of fertilizers and labour, resulting in lower input intensity in women's plots than in men's.[3] The literature also provides insights on the relevance of intra-household resource allocation on the gender gap in agricultural productivity (Kilic et al., 2015; Backiny-Yetna et al., 2015; Slavchevska, 2015). Earlier evidence shows that gender differentials in the number of used resources and in their returns explain part of the lower land productivity of female-managed plots compared to male-managed ones.[4] Returns and use of production factors can be affected by women's position in market transactions, government programs, norms on land inheritance, divorce and marriage payments, but also in negotiations on time, land, and resources allocation with other household members. These mechanisms are relevant in poor African economies. Indeed, in such a context, households perform numerous tasks (from caring for dependents to self-producing food and fuels), and intra-household allocation of resources – capital, land, and labour – depends on internal hierarchies rules, roles and responsibilities, and delegations of authority within the households (Fafchamps, 2001). For instance, the qualitative study by Pierotti et al. (2022) finds that in South-Western Nigeria, women's domestic responsibilities and prioritization of family labour in men's plots affect the labour supply in married women's agricultural production. We delve into intra-household resource allocation since these mechanisms can be particularly relevant when households experience changes in land tenure security and climatic variability. Available scant evidence supports the idea that the intra-household allocation process varies across households and over time and that this heterogeneity may be linked to

[3] Doss (1996b) identifies several reasons why household members do not fully share their income risks.
[4] Information collected from studies on six SSA countries reveals that the difference between the land productivity of female- and male-managed plots ranges from 13 to 25 percent (Banerjee et al., 2014).

the total resources and needs. These, in turn, are affected by exposure to stress factors such as climatic shocks and seasonality. For instance, evidence collected in Nigeria by Pierotti et al. (2022) suggests that labour constraints for women's plots are stronger during the dry season when labour demand on men's lands increases[5]. Differently from Udry (1996), Akresh (2005) shows that, in Burkina Faso, households experiencing negative rainfall shocks are less likely to exhibit inefficient intra-household allocations due to increased labour in the wife's plots. We provide new (indirect) evidence on the role of gender-based intra-household differences when climate variations occur. In particular, differently from previous studies (de Brauw, 2015; Oseni et al., 2015; Slavchevska, 2015), which consider decisions in men's and women's plots as independently taken (Doss and Quisumbing, 2020), our research provides some suggestive evidence on the collective decisions across plots managed by different sexes, allowing us to have some understanding of the intra-household dynamics related to plot management.

3 The *Plans Fonciers Ruraux (PFR)* land tenure reform in Benin

3.1 The Context of PFR

The Benin PFR program represents a pioneer land tenure policy for its innovation in combining land formalization with the traditional customary system (World Bank, 2019). In Benin, as in most rural Africa, land rights are founded on complex customary arrangements. The village's chiefs and elders keep the longstanding historical traditions in force. The customary land system is often fragmented and peculiar to each community and village. In addition, customary laws can coexist within the formal land administration system, which guarantees land ownership, providing the possibility to prove and defend it through land registries and documents to attest property or use rights in administrative courts. However, in the context of Benin, the land administrative system's capacity is often sub-optimal and unable to manage land tenure, particularly in rural areas, ef-

[5] Such within household dynamics may help to understand heterogeneous gender gaps in agricultural productivity. Slavchevska (2015), for instance, shows that gender differences are significant only in the Southern and Central zones of Tanzania, where agricultural conditions tend to be harder.

fectively. Therefore, the PFR program was introduced in a setting where it was complex and expensive for farmers to obtain land titles. Hence, the majority of the rural population relied solely on oral records to claim their access to land (Goldstein et al., 2016) and struggled to see their land rights formally recognized (Goldstein et al., 2018). The issue of land access and land use rights recognition is particularly critical for minority groups such as women, migrants, and pastorals who have limited or no rights to inherit landholdings and invest in the land (*e.g.*, tree planting), especially among certain ethnic groups (World Bank, 2019; Neef and Heidhues, 1994). Moreover, under such a complex land tenure system, land disputes were so long-lasting and frequent to make up more the 70% of Benin's civil court cases (World Bank, 2019; Millenium Challenge Corporation, 2012). In this context, the Benin *Plans Fonciers Ruraux (PFR)* was sponsored by the Millennium Challenge Corporation (MCC) as part of the Access to Land (ATL) Project (World Bank, 2019) which also included a process of decentralizing the Land Registry Services to provide faster and more convenient proof of legal ownership (World Bank, 2019). Compared to state-led programs of individual titling, the PFR program was innovative in recognizing customary practices as the source of preexisting tenure rights. Merging the complex system of customary traditions into a unique land titling process was not without challenges. In addition to the mixed results mentioned in the previous section (Goldstein et al., 2018), the final evaluation report of the PFR activity under the ATL project indicates that in 2015 only 19 percent of expected certificates had been assigned. It also identifies several difficulties in certificate delivery, from technical problems to institutional frictions, inadequate incentives, and information barriers (World Bank, 2019). Other evidence based on qualitative field studies (Delville and Moalic, 2019; Delville, 2019) highlights problems of inadequate diagnosis before the PFR implementation, coordination and training of the staff engaged. It also discusses risks of forms of exclusion due to not clear and dynamic nature of administrative boundaries. In short, the overall and gendered effect of the PFR program on resilience to climate anomalies is an open empirical issue.

3.2 The implementation of the PFR

The *Plans Fonciers Ruraux* program was implemented in two stages. The detailed description of the program rolling out is reported in World Bank (2019). Nonetheless, it is worth summarising here below its main features. The initial step, constituted by the demarcation activities, was meant to create an accurate record of the obligations and rights of village landowners from their point of view. The land boundary was implemented at the village level, where the units of interest were the parcels. The demarcation was performed by using cornerstones to set parcel boundaries. Throughout this process, it was possible to identify and resolve all potential and actual land and frontier disputes. As a result of the first demarcation stage, registries of all landholdings were catalogued in every village. The completion of land demarcation activities was paramount to unfolding the second stage of the PFR program (World Bank, 2019).

The final step of the PFR intervention was the delivery of land certifications. The *Certificat Foncier Rural* (CFR) represents a legally valid certificate recognizing land use in concordance with the preexisting customary traditional rights. The CFR are transferable titles exploitable for transactions and are a formal recognition of ownership of landholding attributed to farmers during the demarcation process (World Bank, 2019; Goldstein et al., 2018). However, this study is based on the PFR demarcation stage only, as publicly available data cover only this stage.

3.3 The experimental design of the PFR

The PFR intervention was planned and designed to be susceptible to a nationwide randomised impact evaluation. The experimental design of the policy implementation represents a remarkable advantage to our analysis, setting the ground for the rightful and sound estimation of the PFR impact to derive policy lessons. The intervention consisted in randomly assigning villages of 40 communes to treatment and control groups (World Bank, 2019). Firstly, 1,543 villages received information about the PFR program and were encouraged to apply to participate. Subsequently, the 1,235 applications received were reviewed to define each village's eligibility against a set of pre-established criteria (*i.e.*, "high levels of poverty, a general acceptance of the rights of women and girls in the village, existence of land conflicts or disputes, and significant agricultural production" (World Bank, 2019)), finally resulting in a sample of 576 eligible villages. Two lotteries were set up for each commune, for a total of eighty lotteries, to select 300 PFR villages and randomly assign them into treatment and control groups (World Bank, 2019; Goldstein et al., 2018).

Concerning the timing of implementation, the PFR program started at the beginning of 2008 with the villages' information campaign after the passing of the Rural Land Act legitimizing the PFR program (October 2007). Subsequently, throughout 2009, the communes' lotteries were set up, allowing the selected villages to start the demarcation activities (June 2009 - February 2011). Right after the completion of the demarcation, between March and April 2011, the World Bank carried out the impact evaluation survey used in this analysis. For this reason, this study focuses only on the impacts of land demarcation rather than land titling, as the delivery of land use certificates, CFR began in 2011 and lasted until early 2015. Unfortunately, only the 2011 data are publicly available.

4 Data

We exploit data from three different sources to explore the interacted impact of land demarcation and climate change on the rural gender gap's resilience among farmers. Our starting point is the data from the impact evaluation survey conducted by the World Bank in March-April 2011 within the MCC PFR program. The survey collects information on the implementation of the PFR program in 289 villages across nine of the twelve regions in Benin. Data also provide information on individual and household socio-demographic characteristics, women empowerment, agricultural activities and production, land ownership status and tenure security. Observations represent the eight agro-ecological zones in Benin (see Figure 1).

Moreover, we match Benin districts' GPS coordinates with the closest grid-cell identified in the Climatic Research Unit (CRU) data to import information on Benin's weather conditions during the 2010 agricultural season (*i.e.*, between March and September 2010).[6] In particular, we look at the grid-level rainfall deviation from its historical trend (between 1960 and 2010) to capture the impact of precipitations' oscillation on agricultural production. We also use temperature deviation to account for additional potential climatic

[6]We initially tried to use the SPEI index but, unfortunately, for Benin it is recorded for a lower number of grid cells compared to the CRU data, therefore giving less climate variability across the country.

stressors that rural farmers may face and that can interact with rainfall deviation.

Finally, we add geo-referenced variables that are likely to be good correlates of agricultural production and its relationship with the land demarcation program and weather conditions. To do so, we imported from AfroGrid data information on the (sum of) night light density for 2011 and the mean of NDVI (Normalized Difference Vegetation Index) for 2011. Controlling for these variables allows us to account for differences within the country regarding economic development (proxied by the night light density) and soil fertility (proxied by NDVI). Finally, we use data about the road map of Benin obtained from 'The Humanitarian Data Exchange'.[7] These data are used to calculate the distance between villages and the nearest road and allow us to control the local infrastructure's development level.

4.1 Summary statistics

The primary unit of analysis of our study is the parcel. Our final sample includes 3,211 parcels, representative of 2,207 households. The research is based on cross-sectional data; therefore, we cannot test the pre-intervention balance among sampled villages. Nonetheless, we can rely on the balance test performed in Goldstein et al. (2018) on the same data to conclude that the sample is balanced. Indeed, these authors use the 2006 EMICoV data survey to test the pre-treatment balance in the 160 sampled villages used in the PFR Impact Evaluation 2011 data. Their analyses confirm the lotteries' validity, finding that a set of observable household characteristics does not diverge across treatment and control groups.[8]

Tables 1 and 2 provide descriptive statistics of the outcome and control variables used in the regression analyses below and their comparison between treatment/control groups and the plot manager's gender. Table 1 shows no statistical significance in the mean differences for the dependent variables across treatment and control groups. In contrast, all geo-referenced variables (rainfall deviation, rainfall deviation squared, temperature deviation, night light, NDVI, and road distance) are statistically different. In

[7]We got this series from the *Centre National de Télédétection et de Suivi Ecologique* (CENATEL).

[8]The only statistically significant differences they report among the two sub-samples are that, on average, household heads are 1.59 years older and with 0.22 fewer years of education than the treated households Goldstein et al. (2018).

particular, the treated group shows lower rainfall, temperature deviations, and NDVI index but a higher night light density than the control group. It must be noted that in the year of the analysis, 2010, rainfall does not present any extreme deviation from its long-term average. For this reason, we use a continuous rainfall-related variable in our regression analyses rather than binary weather shock indicators. The mean standardized rainfall deviation is 0.24, with only about 3% observations below 0, with a minimum value of -0.047 and its maximum level at 0.467. Finally, only a few other household characteristics are statistically different between treatment groups, like the parcel's total area and the household head's marital status.

Table 2 reports gender disparities between female- and male-led parcels. Agriculture output and input use are systematically lower in women-managed parcels compared to men-led parcels. In particular, women-managed parcels show lower total production and a smaller probability of investment, land size and labour supply. We argue that such gaps would reflect pro-men household decision-making rules that, in turn, might influence intra-household reallocation of resources when a negative climate event occurs. This evidence pushes us to explore whether differences intra-household bargaining interact with adverse climate events.

Tables 3 and 4 provide some preliminary insights on parcel differences across the gender of the manager and the household head. These tables first report summary statistics for various variables using all the parcels in our sample. Next, we include only parcels where their manager and the household head are of the same gender[9]. We argue that gender-based reallocation of resources in such a household structure is less plausible. The third group includes female-managed parcels in male-headed households (MHHs), therefore located in households where a gender-based reallocation of household resources is more likely. We find that, where pro-men intra-household reallocation is more plausible (third column), household heads are more likely to be polygamous, to be able to read and write in French, be village advisors or leaders, or group leaders. This may imply that women parcel managers residing in MHHs tend to live in a household whose head has a potentially stronger decision-making power, which is also likely

[9]This group also contains male parcel managers living in a female-headed household, but they are only 27 observations with no effect on the results

to be reflected in the use of household resources. In support of it, it is noteworthy that women parcel managers living in MHHs are more likely to report fear of losing their land. Finally, the last column focuses on parcels located in households where the parcel manager and the household head are women. For this group, evidence on agricultural production, parcel size, investment, labour supply, participation in village institutions and literacy rate reflects women's lower empowerment in rural Benin areas.

5 Empirical strategy

This section presents our empirical strategy for analyzing the effect of the land demarcation program, rainfall deviation, gender of the parcel's manager, and their interactions on the agricultural output.

For this purpose, we rely on the random assignment of the demarcation program described above and the quasi-randomness in rainfall variation to estimate the following baseline ordinary least square (OLS) model:

$$\begin{aligned} Y_{pijg} = \beta_1 PFR_{jg} + \beta_2 WPM_{pijg} + \beta_3 RD_g + \gamma_1 PFR_{jg} \times WPM_{pijg} + \gamma_2 PFR_{jg} \times RD_g + \\ + \gamma_3 WPM_{pijg} \times RD_g + \omega PFR_{jg} \times WPM_{pijg} \times RD_g + \theta_1 X_{ijg} + \theta_2 Z_g + \epsilon_{ijgt}, \end{aligned} \tag{1}$$

where Y_{pijg} denotes the (log of the) value of the total agricultural production harvested on parcel p that belongs to household i, who lives in village j located in grid cell g. PFR_{jg} is a binary variable taking one if the parcel is a in village j, located in grid g, that benefited from the land demarcation program described earlier, and zero otherwise. WPM_{pijg} identifies whether a woman manages the parcel. RD_g is our measure of standardized rainfall deviation in grid-cell g. Finally, S_{pijg}, X_{ijg} and Z_g denote parcel, household and grid-level characteristics, respectively. Adding these control variables to our specification strengthens the identification of our variables of interest – PFR_{jg}, WPM_{pijg}, RD_g, and their interactions. The full list of these variables is reported in Tables 1 and 2. Standard errors are clustered at the village level.

Upon controlling for potential correlates of villages' infrastructure, economic development, and soil fertility, we rely on the randomness of the land program assignment and climatic variation to identify the causal gendered effects of favourable weather conditions and land intervention on agricultural output, and their interaction.

For our purpose, the key coefficients in eq. 5 are γ_1, γ_3 and ω, as they capture any mediating role played by the gender of the parcel manager. As discussed earlier, evidence around the developing world shows that β_2 is negative, pointing to a gender gap in agriculture production. In this case, if γ_1 is positive (cf. negative), we can conclude that the land demarcation program reduces (increases) the gender gap in agricultural production. This, in turn, is widened (reduced) by a negative rainfall deviation if γ_3 is positive (negative). However, if ω is negative, the PFR intervention would help mitigate the gendered effects of low rainfall. In other terms, the PFR intervention and low rainfall would affect parcels' output differently depending on the gender of their manager.

6 Results

6.1 Main results

Here we report the results of the land program, rainfall deviation and gender of parcel manager effects on total agricultural production in Benin. Column 1 of Table 5 reports the key coefficients of eq. 1 when the full sample of parcels is used. It shows that the effect of the land demarcation program (PFR) on agricultural output is not statistically significant. This result is consistent with findings reported in Goldstein et al. (2018). Moreover, conditional on their land size (and other household-, parcel- and grid-level controls), production is significantly lower in parcels managed by women than those operated by men. As expected, an increase (decrease) in rainfall relative to its historical mean is beneficial (detrimental) to agricultural production. In fact, rainfall is a key input for production in rural Benin, where most parcels are rainfed. The next coefficient ($PFR * WPM$) captures any gendered differences in agricultural production attributable to the land demarcation program. We find that this policy intervention does not affect such differences. Hence, the program cannot narrow the gender gaps in agricultural production.

Similarly, the land demarcation policy would not increase farmers' resilience to unfavourable climate events, as shown by the $RD * PFR$ coefficient. Furthermore, our estimates confirm that women-managed parcels are more vulnerable to weather changes. In particular, a negative rainfall deviation would significantly decrease the production in parcels managed by women compared to those by men. Finally, our last key coefficient reports the triple interaction between PFR, the gender of the parcel manager and the rainfall deviation. We do not find any other significant gendered difference in agricultural production due to the treatment and weather variations.

The following columns report results of robustness checks and tentative investigations of possible mechanisms to validate our baseline results. For doing so, we follow Goldstein et al. (2018) and add the enumerators and lottery fixed effects to our baseline specification. Specifically, controlling for the lottery fixed effects accounts for the differences in the timeline of the PFR reform implementation across villages (3 months on average), which introduces (potentially endogenous) heterogeneity in villages' exposure to the reform measured at the time of the survey (on average 11 months). As shown in column 2, our key coefficients are qualitatively comparable to the baseline results.

In the third column, we exclude from the estimation all those parcels that were not in the same village where the household resided at the time of the survey (*i.e.*, 349 parcels out of 3,211). Such a test would account for those observations assigned to the wrong treatment and rainfall deviation (as the data only provide the village where the household lives and not where the parcel is situated). Reassuringly, as shown in column 3, our results survive this test, meaning that our baseline findings are not driven by the wrong identification of a few parcels' villages.

In column 4, we exclude all the parcels managed by a woman and located in households whose head is a man (*i.e.*, 804 observations).[10] The reason for doing so is to explore if any intra-household reallocation is related to the demarcation plan or weather variation. We argue that households with female parcel managers and whose household head is a man might behave differently to policy or weather changes because women-managed parcels are more prone to pro-men intra-household reallocation. In case of positive or negative events, men's resources would be accrued (or cushioned) at the expense of women's budget. The interaction coefficient between the parcel's manager gender and the rainfall deviation ($WPM * RD$) would confirm our hypothesis. Indeed, it is no longer significant, supporting the idea that the higher gender production gap induced by a negative rainfall deviation would be driven by those households where such pro-men reallocation looks more plausible. The implementation of the PFR would generate no

[10]Out of the whole sample – 3,211 parcels – 1,906 are parcels managed by men and located in men-headed households, 27 are operated by men and situated in women-headed households, 804 are managed by women and located in men-headed households, and 474 are managed by women and located in women-headed households.

similar mechanism.

Given that the land demarcation intervention does not affect our outcome nor play a mediating role in the gendered effects, in column (5) we replicate the baseline specification by excluding the PFR indicator and its interaction with the parcel's manager gender and rainfall deviation. Finally, using the same specification, column (6) shows results when parcels managed by a woman and located in households whose head is a man are excluded (the same sample as in column (4)). Columns (5) and (6) confirm the main results. Female-managed parcels are characterized by a larger decline in agricultural production in case of negative deviation from historical rainfall trend than male-managed parcels. Still, this gap is not statistically significant when we exclude parcels run by women who live in men-headed households.

6.2 What drives the main results?

The previous subsection argues that gender-discriminating results of negative weather conditions would be driven by households where pro-men reallocation mechanisms are possible. Indeed, to buffer the negative effects on household welfare induced by negative rainfall, women who manage a parcel might be pushed to use their production inputs or savings in favour of the men in the household when these are the household head. To corroborate this hypothesis, we use three outcomes: (1) the size of the available land (in hectares), (2) the investment made on the parcel (0/1 variable), (3) the labour supply at the parcel level (time in person-days allocated to farming activities in the main agricultural season). Results are reported in Table 6.

Does a negative rainfall deviation induce a pro-men reallocation of the available land? As shown in column 1 of Table 6, women-managed parcels are smaller than men-managed. Also, the weather condition is a key determinant of the parcel's size. In fact, negative rainfall deviations reduce cultivated land (see *RD* coefficient) since farmers may perceive investing in capital and human resources as too risky, given the expected productivity loss in a rainfed agriculture system. Nevertheless, would this mechanism support the main finding of a gender-discriminatory effect of negative climate conditions? As shown by the interaction between being in a woman-managed parcel and rainfall deviation, the cultivated land of parcels managed by women would further decrease in case of negative weather change. However, when we exclude parcels managed by women but located in men-headed households (column 2), the rainfall-induced reduction in the cultivated land is no longer significantly differentiated by the gender of the parcel manager.

These results are consistent with the hypothesis that droughts induce an intra-household land reallocation in favour of men. Nonetheless, these estimates are based on self-reported land area, and we cannot rule out the possibility that adverse weather conditions affect farmers' errors in measuring the total parcels' area by impacting the harvested area. For this reason, we explore the dynamics of other farm management decisions that rainfall anomalies may influence.

Does a negative rainfall deviation induce a pro-men use of investments on the parcel? An alternative way to check if some pro-men intra-household coping mechanisms are in place is through eventual changes in the probability of investment on the parcel. Using a linear probability model, we use specification in eq. 1 where the outcome is a binary variable which takes the value of one if some investment was made on the parcel during the 12 months before the survey. As for the land size, the key parameter is the $WPM * RD$ coefficient. As shown in column 3, a negative rainfall deviation significantly decreases the likelihood of investment in parcels managed by women compared with those by men. As we exclude parcels where the discussed climate-induced reallocation in favour of men is more likely to occur (column 4), a negative rainfall deviation would not further decrease investment in women-managed parcels compared with men-managed.

Does a negative rainfall deviation prompt an intra-household labour reallocation to men-managed parcels? Women farmers usually face stricter constraints than men in access to household labour and hired labour due to gender norms, disproportionate shares of household workload and financial barriers. For instance, Kilic et al. (2015) estimate that in Malawi more than 80% of the gender gap in agricultural productivity (estimated at 25%) is explained by the difference in inputs level, with the shortage in male household labour being a key determinant. Backiny-Yetna et al. (2015) find that in Niger challenges faced by women in accessing and supervising male farm labour affect both the quantity and quality of household adult male labour. Such constraints largely drive the gender productivity gap in agriculture, combined with barriers to access to land and fertilizers. Similarly, Slavchevska (2015) shows that scarcity of land and male family labour largely contribute to the productivity gap between sole female-managed plots and other plots in Tanzania. We found similar results also in the case of Benin: column (3) of Table 6 shows that, upon controlling for land size, household size and composition, female plot managers employ less household and non-household labour than male plot managers (see WPM coefficient). At the same time, labour, a variable and mobile input, may be particularly prone to reallocation across household plots. When all parcels are included in the analysis, negative rainfall deviations lead to a decline in labour supply in parcels managed by women, reinforcing the gender gap in farming labour. However, this effect disappears when we exclude from the sample parcels in which a gender-based labour reallocation is more feasible (i.e. managed by women and located in male-headed households). As shown in column (4) of Table 6, the $WPM * RD$ coefficient becomes non-statistically significant. This result is consistent with previous studies showing that weak female farmers' access to agricultural labour is grounded on intra-household negotiation of labour allocation. Pierotti et al. (2022), for instance, finds that in Nigeria social expectations that prioritize men's farm plots would result in women's time and labour constraints.

Overall, the suggestive findings in Table 6 are compatible with our hypothesis that climate-induced gender-discriminatory effects in agricultural production are associated with some intra-household pro-men reallocation decisions, making men more resilient to adverse climate events. In particular, female parcel managers would cede part of their plot after negative rainfall deviations, reducing investments and labour inputs in their parcels as a buffering mechanism favouring men in the household, and making women-managed parcels more vulnerable.

7 Concluding remarks

Our study investigates the gendered effects of rainfall variability on farmers' resilience in Benin, in the context of a land security intervention. Using plot-level data, our findings show that women-managed parcels are more vulnerable to negative rainfall deviations. Moreover, at least in the short run, the land demarcation program does not narrow preexisting gender disparities among rural farmers and does not prevent climate-induced gender gaps from rising. In addition, we find that women-managed parcels are more likely to suffer from adverse rainfall conditions. Interestingly, negative climate events would not further increase the existing gender gaps in agriculture production and resilience when we exclude women-managed parcels situated in men-headed households, namely parcels which are more prone to inputs reallocation in favour of men. This finding would support the hypothesis that climate-induced gender discriminatory effects in agricultural production are associated with some pro-men intra-household reallocation decisions, making men more resilient to adverse climate events. These results survive several robustness checks, including where enumerators and lottery fixed effects are added to account for possible endogenous differences in the exposure to the land program.

Exploring possible mechanisms, we find that adverse weather conditions would push female parcel managers to reduce cultivated land more than male managers. Unlike men, they also reduce investments and labour supply in their parcel after negative rainfall deviations. However, these results would be driven by parcels managed by women but located in male-headed households. This would strengthen the hypothesis that some intra-household buffering mechanisms favouring men would occur after negative rainfall deviation. In particular, in this specific agricultural household setting, women would cede part of their parcel to men, cut investments on their parcels to divert money and reduce farming labour in favour of men-managed parcels. As a final result, this reallocation would make women-managed parcels more vulnerable. Additional investigations of this mechanism are clearly needed to strengthen our hypothesis, exploring, in particular, its sources (*e.g.*, associated with ancestral norms, type of crops grown, and, more generally, the prevailing informal institutions). These results would show that to increase women's resilience in agriculture, barriers to increased women's agency must be understood and tackled, and existing gender disparities in access to farming inputs must be reduced. Without effective, paramount interventions in this direction, measures like new land policies and adaptation strategies may be ineffective in reducing the existing gender gap in agriculture. Resolving existing gender disparities is particularly urgent in contexts where climate shocks become more and more recurrent, and where women, who mostly rely on rain-fed agricultural activities to generate revenue, are highly vulnerable to such weather events.

To our knowledge, this is the first attempt to bridge the fields of gender disparities in land tenure reform processes and resilience to climate shock. However, we acknowledge three main drawbacks to our analysis. First, our survey data are cross-sectional, so identification cannot rely on the temporal variability of our key variables. Second, at the time of writing, the impact evaluation data cover only the first stage of the PFR program, namely land delimitation activities. Hence, we can only partially grasp the impact of the reform. Third, we provide some suggestive insights about the climate-induced intra-household dynamics that would reallocate resources in favour of men. However, since our data do not provide information on non-farm activities, it is not possible to draw a comprehensive picture of such possible intra-household mechanisms because we cannot account for income diversification strategies (for which men are known to have better options than women). Future research should delve more into the dynamics of bargaining or cooperation between male and female household members in response to adverse climatic events.

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8 Appendix

Table 1: *Descriptive Statistics: Means difference between treated and control groups*

	All		Control group		Treatment group		Means difference
	Mean	SD	Mean	SD	Mean	SD	P-value
Outcomes							
Output (Log USD)	6.14	1.37	6.10	1.34	6.15	1.39	0.296
Log of parcel area (ha)	0.22	1.61	0.20	1.57	0.22	1.63	0.745
Parcel investment in the last 12 months (0/1)	0.15	0.36	0.14	0.34	0.15	0.36	0.169
Total labor supply (person-day)	193.65	280.40	187.63	274.72	196.39	282.96	0.407
Explanatory Variables							
Parcel level							
Parcel is outside the village (0/1)	0.11	0.31	0.10	0.30	0.11	0.31	0.440
Labor supply of non-hh workers (person-day/ha)	91.92	179.72	95.04	185.04	90.50	177.26	0.514
Total area of the parcel (ha)	3.88	10.60	3.18	5.64	4.20	12.20	0.001
Household level	46.22	14.80	46.30	14.86	46.18	14.78	0.825
Age of hh head	0.23	0.42	0.22	0.42	0.23	0.42	0.730
Head can read & write in French (0/1)	0.30	0.46	0.31	0.46	0.29	0.45	0.138
Head is polygamous (0/1)	3.42	2.49	3.62	2.77	3.33	2.34	0.003
# of children in hh	1.70	1.17	1.72	1.17	1.69	1.17	0.434
# of women in hh	1.47	1.11	1.50	1.07	1.46	1.12	0.404
# of men in hh	0.88	0.33	0.89	0.31	0.87	0.33	0.192
Head is married (0/1)	0.02	0.14	0.03	0.17	0.02	0.13	0.037
Head is divorced (0/1)	0.08	0.27	0.06	0.25	0.09	0.28	0.018
Head is a widow/widower (0/1)	0.01	0.11	0.01	0.10	0.01	0.11	0.558
Head is village chief (0/1)	0.43	0.49	0.43	0.50	0.42	0.49	0.710
Head is Catholic (0/1)	0.08	0.27	0.08	0.28	0.08	0.26	0.448
Head is village advisor (0/1)	0.08	0.28	0.07	0.25	0.09	0.29	0.027
Head is a village group member (0/1)	0.06	0.24	0.06	0.24	0.06	0.24	0.917
Head is a village group leader (0/1)	0.04	0.20	0.04	0.19	0.04	0.21	0.420
Head is a leader in the village (0/1)	0.01	0.09	0.00	0.07	0.01	0.09	0.173
Head is a government employee (0/1)	14.48	12.63	14.07	12.57	14.66	12.65	0.217
Land tenure (years)	46.22	14.80	46.30	14.86	46.18	14.78	0.825
Grid-cell level							
Rainfall deviation	0.29	0.14	0.31	0.14	0.28	0.14	0.000
Rainfall deviation squared	0.10	0.07	0.11	0.07	0.10	0.07	0.000
Temperature deviation	0.43	0.12	0.43	0.11	0.42	0.12	0.008
Distance to the nearest road (km)	0.01	0.01	0.01	0.01	0.01	0.01	0.061
Night light (sum 2011)	2,459.10	2,902.00	2,201.16	2,626.90	2,576.61	3,012.28	0.000
NDVI index (mean 2011)	0.69	0.02	0.70	0.02	0.69	0.03	0.000
	3211		1005		2206		

Sources: Own computation from *Plans Fonciers Ruraux* Impact Evaluation 2011, Baseline Survey data; rainfall and temperature data from CRU; NDVI index and night light data from the AfroGrid dataset; Distance to road from Centre National de Télédétection et de Suivi Ecologique (CENATEL).
Notes: observations at parcel level.

Table 2: *Descriptive Statistics: Means Difference between male- and female-managed parcels*

	All		Male-managed parcels		Female-managed parcels		Means difference
	Mean	SD	Mean	SD	Mean	SD	P-value
Outcomes							
Output (Log USD)	6.14	1.37	6.34	1.40	5.83	1.27	0.000
Log of parcel area (ha)	0.22	1.61	0.43	1.59	-0.11	1.59	0.000
Parcel investment in the last 12 months (0/1)	0.15	0.36	0.18	0.38	0.10	0.31	0.000
Total labor supply (person-day)	193.65	280.40	227.66	313.89	142.21	210.17	0.000
Explanatory Variables							
Parcel level							
Parcel is outside the village (0/1)	0.11	0.31	0.10	0.30	0.12	0.33	0.030
Labor supply of non-hh workers (person-day/ha)	91.92	179.72	227.66	313.89	142.21	210.17	0.000
Total area of the parcel (ha)	3.88	10.60	4.71	12.06	2.64	7.75	0.000
Household level	46.22	14.80					
Age of hh head	0.23	0.42	45.54	14.52	47.24	15.16	0.002
Head can read & write in French (0/1)	0.30	0.46	0.24	0.43	0.21	0.41	0.069
Head is polygamous (0/1)	3.42	2.49	0.31	0.46	0.28	0.45	0.118
# of children in hh	1.70	1.17	3.68	2.63	3.02	2.19	0.000
# of women in hh	1.47	1.11	1.78	1.24	1.58	1.04	0.000
# of men in hh	0.88	0.33	1.61	1.09	1.27	1.10	0.000
Head is married (0/1)	0.02	0.14	0.94	0.24	0.79	0.41	0.000
Head is divorced (0/1)	0.08	0.27	0.02	0.13	0.03	0.17	0.019
Head is a widow/widower (0/1)	0.01	0.11	0.02	0.14	0.17	0.38	0.000
Head is village chief (0/1)	0.43	0.49	0.02	0.12	0.01	0.08	0.014
Head is Catholic (0/1)	0.08	0.27	0.41	0.49	0.45	0.50	0.022
Head is village advisor (0/1)	0.08	0.28	0.09	0.29	0.06	0.23	0.000
Head is a village group member (0/1)	0.06	0.24	0.06	0.24	0.12	0.32	0.000
Head is a village group leader (0/1)	0.04	0.20	0.05	0.22	0.08	0.27	0.001
Head is a leader in the village (0/1)	0.01	0.09	0.04	0.19	0.05	0.21	0.218
Head is a government employee (0/1)	14.48	12.63	0.01	0.09	0.01	0.09	0.984
Land tenure (years)	46.22	14.80	14.58	12.41	14.32	12.96	0.565
Grid-cell level							
Rainfall deviation	0.29	0.14	0.26	0.15	0.33	0.11	0.000
Rainfall deviation squared	0.10	0.07	0.09	0.07	0.12	0.06	0.000
Temperature deviation	0.43	0.12	0.40	0.13	0.46	0.09	0.000
Distance to the nearest road (km)	0.01	0.01	0.01	0.01	0.01	0.01	0.248
Night light (sum 2011)	2,459.10	2,902.00	2,644.57	3,282.26	2,178.56	2,177.04	0.000
NDVI index (mean 2011)	0.69	0.02	0.69	0.03	0.70	0.02	0.000
	3211		1933		1278		

Sources: Own computation from *Plans Fonciers Ruraux* Impact Evaluation 2011, Baseline Survey data; rainfall and temperature data from CRU; NDVI index and night light data from the AfroGrid dataset; Distance to road from *Centre National de Télédétection et de Suivi Ecologique* (CENATEL)

Table 3: *Descriptive Statistics: outcomes and explanatory variables, by type of parcel's manager and household head*

	Type of parcels							
	All		*sex of HH = sex of parcel manager*		*WPM in MHH*		*FHH & WPM*	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Outcomes								
Output (Log USD)	6.14	1.37	6.16	1.41	6.08	1.24	5.41	1.21
Log of parcel area (ha)	0.22	1.61	0.27	1.59	0.06	1.68	-0.41	1.38
Parcel investment in the last 12 months (0/1)	0.15	0.36	0.16	0.36	0.12	0.33	0.07	0.26
Total labor supply (person-day)	193.65	280.40	202.67	290.18	166.66	247.02	100.74	113.69
Explanatory Variables								
Parcel level								
Parcel is outside the village (0/1)	0.11	0.31	0.10	0.30	0.13	0.34	0.11	0.31
Labor supply of non-hh workers (person-day/ha)	91.92	179.72	91.17	183.69	94.16	167.35	99.72	199.46
Total area of the parcel (ha)	1.66	3.14	1.74	3.40	1.42	2.18	0.76	1.01
Household level								
Age of hh head	46.22	14.80	46.49	14.78	45.38	14.85	50.40	15.17
Head can read & write in French (0/1)	0.23	0.42	0.20	0.40	0.30	0.46	0.05	0.22
Head is polygamous (0/1)	0.30	0.46	0.28	0.45	0.34	0.48	0.17	0.38
# of children in hh	3.42	2.49	3.40	2.56	3.47	2.24	2.26	1.89
# of women in hh	1.70	1.17	1.71	1.20	1.69	1.07	1.39	0.98
# of men in hh	1.47	1.11	1.46	1.11	1.51	1.10	0.87	0.98
Head is married (0/1)	0.88	0.33	0.84	0.37	0.99	0.12	0.45	0.50
Head is divorced (0/1)	0.02	0.14	0.03	0.16	0.00	0.04	0.08	0.27
Head is a widow/widower (0/1)	0.08	0.27	0.11	0.31	0.00	0.07	0.46	0.50
Head is village chief (0/1)	0.01	0.11	0.01	0.11	0.01	0.10	0.00	0.00
Head is Catholic (0/1)	0.43	0.49	0.41	0.49	0.46	0.50	0.43	0.50
Head is village advisor (0/1)	0.08	0.27	0.07	0.26	0.09	0.29	0.00	0.05
Head is a village group member (0/1)	0.08	0.28	0.07	0.26	0.11	0.31	0.13	0.34
Head is a village group leader (0/1)	0.06	0.24	0.05	0.22	0.10	0.29	0.05	0.22
Head is a leader in the village (0/1)	0.04	0.20	0.03	0.18	0.07	0.25	0.01	0.12
Head is a government employee (0/1)	0.01	0.09	0.01	0.08	0.01	0.11	0.00	0.00
Land tenure (years)	14.48	12.63	14.12	12.39	15.56	13.26	12.21	12.15
Grid-cell level								
Rainfall deviation	0.29	0.14	0.28	0.15	0.32	0.11	0.34	0.12
Rainfall deviation squared	0.10	0.07	0.10	0.07	0.12	0.05	0.13	0.06
Temperature deviation	0.43	0.12	0.41	0.12	0.46	0.09	0.45	0.09
Distance to the nearest road (km)	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Night light (sum 2011)	2,459.10	2,902.00	2,509.74	3,108.68	2,307.49	2,163.11	1,959.86	2,185.39
NDVI index (mean 2011)	0.69	0.02	0.69	0.03	0.70	0.02	0.70	0.02
Number of parcels	3211		2407		804		474	

Notes: WPM: women parcel managers, MHH: male-headed households, FHH: female-headed households. The first column "All" identifies all parcels in our entire sample; in the second column "sex of HH = sex of parcel manager" there are parcels managed by a household member who has the same gender of the household head (no gender-based reallocation possible); in the third column "WMP in MHH" there are women-managed parcels in male-headed households (gender-based reallocation possible); the fourth column "FHH & WPM" include parcels managed by women in female-headed households (no gender-based reallocation possible).
Sources: Own computation from *Plans Fonciers Ruraux* Impact Evaluation 2011, Baseline Survey data; NDVI index and night light data from the AfroGrid dataset; Distance to road from *Centre National de Télédétection et de Suivi Ecologique* (CENATEL).

Table 4: *Descriptive Statistics: additional parcel level variables, by type of parcel's manager and household head*

	Type of parcels							
	All		*sex of HH = sex of parcel manager*		*WPM in MHH*		*FHH & WPM*	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Parcel use, characteristics, and inputs								
HH used improved inputs on the parcel	0.33	0.47	0.33	0.47	0.31	0.46	0.39	0.49
Labor supply of household members (person-day/ha)	120.37	194.00	121.68	199.38	116.44	176.97	133.31	274.85
Do you fear of losing this parcel?	0.73	0.44	0.71	0.46	0.81	0.39	0.76	0.43
Fallowed this parcel in last 12 months?	0.01	0.08	0.01	0.08	0.01	0.10	0.01	0.08
Planted any tree in last 12 months?	0.07	0.26	0.07	0.26	0.07	0.26	0.04	0.20
Parcel demarcated with a corner stone	0.24	0.43	0.24	0.43	0.24	0.43	0.19	0.39
Water resources								
Water point in the village (/ with 10 km)	0.93	0.26	0.92	0.27	0.94	0.23	0.92	0.28
Is the water point functioning?	0.95	0.21	0.95	0.23	0.97	0.16	0.91	0.29
Time dist. village center–water point	10.28	12.90	10.28	14.02	10.29	8.86	8.35	9.02
Cost to travel to the water point (CFA)	20.44	67.28	19.28	62.05	23.83	80.58	13.14	55.69
Cultivated crops								
Cereals	0.81	0.39	0.82	0.39	0.78	0.41	0.81	0.39
Pulses	0.25	0.43	0.25	0.43	0.26	0.44	0.29	0.45
Roots and tuber	0.36	0.48	0.37	0.48	0.32	0.47	0.29	0.45
Vegetables	0.07	0.25	0.06	0.24	0.08	0.28	0.09	0.28
Annual cash crops	0.99	0.09	0.99	0.09	0.99	0.11	1.00	0.06
Perennial crops	0.02	0.13	0.01	0.11	0.03	0.16	0.01	0.08
Care intensive crops	0.83	0.38	0.83	0.38	0.84	0.37	0.84	0.37
Care saving crops	0.08	0.27	0.10	0.30	0.03	0.16	0.03	0.18
Drought tolerant crops	0.34	0.47	0.35	0.48	0.29	0.45	0.35	0.48
Number of parcels	3211		2407		804		474	

Notes: WPM: women parcel managers, MHH: male-headed households, FHH: female-headed households. The first column "All" identifies all parcels in our entire sample; in the second column "sex of HH = sex of parcel manager" there are parcels managed by a household member who has the same gender of the household head (no gender-based reallocation possible); in the third column "WMP in MHH" there are women-managed parcels in male-headed households (gender-based reallocation possible); the fourth column "FHH & WPM" include parcels managed by women in female-headed households (no gender-based reallocation possible). Annual cash crops: cotton, pineapple, sesame. Perennial crops: cashew, oil palm, teak, acacia trees. Care intensive crops: cotton, rice, peanuts, maize, peppers, onion, tomatoes, sesame, sweet potato. Care saving crops: sorghum, millet, fonio. Drought tolerant crops: sorghum, cassava, sweet potato, millet, peanuts.
Sources: Own computation from *Plans Fonciers Ruraux* Impact Evaluation 2011, Baseline Survey data; NDVI index and night light data from the AfroGrid dataset; Distance to road from *Centre National de Télédétection et de Suivi Ecologique* (CENATEL).

Table 5: *Baseline results: effect of rainfall deviation, land demarcation (PFR) and parcel's gender manager on agricultural output*

Output: log of total value (USD)	(1) *All parcels*	(2) *All parcels*	(3) *Parcels in the same village only*	(4) *sex of HH = sex of parcel manager*	(5) *All parcels*	(6) *sex of HH = sex of parcel manager*
PFR ITT	-.04	.003	-.014	-.011		
	(.179)	(.188)	(.181)	(.178)		
Woman parcel manager (WPM)	-.56**	-.616**	-.583**	-1.089**	-.459***	-.837***
	(.252)	(.24)	(.247)	(.478)	(.143)	(.198)
PFR ITT * WPM	.153	.118	.203	.318		
	(.289)	(.268)	(.285)	(.499)		
Rainfall deviation (RD)	6.261***	12.861*	5.157**	3.692	6.399***	3.796
	(2.18)	(6.844)	(2.246)	(2.425)	(2.151)	(2.385)
RD * PFR ITT	.314	-.11	.346	.206		
	(.597)	(.556)	(.61)	(.596)		
WPM * RD	1.463*	1.358**	1.597**	1.568	.941**	.575
	(.746)	(.651)	(.731)	(1.31)	(.434)	(.554)
PFR ITT * WPM * RD	-.805	-.559	-.907	-1.339		
	(.871)	(.764)	(.868)	(1.403)		
Enumerators and lotteries F.E.	no	yes	no	no	no	no
Observations	3211	3211	2862	2407	3211	2407
R-squared	.335	.459	.347	.373	.334	.372

Notes: Specifications (1), (2), and (5) use the full sample of parcels; specification (3) uses only parcels in the same village where the manager lives; specifications (4) and (6) exclude parcels managed by women & in female-headed households. Explanatory variables: rainfall deviation squared; Labor supply of non-hh workers (person-day/ha); Total area of the parcel (ha); Age of hh head; Head can read & write in French (0/1); Head is polygamous (0/1); # of children in hh; # of women in hh; # of men in hh; Land tenure (years); Head is married (0/1); Head is divorced (0/1); Head is a widow/widower (0/1); Head is Catholic (0/1); Head is a village group member (0/1); Head is a village group leader (0/1); Head is a leader in the village (0/1); Head is a government employee (0/1); Head is village chief (0/1); Distance to the nearest road (km); Night light (sum 2011); NDVI index (mean 2011). Standard errors are clustered at village level and reported in parentheses. * p<0.1, ** p<0.05, *** p<0.01.
Sources: Own computation from Plans Fonciers Ruraux Impact Evaluation 2011, Baseline Survey data; rainfall and temperature data from CRU; NDVI index and night light data from the AfroGrid dataset; Distance to road from Centre National de Télédétection et de Suivi Ecologique (CENATEL).

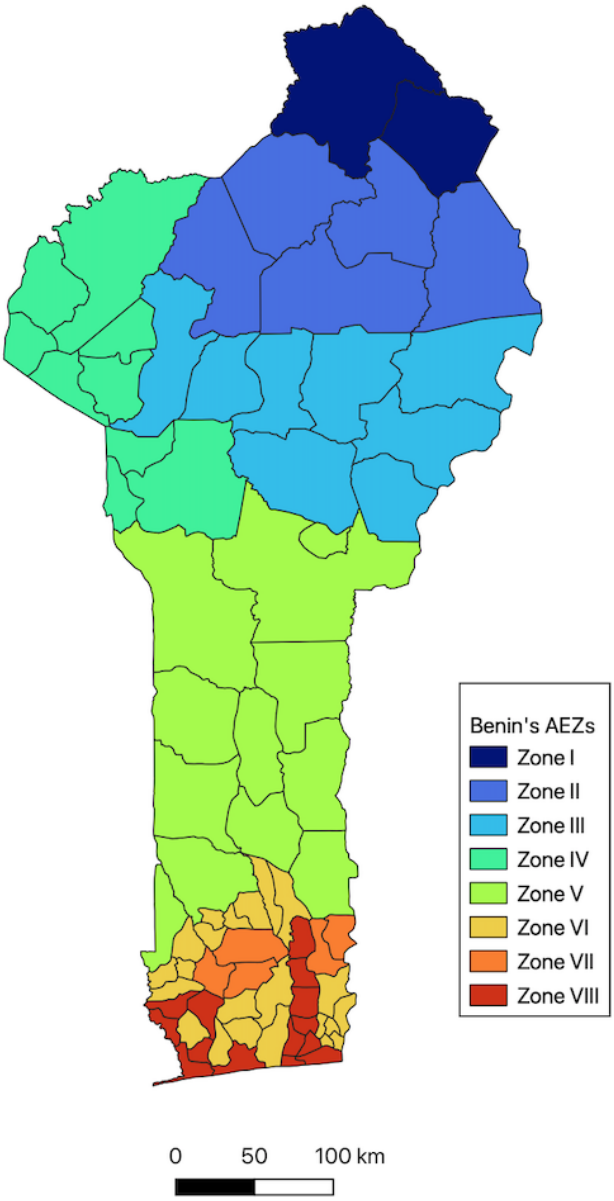
Table 6: *Mechanisms: effect of rainfall deviation, land demarcation (PFR) and parcel's gender manager on parcel land size, investment on parcels, and labour supply*

	Parcel area (log ha)		Parcel Investments (0/1)		Total labor supply (person-day)	
	(1)	(2)	(3)	(4)	(5)	(6)
	All parcels	*sex of HH = sex of parcel manager*	*All parcels*	*sex of HH = sex of parcel manager*	*All parcels*	*sex of HH = sex of parcel manager*
PFR ITT	.16	.162	-.042	-.039	22.629	22.105
	(.27)	(.258)	(.05)	(.049)	(55.951)	(53.261)
Woman parcel manager (WPM)	-.577**	-.921*	-.193***	-.122	-133.516*	-52.458
	(.286)	(.472)	(.065)	(.094)	(75.249)	(92.775)
PFR ITT * WPM	.242	.538	.117	.011	-3.912	-84.513
	(.365)	(.558)	(.078)	(.102)	(86.901)	(104.175)
Rainfall deviation (RD)	19.565***	17.378***	.757	.903	958.142	1141.633*
	(3.121)	(3.297)	(.613)	(.642)	(586.682)	(669.05)
RD * PFR ITT	-.028	-.047	.192	.178	-67.136	-62.732
	(.865)	(.843)	(.154)	(.155)	(162.487)	(155.749)
WPM * RD	1.748**	1.914	.438**	.267	371.93*	57.633
	(.846)	(1.366)	(.217)	(.276)	(211.461)	(250.479)
PFR ITT * WPM * RD	-1.662	-2.837*	-.336	-.14	3.327	223.798
	(1.091)	(1.593)	(.256)	(.304)	(244.362)	(284.483)
Observations	3211	2407	3211	2407	3211	2407
R-squared	.355	.388	.079	.077	.281	.31

Notes: Specifications (1), (3) and (5) use the full sample of parcels; (2), (4) and (6) exclude parcels managed by women & in female-headed households. Explanatory variables: rainfall deviation squared; Age of hh head; Head can read & write in French (0/1); Head is polygamous (0/1); # of children in hh; # of women in hh; # of men in hh; Land tenure (years); Head is married (0/1); Head is divorced (0/1); Head is a widow/widower (0/1); Head is Catholic (0/1); Head is a village group member (0/1); Head is a village group leader (0/1); Head is a leader in the village (0/1); Head is a government employee (0/1); Head is village chief (0/1); Distance to the nearest road (km); Night light (sum 2011); NDVI index (mean 2011). In (3) and (4) we also control for the total area of the parcel (ha). Standard errors are clustered at village level and reported in parentheses. * p<0.1, ** p<0.05, *** p<0.01.

Sources: Own computation from *Plans Fonciers Ruraux Impact Evaluation* 2011, Baseline Survey data; rainfall and temperature data from *CRU*; NDVI index and night light data from the AfroGrid dataset; Distance to road from *Centre National de Télédétection et de Suivi Ecologique* (CENATEL).

Figure 1: *Agro-Ecological zones of Benin*



Source: Authors' elaboration