

Crop Choice, Drought and Gender: New Insights from Smallholders' Response to Weather Shocks in Rural Uganda

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(Original submitted June 2020, revision received January 2021, accepted January 2021.)

Abstract

We analyse gender differences in the response of smallholder farmers to droughts, taking the duration and severity of the event into account. Using a novel weather shock measure that combines spatial rainfall data with detailed cropping calendars, survey data from Uganda and standard econometric techniques, we find that adverse weather events provide an opportunity for women to enter the commercial crop market by allocating land from subsistence to income generating crops. This counterintuitive pattern is, in part, explained by the greater propensity of men to allocate time to non-agricultural activities in the event of weather shocks.

Keywords: *Crop choices; gender; land allocation; smallholder farmers; sub-Saharan Africa; weather shocks.*

JEL classifications: *Q12, Q15, Q54.*

1. Introduction

Over the past decades, the incidence of weather shocks has increased, mainly due to climate change. There are arguments that the length of the rainfall seasons has become shorter and the amount of rainfall received in tropical countries has decreased (Wainwright *et al.*, 2019). Much of the economics literature on climatic shocks

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indicates that weather variability in sub-Saharan Africa is associated with droughts, which have made the situation of smallholder farmers particularly precarious because they predominantly practise rain-fed agriculture with minimal usage of irrigation technologies (Toenniessen *et al.*, 2008; Gray and Mueller, 2012). With the rise in intensity and frequency of weather shocks, the food security of African smallholders is threatened and understanding their responses to shocks becomes increasingly important.

Women are believed to contribute disproportionately to cultivating low risk crops that enhance households' food security (Duflo and Udry, 2004; Lovo and Veronesi, 2019). This is driven, at least in part, by women's lower access to productive resources, which restricts their potential adoption of more remunerative commercial agricultural options (Udry, 1996; Goh, 2012; Bhaumik *et al.*, 2016). Although men are generally more likely to capitalise on these options than women, adverse weather events induce relocation of resources between crops, so that priority is given to those that are either drought resistant or are critical in meeting household subsistence needs (Fafchamps, 1992; Kurukulasuriya and Mendelsohn, 2008; Salazar-Espinoza *et al.*, 2015). The strategy of reallocating land out of cash into traditional food crops is consistent with the tendency of smallholders to be risk averse (Grisley and Kellog, 1987). The resulting low risk and low return portfolio is not only likely to lead households down a spiral of greater longer-term destitution (Dercon, 1996; Carter and Barrett, 2006), but may even have negative implications for short-term household welfare. Indeed, numerous studies indicate that opting for commercial agriculture has welfare ameliorating implications compared to exclusively relying on subsistence farming (e.g. von Braun and Webb, 1989; Dimova and Gbakou, 2013). Little attention has been given to the possibility that shocks, particularly those that are intense and persistent, may change the traditional pattern of gender-based crop allocation.

Although in principle smallholders can rely on the adoption of irrigation techniques, practising agro-forestry and changing planting times to cope with adverse weather events, in practice these options are often not feasible given cost and time consideration, as well as inaccurate weather forecasting regimes in many developing countries (Rockstrom, 2000; Patt and Gwata, 2002; Kulecho and Weatherhead, 2005). Recent research indicates that few men and even fewer women adopt such practices (Kristjanson *et al.*, 2017). The same is true for the adoption of improved crop varieties that are bred to withstand weather shocks via early maturing or resistance to droughts. Their use as shock-mitigating practice tends to be an expensive option that is seldom used in practice (Bryan *et al.*, 2013). An alternative shock-coping mechanism is off-farm employment (Kochar, 1999; Rose, 2001; Cameron and Worswich, 2003; Ito and Kurosaki, 2009; Dimova *et al.*, 2014). Once again, it has been established that better-off individuals, particularly men, have an advantage due to prevailing barriers to non-agricultural job opportunities (Leones and Feldman, 1998; Ruben and van den Berg, 2001; Canagarajah *et al.*, 2001; Dzanku, 2019). When very few non-agricultural opportunities are available in a given locality, excess labour supply in the event of village-level shocks may result in falling wages and relatively more vulnerable farmers being crowded out of the off-farm labour market (Dimova *et al.*, 2014). The natural alternative would then be rural-urban or international migration. Yet reviews of the literature on the links between climate change, natural disasters and migration indicate that relatively wealthier and better educated individuals, particularly men, are among those who benefit most from this alternative (Mbaye, 2017).

Several important questions have not received unambiguous answers in the literature on farmers' adaptation to weather-related shocks. Would negative production shocks of increased intensity and duration increase the tendency of both men and women to revert to the safer option of dominant subsistence farming? Or would boosting the tendency of men to supply off-farm labour open greater opportunities for women to enter commercial food crop and even tropical cash crop markets, thus improving welfare through the generation of higher incomes?

Previous literature on cross-gender responses to positive shocks suggests that the latter outcome might be unlikely. For Gambia, von Braun and Webb (1989) find that when the productivity of rice improved after the introduction of a new technology, it attracted the attention of male producers and changed its status from being a 'female' crop to becoming a 'male' crop. Jones (1983) highlights a similar example for Cameroon, where improved productivity induced male managers to demand more working hours on the rice fields from their wives but did not increase the incidence of female rice field management and income generation. We are not aware of similar rigorous analyses of the implications of negative weather shocks for the possible reversal of farming patterns and the qualitative evidence on the link between droughts and crop choices is mixed. For example, Nelson and Stathers (2009) find that, while in general the climate adaptation strategies of farmers in Tanzania favoured the cultivation of drought-resistant crops like sorghum, chibelela women increased the production of cash-generating crops like maize, groundnuts, bambara nuts and cowpeas in order to compensate for the loss of income and subsistence as a result of the shock.

To explore the possibility that droughts induce greater allocation of land to commercial crops, we study the impact of exogenous weather shocks – droughts – on farmers' cropland share allocation across eight major crops: maize, sorghum, beans, groundnuts, cassava, sweet potato, bananas and coffee. Our main contribution to the literature is to disentangle underlying gender effects, especially for the choice between not only tropical cash crops and food crops, but also between subsistence and commercial crops within the food crop category. Our construction of a manager-crop level panel data set for Uganda enables us to link the shock measure to the manager of a specific crop and thus allows us to analyse gender-related trends in the land share allocation across traditional food crops, commercial food crops and a tropical cash crop. In the process, we make a technical innovation in the definition of crop specific shocks. Specifically, we model weather shocks in terms of deviation of rainfall from the minimum agronomic seasonal water requirements of a specific crop. To the best of our knowledge, this innovation in the definition of rainfall shocks has only been applied by Imbert *et al.* (2017). Since we use daily spatial rainfall data measured at the enumeration area level and exploit detailed information on cropping calendars that account for seasonal variation across different regions in terms of the planting dates and growth periods of specific crops, our shock measures vary within a district as well as over time and more importantly between crops in the same enumeration area and within crops across regions. As we observe the cropping portfolio at the farmer level, our shock measure varies at the crop and enumeration area level and is not aggregated at the district/prefecture level as in Imbert *et al.* (2017).

Aside from providing an interesting context for the study of gender relations in agricultural production, Uganda represents a particularly appealing case for a study of vulnerability to droughts. For instance, as recently as 2010/2011, several parts of Uganda experienced a major drought which led to a 37% estimated drop in food and cash crop production and threatened the food security of farmers (Republic of

Uganda, 2012). By 2050 maize yields have been predicted to decline by approximately 4.7% in fast-warming, low-rainfall climatic areas of Uganda (Kikoyo and Nobert, 2016). Further, yield losses of 20–65% in the production of East African highland bananas are expected to result from climate-induced weather shocks (van Asten *et al.*, 2011). Considering that banana and maize are key staple crops in Uganda, this will seriously affect the food security of millions of people in the country. Nevertheless, we are not aware of systematic analysis of the role of weather shocks on crop portfolio allocation in Uganda.

2. Data

Our main data are the 2009/2010, 2010/2011, 2011/2012 and 2013/2014 waves of the Uganda National Panel Survey (UNPS) (Uganda Bureau of Statistics, 2009, 2010b, 2011, 2013). The UNPS is a multi-topic panel survey conducted by the Uganda National Bureau of Statistics with financial and technical support from the Dutch government and the World Bank Living Standards Measurement Study – Integrated Surveys on Agriculture. Data collection is conducted twice in each wave to accommodate the two major agricultural seasons in Uganda. Given the importance of the first season for agricultural production (Bashaasha *et al.*, 1995) and the fact that less than half of the survey respondents report agricultural production in the second agricultural season, we use only data from the first season. Farmers preference for undertaking most of their cropping in the first season can be explained by the varying length of the dry spell between the seasons (discussed in more detail in section 2.1.1). We combine the UNPS with high-resolution spatial rainfall data from the National Oceanic and Atmospheric Administration's (NOAA) Climate and Prediction Center (CPC) rainfall estimates (RFE) 2.0 database and detailed crop calendar data from FAO (2018). The latter two data sources are described in more detail in the next section.

2.1. Shock measurement

A common measure of adverse climate conditions used in the literature on smallholder responses to weather shocks is the rainfall deviation from a long-run average (Paxson, 1992; Bezabih and Di Falco, 2012; Di Falco and Veronesi, 2013; Arslan *et al.*, 2017, among others). An alternative popular measure is the standardised precipitation evapotranspiration index (SPEI), which is calculated as the difference between precipitation and potential evapotranspiration (PET) (Vicente-Serrano *et al.*, 2010; Kubik and Maurel, 2016; Bozzola *et al.*, 2018). These measures, however, treat the water requirement of different crops as homogenous, which is not agronomically correct.

To our knowledge, only Imbert *et al.* (2017) propose a measure of individual crop vulnerability based on the minimum crop water requirements, which they use in an empirical analysis of internal migration at the Chinese prefecture level. A potential constraint to observing a larger number of similar empirical applications comes from the fact that rainfall and crop water requirement data is available on either a daily or a monthly basis, while the majority of stylised household surveys are conducted, at best, on a seasonal basis. We operationalise Imbert *et al.*'s (2017) measure for use with stylised household survey data by relying on detailed cropping calendars. As we observe the cropping portfolio of each farm manager, we do not need to aggregate our measure across crops at a geographical level. Instead, we have a shock measure

for each crop within the enumeration area (approximately village-level) within which the crop is grown. We define crop-specific shock variables that vary both within and between crops and regions. This is achieved by exploiting the different crop-specific seasonal water requirements and the different cropping calendars of the crops in our sample across regions.

A large proportion of the literature examining farmers' responses to production risks associated with weather shocks in low income (particularly African) countries make the assumption that farmers' decisions are largely influenced by past shock events (see Dercon, 1996; Fafchamps *et al.*, 1998; Di Falco, 2014; Salazar-Espinoza *et al.*, 2015; Bozzola and Smale, 2020). For example, Salazar-Espinoza *et al.* (2015, p. 11) assume that 'farmers respond to prospects of a good/bad season which is a function of how good/bad the general growing condition was in previous periods'. Di Falco (2014) also notes that in sub-Saharan Africa farmers' adaptation choices are influenced by past shocks. Further, there is a statistically significant correlation between present and past rainfall shocks in our data. Using 4 years of rainfall information, we find a strong, positive and significant correlation over the years. Rainfall each year is correlated with rainfall in the preceding year and there is a lag in the rainfall correlation pattern over the years. For example, 67% of the (unconditional) variation in rainfall in 2010 is accounted for by rainfall in 2009 (Table S11). We also find that there is a time-persistent rainfall trend.

While it is theoretically possible for farmers to use rainfall forecasts when making their crop land allocations for the proceeding season, rainfall forecasts in most developing countries suffer from credibility and accuracy problems. For example, Patt and Gwata (2002) examine seasonal rainfall forecasts for smallholder farmers in Zimbabwe. They find that there are inherent problems with the accuracy of forecasts, which is also driven by the fact that forecasts tend to be generalised at higher geographical scale with little projection for small local areas in which smallholders operate. In Uganda routine seasonal rainfall forecasts have been issued by the Ministry of Water and Environment for over a decade. In line with Patt and Gwata's (2002) findings for Zimbabwe, the Ugandan forecasts are released at the regional level, which implies that they do not give a clear prediction for farmers at the local level, especially given that there is agroecological heterogeneity within a region. As a result, we expect farmers to consider past rainfall when making their planting choices.

Our measurement of shocks proceeds in two steps. First, we construct a measure of minimum agronomic seasonal crop water needs that vary by region. Second, we use this information to define crop-specific shock levels that vary by intensity and length.

2.1.1. Minimum agronomic seasonal water requirement

Rainfall follows a bimodal pattern in most regions of Uganda. This gives rise to the two annual agricultural seasons. The first season starts in March and ends in June. The second season starts in August/September and ends in November. The periods from December to February and July to August are characterised by a dry spell with minimal rain. During this time, farmers do not plant crops but harvest and prepare the land for the next season. There is heterogeneity in the distribution of rain across the different regions of Uganda, with average annual rainfall ranging from a minimum of 500 mm to a maximum of 2,800 mm (Asadullah *et al.*, 2008; Nsubuga *et al.*, 2014). Farmers tend to plant crops that grow to full maturity within a season (such as maize, sorghum, beans, groundnuts and sweet potato) in both agricultural seasons;

however, crops that grow to full maturity in more than one season (such as cassava, banana and coffee) are normally planted in the first season of the year. This is because the dry spell after the second season (December–February) is longer than the dry spell after the first season (July/August). Planting these crops in the first season reduces their exposure to the prolonged stress after the second season.

We construct crop-specific water requirements for the first season in line with our data. To construct a crop-level index of seasonal water needs, we need to take the heterogeneity of rainfall and cropping portfolios of the different regions of Uganda into account. Because of the variation in the start dates of rainfall seasons in Uganda, which results in variation in the start of crop planting dates, we expect to observe variation in the growth season between and within crops across the country. Importantly, for crops that grow to maturity in more than one season, their minimum agronomic water requirements are distributed over the number of growth seasons.

Following Brouwer and Heibloem (1986), we define the growth period, g_c , for crop c as the number of dekads (10-day intervals) required for the crop to grow from planting to harvesting maturity. We calculate the end of the growth cycle dekad, ed_c , for each crop c by adding g_c to the crop planting dekad, pl_c : $ed_c = g_c + pl_c$. The crop planting dekad, and subsequently the end of growth cycle dekad, varies by region and crop. Information on the timing of the crop planting dekad is taken from comprehensive seasonal crop calendars that have been constructed by FAO (2018) for Uganda's main regions.

We use g_c to convert the minimum crop water requirement wr_c – the amount of water needed to meet the agronomic needs of crops from planting to harvesting maturity – into a minimum seasonal crop water requirement mw_c . As there are 12 dekads in a typical cropping season (4 months) in Uganda (illustrated in more detail in Table S1), we divide the number of dekads of the crop growth period by 12 to obtain the number of growth seasons from planting to harvesting maturity. Considering that 37.5% of the crops in our sample (cassava, banana and coffee) grow to harvesting maturity in more than one season, we multiply the inverse of the number of growing seasons, g_c by the minimum crop water requirement to obtain the minimum seasonal crop water-needs of crop c , mw_c , as follows:

$$mw_c = \frac{1}{(g_c/12)} * wr_c$$

For crops which grow to full maturity in more than one season, we assume that the minimum seasonal agronomic water requirements are the same over different seasons.¹ Table S1 summarises the minimum seasonal agronomic water needs of the crops selected in our analysis. Let us take the example of cassava. Cassava takes on average 240 days to grow from planting to harvesting maturity. Dividing 240 by 10, we obtain an estimate of the total growing period in dekads. According to FAO

¹While this is a strong assumption, our data does not contain detailed information on crop physiology and soil physical characteristics that would allow us to empirically differentiate the water needs over the cropping cycle for multi-season crops. This assumption is not completely unfounded considering the work of Alégre (1959) which, for instance, shows that the annual water requirement of certain crops, such as coffee, is distributed roughly equally over its lifecycle. Additionally, Coste (1992) and DaMatta and Ramalho (2006) also show that coffee requires an equal distribution of rainfall across the seasons with at least 1,200 mm per year (600 mm per season).

(2018), the earliest time cassava can be planted in a calendar year in central Uganda is 25 February, which is the sixth dekad in the calendar year. Considering that cassava grows to harvestable maturity in 24 dekads, an equivalent of two growth seasons, this means the last dekad in its growth cycle in the central region is the 30th dekad. Given that the minimum water needs of cassava to grow from planting to harvesting maturity is 1,000 mm, its minimum seasonal water need is 500 mm.

To measure rainfall, we extract high resolution spatial daily rainfall data from the NOAA's CPC RFE 2.0 database. The daily rainfall is then aggregated to the dekad level within the year and matched to the georeferenced Uganda National Panel Survey household data at enumeration area (EA) level.² The spatial rainfall estimates used in the construction of the rainfall database are set at 2.5° latitude × 2.5° longitude of the global graticule.

2.1.2. Constructing shock measures

Our definition of drought-related shocks covers two dimensions: intensity and duration of the shock. To measure shock exposure, we first define a shock variable which takes the value one if the amount of rainfall received is less than the minimum seasonal agronomic crop water requirement for that specific crop and zero otherwise. To do so, we aggregate the rainfall per enumeration area across the planting dekad until the last dekad of growth for each crop in each growth season and subtract the crops' minimum agronomic requirement.

We also construct a continuous measure of shock intensity. It captures the shortfall in rain vis-à-vis the minimum seasonal crop water requirement. This measure is analogous to the poverty gap index. It is defined as: $\frac{\sum_{plc}^{edc} |ra_e - z_c| \cdot I(\sum_{plc}^{edc} ra_e < z_c)}{z_c}$ where z is the minimum crop seasonal water requirement of crop c and ra_e is the amount of rainfall received in an enumeration area e from the planting dekad to the end of growth cycle dekad for crop c .

Since shocks are only likely to affect choices in the next planting season, both our discrete shock measure and the measure of shock intensity are lagged by one period. Still, farmers may be unlikely to respond to shocks that are deemed to be of a short duration. They are more likely to do so only in the event of shocks perceived as long-lasting. To measure long-lasting impacts of adverse weather shocks, we define a discrete shock variable that takes the value of one if the shock persisted for two consecutive planting seasons. We also experimented with a version based on three-period shock duration. The results were consistent with those based on two-period shock persistence, but this reduced our sample size considerably.

2.2. Selection and categorisation of crops

Since our shock definition is crop specific, the selection of crops into our sample is based on both their importance for food and livelihood strategies in Uganda and on the number of observations.

Although our empirical analysis is performed at crop level, to facilitate interpretation and attain conceptually more sensible results, we think of crops as belonging to

²There are 320 EAs in our sample and each EA typically covers one village, which is the smallest government administrative unit in Uganda.

three major categories: subsistence food crops, commercial food crops and cash crops. Despite the wide use of these terms in the literature, there are no universally accepted crop classification criteria. For instance, the literature on high value agriculture typically identifies non-food crops such as coffee, tea, and sugar cane as 'cash crops' (Dinham and Hines, 1984; Coote, 1987). Traditional horticultural crops such as pineapple and certain vegetables are often also classified as 'cash crops' due to their income-generating and export potential, despite constituting a source of local food consumption (Barrett and Browne, 1996; Takane, 2004).

There is consensus that beans, groundnuts, cassava, sweet potato and banana can be identified as key subsistence crops in Uganda (Haggblade and Dewina, 2010; FAO, 2017). Using the marketing potential as a criterion, we identify maize, sorghum and coffee as income-generating crops, largely due to considerable increases in their prices in the past several decades (Benson *et al.*, 2008; Dancause *et al.*, 2010). Based on household survey data from Uganda, Andrews *et al.* (2015) find that the average ratio of revenue to total output value for coffee is over 90%, while for maize it is 40%. Even though sorghum has only a ratio of about 19% in their study, we think of it as belonging to the 'commercial crop' category due to the recent transformation in its marketing potential (Coulter *et al.*, 2007; Elepu and Nalukenge, 2009). Given that maize and sorghum are both used locally for consumption and have a high marketable potential, while coffee is only used for income generation, we subdivide the category of income-generating crops into commercial food crops (maize and sorghum) and cash crops (coffee).

Figure S1 highlights the distribution of negative rainfall shocks and cropland share allocation to groups of traditional subsistence food crops, commercial food crops and cash crops across Uganda. For presentational purposes, the figure only depicts shocks related to a minimum water requirement of 450 mm, which is about the average minimum crop water requirement of crops in our sample – unlike the empirical analysis, which is based on individual crop level negative rainfall shocks. Averages of the binary rainfall shock measure are displayed at the district-level geographical boundary in the map. As such, these averages represent the fraction of shocks in each geographical area, visualising the intensity of shocks. During the relevant period, droughts were most intense in the south-west and north-east of the country, particularly in Wave 2 and Wave 3. These two regions have been relatively more exposed to erratic rainfall in the past decades compared to other regions of the country. We also observe that groups of subsistence food crops, commercialised food crops and cash crops are present in most of the different regional zones of Uganda. For instance, although the Central region is known to produce Robusta coffee and the Western region is the dominant producer of Arabica coffee in Uganda, some production of each happens also in the Southern and Northern regions (Uganda Bureau of Statistics, 2010a). Maize and sorghum are produced across all regions and the same is true for at least one of the crops included in the traditional food crops category. In other words, the choice of crops and the potential allocation of land across these crops resulting from a negative shock is relevant for the country as a whole and not only for selected regions.

2.3. Descriptive statistics

Table 1 summarises key sample characteristics. We use the information on who makes production decisions on the plot to identify the manager of a plot. Not only are there more male than female managers, but also male managers are responsible for more

Table 1
Sample characteristics

Attribute	Wave 1	Wave 2	Wave 3	Wave 4	Total obs
Households	1,992	1,909	1,786	1,180	6,867
Individual managers	2,053	1,953	1,798	1,182	6,986
Male	1,244	1,214	784	469	3,711
Female	809	739	1,014	713	3,275
Proportion of individuals that exit the sample*		-4.87	-7.94	-34.26	
Male		-2.41	-35.42	-40.18	
Female		-8.65	37.21	-29.68	
Average no. managers/household	1.03	1.02	1.01	1.00	1.02
Total no. plots – male	4,381	4,462	2,447	1,300	12,590
Total no. plots – female	2,690	2,639	3,206	1,984	10,519
Average no. plots – male	3.52	3.68	3.12	2.77	3.39
Average no. plots – female	3.33	3.57	3.16	2.78	3.21

Note:: *This is the fraction of individuals that leaves the sample from the preceding wave. In wave 4 of the survey the sampling frame was partially refreshed.

Source : Authors' calculation based on UNPS Panel 2009/10 (Wave 1), 2010/11 (Wave 2), 2011/12 (Wave 3) and 2013/14 (Wave 4).

plots than female managers. It is interesting to note that the number of male managers goes down from 1,244 in the second wave to 784 in the third wave and 469 in the fourth wave. Meanwhile, the number of female managers increases from 739 in the second wave to 1,014 in the third wave to 713 in the fourth wave.

The relocation of plot management between wave two and three could be because droughts across many regions in 2010/11 led men to devote more labour off the farm, leading to more women taking over management of plots in the households. This is consistent with the finding that 21% of the men in the sample are engaged in wage work and 35% of the men are engaged in secondary activities, while the proportions for women are 13% and 21%, respectively. We explore gender differences in labour supply in response to shocks in more detail in section 4.2 below. At the same time, the overall reduction in the number of households in the fourth wave can be explained by the refreshment of the sample frame. In 2013/14, a partial refreshment of the sampling frame took place and a third of the original households were rotated out of the sample and replaced by new households. As we study the effect of past weather shocks, we excluded new households from our sample.

Table S2 and Table 2 provide key individual and household summary statistics of managers and their land allocations to the different crops. The statistics are presented both at the cross-sectional level by survey wave (Table S2), as well as for the pooled sample as a whole and the pooled sample disaggregated by male plot managers who are heads of household, female plot managers who are heads of household and female plot managers in a male-headed household (Table 2). The total land area controlled by a manager is 2.85 acres on average, of which managers cultivate 2.03 acres.³

³Managers do not devote their parcels in their entirety to crop cultivation because parts of the parcel are used for settlement, animal rearing or are left to fallow.

Table 2
Manager and crop characteristics by gender and household head status

Variables	Male household heads			Female household heads*			Females in male-headed household			Pooled						
	Mean	SD	Max	Min	Max	Min	Mean	SD	Max	Mean	SD	Min	Max			
Age (in years)	46.11	14.50	17	96	52.23	14.41	14	98	39.17	12.69	1	84	45.85	15.07	1	98
Head (=1)																
Spouse (=1)									0.95	0.22	0	1	0.76	0.42	0	1
Child (=1)									0.03	0.17	0	1	0.20	0.40	0	1
Married (=1)	0.92	0.26	0	1	0.32	0.47	0	1	0.96	0.20	0	1	0.03	0.16	0	1
Household size	6.42	2.92	0	22	5.18	2.65	1	18	6.93	2.83	1	24	0.76	0.43	0	1
No education (=1)	0.11	0.32	0	1	0.42	0.49	0	1	0.24	0.43	0	1	6.20	2.92	0	24
Primary (=1)	0.65	0.48	0	1	0.47	0.50	0	1	0.61	0.49	0	1	0.23	0.42	0	1
Secondary (=1)	0.18	0.38	0	1	0.08	0.28	0	1	0.13	0.33	0	1	0.59	0.49	0	1
Post-secondary (=1)	0.05	0.22	0	1	0.02	0.15	0	1	0.02	0.15	0	1	0.14	0.35	0	1
Occupation													0.04	0.20	0	1
Wage work (=1)	0.21	0.41	0	1	0.14	0.35	0	1	0.09	0.28	0	1	0.16	0.37	0	1
Private business (=1)	0.24	0.43	0	1	0.22	0.42	0	1	0.20	0.40	0	1	0.23	0.42	0	1
Secondary work (=1)	0.34	0.47	0	1	0.27	0.44	0	1	0.21	0.41	0	1	0.29	0.45	0	1
Farm work (=1)	0.74	0.44	0	1	0.73	0.44	0	1	0.77	0.42	0	1	0.74	0.44	0	1
Parcel size (acres)	3.29	7.94	0	250	2.37	6.71	0	135	2.18	3.53	0	54	2.85	7.03	0	250
Total crop area (acres)	2.38	9.36	0	300	1.65	6.00	0	200	1.59	1.69	0	18	2.03	7.49	0	300
Crop land area (acres)																
Maize	0.50	4.43	0	200	0.29	2.53	0	100	0.26	0.53	0	6.4	0.39	3.42	0	200
Sorghum	0.15	1.76	0	100	0.16	0.49	0	6	0.09	0.34	0	3.5	0.14	1.29	0	100
Beans	0.30	1.01	0	49	0.23	0.53	0	15.1	0.27	0.52	0	9.5	0.28	1.01	0	50
Groundnuts	0.15	0.96	0	48	0.14	0.71	0	20	0.14	0.40	0	6	0.15	0.87	0	48
Cassava	0.60	4.59	0	200	0.29	0.57	0	10	0.33	0.70	0	10	0.47	3.32	0	200
Sweet potato	0.20	1.81	0	100	0.17	2.39	0	100	0.15	0.36	0	4	0.18	1.78	0	100
Banana	0.34	2.04	0	103	0.28	2.39	0	90.3	0.28	0.69	0	10	0.31	1.92	0	103

Table -0002
(Continued)

Variables	Male household heads				Female household heads*				Females in male-headed household				Pooled			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Coffee	0.17	1.01	0	0.12	1.63	0	60.8	0.30	0	4.5	0	60.8	0.14	0	60.8	
Crop land share (%)																
Maize	0.17	0.23	0	1	0.15	0.22	0	1	0.16	0.23	0	1	0.16	0.23	0	1
Sorghum	0.06	0.18	0	1	0.10	0.24	0	1	0.06	0.18	0	1	0.07	0.20	0	1
Beans	0.16	0.22	0	1	0.17	0.22	0	1	0.18	0.22	0	1	0.17	0.22	0	1
Groundnuts	0.06	0.15	0	1	0.07	0.16	0	1	0.07	0.17	0	1	0.07	0.16	0	1
Cassava	0.24	0.29	0	1	0.20	0.28	0	1	0.20	0.27	0	1	0.22	0.28	0	1
Sweet potato	0.08	0.16	0	1	0.08	0.17	0	1	0.11	0.21	0	1	0.09	0.18	0	1
Banana	0.16	0.26	0	1	0.17	0.27	0	1	0.18	0.27	0	1	0.16	0.27	0	1
Coffee	0.07	0.18	0	1	0.05	0.14	0	1	0.05	0.15	0	1	0.06	0.16	0	1
% Managers land share > 0																
Maize	0.53	0.50	0	1	0.50	0.50	0	1	0.50	0.50	0	1	0.52	0.50	0	1
Sorghum	0.15	0.36	0	1	0.22	0.41	0	1	0.13	0.33	0	1	0.17	0.37	0	1
Beans	0.54	0.50	0	1	0.53	0.50	0	1	0.56	0.50	0	1	0.54	0.50	0	1
Groundnuts	0.21	0.41	0	1	0.23	0.42	0	1	0.24	0.42	0	1	0.22	0.42	0	1
Cassava	0.59	0.49	0	1	0.51	0.50	0	1	0.52	0.50	0	1	0.55	0.50	0	1
Sweet potato	0.32	0.47	0	1	0.29	0.45	0	1	0.33	0.47	0	1	0.31	0.46	0	1
Banana	0.40	0.49	0	1	0.40	0.49	0	1	0.44	0.50	0	1	0.41	0.49	0	1
Coffee	0.24	0.43	0	1	0.18	0.38	0	1	0.18	0.39	0	1	0.21	0.41	0	1
Observations	3,538				1,803			1,375					6,986			

Note: * The proportion of total females that are household heads is 57%.

Source : Authors' calculation based on UNPS Panel 2009/10, 2010/11, 2011/12 and 2013/14.

Irrespective of the crop, male managers cultivate larger land areas than their female counterparts. The notable cross gender patterns are that: (i) men who are household heads allocate approximately twice the amount of land to maize (commercial food crop) and cassava (traditional food crop) than women who are heads of household or women who reside in male-headed households; and (ii) male household heads allocate substantially more land to coffee (traditional cash crop) than women who are household heads or women who reside in male-headed households. The fact that men appear to devote more land to commercial and cash crops than women is consistent with expectations. What appears more surprising is that men devote more land than women to traditional food crops like cassava and that in *relative terms* the land shares devoted to the crops do not seem to differ much by gender. Table S3 and Table 3 provide summary statistics of farm characteristics by manager type – 53% of all managers' land falls under customary tenure system. The predominance of customary tenure system also persists within the disaggregated sample of male and female household heads and females in male-headed households. But men who are heads of household have slightly more plots that are of good soil quality than those of both female household heads or females who reside in male-headed households⁴

3. Empirical Model

We estimate the impact of drought-related shocks on managers' crop land share allocation using seemingly unrelated regression (SUR).

Our system of linear regression equations for the different crops can be written as:

$$Y_{i,t}^c = \alpha^c + \beta_1^c K_{i,t-1} + \beta_2^c F_{i,t} + \beta_3^c (K_{i,t-1} \times F_{i,t}) + \beta_4^c X_{i,t} + \beta_5^c Q_{i,t} + \gamma_t + \mu_{i,t}^c,$$

where $Y_{i,t}^c$ is the land share which is a proportion of manager i 's total cultivated land area allocated to crop c at time t (with $t = 2009, 2010, 2011, 2013$).⁵ K measures the lagged water shock (at time $t - 1$) affecting the manager's land allocation to crop c at time t . To reiterate, while our baseline specification captures shock incidence, proxied by a dummy variable of a shock that has occurred in the previous season, we also analyse the effect of shock intensity and duration.

Our key interest is in exploring the heterogeneity in response to shocks by gender. In keeping with the literature, we expect that weather shocks (in particular those of

⁴A full list of all variables used in the analysis can be found in Table S4.

⁵Given that some of the managers' plots are intercropped and in order not to count the land area of a single plot multiple times for the different crops planted on it, we divide the area of the intercropped plots based on the proportion of the individual crops in the plot, which is reported in the data at plot level. (See section 4A of the agricultural questionnaire of the survey, question 9 on page 10: 'if intercropped, what percentage of intercropped area was under this crop?': <http://microdata.worldbank.org/index.php/catalog/2166/download/31658>). Even though intercropping improves water conservation by reducing evaporation of moisture from the soil and thereby minimising the impact of the negative rainfall shocks, we cannot account for this because our data does not have sufficient information on soil physical characteristics which would allow computing the water retention due to intercropping. The benefit of reduced evaporation of moisture from soil is expected to be negligible especially when spread over the whole crop growing season. O'Callaghan *et al.* (1994) show that due to the variation in the growth duration of the different crops, the vegetative advantage that one crop may offer to reduce evaporation may not cover the other crop(s) for their entire growth season.

Table 3
Farm characteristics by gender and household head status

Variables	Male household heads						Females in male-headed household						All					
	Mean		SD		Max		Mean		SD		Max		Mean		SD		Max	
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max		
Land tenure																		
Freehold (=1)	0.39	0.49	0	1	0.39	0.49	0	1	0.43	0.50	0	1	0.40	0.49	0	1		
Leasehold (=1)	0.01	0.11	0	1	0.02	0.14	0	1	0.01	0.11	0	1	0.01	0.12	0	1		
Mailo (=1)	0.03	0.18	0	1	0.03	0.18	0	1	0.05	0.21	0	1	0.04	0.19	0	1		
Customary (=1)	0.54	0.50	0	1	0.54	0.50	0	1	0.47	0.50	0	1	0.53	0.50	0	1		
Multi tenure/manager (=1)	0.03	0.16	0	1	0.01	0.12	0	1	0.03	0.17	0	1	0.02	0.15	0	1		
Land acquisition																		
Purchased (=1)	0.26	0.44	0	1	0.24	0.43	0	1	0.31	0.46	0	1	0.26	0.44	0	1		
Inherited (=1)	0.58	0.49	0	1	0.65	0.48	0	1	0.53	0.50	0	1	0.59	0.49	0	1		
Leased (=1)	0.00	0.05	0	1	0.00	0.03	0	1	0.00	0.00	0	0	0.00	0.04	0	1		
Cleared (=1)	0.02	0.15	0	1	0.02	0.15	0	1	0.02	0.13	0	1	0.02	0.15	0	1		
Multi acqui./manager (=1)	0.13	0.34	0	1	0.08	0.28	0	1	0.14	0.34	0	1	0.12	0.32	0	1		
Soil quality																		
Good (=1)	0.57	0.49	0	1	0.52	0.50	0	1	0.53	0.50	0	1	0.55	0.50	0	1		
Fair (=1)	0.25	0.44	0	1	0.31	0.46	0	1	0.28	0.45	0	1	0.28	0.45	0	1		
Poor (=1)	0.04	0.19	0	1	0.05	0.21	0	1	0.05	0.21	0	1	0.04	0.20	0	1		
Multi qual./manager (=1)	0.14	0.34	0	1	0.13	0.33	0	1	0.14	0.35	0	1	0.13	0.34	0	1		
Rained agriculture (=1)	0.96	0.20	0	1	0.96	0.20	0	1	0.96	0.20	0	1	0.96	0.21	0	1		

Table 3
(Continued)

Variables	Male household heads				Female household heads				Females in male-headed household				All			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Erosion problem (=1)	0.74	0.44	0	1	0.68	0.47	0	1	0.62	0.49	0	1	0.69	0.46	0	1
Fallow years	2.02	3.09	0	31	1.88	2.95	0	21	1.47	2.22	0	26	1.87	2.88	0	31
Region																
Central (=1)	0.18	0.39	0	1	0.22	0.42	0	1	0.22	0.41	0	1	0.20	0.40	0	1
Northern (=1)	0.28	0.45	0	1	0.29	0.45	0	1	0.21	0.41	0	1	0.27	0.44	0	1
Eastern (=1)	0.27	0.45	0	1	0.24	0.43	0	1	0.27	0.44	0	1	0.26	0.44	0	1
Western (=1)	0.25	0.43	0	1	0.21	0.41	0	1	0.28	0.45	0	1	0.24	0.43	0	1
Observations	3,538				1,803				1,375				6,986			

Note:: Acqui = Acquisition; qual = quality.

Source : Authors' calculation based on UNPS Panel 2009/10, 2010/11, 2011/12 and 2013/14.

longer duration and intensity) lead managers and in particular female managers to relocate land towards crops that enhance food self-sufficiency. For the purpose, we interact the different shock measures, K , with a binary variable F that takes the value of one if manager i is female and zero otherwise.

To ease interpretation, consider the one-period lagged binary shock measure, the parameters are $E(Y_{i,t}^c | F=0, K_{i,t-1}=0, X_{i,t}) = \alpha^c + \beta' X_{i,t}$, the average land share allocated to crop c for men that are not exposed to shock and $E(Y_{i,t}^c | F=0, K_{i,t-1}=1, X_{i,t}) = \alpha^c + \beta_1^c + \beta' X_{i,t}$ so that β_1^c is difference in land allocation to crop c for men whose plots have been exposed to a shock as opposed to not at time $t - 1$. β_3^c measures how much the shock response varies by gender. The interpretation of the continuous shock measure is more challenging. β_1^c is the additional (average) increase in y due to a one unit increase in past shock for men, all other things being equal. In this case β_3^c is the gender difference in the 'returns to shock'. If $\beta_3^c = 0$, the response to a weather shock does not vary by gender in Uganda. If $\beta_3^c > 0$, a unit increase in lagged shock has a greater effect for women's land allocation to crop c than for men, and if $\beta_3^c < 0$, a unit increase in past weather shock leads to a smaller increase in land allocated by women to crop c than for men.

X is a vector of manager characteristics including marital status, age and education, where the latter includes mutually exclusive dummy variables ranging from primary education to university education.⁶ Q captures farm characteristics that have been found to explain productivity differences across crops, such as the land tenure system, land acquisition methods, water sources, topography, and the total number of plots controlled by a manager. To proxy different land tenure regimes, we use a range of dummy variables related to the different tenure systems in Uganda.⁷ We also control for a set of farm characteristics proxying the different water sources used by the managers. As noted by Doss (2001, 2002) gender and farm characteristics, such as land tenure, crucially affect smallholders' farming decisions in areas such as agricultural technology adoption and crop choices.

We also control for region and wave fixed effects, γ_i , to account for time-varying agricultural shocks affecting all managers to an equal extent. $\mu_{i,t}$ is the idiosyncratic error. Since we pool panel data across waves, the observations are correlated at the manager level and as a result the standard errors may be under-estimated. We correct for this manager-level correlation by cluster-bootstrapping the standard errors.

The system of linear regression equations for the different crops is estimated jointly using the feasible generalised least-squares (FGLS) model (Cameron and Trivedi, 2010). If the error terms are correlated across the equations, SUR is more efficient than OLS (Zellner and Huang, 1962; Binkley, 1982). As the error terms of the different equations are likely to include unobservable manager characteristics – such as the managers' knowledge of farming, which may affect their land share allocation – they are likely to be correlated across the equations. Further, decisions to allocate land to certain sets of crops are taken by managers at the same time. For example, a possible combination of crops that complement each other in a traditional diet in Ugandan households could include traditional crops such as beans, groundnuts or cassava.

⁶The different levels of school education in Uganda are: (i) primary; (ii) secondary; (iii) post-secondary tertiary; and (iv) university. Nursery school education for children is not universal in the country yet. The vast majority of the population has at least primary education.

⁷There are four main land tenure systems in Uganda: freehold, leasehold, mailo and customary.

By construction, the sum of the land shares $Y_{i,t}^c$ allocated to the different crops cultivated by the same manager in a year adds to one. As a result, the system imposes the following parameter restrictions on our estimates: the sum of the intercept coefficients for all the different equations in the system add to one ($\sum \alpha^c = 1$), the sum of the coefficients of all the other explanatory variables and the sum of the error terms add to zero across the different crops ($\sum \beta = 0$ and $\sum \mu_{i,t}^c = 0$). Given that $\mu_{i,t}^c$ adds to zero across all crops at every data point, we exclude one crop category from our estimations (see Greene, 2012). In our case the omitted category comprises all the other crops we did not select and tends to be crops of lower importance in the agricultural setting in Uganda.⁸

There are several empirical challenges to our specification. First, given that by construction a prolonged shock measure requires managers to be present in multiple waves of the panel survey, the inclusion of this measure requires balancing out the data and restricts the estimation sample considerably, by approximately 70%. If managers who are more able to cope with adverse weather events have a lower attrition probability, the parameter estimates of this specification are likely to be biased. Recognising that sample selection may bias our estimator when including the prolonged shock measure, our main analysis on shock duration is based on the yearly lagged shock measures, as these require managers to be present in either one of the two period intervals only (i.e. 2009 and 2010, 2010 and 2011 or 2011 and 2013). We note the potential bias of the estimates of shock duration when interpreting the estimated coefficients.

Another empirical challenge presented by our sample is that on average there are only 1.02 plot managers per household (see Table 1). Furthermore, female household heads constitute about 57% of the females in the sample (see Table 2). In other words, generally only one person per household – typically the household head – manages all plots. Hence, if we observe gender-based dynamics in response to shocks, this is more likely to be driven by male/female heads of households behaving differently rather than by intra-household allocation of resource dynamics. To differentiate gender dynamics within these different household structures, we report an additional set of results for three separate subsamples: men in male-headed households, female heads of households and women in male-headed households.⁹

As our shock measures are contingent on crop choice, which may pose a threat to identification, we also use a binary indicator taking the value of one if rainfall is below the 20th percentile value in a given enumeration area (Shah and Steinberg, 2017) as an alternative shock measure in a robustness analysis. Finally, it is possible that changes in prices affect farmers' crop portfolio choices over the years. Price effects are likely to be particularly relevant for managers who live near markets, but this information is not available in the fourth wave of the survey. In order to proxy price effects, we also include a full set of district fixed effects and district-wave-interaction to our core specification as a robustness check.

⁸By using shares as our dependent variables, we combine crop 'take-up' and 'deepening' in a single measure. Given that most managers allocate at least some land to the crops included in our sample, we report shares as our key outcome measure. Binary choice models of crop choice yield consistent results and are available upon request.

⁹Given the limited sample size, we cannot restrict our sample to men and women living in the same household.

4. Results

Table 4 reports the parameter estimates of the (lagged) discrete shock measure, Table S5 reports those related to the (lagged) shock intensity measure and Table S6 those associated with a two-period shock duration. The dependent variable in each column of these tables relates to the land allocated to each crop of interest to us, namely maize, sorghum, beans, groundnuts, cassava, sweet potato, banana, and coffee. The estimates in Table 4 indicate that in the absence of shocks women allocate less land to maize (coefficient of -0.052 significant at the 1% level) and coffee (coefficient of -0.016 , significant at the 5% level) and more land to banana (coefficient of 0.024 , significant at the 5% level) than men. At the same time, the positive and significant coefficient of the interaction term between the shock and female variables in the maize and sorghum specification, and the negative and significant coefficients of the interaction terms in the cassava and banana equations, indicate that in the event of a shock women are more likely than men to allocate land to commercial from subsistence crops. In terms of magnitude of effects, the difference in shock response in land devoted to maize by women is about the same size as the reduction of land allocated to maize by men when exposed to a shock (corresponding to a coefficient of -0.055 of the non-interacted shock variable and a coefficient of $+0.042$ of the interaction of the shock variable with the female dummy variable). In the case of cassava, the relative reduction of land that women devote to the crop when exposed to shock more than exceeds the increase in land allocated to the crop by men in response to a shock (corresponding to a coefficient of $+0.063$ of the non-interacted shock variable and -0.075 of the interacted term).

The results based on the shock intensity variable (Table S5) are consistent with those based on the discrete shock variable. Once again, the positive and significant coefficients of the interaction terms between the shock variable and the female dummy variable in the maize and sorghum equations and the negative and significant coefficients of the interaction terms in the cassava and banana equations indicate greater propensity of women (compared to men) to relocate land out of subsistence into commercial crops in the event of a shock. Indeed, the sizes of the interaction term coefficients of 0.067 in the maize equation, of 0.226 in the sorghum equation of -0.124 in the cassava equation and of -0.149 in the banana equation by far exceed those of the corresponding interaction terms in Table 4. A key difference between Table 4 and Table S5 is the negative and significant coefficient of -0.054 of the interaction term in the coffee equation. It highlights the fact that shocks of greater intensity are more likely to induce women to relocate land out of perennial cash crops than men.

The estimates reported in Table S6 help us test the hypothesis whether farmers' reaction to shocks differs depending on the observed duration of the shock, even though we need to interpret these results with caution given the reduction of the size of the sample and potential selection bias. The key results observed in Table 4 and Table S5 continue to hold in that the coefficients of the interaction terms in the maize and sorghum equations are positive and that in the cassava equation is negative. The fact that the coefficients are larger in magnitude in Table S5 than the corresponding coefficients in Table 4 indicates potentially stronger response to long-lasting shocks compared to shocks of short duration; even though due to the sample size reduction these results are suggestive at best. It is worth highlighting that the fraction of variation in crop share allocation explained by our covariates is low across the

Table 4
SUR estimation results of a lagged shock

Variable	Maize	Sorghum	Beans	Groundnuts	Cassava	Sweet potato	Banana	Coffee
Shock	-0.055*** (0.014)	0.002 (0.003)	0.002 (0.002)	-0.012 (0.013)	0.063*** (0.014)	0.001 (0.010)	0.001 (0.002)	-0.002 (0.004)
Shock × Female	0.042** (0.021)	0.010** (0.004)	0.002 (0.002)	0.006 (0.019)	-0.075*** (0.022)	0.021 (0.014)	-0.007** (0.003)	0.001 (0.005)
Female	-0.052*** (0.020)	0.005 (0.009)	0.006 (0.009)	0.005 (0.018)	0.027 (0.022)	-0.000 (0.012)	0.024** (0.012)	-0.016** (0.008)
Primary	-0.021** (0.011)	-0.079*** (0.014)	-0.002 (0.011)	0.022*** (0.008)	0.037** (0.015)	0.018** (0.008)	0.018 (0.014)	0.008 (0.007)
Secondary	-0.013 (0.014)	-0.115*** (0.015)	0.014 (0.015)	0.018* (0.011)	0.016 (0.018)	0.026** (0.010)	0.036* (0.019)	0.018* (0.010)
Post-secondary	0.010 (0.022)	-0.094*** (0.018)	-0.029 (0.020)	0.034 (0.022)	0.013 (0.029)	0.012 (0.014)	0.043 (0.029)	0.012 (0.018)
Household size	0.007*** (0.002)	0.001 (0.001)	-0.001 (0.001)	0.002 (0.001)	-0.004** (0.002)	0.000 (0.001)	-0.003 (0.002)	-0.001 (0.001)
Number of plots	0.003 (0.002)	-0.011*** (0.002)	0.003 (0.002)	0.002 (0.001)	-0.009*** (0.003)	0.010*** (0.001)	-0.003 (0.002)	0.005*** (0.002)
Soil quality								
Good	0.020*** (0.008)	0.006 (0.007)	-0.014* (0.008)	0.008 (0.005)	-0.007 (0.010)	-0.019*** (0.006)	0.008 (0.008)	-0.001 (0.005)
Poor	-0.009 (0.023)	-0.021 (0.022)	-0.019 (0.026)	0.012 (0.020)	-0.085*** (0.033)	0.036 (0.028)	0.065* (0.036)	0.021 (0.019)

Table 4
(Continued)

Variable	Maize	Sorghum	Beans	Groundnuts	Cassava	Sweet potato	Banana	Coffee
Rainfed	0.030* (0.015)	0.014 (0.014)	0.023 (0.014)	-0.020 (0.014)	0.023 (0.025)	-0.026* (0.014)	-0.035* (0.020)	-0.007 (0.011)
Wave 2	0.005 (0.009)	0.012 (0.007)	-0.020** (0.009)	-0.018*** (0.007)	0.005 (0.012)	0.022*** (0.007)	-0.066*** (0.011)	0.059*** (0.005)
Wave 3	0.009 (0.010)	-0.002 (0.007)	-0.007 (0.009)	-0.003 (0.008)	-0.012 (0.012)	0.024*** (0.007)	-0.078*** (0.010)	0.069*** (0.006)
R-squared	0.0224	0.0553	0.0059	0.0107	0.0191	0.0300	0.0268	0.0447
Observations	3,411	3,411	3,411	3,411	3,411	3,411	3,411	3,411

Notes: The dependent variable in all the regressions is the land share allocated to specific crops as listed in the column head. Manager bootstrapped standard errors are in parentheses (replications = 400).

* $P < 0.10$, ** $P < 0.05$, *** $P < 0.01$.

specification, indicating that there are other factors affecting farmers' crop portfolio choices that we are not taking into account.

4.1. Heterogeneity analysis

To better rationalise the land reallocation patterns that we observe, we split our sample into male-headed households, female heads of households and women in male-headed households. Tables S7a–c report the (binary) one-period shock response for these subsamples.

The story emanating from these results is mixed. In line with our previous findings, we find that male heads of households reduce the land share allocated to maize and increase the land share allocated to cassava (Table S7a). Also, in line with our previous findings, female heads of households increase their land share devoted to sorghum while reducing their land share to bananas (Table S7b). It appears that while men relocate land rationally (from more vulnerable commercial food crops – maize – to traditional crops – cassava), the behaviour of women is at first sight irrational, particularly given that sorghum is less drought resistant than bananas. It is possible that as the stress levels experienced by female heads of households are likely to be more severe than those of their male counterparts when exposed to a shock, it could be that their cropping choices are less objectively rational (Mani *et al.*, 2013) as a consequence. Alternatively, women may be more prone to taking risk than men for negative payoffs or simply trying to compensate for loss of income by engaging in more profitable crops, as argued with reference to the qualitative literature at the outset of this study. For women in male-headed households we do not find a similar pattern (Table S7c).

Tables S8a–c report the shock response to a one-period shock using the intensity shock measure for the three subsamples. For those managers experiencing a shock, an increase in the shortfall of rains relative to the minimum water needs, leads female heads of household to reallocate land from subsistence crops (cassava and banana) and traditional cash crops (coffee) towards commercial crops (sorghum) (Table S8b). A similar pattern emerges for female plot managers in male-headed households (Table S8c). Male household heads reduce their land allocation to maize and increase their land allocation to sorghum but no reduction in land allocated to subsistence crops is overserved at the intensive margin (Table S8a). Interestingly, the results in Table 4 and Table S5 indicated that movement into commercial food crops like sorghum and out of potentially more drought resistant crops like cassava is more prevalent for women than for men. This confirms the income compensation hypothesis that we ventured in the explanation of the results in Tables S7a and b, which would be particularly plausible in the face of an alternative potential dynamics, namely the greater propensity of men to migrate out of the farm, opening opportunities for women to relocate land (conditional on the strength of the shock) to commercial agriculture.

4.2. Mechanism

To reiterate, one plausible mechanism that explains the increased adoption of 'non-traditional crops' by women is the fact that men disproportionately allocate more time off the farm in response to negative weather shocks, which opens the opportunity for women to reallocate land from subsistence to commercial crops while those men who keep cultivating crops may be more concerned to preserving household food security.

To corroborate this in our context, we analyse gender differences in labour supply in response to shocks. Specifically, we examine the share of total labour time allocated to wage work, household businesses, secondary wage work and farm work.

The results in Table 5 summarise the SUR estimates of the lagged weather shock on labour shares by sector of employment; those highlighted in column 1 relate to wage employment, those reported in column 2 are related to employment in household businesses, column 3 highlights the results on farm employment and column 4 on secondary wage employment. These results align with our main hypothesis. When exposed to a shock, men allocate on average less time to farm activities (coefficient of

Table 5
Gender differences in lagged rainfall shocks on labour supply

	Wage	HH business	Farm	Secondary
Shock	0.014 (0.014)	0.033*** (0.012)	-0.053** (0.023)	-0.013 (0.013)
Shock × Female	-0.009 (0.018)	-0.019 (0.017)	0.061* (0.032)	0.024 (0.016)
Female	-0.024 (0.017)	0.025* (0.015)	-0.028 (0.028)	-0.037** (0.015)
Primary	0.005 (0.009)	0.033*** (0.010)	-0.005 (0.019)	0.012 (0.009)
Secondary	0.069*** (0.016)	0.071*** (0.016)	-0.045* (0.024)	0.010 (0.012)
Post-secondary	0.226*** (0.037)	0.072*** (0.025)	-0.146*** (0.034)	0.035* (0.020)
Household size	-0.002 (0.001)	0.001 (0.002)	0.003 (0.003)	-0.001 (0.001)
Number of plots	-0.007*** (0.002)	-0.006*** (0.002)	0.005 (0.004)	0.000 (0.002)
Soil quality good	-0.014* (0.009)	0.019** (0.008)	-0.018 (0.014)	-0.000 (0.008)
Soil quality poor	0.023 (0.028)	0.033 (0.031)	-0.006 (0.044)	-0.023 (0.017)
Fallow	0.026 (0.035)	-0.009 (0.035)	-0.234*** (0.041)	0.031 (0.036)
Rainfed	-0.002 (0.019)	0.031* (0.016)	-0.111*** (0.034)	0.035** (0.014)
Wave = 2	0.032*** (0.010)	0.130*** (0.009)	0.359*** (0.014)	0.104*** (0.008)
Wave = 3	0.027*** (0.009)	0.104*** (0.008)	0.414*** (0.014)	0.086*** (0.007)
Constant	0.082*** (0.027)	-0.091*** (0.023)	0.133*** (0.046)	-0.010 (0.022)
Observations	3,460	3,460	3,460	3,460
R-squared	0.058	0.055	0.162	0.046

Notes: Cluster-robust standard errors are reported in parentheses. The dependent variable is the (annual) labour share allocated to off-farm wage work, household business and secondary work and on-farm household farm work.

* $P < 0.10$, ** $P < 0.05$, *** $P < 0.01$.

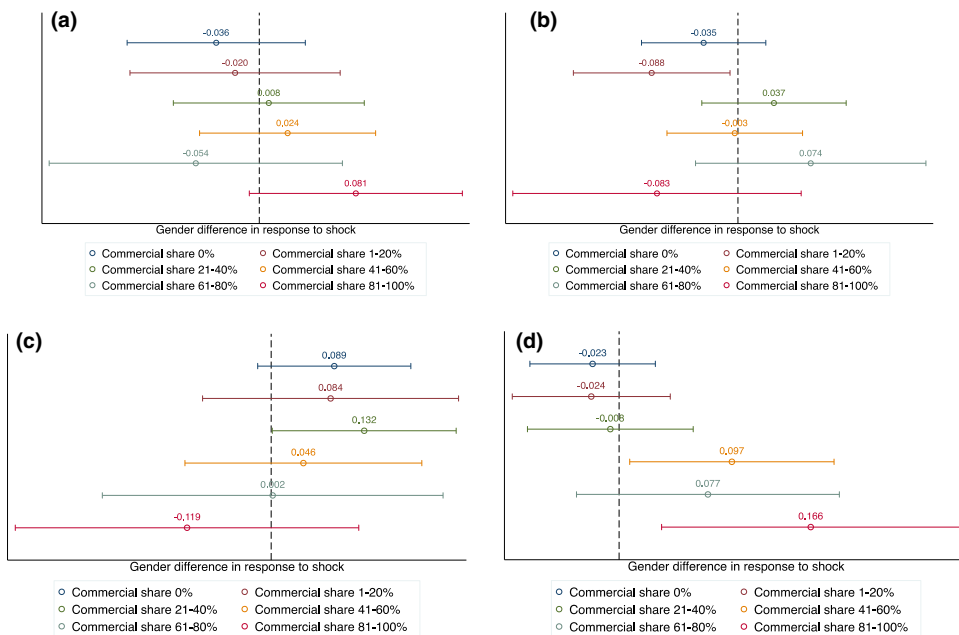


Figure 1. Heterogeneity in gender differentiated shock response by initial commercialisation.

(a) Gender difference in shock response on wage labour share (b) Gender difference in labour share in household enterprises. (c) Gender difference in farm labour share. (d) Gender difference in labour share in secondary activities. [Colour figure can be viewed at wileyonlinelibrary.com]

−0.053, significant at the 5% level in column 3) and increase the time spent in household enterprise (coefficient of −0.033, significant at the 1% level in column 2). Although not significantly at conventional levels, females increase their time on the farm when exposed to an adverse weather shock relative to men (coefficient of 0.06, significant at the 10% level in column 3).

To analyse whether the gender shock response varies by the degree to which the household cultivates marketed crops to start with, we disaggregate the analysis by the households' initial land share devoted to commercialised crops.¹⁰

The results (summarised in Figure 1) suggest that the female response to shocks in the form of farm and secondary/wage employment move in opposite directions. As the share in commercialisation increases, so does the gender difference in response to a shock, which translates into a relative increase in secondary and wage employment compared to men and vice versa for farm employment. This pattern supports the argument that as the initial allocation of land to marketed crops increases, so does the opportunity cost of male off-labour in response to adverse weather shocks. However, we do not find a similar pattern for household non-farm enterprise labour supply.

¹⁰The land share is the proportion of manager i 's total crop land area cultivated devoted to commercial crops in wave 1. The commercial crop land share includes the share of farmers total crop land area allocated to maize and sorghum (food crops with high marketing potential as explained in section 2.2) and coffee (typical tropical cash crop).

4.3. Robustness checks

It is possible that differences in prices across time and space affect our results. In order to analyse whether our results are driven by price effects, we include a full set of district and district-wave fixed effects to our core specification. The results are generally in line with our previous findings even though with less precision (Table S9). Given the sheer magnitude of parameters to estimate when including district/district-wave fixed effects, we cannot conduct consistent subsample analysis when using this specification and we report these results for completeness only.

As our shock measure is based on observed cropping patterns, we also use a binary shock indicator that takes the value of one if rainfall is below the 20th percentile value in a given enumeration area. Using the enumeration area-based shock measure yields results that are consistent with our main findings (Table S10).

5. Conclusion

Over the past decades, there has been an increase in climate change induced rainfall shocks. These shocks threaten food security and broader aspects of welfare for smallholder farmers in tropical countries like Uganda. While farmers can use a variety of mechanisms to cope with these shocks, such as adopting irrigation technologies, agroforestry, changing crop varieties and planting times, the majority cannot afford these adaptations. Most smallholder farmers react to weather shocks by reallocating land to different crops. The situation is particularly difficult for female farmers, for whom the barriers to either adopting shock mitigating technologies or increasing their off-farm employment are often much higher than for men.

Most of the theoretical literature argues that the allocation of land in such circumstances should be driven by the motive of farmers to reduce risk and enhance subsistence. Although little detailed rigorous analysis is conducted by gender, the assumption usually is that women will tend to use less risky though lower return crops than men. This argument is consistent with the empirical evidence that women tend to engage more in subsistence crop production and that in response to shocks women tend to increase their subsistence crop production (Udry, 1996; Duflo and Udry, 2004). Although this strategy may ensure better subsistence in the short term, it may push (female) farmers and their families down a spiral of greater longer-term destitution.

Using a manager-crop panel data set from Uganda and a novel measure of negative production shocks based on individual crops' water requirements, regional heterogeneity in the crop planting cycle and high resolution rainfall data, we make several contributions to this literature. In contrast to the literature, our results suggest that shocks induce disproportionate allocation of land out of subsistence into commercial food crops by women. This effect is particularly pronounced in the case of long-lasting shocks compared to shocks of a shorter duration. In response to shocks of greater intensity, women tend to relocate relatively more land out of perennial cash crops than men.

We find that a mechanism explaining our findings is that in the event of negative weather shocks men are more likely to opt for off-farm labour opportunities while women increase their relative time on the farm. We also find suggestive evidence that this male off-farm/female on-farm labour supply response is especially pronounced when the opportunity costs of male labour on the farm are low. It is also plausible to

assume that female farmers are more likely to reveal greater affinity to risk-taking behaviour when the main risk is downside. While it is not possible to test this proposition with our data, this suggests new areas for further investigation.

Our findings have potentially important policy implications. For instance, if relatively deprived farmers tend to engage increasingly in income-generating (though less secure) activities in the face of negative shocks, then governments and donors might need to enhance the adoption of such activities and related technologies as climate change effects continue to materialise. Given our findings of gender-differentiated responses to adverse weather events, and the increased intensity and duration of climate change induced weather shocks in developing countries, accounting for differences in household structures is likely to be important in the design of policy interventions.

Supporting Information

Additional supporting information may be found online in the Supporting Information section at the end of the article.

Figure S1. Distribution of negative rainfall shocks and cropland share allocations

Table S1. Minimum seasonal agronomic crop water needs.

Table S2. Manager and crop characteristics.

Table S3. Farm characteristics.

Table S4. Definition of variables.

Table S5. SUR estimation results of one period lagged shock intensity.

Table S6. SUR estimation results of a consecutive two wave binary shock.

Table S7a. SUR estimation results of a one period lag of shock (binary) for male household heads.

Table S7b. SUR estimation results of a one period lag of shock (binary) for female household heads.

Table S7c. SUR estimation results of one period lag of shock (binary) for female plot managers in male headed households.

Table S8a. SUR estimation results of a one period lag of shock intensity for male household heads.

Table S8b. SUR estimation results of a one period lag of shock intensity for female household heads.

Table S8c. SUR estimation results of one period lag of shock intensity for female plot managers in male headed households.

Table S9. Gender differences in lagged rainfall shocks (binary) on cropping shares, SURE estimates accounting for district-time trends.

Table S10. SUR estimation results of one period lagged binary shock (rainfall being below the 20th percentile).

Table S11. Correlation of rainfall across waves.

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