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A gender-differentiated analysis

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FOODSECURE Working paper no. 32
May 2015

INTERDISCIPLINARY RESEARCH PROJECT
TO EXPLORE THE FUTURE OF GLOBAL
FOOD AND NUTRITION SECURITY

THE ROLE OF CROP DIVERSITY IN HOUSEHOLD PRODUCTION AND FOOD SECURITY IN UGANDA: A GENDER-DIFFERENTIATED ANALYSIS

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Abstract: The linkages between gender, crop choice and agricultural output must be explored if food security is to be ensured under changing climates. Using a rich nationally representative household panel dataset from Uganda, this paper addresses the topic empirically, bringing new evidence to a literature that has not yet fully examined the role of gender in responding to environmental shocks that increase agricultural production variability. A longitudinal analysis that endogenizes production portfolios and agricultural decision-maker gender in ascertaining productivity outcomes indicates parcel manager gender and crop diversity are distinguishing factors in the household food security function. Heterogeneity is explored in the context of diverse agro-ecological zones and differential access to factors of production.

Keywords: Agriculture; crop diversity; food security; gender; risk management; Uganda.

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Acknowledgement: The research leading to these results has received funding from the European Union's Seventh Framework Programme FP7/2007-2011 under Grant Agreement n° 290693 FOODSECURE. This paper is work in progress; comments are welcome. The authors only are responsible for any omissions or deficiencies. Neither the FOODSECURE project and any of its partner organizations, nor any organization of the European Union or European Commission are accountable for the content of papers in this series.

1. Introduction

The linkages between gender, crop choice and food security must be explored if food security is to be ensured under changing climates and increasing variability. Using a rich two-year panel dataset from Uganda, this paper addresses the topic empirically, bringing new evidence to a literature that has not yet fully investigated the role of gender in responding to climate change-induced environmental shocks that increase agricultural production variability.

The gender-sensitive nature of intra-household resource allocation and production strategies has been widely documented by economic studies (Udry, 1996; Qian, 2008; Quisumbing and Maluccio, 2000). Agricultural output has been shown to be higher among male farmers as compared to female producers, a finding that is generally attributed to differences in access to productive assets and inputs (Peterman et al., 2011). At the same time, cultural norms have been documented as defining production portfolios, differentiating crop choice according to gender (Doss, 2002; Hoddinott and Haddad, 1995; Peterman et al., 2010; Qian, 2008). Whether crop portfolios are differentiated by gender in response to variability (Nhemachena and Hassan, 2007) and how that affects food security is of particular importance in light of the broad documentation of increased global climatic variability and the renewed attention being given to the importance of women in agriculture (World Bank, 2008).

Gender is a factor understood to define intra-household resource allocation according to individual bargaining power. Household resources, when controlled by women rather than men, have been found to be better allocated in the interest of household member welfare in terms of education, health and food security (Thomas, 1990; Deaton, 1989). However, women's intra-household bargaining power is often challenged by cultural and societal norms that translate into a limited set of resources under their control, relative to their spouses or other males in their households. Unequal or disproportionate resource allocation between genders implies decisions on resource use are also conditioned according to gender-differentiated risk profiles (Dercon, 1996). With risk profiles being linked to access to resources and assets, both of which relate to gender and bargaining power (Quisumbing et al., 2013), the evidence indicates that women are more risk averse than men (Croson and Gneezy, 2009; Eckel and Grossman, 2002). The degree of risk aversion is likely to affect decision-making on the farm. In the context of rural households in developing countries that rely on agricultural production to sustain household subsistence needs and are subject to missing markets, production and consumption decisions will likely be non-separable (Benin et al, 2006; Singh et al., 1986), thus rendering the implications for food security of notable interest.

While this paper does not explicitly isolate the role of climate change induced agricultural variability on female agricultural production outcomes, the existing set of evidence on climate change and adaptation strategies presents a fundamental motivation and basis for understanding the implications for one particular strategy – crop portfolio diversity– to influence food security. Whereas diversity is often portrayed in the context of intra-crop varietal diversity[1], an alternative definition is adopted in this paper in terms of the degree to

[1] See Smale (2006) for a compendium of studies analysing crop diversity in this manner.

which multi-cropping is employed, when the alternative is a mono-cropping production strategy. A series of diversity indices are utilized to study the different aspects of multi-cropping regimes and to gain understanding of the sensitivity of results to those different measures.

The evidence generated by this paper thus serves to highlight the extent to which and conditions under which a broader notion of crop diversity can be utilized as a low entry-barrier adaptation strategy for poor rural producers with a priori limited capacity to adapt to the effects of climatic change. Of further value-added is the possibility to explore the utilization of inter-crop diversity comparatively across female and non-female managed parcels, which has not been investigated by the economic literature addressing agro-biodiversity. In section 2, an overview of the relevant literature is provided, while the following section describes the dataset, key variables, and a set of summary statistics. Section 4 explains the econometric approach, section 5 presents results and the final section reassesses the evidence and concludes.

2. Literature

2a. Gender, agriculture and food security

Pieters et al. (2012) highlight the role of gender as a pervasive topic in the study of household decision-making, notably under the umbrella of issues related to food and nutrition security. However, the literature that directly connects gender, on-farm decision-making and food security in the context of adaptation is limited, generally treating gender as one of various factors influencing the decision to engage in some adaptive strategy. Most papers have focused separately on either the relationship between gender and food security or that between gender and agriculture. It is under the latter in which differentials in agricultural production according to farmer characteristics have been increasingly documented (for comprehensive reviews see Quisumbing, 1996 and Peterman et al., 2011), largely in relation to the constraints faced by female farmers, but also with respect to the differences in production strategies, decisions employed, and roles held by male and female farmers. The major findings from that literature highlight that (1) households are complex bargaining units subject to allocative inefficiencies that explain lower productivity among female farmers; (2) female farmers are constrained in access to inputs, assets, information and markets relative to male farmers (Gladwin et al., 2001; Quisumbing et al., 2013); (3) once differences in access to productive inputs are controlled for, differences in productivity across gender generally (though not always) disappear.

Recent evidence has estimated the global gender gap in agriculture at 20 to 30 per cent (FAO 2011); region-level estimations for Sub-Saharan Africa that factor in plot area and geographic characteristics place that figure between 23 and 66 per cent (O'Sullivan et al., 2014). With women comprising 43 per cent of the agricultural labour force (FAO 2011), it is necessary to understand what drives and how to close those gaps. The seminal Udry (1996) paper on agricultural productivity differences across gender in Burkina Faso introduced the idea that household resources are inefficiently allocated across male and female plots, noting that re-allocating inputs from male to female farmers can raise household production by nearly 6 per cent. Udry et al. (1995) put the potential productivity gains from productive input reallocation across plots at 10-20 per cent, while O'Sullivan et al. (2014) estimate the gains as high as 20-30 per cent. Equalizing the productive resource base across gender would correspond with a potential 2.5 – 4 per cent gain in the level of agricultural output and reduce global food insecurity by up to 17 per cent (FAO 2011). Rangel and Thomas (2005) also confirm Pareto inefficiencies in production among farm households in Ghana and Senegal.

The conclusion that resources are inefficiently utilized within household production schemes is a unifying theme, despite some discrepancies in point estimates. At the same time, while inputs and assets are nonetheless relevant variables, explaining the complexities of gender differentials must also factor in societal conditions, particularly in the context of multi-generational, multi-family composite households where culture and ethnographic factors influence labour, asset and resource allocation and decision-making, as much as household bargaining (Collins and Fotz, 2013). Akresh et al. (2011) raise the issue of intra-household altruism in polygamous households as a factor influencing efficient production, with lower altruism among co-wives in polygamous households resulting in greater productive efficiency than among husbands and wives in Burkina Faso. In this light, individual utility maximization may pursued in household decision-making processes, taking into consideration parallel responsibilities that may assigned along gender lines and conditional on cultural, societal or ethnographic norms (Just, Heiman and Zilberman, 2007). At the same time, women are subject to what is described as "time poverty" in that their role as caregivers and providers within the household is inelastic to their role as contributors to the household economy and food security (Blackden and Wodon, 2006). This inelasticity is due to some responsibilities being invariably female (such as breast-feeding infants) while others cultural (such as the role of women in food processing and preparing). Female power in household decision-making process may be limited or enhanced by these fixed responsibilities.

Qualitative research (Lu, 2004) has found cultural factors in agriculture to influence crop selection through gender. Cash crops, or rather, marketable crops, have often been designated as male crops, while staple, traditional or food crops generally classified under the realm of female producers (World Bank, 2008). The notion of gendered crops can be quite nuanced, depending on country and regional factors**.** While Hoddinott and Haddad (1995) attribute crops to each gender according to ethnographic trends in Cote d'Ivoire, Doss (2002) points out for Ghana that the allocation of crops into male or female categories can vary according to whether gender is observed for plot owner, output manager or household heads, and whether a crop is produced for sale or consumption. Crops traditionally under female control may be converted to "male crops" if they become profitable, such as if their market price rises (Weekes-Vagliani, 1990). From another angle, a study of gender, agricultural income, and child survival rates by Qian (2008) indicates that the production of tea versus orchard crops in China is given by physical comparative advantage such that labour and care intensive tea crop is produced by women, but height and strength intensive cultivation of orchards is dominated by men. This is in line with Peterman et al. (2011) who describe how labour responsibilities differ across men and women in agricultural production. However, if women are able to access “male” crops, the repercussions for household food security could be positive.

These gendered distinctions could also be extended to the case of the adoption of modern varieties. While their use is generally not widespread in Sub-Saharan Africa, male farmers tend to have higher adoption rates of modern or improved seeds (Peterman et al., 2011). Doss and Morris (2001) explore this gender disparity for maize in Ghana and find that differences in adoption rates can be explained by differences in access to complementary productive inputs and factors for which gender gaps are also prevalent ex ante. Similarly, in a study of female involvement in cash crop production and marketing, Hill and Vigneri (2011) find that the constraints faced by women in accessing assets and markets place obstacles to and condition the nature of their involvement in the cultivation and sale of such crops. More specifically, central factors for the successful cultivation and marketing of high value crops would include the need to produce at large-scale, to obtain high quality output and to minimize market transaction costs. The limitations faced by female farmers in accessing land, labour, inputs and technology, and the gender differences in human capital, credit, extension, information and output markets present major challenges to achieving each of those conditions and thus to diversification into modern variety crops, as well as to facing the production risks induced by climate change.

2b. Adaptation in agriculture to variability

Increasing climatic variability has contributed to the adoption of a variety of strategies in order to mitigate the implications of production and consumption risks. Climatic variability implies production variability, which has unavoidable consequences for food security in terms of access, availability and stability. Furthermore, with household resource and asset endowments identified as central factors in conditioning food availability, food access, and the coping strategies that influence vulnerability and resilience to risks such as climatic variability (Pieters et al., 2012), poor and marginalized producers facing market imperfections may also be those most susceptible to food insecurity.

The range of adaptation strategies available to Sub-Saharan farmers is extensive, and can be classified into (1) productive agricultural adaptation approaches such as the diversification of crops and varieties; diversification of the agricultural production system across crop, livestock, forestry and fisheries; moving planting and harvesting dates in response to temperature and rainfall; adoption of technologies such as high yield variety seeds or irrigation; applying soil conservation techniques; (2) productive non-agricultural adaptation strategies such as diversification into non-farm income activities and migration; and (3) unproductive or low risk-low return approaches such as selling assets; adopting drought resistant but lower yielding crops; reducing consumption; and relying on public assistance (Below et al., 2010; Nhemachena and Hassan, 2007; Deressa and Hassan, 2008; Dercon, 1996; Maddison, 2007).

Even with a gamma of possibilities available, adoption of specific productive adaptation strategies is conditioned on factors that differentiate better-off producers from worse-off producers (Ringler et al., 2010). While some strategies, such as modifying planting and harvesting dates can be implemented with marginal external assistance or additional resources, the capacity to adapt to climate change in other manners is hampered by information asymmetries, lack of access to markets and extension, as well as liquidity or credit constraints for acquiring technology and implementing innovative production approaches (Nhemachena and Hassan, 2007; Maddison, 2007). While incorporating modern varieties is often limited by access to fertilizer and irrigation (Rahman, 2008), the non-separability of production and consumption decisions, largely prevalent in developing countries (de Janvry and Sadoulet, 2004) has also been cited as a barrier to technology adoption (Dercon and Christiaensen, 2011), an unavoidable issue among subsistence producers that may have major implications in responding to increased variability.

Diversification has been demonstrated to be a common approach in order to spread risk across various sources of income, or in terms of the agricultural sector, across crop and livestock production or various crop varieties. As noted by Dercon (1996), the effectiveness of diversification as a risk management strategy is inversely related to the covariance between the activities into which diversification takes place. This outcome supports approaches in which risk is spread across agricultural and non-agricultural activities, but also in which production portfolios are diversified into crops with varying climatic requirements. Dercon (1996) and Rosenzweig and Binswanger (1993) find that agricultural portfolio and risk preferences vary with total wealth, when wealth is measured by liquid assets. At the same time labour constraints may also condition the scope and magnitude of the agricultural portfolio (Feder, Just, and Zilberman 1985), bringing attention to the role of household composition in crop choice.

The environmental and economic conditions faced by producers thus point to the potential utility of crop diversity as a mechanism to mitigate risk of production failure for producers with different levels of asset endowments. Even if diversification has been shown to be positively associated with educational attainment, asset ownership and non-agricultural income, it is also a viable strategy for smallholder farmers who may lack such capital (Maddison 2007; Rahman, 2008). Of even greater interest is the finding that engaging in crop diversification is linked not only to greater agricultural output (Di Falco et al., 2010), but also to greater agricultural productivity (Chavas and Di Falco, 2012). These findings model a direct relationship between climatic variables and crop diversity, building evidence for crop diversification as a viable adaptation strategy to climate change, even for marginal producers.

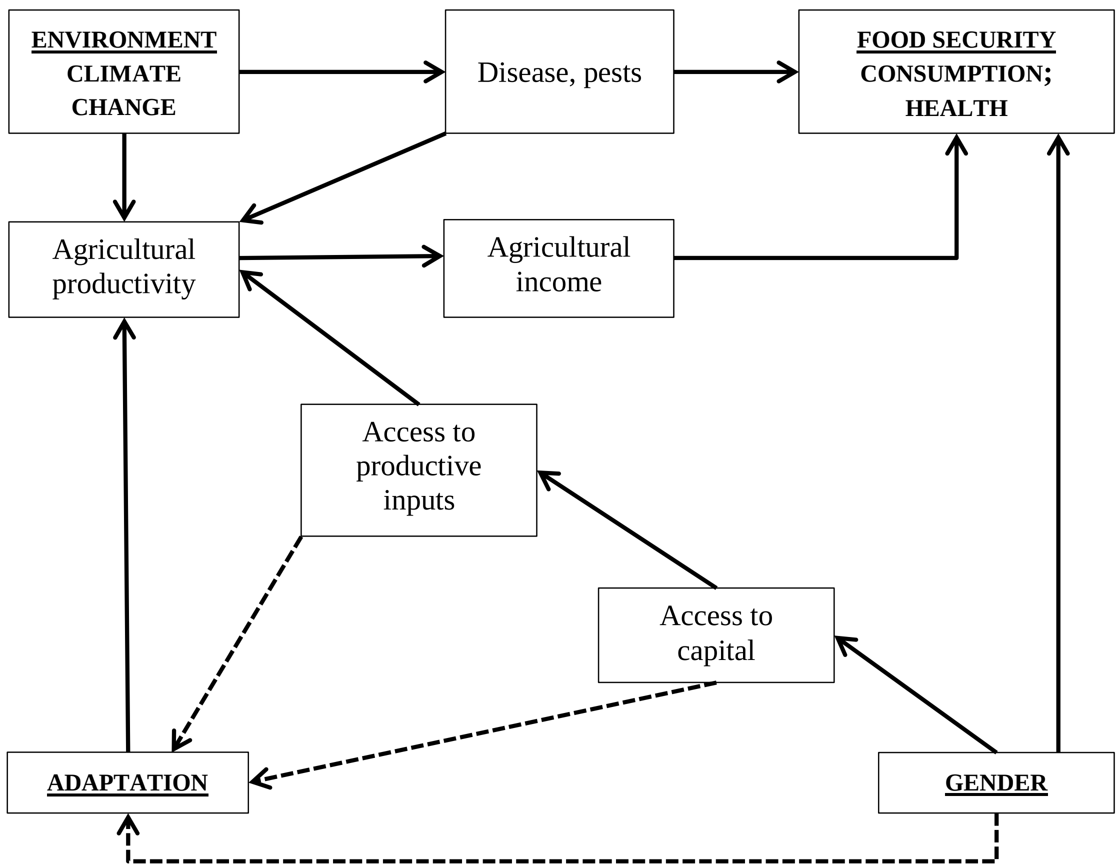
Considering the relevance of crop diversity for agricultural adaptation in conjunction with the myriad of factors defining the role for gender in cropping decisions highlights the difficulty in anticipating how female versus male producers will respond to the risk of production variability through crop selection. With the literature showing that the gendered control of income and its implications on expenditure shares and anthropometrics is associated with a positive link between female power and the prioritization of household needs (Thomas, 1990; Hoddinott and Haddad, 1995; Deaton, 1989), household dynamics are likely to affect how agricultural choices are made in the interest of household welfare and food security. More recent work provides further support of intra-household bargaining based on income and assets shares with implications for household welfare expenditure (Quisumbing and Maluccio

2000). In terms of agricultural activities, the role of commercialized agriculture was found to improve incomes overall, but to only result in improved food and nutrition security with greater female income control (Kennedy and Cogill, 1987). Njuki et al. (2011) also finds a link between cropping decisions and female income share as well as between gender and consumption expenditure, though an explicit link between agricultural production decision-making and expenditure is not made.

2c. Linking themes

While each stream of literature described in Sections 2a and 2b can stand alone, linkages between themes can easily be drawn, as illustrated by the conceptual framework in Figure 1, adapted from Lazzeroni (2013) and Skoufias et al., (2011). This framework seeks to highlight the principal avenues that connect climate change, adaptation and gender, in the context of their implications for food security. It does not pretend to be an exhaustive map of all channels and mechanisms; simply an illustration of the primary channels that are relevant for rural households. As the framework indicates, various points of intersection exist between climate change, adaptation, gender, and food security. The relationship between these four topics is conditioned on the presence of non-separable production and consumption decisions, especially if a crop portfolio has at minimum the objective of satisfying household consumption needs and is subject to constraints limiting access to input, labour and/or credit markets (Benin et al., 2006).

Figure 1. Conceptual framework



Although the direct connection between environmental changes and food security are not the focus of this paper, they do present a motivation for a micro-level analysis of the influence of adaptation on agriculture and food security. Changing climates have been demonstrated to create environmental challenges for individuals in terms of raising the prevalence of transmissible water and airborne diseases, which may affect agricultural labour productivity as well as individual health outcomes (Badiane and Ulimwengu 2012; Ringler et al., 2010, Skoufias et al., 2011). Agricultural productivity may also be directly affected in terms of unpredictable temperature and rainfall patterns that affect crop phenology as well as favouring conditions for the spread of pests that can harm agricultural output (Caffrey et al., 2013; Skoufias et al., 2011). The introduction of increased variability in agricultural productivity will have consequences for the stability of household food security, with implications for the level of agricultural income, whether it is through sales or implicitly via household consumption of own production, affecting in turn the degree to which household consumption is self-sustaining (Pieters et al., 2012; Skoufias et al., 2011).

Gender is portrayed as having both direct and indirect effects on individual and household food security. As indicated in Section 2a, a broad set of evidence demonstrates that gender will affect food security directly through differences in decision-making processes related to household expenditures (Thomas, 1990; Deaton, 1989). An agricultural channel also exists through which gender will influence household food security, mapped in Figure 1 via differences in access to various kinds of capital, such as human (education), physical (assets), natural (land), and social and public capital (information, networks) (Gladwin et al., 2001; Quisumbing et al., 2013). Unequal access to capital will affect the extent to which productive inputs are within reach, be it through physical market access, or having the financial resources to invest in seed, pesticide and fertilizer purchases. Access to such inputs will have consequences for agricultural productivity and eventually food security.

In addition to the economic channels described in the figure, gender will also have implications for agricultural decision-making and food security in the context of cultural or societal norms and expectations. Time poverty is likely to condition agricultural and food security decisions, especially in light of inelastic involvement of domestic responsibilities (Blackden and Wodon 2006). Activities traditionally in the female domain such as childcare and food preparation, and those biologically in the female arena, such as child-bearing and breastfeeding, present barriers for women to engage in agricultural or other economic activities. For example, traveling to markets to commercialize output or cultivating labour-intensive crops may be beyond the time and effort capability of many women. Similarly, as discussed in Section 2c, culture may designate gendered crops, which in turn may constrain a female producer’s cash flow, when her crop choice is limited to subsistence crops.

The adaptation channel mapped in Figure 1 is intended to capture the broad array of strategies available to producers, among which is contained crop diversity, of central interest to this paper. The dotted lines represent the channels hypothesized to connect gender with adaptation strategies directly or indirectly. Influenced by gender (Doss and Morris, 2001), access to capital (Nhemachena and Hassan, 2007; Maddison, 2001) and access to productive inputs, the use of one or more adaptation strategies is expected to influence food security through its feedback on the degree of agricultural productivity. Whether a significant relationship links gender, crop diversity, productivity, and ultimately food security is the main question raised by the present study and what the empirical analysis seeks to evaluate.

3. Context, data and descriptive statistics

3a. Ugandan context

As a small, landlocked country in Eastern Africa with diverse terrain and several recognized biodiversity hotspots[2], the conservation of agricultural diversity in Uganda is of key interest. The country's agro-ecological diversity characterises it as having high potential, which can feed into agricultural biodiversity (McDonagh and Bahiigwa, 2002). A related feature of that biodiversity is the presence of genetic diversity in crop production, which is essential for food security, livelihoods and adaptation to changes in global food systems, as required under climate change (Smale, 2006). As with other countries in the region, climatic changes may have serious implications for the 85 per cent of the population that resides in rural areas and the 70 per cent of its labour force that is employed in the predominately rain fed agricultural sector (Bashaasha et al., 2012; Ellis et al., 2006; Kasente et al., 2000). Bahiigwa (1999) finds that rural household food insecurity is directly associated with the level of rainfall and the presence of agricultural pests/diseases that could compromise stable production. Whereas most rural households are subsistence-oriented, increased variability places them in the role of net buyers in local agricultural markets in order to sustain household food security. Climate change has furthermore been found to generate negative effects on food consumption in Uganda, particularly when temperature variability is considered, but since climatic variability is an observed event, households engage in ex-ante consumption smoothing strategies to deal with such shocks (Lazzaronni, 2013).

A review of climate change impacts and necessary adaptation strategies in Uganda finds women, being more vulnerable to the effects of climatic variability, should receive direct attention in the promotion of adaptation strategies (Muhanguzi et al., 2012). Their vulnerability is aggravated by the "standard" set of obstacles encountered by women when engaging in agricultural production and livelihood strategies. These include credit constraints, which link back to a lack of collateral and information regarding financial instruments (Petracco and Pender, 2009) as well as a biased allocation of credit in which it is disproportionately allocated to women for food not cash crop production (Kasente et al., 2000); constrained access to registered agricultural land; traditional norms regarding intra-household decision-making, the division of labour and control over household income; limited access to inputs, seasonal labour, extension, and assets (Ellis et al., 2006; FAO, 2013; Kasente et al., 2000). Combined with other limitations, such as proximity, quantity and wealth differences, and difficulties in adding value to production, female producers are challenged in improving productivity but also on in their potential to adopt and market high value crops

[2] Convention on Biological Diversity Country Profile: Uganda. Available from www.cbd.int/countries/profile/?country=ug. Accessed 5 November 2013.

such as coffee, as found in a study of male versus female headed households in five districts in Uganda's coffee producing areas (Hill and Vigneri, 2011). With 84 per cent of rural women reported to be employed in the agricultural sector (UBOS and Macro International, Inc. 2007), the relevance of exploring gender in Ugandan agricultural production is underscored.

Agricultural strategies and responsibilities across gender in Uganda appear to be conditioned on the extent to which an activity is lucrative. While male farmers produce cash crops, female farmers specialize in subsistence crops will still providing labour for male cash crop production (FAO, 2013; Kasente et al., 2000; NAADS, 2003). Furthermore, if market prices for subsistence crops rise, making them more profitable, male farmers have been documented to take over such a crop (UPPAP, 2002). On farm decision-making is conditioned on plot owner versus manager gender vis-à-vis intra-household power. While female-managed plots attest to making their own decisions, males within the same households indicate that they take the final decision even for female-managed plots (Behrman, 2011). This evidence underscores the relevance of household composition, marital dynamics and competing domestic obligations such as child rearing that are specific to women and can affect time allocation and decision-making power.

The outcome of these decision-making processes may be conveyed in terms of productivity measures. Peterman et al. (2011) find the presence of bargaining within households in terms of decision-making across plots in Uganda, such that plots under mixed ownership were less productive than those under only sole gender management. This result conveys a different aspect of intra-household decision-making on agricultural outcomes, suggesting various levels of complexity that relate to the act of decision-making, as well as to the nature of the crops planted and their future uses.

3b. Survey

This paper sheds light on the interaction between crop portfolio diversity and gender in agricultural productivity by analysing rural agricultural households from the 2009/10 and 2010/11 waves of the Uganda National Panel Survey (UNPS)[3]. As well as capturing detailed demographic, economic and living standards information at the individual, household and business level, the UNPS contains a detailed multi-level agricultural module collecting information on tenure, inputs, assets and productive agricultural activities spanning crop, livestock and fisheries.

Crop data is collected in two visits to capture the first and second seasons, enabling an annual picture of household agricultural activities to be generated and providing a more precise account of agricultural decision-making and its outcomes at different periods of the year. At the same time, since seasonality issues may affect cropping decisions, especially in response to rainfall patterns over the year, only first season agricultural data is analysed in this paper. The first season also corresponds with the main rainy season throughout the country, allowing

[3] This dataset was implemented by the Ugandan Bureau of Statistics as part of the World Bank Integrated Surveys on Agriculture project. For more detail regarding the survey, see: http://go.worldbank.org/D3ZAKU07K0

the analysis to be run on the national sample when participation in cropping activities is highest[4], and therefore when rural households are more likely to concentrate all resources in agriculture and less likely to diversify into non-farm income activities.

In the same light, only parcels that are cultivated in both survey rounds are considered in the analysis so to not confound the analysis with selection issues regarding the decision to leave land fallow across years. This reduces the sample of parcels by about 40 per cent; however, by abstracting from the fallow decision-making process and the influence of plot/parcel rotation practices, the relationship between crop diversity, gender and output is more clearly isolated, while the validity of the set of conclusions regarding crop portfolio diversity is strengthened. The analytical sample for this paper consequently contains the 1,231 rural[5] households interviewed in both rounds, yielding a panel of 1,751 parcels cultivated at both points in time.

3c. Key variables and descriptive statistics

Gender

The UNPS offers various ways to identify gender. The broadest, most rudimentary approach would be to analyse male versus female-headed households as has taken place in numerous studies of gender and agricultural productivity in the absence of more specific data. This approach would assume that the household head is the key decision-maker for all parcels within the household and ignore the potential existence of multiple decision-makers within the household regarding production and consumption decisions.

A second approach would be to take advantage of the UNPS parcel level data on owners, managers and labourers. Respondents of the agricultural module are prompted to list up to two household members when asked who owns or holds use rights on each parcel, who manages the output harvested from each parcel, and who mainly performs the work on each parcel. These questions offer three additional ways in which to identify gender within the analysis, each providing greater insight to the agricultural decision-making process at a sub-household level, but each also accompanied by some limitation.

The concept of parcel ownership or use rights in Uganda is one that is likely to be embedded with its own gender bias. Whereas the 1998 Land Act and the 1995 Constitution attempt to equalize land rights across gender, granting spousal equality in land endowments, in practice land is disproportionately allocated according to customary law, which denies women the right to formally own land (Doss et al., 2014). Under these traditional norms, women are able to access land through male family members, enabling their involvement in agricultural production. A measure of gender according to ownership or use rights would therefore

[4] In the first season of 2009, 90 per cent of parcels cultivated any crop whereas only 87 percent reported cropping activities in the second season. For 2010, the corresponding shares were 96 versus 87 per cent of parcels. Among the set of parcels that were not fallow in the first season of 2009 or 2010, 88 reported cultivating the land in the second season.

[5] The full rural panel is nearly universally agriculturally oriented and contains 1,512 households (95.5-99.8% of which cultivated some land in 2009 and 2010) and 2,665 parcels.

significantly understate the share of women who may actually be in charge of parcel decisions, and probably more closely approximate a classification of gender according to the household head.

The possibility to identify gender according to the identity of the parcel output manager thus presents as a more attractive option since it abstracts from the issue of land tenure. A potential concern with the parcel output manager definition is that female parcels may be subject to handing over some or all of their production to a male household member or to the household head who might in turn be the main decision-maker with respect to the allocation of that output to various uses (sales, consumption, storage, gifts, fodder, etc.). However, no evidence of this possibility has been identified. Instead, Doss et al. (2014) demonstrate for a large sample of parcels in Uganda that there is a close correspondence between the individual who makes planting decisions and who is in charge of parcel output. This finding permits the assumption to be drawn that the parcel output manager is also the parcel decision-maker.

The use of family labour on household parcels also enables the differentiation of parcels by gender according to the main worker(s) on a parcel. Given that women comprise over half of Uganda's cropping labour force (O'Sullivan et al., 2014) this classification may be an accurate representation of the cropping decisions on parcels, in particular if crops are differentiated according to their labour requirements, as in the case of Qian (2004) in China. Evidence from sub-Saharan Africa indicates that gender in agricultural labour may be a more nuanced concept that varies according to the tasks required at different points of the agricultural season (Peterman et al., 2011). For example, male household members may be the main labourers when land preparation activities take place, whereas female household members may be responsible for the upkeep of a parcel during the growing seasons, engaging in weeding or fertilizing. Harvest activities may be the responsibility of both genders. Another complicating factor is whether male household members have more power in the household in terms of recruiting members to work on their parcels, whereas female household members must rely on their own, or their children's contributions. Similarly, the extent to which hired labour can be accessed by male versus female producers, demonstrated to be different according to O'Sullivan et al. (2014), will also condition the extent to which household labour is utilized and who ends up working on each parcel. Each of these possibilities exists for Uganda, rendering unclear how survey respondents end up identifying the gender of the main workers on a given parcel.

A final way in which gender in agriculture can be differentiated in the UNPS is at the crop level, since for every crop produced on a parcel, the individual who controls its harvest is identified. This is an attractive measure given its level of disaggregation, and for an analysis at the crop level would permit the gender dynamics with respect to specific crops to be identified. However, since the current study is at the parcel level, seeking to relate crop *portfolio* diversity on parcels to gender, the preferred measure of gender is that of the *parcel* output manager. Parcels are classified as female if both individuals named as output managers are women; as male if both reported individuals are male; and as mixed parcels if both male and female managers are identified (irrespective of the order in which they are named).

Of the sample of rural, non-fallow parcels, Table 1 indicates that approximately 30 per cent are female managed, 17 per cent are male managed and joint male-female management accounts for the remaining 53 per cent of parcels. A closer look at the characteristics of female parcels in 2009[6] portrays some of the issues described above regarding gender constraints. Belonging largely to female-headed households (68.3%), and to a much greater extent than on male or jointly managed plots (5.7 and 7.7%, respectively), suggests female parcels are also likely to be part of single-headed households. At 46 years old on average, managers of female parcels are also significantly older than their counterpart male or mixed parcels by about 3 to 4 years. Given the mean age of managers it is not surprising that only about one-tenth of parcel managers in households with under five years of age hold nursing responsibilities at the time of the survey, a figure that is not significantly different for managers on mixed parcels. However, childcare is nonetheless a competing activity for households with female managed parcels, who report a dependency ratio of 2.4, which is significantly higher than for households associated with male or joint parcels (1.8 and 1.5, respectively).

Following the parcel gender classification, important differences are observed in terms of parcel size and productivity. At 2.9 acres large, female parcels are on average two-thirds the size of mixed and male parcels, which respectively range from 4.3 to 4.5 acres in size. Differences in land area translate into significant differences in the total annual value of harvested production, which for female parcels was recorded as 174,397 USh, as compared to 239,772 USh for male parcels and 252,950 USh for mixed parcels. However, in per acre terms, significant differences are observed only between female (102,260 USh) and mixed parcels (137,929 USh). These differences can possibly be attributed, to some extent, to differential use of productive inputs such as chemical fertilizer, pesticides, and the use of improved seeds, each of which is significantly lower among female parcels.

Table 1. Parcel-level descriptive statistics by year and gender of parcel manager

	2009					2010				
	(1) Female	(2) Male	(3) Mixed	p[3] (1-2)	p (1-3)	(4) Female	(5) Male	(6) Mixed	p (4-5)	p (4-6)
% Parcels	30.40	17.13	52.47			28.75	14.17	57.08		
Parcel characteristics										
Area (acres)	2.90	4.51	4.28	**0.00**	**0.00**	2.91	3.50	3.79	**0.04**	**0.00**
Soil quality good (%)	0.57	0.58	0.58	0.77	0.56	0.54	0.54	0.62	0.94	**0.01**
Slope: Flat (%)	0.47	0.43	0.48	0.35	0.59	0.47	0.49	0.48	0.67	0.65
Irrigated parcel (%)	0.01	0.02	0.03	0.69	0.12	0.04	0.03	0.03	0.41	0.11
Technology and inputs (% using)										
Hired labour	0.32	0.43	0.38	**0.00**	**0.03**	0.36	0.45	0.40	**0.02**	**0.10**
Organic	0.17	0.14	0.20	0.27	0.16	0.17	0.14	0.22	0.20	**0.04**

[6] The corresponding set of descriptive statistics for female parcels in 2010 is available upon request.

fertilizer										
Chemical fertilizer	0.04	0.13	0.05	**0.00**	0.24	0.03	0.10	0.03	**0.00**	0.79
Pesticides	0.11	0.21	0.17	**0.00**	**0.01**	0.11	0.19	0.16	**0.00**	**0.03**
Improved seeds	0.08	0.19	0.13	**0.00**	**0.00**	0.05	0.15	0.11	**0.00**	**0.00**
Cultivated (%)										
Banana	0.43	0.41	0.44	0.68	0.83	0.51	0.45	0.49	0.28	0.58
Beans/peas	0.59	0.54	0.60	0.22	0.64	0.60	0.52	0.58	0.12	0.65
Maize	0.46	0.56	0.46	**0.01**	0.79	0.41	0.49	0.46	**0.04**	**0.08**
Sweet potato	0.26	0.25	0.24	0.58	0.28	0.30	0.24	0.26	**0.10**	**0.09**
Sorghum	0.13	0.05	0.14	**0.00**	0.87	0.13	0.10	0.11	0.41	0.28
Cassava	0.42	0.45	0.42	0.50	0.95	0.43	0.46	0.47	0.59	0.25
Groundnut	0.16	0.15	0.15	0.76	0.70	0.18	0.19	0.16	0.83	0.29
Coffee	0.18	0.20	0.16	0.34	0.56	0.16	0.22	0.18	**0.05**	0.27
Millet	0.08	0.07	0.11	0.44	**0.10**	0.06	0.05	0.09	0.79	**0.06**
Fruits/vegetables	0.03	0.09	0.11	**0.00**	**0.00**	0.06	0.15	0.12	**0.01**	**0.02**
Rice, wheat	0.00	0.01	0.02	**0.10**	**0.01**	0.01	0.03	0.02	**0.03**	**0.03**
Cash crops	0.03	0.10	0.06	**0.00**	**0.04**	0.02	0.06	0.05	**0.01**	**0.01**
Oilseed crops	0.02	0.01	0.03	0.32	0.47	0.01	0.02	0.03	0.80	**0.06**
Other roots	0.06	0.03	0.08	**0.09**	0.22	0.05	0.07	0.07	0.28	0.16
Annual Harvest (real USh, thousands)	174.4	239.8	252.9	**0.00**	**0.00**	85.9	93.3	124.6	0.55	**0.00**
% consumed	0.62	0.44	0.54	**0.00**	**0.00**	0.65	0.54	0.57	**0.00**	**0.00**
% sold	0.22	0.37	0.30	**0.00**	**0.00**	0.22	0.28	0.28	**0.03**	**0.01**
Gross margin/acre	146.0	190.2	210.8	**0.01**	**0.00**	60.6	51.0	90.0	0.43	**0.00**

Notes: Weighted averages reported; P-values indicate the result of the t-test of difference in means between the indicated columns; Bold denotes significance of at least 90% confidence; Excluded categories for soil quality are: fair, poor; Excluded categories for slope are: steep, hilly, gentle; Main crops cultivated are identified as in Peterman et al. (2010).

Also differentiated across parcels managed by different genders is the allocation of harvest to consumption versus sales. As expected, female parcels disproportionately allocate production to household consumption (62 per cent) and market only 22 per cent. The corresponding shares for male and mixed parcels range from 44-54 per cent for consumption and 30-37 per cent for sales. These differences in the allocation of harvest are potentially linked to the production portfolios of the different parcel types. Female parcels are significantly less likely to produce cash crops and high value crops such as fruits and vegetables, yet are no more likely than their male and mixed gender parcel counterparts to produce traditional crops such as banana, sweet potato, cassava and beans/peas. These trends illustrate the presence of gendered crop choice, whereby women are disproportionately involved in staple crop production and men typically involved in market-oriented production.

Crop diversity

The measurement of crop portfolio diversity has often been undertaken at the crop level from a genetic resource perspective in terms of the range of varieties produced (see Smale, 2006 for a compendium of studies). At the parcel or household level, diversity has been most easily captured in terms of the number of crops produced (Di Falco et al., 2010) or by focusing on the portfolio composition of a subset of most-produced crops (Kurukularsuriya and Mendelsohn 2008). The limitation of measuring crop diversity at the parcel level in terms of the number of crops produced is that it masks across-parcel heterogeneity in the distribution of parcel land over the components of the crop portfolio. At the same time, limiting a crop diversity analysis to a subset of main crops may equivalently conceal production diversity that could represent an important contribution to household food security via dietary diversity, particularly if small-scale production of additional crops is utilized to supplement the consumption of staple goods.

A set of indicators drawn from the ecological literature are able to overcome these limitations, being constructed based on the number of crops cultivated on a given land area and, in three of the four indices, the way in which land is allocated to each crop[7]. Table 2 provides the equations for each index while Table 4 presents descriptive statistics of the indices. Note that J denotes the total number of crops produced; α_{ji} represents the area of parcel i planted with crop j; and α_i the total area of parcel i. In all cases a greater value of D_{iht} represents a higher level of inter-crop diversity.

Table 2. Construction of crop diversity indices

Index	Diversity formula (D_{iht})		Concept	
Margalef	$(J-1)/\ln\alpha_i$	$0 \le D_{iht}$	Richness	(1)
Shannon	$-\sum \alpha_{ji}/\alpha_i * \ln\alpha_{ji}/\alpha_i$	$0 \le D_{iht}$	Evenness	(2)
Simpson	$1-\sum(\alpha_{ji}/\alpha_i)^2$	$0 \le D_{iht} \le 1$	Relative abundance	(3)
Berger-Parker	$1/\max(\alpha_{ji}/\alpha_i)$	$1 \le D_{iht}$	Inverse dominance (proportional abundance)	(4)

Source: Smale (2006).

The Margalef index, which is an approximate equivalent to calculating per land-unit the number of crops produced, is increasing in the richness of the crop portfolio. The benefit of the Margalef index over the count index is that land units are scaled into log terms, thus generating a cross-parcel comparable measure of portfolio richness.

[7] Smale (2006) describes the use of these indices in measuring crop biodiversity in terms of intra- and inter- crop varieties; the former has been the most prevalent application of the indices to crop diversity.

Portfolio evenness indicates the extent to which the parcel surface area is evenly (or disproportionately) distributed over the number of crops produced. Captured by the Shannon index, the area share dedicated to each crop is multiplied by the log area share and summed over the total number of crops produced on the parcel. When only one crop is cultivated, no diversity is observed and $D_{iht} = 0$. The greater the number of crops, the higher the value of D_{iht}, but the rate at which it increases is slower when land is less evenly distributed.

Inverse dominance (or proportional abundance) in terms of crop diversity is similar to evenness, reflecting the extent to which a single crop is disproportionately cultivated on a parcel, by measure of the maximum area share dedicated to a single crop. If the Berger-Parker index takes a value of 1, a parcel is specialized in a single crop. Under a perfectly even land distribution, the Berger-Parker index equals the number of crops, J, the maximum value it can attain under any given number of crops. Under any degree of un-evenness, the index will result in $D_{iht} \leq J$.

The Simpson index, also known in industrial economics as the Herfindahl-Hirschmann index, is a measure of relative abundance. As with the previous indices, greater values are associated with greater crop diversity. In this case, diversity is measured in terms of the squared area share of each crop, summed over all crops produced on a parcel. Although achieving greater diversity requires the production of a more abundant crop portfolio, the rate at which the index increases is decreasing in the number of crops cultivated. Finally, as with the Shannon and Berger-Parker indices, the Simpson is maximized when land is evenly distributed over all crops.

The behaviour of the spatial crop diversity indices is presented under various examples in Table 3. The top panel presents the value of each index for an increasing number of crops when land is equally distributed across crops. This panel demonstrates how each index is increasing in J, and how the value of each index is maximized under an even land distribution. Inequality in the land distribution over crops is introduced in the bottom panel. A different maximum area share is presented for each row; comparison of each respective index for a given number of crops demonstrates how un-evenness lowers the resulting value of D_{iht}.

As indicated by the test statistics in Table 4 significant differences in the diversity indices across parcel manager gender are observed. Whereas differences in mean levels of crop diversity emerge only for the count indices, the second moment of each diversity distribution – the variance – is significantly different for nearly all the count and spatial indices. This result indicates that even if crop diversity on female versus male or mixed gender manager parcels might be centred on the same average level, the shape of the diversity distribution across parcel types is not equal. Parcels, and the producers taking decisions on those parcels, are subject to considerable heterogeneity in the crop portfolio and corresponding land distribution.

Table 3. Examples of crop diversity indices under even and uneven land distribution

	Regime: Even Land Distribution				
J (# crops)	Maximum area share of 1 crop	Margalef	Berger-Parker	Shannon	Simpson
1	1.00	0	1	0.00	0.00
2	0.50	1	2	0.69	0.50
3	0.33	2	3	1.10	0.67
4	0.25	3	4	1.39	0.75
5	0.20	4	5	1.61	0.80

	Regime: Uneven Land Distribution				
J (# crops)	Maximum area share of 1 crop	Margalef	Berger-Parker	Shannon	Simpson
1	1.00	0	1.00	0.00	0.00
2	0.75	1	1.33	0.56	0.38
3	0.60	2	1.67	0.95	0.56
4	0.49	3	2.04	0.79	0.52
5	0.50	4	2.00	0.84	0.53

Note: Total land area assumed fixed at 10 units. Under the uneven land distribution regime, the Shannon and Simpson indices are presented as distributing the total land in the following manner: (1) 3 crops: 60%, 20%, 20%; (2) 4 crops: 49%, 49%, 1%, 1%; (3) 5 crops: 50%, 47%, 1%, 1%, 1%.

If the same statistics are computed for different subsets of the sample that characterise the major production profiles across Uganda[8], further differences emerge[9]. For these subsamples, the spatial indices reveal female-managed land is generally less diverse, if and when significant differences with male or mixed-gender land are observed. In areas characterised by banana-coffee production as well as the West Nile area where mixed cropping, cash crops and tobacco production are most prevalent, female plots underperform male and/or mixed plots in crop diversity when measured by the Shannon and Berger-Parker indices.

Table 4. Crop diversity descriptive statistics (2009)

	Weighted average			Diff means		Diff variance	
	Female	Male	Mixed	p (1-2)	p (1-3)	p (1-2)	p (1-3)
N crops cultivated	2.95	3.43	3.31	**0.00**	**0.01**	**0.00**	**0.00**
Traditional	2.72	2.84	2.82	0.37	0.30	**0.08**	**0.06**
Improved	0.23	0.59	0.49	**0.00**	**0.00**	**0.00**	**0.00**
N crops cultivated / acre	2.11	1.92	2.11	0.40	0.99	0.12	**0.00**
Traditional	1.97	1.68	1.89	0.16	0.66	0.12	**0.00**

[8] Mwebaze (2006) describes seven production zones that characterise Uganda according to rainfall, soil type, elevation/vegetation; livestock potential; and the main crops produced. These zones include: (1) banana-coffee ; (2) banana-millet-cotton ; (3) Montane ; (4) Teso ; (5) Northern; (6) West Nile; and (7) pastoral. Appendix Table A1 describes the characteristics of each zone.

[9] Results not reported.

Improved	0.14	0.24	0.22	0.11	**0.09**	1.00	**0.04**
Margalef	0.40	0.40	0.40	0.92	0.73	**0.09**	0.95
Shannon	2.68	2.97	2.95	0.22	0.15	**0.00**	**0.00**
Berger-Parker	2.66	2.51	3.35	0.60	0.20	**0.00**	**0.00**
Simpson	0.63	0.64	0.62	0.87	0.50	0.93	0.70

Note: Bold denotes significance of at least 90% confidence.

Among producers of the banana-millet-cotton system, female land is also represented by lower diversity when measured by the Margalef, Shannon and Simpson indices. A similar outcome is observed for female producers in the "Montane" area, which is characterised by higher elevation, generous rainfall and the cultivation of both higher-value and subsistence crops. The outcomes of these additional comparisons demonstrate that crop diversity in Uganda is not only differentiated across production systems, as suggested by the calculations on the whole rural panel sample in Table 3, but also within systems. This differentiation indicates that expectations regarding the behaviour of the diversity indices in a multivariate framework are ambiguous and conditional on production strategy heterogeneity, parcel manager characteristics and unobservable factors such as capabilities. The use of these indices will serve to shed light on whether they are consistent with findings based on elementary count indices.

Food security

The 1996 and 2008 World Food Summits declared food security to represent the case when "all people at all times have sufficient and regular access to safe and nutritious food". This concept is illustrated by satisfying what are known as the four pillars of food security: (1) availability; (2) access; (3) utilization; and (4) stability (Pieters et al., 2012). The first two pillars are indicative of the ability of households to produce and/or purchase food for consumption. The third and fourth pillars represent the extent to which consumption is based on a nutritious and complete diet, and unaffected by seasonality. This paper will measure food security using parcel level indicators in such a way that allows them to be related to crop diversity and the role of gender in agricultural decision-making.

Agricultural output often serves as an indicator of food security among rural households, representing the capacity of households to produce for own consumption, or to market consumption, thus generating income for the purchase of food and other items. In attempting to capture the role of gender in crop diversity and food security, the parcel level contribution to food security is of interest. Output is thus measured at the parcel level in terms of the value of agricultural production, based on self-reported valuations and market prices derived from the reported data on crop sales from the full survey. In order to avoid typical endogeneity issues related to the estimation of an agricultural production function, the value of parcel production is net of variable input costs (seeds, fertilizer, pesticides, hired labour, family labour[10]), thus representing parcel productivity or profitability. Subsistence producers are captured by this measure by valuing consumption from home production using the aforementioned set of market prices. This gross margins estimate is analysed in log per-acre terms.

As in the case of overall harvest, significant differences are observed across gender for output in terms of gross margins per acre. Of the sample of rural, non-fallow parcels, Table 1 indicates that approximately 30 per cent are female managed, 17 per cent are male managed and joint male-female management accounts for the remaining 53 per cent of parcels. Female managed parcels come from predominantly female-headed households and are characterized by managers who are older than on male or mixed plots, about half of whom are married and a tenth of who are nursing, highlighting important competing household responsibilities.

Following the parcel gender classification, important differences are observed in terms of parcel size and productivity. At 2.9 acres large, female parcels are on average two-thirds the size of mixed and male parcels, which respectively range from 4.3 to 4.5 acres in size. Differences in land area translate into significant differences in the total annual value of harvested production, which for female parcels was recorded as 174,397 USh, as compared to 239,772 USh for male parcels and 252,950 USh for mixed parcels. However, in per acre terms, significant differences are observed only between female (102,260 USh) and mixed parcels (137,929 USh). These differences can possibly be attributed, to some extent, to differential use of productive inputs such as chemical fertilizer, pesticides, and the use of improved seeds, each of which is significantly lower among female parcels.

Table 1 demonstrates that female parcels under-produce male parcels and that both female-only and male-only parcels are out-produced by mixed-gender parcels. Given that the gross margin estimates are in per-acre terms, and that they account for variable input costs, the differences in output must be attributable to factors such as the crop portfolio components, producer skill level, and production conditions such as land quality. The fixed effects approach that will be implemented in the empirical analysis will remove observed and unobserved time invariant factors, such as land characteristics and producer skill level[11], allowing portfolio effects to be isolated.

4. Empirical approach

The structural equation of interest estimates agricultural productivity (y^*_{iht}) of parcel i from household h at time t as a function of inputs (I_{iht}), the level of crop diversity (D_{iht}), gender of

[10] Returns to family labour are calculated based on the number of household member person-days worked on the parcel.

[11] The short time lapse between the two rounds of the panel analysed in this paper allow the assumption to be drawn that unobserved skill level is fixed over time.

the parcel manager (F_{iht}; Mix_{iht})[12], a set of exogenous parcel and household level covariates (X_{iht}), a parcel-specific fixed effect (u_i) and a stochastic error term (ε_{iht}):

$$y^*_{iht} = a_0 I_{iht} + a_1 D_{iht} + a_2 F_{iht} + a_3(D_{iht} * F_{iht}) + a_4 Mix_{iht} + a_5(D_{iht} * Mix_{iht}) + bX_{iht} + u_i + \varepsilon_{iht} \,. \qquad (5)$$

Given that the quantity of inputs accessed and used is based both on unobservable factors that would be correlated with the error term (such as farmer knowledge and skill level), and the quasi-simultaneous rather than sequential nature of the input-output relationship since producers may adjust inputs over the course of the agricultural season in response to factors that will affect output levels, the inclusion of inputs presents an endogeneity problem. In order to avoid this estimation issue, the returns to production are instead estimated in a gross margins function that nets the value of agricultural production of all variable input costs, I_{iht}. In addition to eliminating the input endogeneity issue, this approach is most useful for the parcel-level analysis of this paper in which production and input quantities are not readily converted into a common unit other than monetary values, and in which crop production is aggregated over the parcel area. The reporting of harvest in non-standard units in the UNPS makes the aggregation of output in monetary units more feasible, especially since different units are likely to be utilized for the output from different crops. The equation of interest is therefore:

$$y_{iht} = (y^*_{iht} - I_{iht}) = \alpha_1 D_{iht} + \alpha_2 F_{iht} + \alpha_3(D_{iht} * F_{iht}) + \alpha_4 Mix_{iht} + \alpha_5(D_{iht} * Mix_{iht}) + \beta X_{iht} + u_i + \varepsilon_{iht} \qquad (6)$$

in which y_{iht} represents the parcel level gross margin, expressed in per-acre terms to account for differences in the scale of production across parcels of different sizes. Outliers in y_{iht} are addressed by applying a natural log transformation.

Di Falco et al. (2010) point out that crop diversity may be endogenous in the estimation of an agricultural production function since unobserved factors associated with diversity may also determine output, resulting in a correlation between D_{iht} and ε_{iht} and introducing bias to estimates of α_1, α_3 and α_5. If this is the case in equation (6), the diversity variable and its interaction with gender must be instrumented in order to eliminate from the estimation the effect of any unobservable factors that would result in biased parameter estimates. The adaptation literature suggests a series of instruments for D_{iht} that would be uncorrelated with agricultural output. These include access to agricultural extension services by the parcel manager, capturing unobserved skill and knowledge of production practices (Di Falco et al., 2011), proxied by parcel manager educational attainment; and access to a seed vendor in the community, capturing the extent to which crop diversification is possible or relies solely on farmer self-production of seeds (Asfaw et al., 2013)[13].

[12] Male parcels are excluded as the base category.

[13] An additional instrument proposed by the literature that is not utilized in this paper is the degree of land tenure security, influencing the riskiness of the portfolio decision (Di Falco et al., 2010; Maddison 2007; Nkonya et al., 2004).

In addition to those instruments, if the selection of the crop portfolio is conditioned according to the risk profile of the producer (Below et al., 2010; Dercon, 1996; Dercon and Christiaensen, 2011; Rosenzweig and Binswanger, 1993), then the exposure of a parcel to idiosyncratic shocks in earlier periods may also serve as instruments for crop diversity. The shocks module of the household-level questionnaire of the UNPS captures agricultural and non-agricultural shocks experienced by the household for a period of up to five years prior to the data collection. Whether a household suffered an economic shock, such as one related to agricultural prices, or a natural disaster/weather shock, as in drought or flooding, in the year prior to the survey are used as shock instruments. The validity of these variables as instruments is based on evidence that a household's level of income diversification is a function of its exposure to income risk (Dercon et al., 1996), that it may condition its crop choice decisions on exposure to weather shocks (Kurukulasuriya and Mendelsohn 2007), and that liquidity constraints may present constraints to crop diversification (Gebremedhin et al., 2006).

Similarly, data on specific commodity market prices[14] allows the price effect of key crops to be used as instruments for diversity. The market price for coffee, an important cash crop, and groundnuts, a production staple, in the previous year and quarterly lagged rice and maize prices, important marketable food crops, calculated at the district level, serve as additional instruments. These variables identify crop diversity through the same mechanism as price shocks using a continuous measure. Their exogeneity is based on their estimation at the district, rather than individual level, as well as their lagged nature; crop prices in periods $(t-n)$ may affect whether a crop is produced on a given parcel at time t, as indicated by the gendered crop literature; but should not have a direct bearing on the value of output from that crop at t. Appendix Table A2 summarizes the specific combination of instruments used for each of the diversity indices.

Rather than taking a two-stage least squares (2SLS) estimation to deal with this endogeneity problem, a control function approach is adopted as suggested by Wooldridge (2010). By this approach, the error term in (6), ε_{iht}, can be decomposed into two components: one that is correlated with D_{iht}, represented by $v_{k,iht}$, and the remainder, ϵ_{iht}, which must be uncorrelated with D_{iht}. The $v_{k,iht}$ represent the error term from the reduced form estimation of D_{iht}:

$$D_{iht} = \pi_1 Z_{1,iht} + \gamma_1 X_{iht} + v_{1,iht} \tag{7a}$$

$$(D_{iht} * F_{iht}) = \pi_2 Z_{2,iht} + \gamma_2 X_{iht} + v_{2,iht} \tag{7b}$$

$$(D_{iht} * Mix_{iht}) = \pi_3 Z_{3,iht} + \gamma_3 X_{iht} + v_{3,iht} \tag{7c}$$

where $Z_{k,iht}$ $(k \in \{1,2,3\})$ is a matrix composed of the vectors of aforementioned instruments that explain D_{iht} (and its interactions), that are uncorrelated with $v_{k,iht}$, and that can justifiably be excluded from the y_{iht} function. These are the same identifying assumptions

[14] Obtained from the Agricultural Market Information System (http://www.infotradeuganda.com/index.php/products/agmis.html).

governing a 2SLS model. By including the $v_{k,iht}$ as additional explanatory variables in the estimation of y_{iht} as in equation (7) below[15],

$$y_{iht} = \alpha_1 D_{iht} + \alpha_2 F_{iht} + \alpha_3 Mix_{iht} + \alpha_4 (D_{iht} * F_{iht}) + \alpha_5 (D_{iht} * Mix_{iht}) + \beta X_{iht} + \sum \delta_k v_{k,iht} + u_i + \epsilon_{iht} \, , \tag{7}$$

the error term is purged of the factors that previously endogenized D_{iht}. Since $v_{k,iht}$ cannot be directly observed, its predicted value is used instead by estimating the residuals from the estimation of D_{iht}:

$$\hat{v}_{1,iht} = D_{iht} - \widehat{\pi_1} Z_{1,iht} - \widehat{\gamma_1} X_{iht} \tag{8}$$

$$\hat{v}_{2,iht} = (D_{iht} * F_{iht}) - \widehat{\pi_2} Z_{2,iht} - \widehat{\gamma_2} X_{iht} \tag{9}$$

$$\hat{v}_{3,iht} = (D_{iht} * Mix_{iht}) - \widehat{\pi_3} Z_{1,iht} - \widehat{\gamma_3} X_{iht}. \tag{10}$$

Since the inclusion of these terms violates the homoscedasticity assumption of ϵ_{iht} standard errors are bootstrapped in order to account for the estimated nature of the residuals[16].

In addition to resolving the endogeneity problem, the predicted residual terms provide an augmented regression test for the exogeneity of D_{iht} (Davidson and MacKinnon 1993). Rejecting the null hypothesis of exogeneity confirms the endogeneity of the diversity variable and substantiates the control function approach. Estimates obtained from (7) are more efficient- and can be more precise[17]- than estimates from a standard instrumental variables or 2SLS regression (Wooldridge, 2010).

In order for the control function approach to yield unbiased and consistent estimates, in addition to satisfying a set of assumptions described by Wooldridge (2010), the performance of the set of instrumental variables $Z_{k,iht}$ must be evaluated. Their quality is assessed in the same manner as in an IV estimation: through the first stage reduced form F statistic to gauge the strength and relevance of the instruments and the Sargan-Hansen J statistic for testing the over-identification condition. The F statistics and p-values from the Sargan-Hansen test are reported with the main regression results in Table 6. In most cases, the F statistic is very close to or greater than 10, demonstrating the strength of the instruments across specifications. Similarly, in nearly all cases, the p-values from the Sargan-Hansen over-identification test fail to reject that the restriction is satisfied, supporting the validity of the instruments across specifications. In cases where these two conditions are not met, results should be interpreted with caution.

The exogeneity of the instruments is instead guided by intuition. Lagged quarterly and annual prices should not directly affect the valuation of agricultural output in subsequent periods; similarly, while shocks experienced with a lag of one year and at the household level may

[15] The interaction of D_{iht} and $Male_{iht}$ does not appear in this estimation, since male-managed parcels serve as the reference category.
[16] Bootstrapping of the standard errors takes into consideration the panel structure of the data.
[17] Particularly in the case of a nonlinear endogenous variable.

affect agricultural output contemporaneously, the mechanism is through the selected adaptation strategy, which in the analysis of this paper is the level of crop diversity. Finally, while parcel manager characteristics such as educational attainment have been demonstrated to affect gross margins since education represents knowledge acquisition that can improve problem-solving (Shultz 1975), which in the case of agriculture could lead to improved productivity, we argue that once input decisions and technology use have been accounted for, the relation between education and productivity is channelled through agricultural decision-making as represented by crop diversity. Placebo tests of each instrument's exogeneity are implemented by including the instrument as an additional explanatory variable in the specification, supporting the assertion of their exogeneity[18].

The residual and diversity estimates obtained from equations (7) through (7c) are conditional on the set of time-varying exogenous covariates, X_{iht}[19]. Included in that vector are parcel level variables that can explain the level of productivity such as an indicator of whether the parcel is irrigated[20]; whether improved seeds are used on the parcel; and the slope of the parcel. Household level variables captured by X_{iht} include the proximity of the dwelling to the nearest major road; proximity to the nearest major market; an indicator for a female household head; the age of the household head; the dependency ratio of the household; a rural non-agricultural wealth index[21]; and a measure of exogenous household income (the share of total income coming from private transfers). Time-invariant covariates are not captured in the estimation since they are accounted for in the fixed effects estimation that is implemented[22].

One additional concern regarding whether parameter estimates from equation (7) will be consistent and unbiased is with respect to the exogeneity of gender. Identification of equation (7) relies in part on the variability over time of D_{iht} and G_{iht}. The descriptive statistics presented in section 3c demonstrate this is the case for both variables. However, variability in parcel manager gender over time could signify a violation of the exogeneity of gender, especially if that variability is due to unobserved factors that are associated not only with the crop portfolio composition, but also with the value of agricultural output.

Crop prices could be one factor endogenizing gender. The evidence on gendered crops (Doss 2002; Hoddinot and Haddad 1995; Weekes-Vagliani, 1990; World Bank 2008) indicates male producers are more likely to specialize in higher-value crops; hence, if the market price of a lower-value "female" crop rises, production portfolios may change, as would potentially the organization of management roles on specific parcels held by a household. Another likely scenario influencing changes in parcel manager roles could be changing household structure,

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[18] Results not reported.
[19] Descriptive statistics of these covariates are reported in Appendix Table A3
[20] It should be noted that less than three (four) per cent of parcels in 2009 (2010) report using irrigation.
[21] The wealth index is constructed by principal components factor analysis and captures ownership and value of non-agricultural assets.
[22] Also excluded from X_{iht} is an indicator for whether intercropping takes place on a parcel. Though the use of intercropping can provide productivity gains for certain combinations of crops, the diversity indices are indirectly capturing the effect of this practice. The strong and significant correlation between intercropping and each of the diversity indicators ($p < .01$) supports this assertion.

in which adult women and men enter or leave the household due to marriage, divorce, migration or death, influencing the available household labour force. While migration has been demonstrated to influence the level of crop diversity through changes in household structure and labour availability (Van Dusen 2006), it may also affect the gender of the agricultural decision-maker. If the individuals entering or leaving were male, the hierarchy of priority over land, which under customary law gives preference to male household members, would imply a rotation in the management roles on the parcel. The transition matrices in Table 5a and Table 5b illustrate these potential mechanisms, reporting the probability of a change in parcel manager gender across rounds for households that did and did not experience shocks. The diagonal elements are the share of persistence in manager gender while off-diagonal elements indicate a transition in parcel manager gender.

Table 5a. Manager gender transition matrices: household structure shocks

No shock experienced

		2010		
		Female	Male	Mixed
2009	Female	64.1	5.8	30.1
	Male	10.6	45.1	44.3
	Mixed	10.7	9.8	79.5

Shock experienced

		2010		
		Female	Male	Mixed
2009	Female	81.8	0.0	18.2
	Male	0.0	0.0	100.0
	Mixed	9.1	4.6	86.4

Table 5b. Manager gender transition matrices: economic shocks

No shock experienced

		2010		
		Female	Male	Mixed
2009	Female	65.1	4.4	30.6
	Male	9.1	44.1	46.8
	Mixed	9.8	9.3	81.0

Shock experienced

		2010		
		Female	Male	Mixed
2009	Female	83.3	8.3	8.3
	Male	33.3	33.3	33.3
	Mixed	11.1	33.3	55.6

The transition matrices reveal that both types of shocks are correlated with a greater probability of change in the parcel manager gender for parcels originally under male or mixed management. In the case of shocks to household structure, the matrices point out that male parcels always transition to mixed-gender management, and that in the context of such shocks, parcel management under female and mixed management is highly persistent at over 80 per cent. In the case of economic shocks, persistence in female parcels is also high whereas considerable variability in parcel manager gender is observed for parcels originally under male or mixed management. Under economic shocks, male parcels become female parcels with 33 per cent probability. The same probability is observed for the male-to-mixed and mixed-to-male transitions.

Even in the absence of shocks, female and male parcels exhibit relatively high degrees of transition at 30 to 47 per cent. This outcome could be linked to crop rotation practices that lead the parcel manager gender to change depending on the crop portfolio being cultivated. Another explanation could be related to non-shock-related shifts in household labour supply that lead female parcels to be managed by both genders in consecutive years. Finally, shocks that are neither economic nor related to household structure could explain the transitions observed in the absence of economic and household structure shocks.

The endogeneity of gender raises the need for additional instrumental variables, increasing the number of parameters to be estimated and presenting the challenge of finding sufficient instruments to jointly identify crop diversity and gender[23]. In order to constrain the number of parameters to be estimated while still satisfying the identification conditions, the specification is adapted by limiting the gender categorization to a dichotomous classification of female-only managed parcels versus the joint categorization of male and mixed parcels. This reduces the estimation to the following set of equations:

$$y_{iht} = \alpha_1 D_{iht} + \alpha_2 F_{iht} + \alpha_3 (D_{iht} * F_{iht}) + \beta X_{iht} + \sum \delta_k v_{k,iht} + u_i + \epsilon_{iht} \quad (11)$$

$$D_{iht} = \pi_1 Z_{1,iht} + \gamma_1 X_{iht} + v_{1,iht} \quad (11a)$$

$$F_{iht} = \pi_2 Z_{2,iht} + \gamma_2 X_{iht} + v_{2,iht} \quad (11b)$$

$$(D_{iht} * F_{iht}) = \pi_3 Z_{3,iht} + \gamma_3 X_{iht} + v_{3,iht} \quad (11c)$$

constraining the number of parameters estimated, and limiting the minimum number of instruments per estimation. With this linear estimation approach $\alpha_1 + \alpha_3$ can be interpreted as the marginal effect of a one-unit change in crop diversity on female-managed parcels, relative to parcels where management is only in the hands of men, or jointly held by both genders[24]. Given the scale of the indices, results are also reported in terms of a one per cent change in crop diversity.

5. Findings

5a. Overall results

Table 6 reports the main results from the estimation of equation (11) on the full sample of rural, non-fallow parcels[25]. Panel A reports parameter estimates while panel B reports the marginal effect of a one per cent increase in crop diversity for female parcels. Each column

[23] With five endogenous terms in (7), a minimum of five instruments per equation are needed- six in order to test for over-identification- thus representing a need for approximately 20-26 instruments given the six diversity indices of interest described in section 3c. One way to circumvent the estimation of additional parameters would be to run separate estimations for each gender category obtaining an estimate of the effect of crop diversity on agricultural productivity for female, male and mixed-managed parcels. This would involve estimating the following set of equations: $D_{iht,g} = \pi_g Z_{iht,g} + \gamma_g X_{iht,g} + v_{iht,g}$ and $Y_{iht,g} = \alpha_g D_{iht,g} + \beta_g X_{iht,g} + \sum \delta_g \hat{v}_{g,iht} + \varepsilon_{iht,g}$, where $g \in \{1,2,3\}$ indexes the gender of the parcel manager as female (1), male (2) or mixed (3). However, with such an approach, it is not possible to test for differences in diversity across gender since the interaction between gender and diversity would no longer be estimated.

[24] The effect of diversity on parcels with male-only/mixed-gender management is captured by α_1.

[25] The full set of results is provided in Appendix Table A4.

represents a separate estimation, differentiated by the choice of diversity index. The parameter estimates indicate that increasing diversity on male[26]-managed parcels is associated with greater productivity, when diversity is measured by crops per acre, the number of traditional crops per acre and the Shannon index. Measuring crop diversity by the Margalef or Simpson indices yields a negative association between greater diversity and agricultural productivity on male-managed parcels.

Table 6. Diversity and gender on log gross margins per acre, all rural non-fallow parcels.

	(1) Crops/acre	(2) Traditional crops/acre	(3) Shannon	(4) Berger-Parker	(5) Margalef	(6) Simpson
A. Parameter Estimates						
Diversity	4.92	3.26	5.68	0.00	-29.84	-50.82
	(0.00)	(0.00)	(0.00)	(0.99)	(0.00)	(0.00)
Female manager	54.59	33.30	-35.88	91.74	18.24	-7.52
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.52)
Diversity* Female	-24.81	-13.89	15.10	-27.62	-32.56	-2.46
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.86)
B. Marginal effects						
1% change on gross margins	-18.0%	-10.1%	23.1%	-24.1%	-46.4%	-41.3%
Confidence intervals	[-21.6, -14.3]	[-13.4, -6.7]	[17.8, 28.6]	[-27.0, -21.2]	[-53.7, -38.0]	[-49.6, -31.6]
‘000 USh equiv.	-15.8	-8.9	20.3	-21.2	-40.7	-36.2
First stage F						
Diversity	4.88	4.72	15.68	6.00	12.16	13.78
Interaction	8.35	9.72	13.03	9.63	10.56	7.76
Hansen J (p)	0.10	0.00	0.97	0.56	0.14	0.79
N	3266	3257	3266	2925	3242	3252

Notes: p-values in parentheses below parameter estimates. First stage F statistic for gender variable equals 11.36 in all specifications.

In all cases, the marginal effect of increasing crop diversity on female parcels is strongly significant at more than 99 per cent confidence. With the exception of the Shannon index, the effects are negative, suggesting that greater crop diversity on female parcels is associated with lower returns in terms of agricultural productivity. The magnitude of these negative effects is substantial, amounting to a 10 to 46 per cent reduction in per acre gross margins when crop diversity is increased by one per cent. These effects are equivalent to an annual reduction in per acre gross margins on female managed parcels of 8,900 USh to 40,700 USh[27]. The food security implications of these effects can be interpreted in terms of the share in the parcel

[26] In this section, male-managed parcels refer to male and mixed management, both of which are excluded as the alternate to sole-female management.
[27] The USh – USD exchange rate at the end-2009 period was 1899 USh.

harvest allocated to consumption that these changes in gross margins represent. With the mean 2009 harvest per acre consumed by the household from female parcels estimated at 34,000 USh, the effect of increasing crop diversity on those parcels represents approximately 26.2 to 120 per cent of the consumption value, depending on the diversity indicator. This finding suggests some mechanisms or channels mediate the diversification-productivity relationship for female producers. While a superficial interpretation could conclude that crop diversity lowers productivity on female parcels, it is more likely that in light of the multiple responsibilities faced by female producers, crop specialization is a more viable strategy for improving productivity over time.

The positive effect for the Shannon index corresponds with an increase in per acre gross margins by 20,300 USh on female managed parcels when diversity rises by one per cent. In terms of food security, this effect stands at 60 per cent of the value of output allocated to household food consumption. The opposite effect reflects the different nature of the construction of this index relative to the other entropy and count indices of diversity, but also the sensitivity of results to the choice of diversity index.

5b. Locational effects

The overall results by gender mask a degree of heterogeneity that is inherent in a country with marked climatic and topographic differences across regions. Whereas Uganda has been divided broadly into seven agro-ecological zones that are linked to the country's main production profiles[28], or more narrowly into 38 livelihood zones (Browne and Glaeser 2010), sample size considerations limit the agro-ecological zone analysis to two major sub-divisions: (1) tropical-warm areas and (2) tropical-cool areas[29].

Table 7. Descriptive statistics, by agro-ecological zone (2009)

	Tropical-warm (51%)	**Tropical-cool** (49%)	**T-test p**
Parcel characteristics			
Parcel size (acres)	4.90	2.93	**0.00**
Slope (%)	3.92	15.14	**0.00**
Elevation (m)	1099	1526	**0.00**
Mean annual temperature 1960-1990 (°C)	23	20	**0.00**
Technology and inputs (% using)			
Hired labour	0.42	0.33	**0.00**
Organic fertilizer	0.08	0.28	**0.00**
Chemical fertilizer	0.07	0.06	0.39
Pesticides	0.19	0.13	**0.00**
Used improved seeds	0.16	0.10	**0.00**

[28] See footnote 8.
[29] The UNPS data contains an agro-ecological zone classification for each household according to its spatial coordinates and based on the elevation and climate of the location of households. Four areas are identified: (1) tropical, cool & sub-humid; (2) tropical, cool & humid; (3) tropical, warm & sub-humid; and (4) tropical, warm & sub-humid. The first two and last two categories were respectively aggregated in order to obtain a workable classification for this analysis. See: http://harvestchoice.org/topics/agroecological-domains.

Cultivated (%)			
Banana	0.25	0.62	**0.00**
Beans/peas	0.53	0.65	**0.00**
Maize	0.57	0.39	**0.00**
Sweet potato	0.29	0.20	**0.00**
Sorghum	0.15	0.08	**0.00**
Cassava	0.59	0.26	**0.00**
Groundnut	0.21	0.10	**0.00**
Coffee	0.13	0.22	**0.00**
Millet	0.15	0.04	**0.00**
Fruits/vegetables	0.10	0.07	0.21
Other grains (rice, wheat)	0.03	0.00	**0.00**
Cash crops	0.08	0.04	**0.00**
Oilseed crops	0.04	0.00	**0.00**
Other roots/tubers	0.03	0.10	**0.00**
Crop diversity			
Number of crops cultivated	3.51	2.96	**0.00**
Traditional crops	2.95	2.65	**0.00**
Improved variety	0.55	0.31	**0.00**
Margalef	0.41	0.39	0.44
Shannon	3.40	2.36	**0.00**
Berger-Parker	3.16	2.86	0.49
Simpson	0.62	0.63	0.46
Output (USh)			
Annual value of harvest	232,138	225,220	0.58
Harvest/acre	97,899	151,613	**0.00**
Harvest/acre, gross margins	80,949	129,767	**0.00**
Seed purchases/acre	3,720	9,901	**0.02**
Organic fertilizer purchases/acre	246	195	0.74
Chemical fertilizer purchases/acre	760	903	0.69
Pesticide purchases/acre	609	1,814	**0.00**
Hired labour wages paid/acre	8,275	6,183	**0.08**

Note: Bold denotes significance of at least 90% confidence.

While providing a parsimonious classification of Uganda's agro-ecological zones, this aggregation is nonetheless useful for highlighting key differences across production systems across the country. No important differences are observed in the gender distribution of parcels across tropical-warm and tropical-cool areas; however, parcel characteristics, crop portfolios, production practices and outcomes are significantly different across zones. Table 7 presents these differences, indicating that tropical-warm areas are characterised by larger parcels, situated on flatter terrain and at lower altitudes. Crop portfolios are dominated by maize, beans/peas, cassava, sweet potato and groundnuts, while in tropical-cool areas production is largely concentrated in banana, beans/peas, maize, cassava and coffee. Agriculture in warm zones is more labour intensive, as indicated by the share of parcels using hired labour and the per-acre hired labour expenditure, while in cool zones, the use of organic fertilizer and the per-acre expenditure on seeds and pesticides are disproportionately higher. The result of these input use differences translates into greater productivity in tropical-cool areas, which report significantly higher harvest per acre and gross margin per acre.

Table 8. Diversity and gender on log gross margins per acre, by agro-ecological zone

	(1) Crops/acre	(2) Traditional crops/acre	(3) Shannon	(4) Berger-Parker	(5) Margalef	(6) Simpson
		I.	**TROPICAL WARM AREAS**			
A. Parameter Estimates						
Diversity	-8.22	-6.16	3.13	-1.48	-42.19	-42.08
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Female manager	-19.26	-4.28	-10.70	64.96	0.43	5.31
	(0.00)	(0.27)	(0.01)	(0.00)	(0.90)	(0.45)
Diversity* Female	18.00	11.42	8.01	-13.04	19.54	-15.49
	(0.00)	(0.00)	(0.00)	(0.00)	(0.02)	(0.15)
B. Marginal effects						
1% change on gross margins	10.3%	5.4%	11.8%	-13.5%	-20.3%	--43.8%
Confidence intervals	[5.9, 14.8]	[2.4, 8.5]	[9.2, 14.4]	[-16.2, -10.8]	[-30.7, -8.2]	[-51.7, -34.5]
2009 Female diversity	3.02	2.74	2.96	2.58	0.40	0.60
‘000 USh equiv.	6.9	3.6	7.9	-9.0	-13.5	-29.2
N	1786	1783	1786	1652	1781	1784
		II.	**TROPICAL COOL AREAS**			
A. Parameter Estimates						
Diversity	4.18	5.75	14.19	3.53	-23.12	-40.05
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Female manager	50.51	53.57	18.92	131.63	15.48	21.52
	(0.00)	(0.00)	(0.01)	(0.00)	(0.00)	(0.11)
Diversity* Female	-22.76	-25.73	-5.40	-34.04	-20.39	-41.24
	(0.00)	(0.00)	(0.02)	(0.00)	(0.02)	(0.01)
B. Marginal effects						
1% change on gross margins	-17.0%	-18.1%	9.2%	-26.3%	-35.3%	-55.6%
Confidence intervals	[-19.5, -14.4]	[-20.7, -15.4]	[4.8, 13.8]	[-31.4, -20.8]	[-42.0, -27.8]	[-63.5, -46.0]
2009 Female diversity	2.89	2.71	2.44	2.73	041	0.66
‘000 USh equiv.	-18.0	-19.2	9.8	-27.9	-37.5	-59.1
N	1480	1474	1480	1273	1461	1468

Notes: p-values in parentheses below parameter estimates.

The estimations on the tropical-warm agro-ecological zone subsample (Table 8, Panel I) reveal different trends from the overall sample, substantiating the presence of production heterogeneity across the country. In these areas, non-female managed parcels are linked to lower gross margins per acre when crop diversity increases for all indices except the Berger-Parker, and greater diversity among female parcels is associated with improvements in productivity for three of the six indices. Increasing crop diversity by one per cent as measured by the number of crops per acre, the number of traditional crops per acre, and the Shannon index is associated with an increase of approximately 5 to 12 per cent in the per acre gross margin on female-managed land. In monetary units, this effect signifies an increase in 3,600 USh to 7,900 USh. Conversely, the measures of proportional abundance, richness and relative abundance (respectively, columns 4, 5, and 6), indicate that a one per cent increase in crop diversity on female-managed land reduces agricultural productivity by about 13 to 44 per cent. These last estimates should be interpreted with caution given the wide confidence bounds around the Margalef and Simpson indices. The bounds on each of the other four indices are much tighter, indicating the point estimates of the marginal effects are estimated with greater precision.

Unlike tropical-warm areas, Table 8 (Panel II) indicates that female management in tropical cool areas does not necessarily improve productivity with greater crop diversity, reflecting the results reported in Table 6. As in the case of the overall results, increasing crop diversity on female parcels is associated with a net negative marginal effect on the per acre gross margin. This result is robust across all crop diversity indices except for the Shannon index, which continues to be associated with increases in gross margins per acre, though of a smaller magnitude than in the overall sample. As in Table 8, the Margalef and Simpson indices are estimated with less precision.

The results by agro-ecological zones may be linked to the agricultural potential of the land in each area, as well as gender differences in production portfolios across those areas. Whereas an explicit measure of agricultural potential is not available in the dataset, indications of soil nutrients and rainfall potential provide insight as to differences in productivity potential across agro-ecological zones. Descriptive statistics indicate that parcels in tropical warm areas are more likely to receive bi-modal rainfall, while tropical cool area parcels are disproportionately in uni-modal rainfall areas, providing an initial indication of greater agricultural potential in tropical warm zones.

The differences in terrain and climate could contribute to observed differences in crop portfolios, which are markedly more diverse in tropical warm areas. Whereas production in tropical cool areas is largely concentrated in bananas, beans and pulses, with nearly two-thirds of parcels involved in their cultivation, more than half of the parcels in tropical warm areas produce beans and pulses, maize and cassava. Participation in the cultivation of sweet potato, sorghum, groundnuts and millet is also significantly greater in tropical warm rather than cool areas. Tropical cool areas are more likely to produce coffee and other roots/tubers, but no other crops.

While these differences in production portfolios are likely a reflection of land fertility and cropping conditions, they may also be indicative of the capacity of the land to engage in further crop diversity. With tropical cool areas exhibiting lower diversity in their portfolios in

2009, the overall negative effects of increasing crop diversity suggests female managed parcels in those areas could be exhausted in terms of the possibility to absorb and benefit from additional diversification. The greater level of crop diversity among female parcels in tropical warm areas combined with the positive effects observed for three of the six estimations signifies that parcels in those areas may have a greater capacity to engage in additional production diversity, either through the addition of new crops to the portfolio or the redistribution of land more equitably across the production portfolio. Conversely, these trends in the results could also be evidence of an underlying motivation for increasing crop diversity linked to exploring a more lucrative or productive production portfolio in which farmers can engage when weather conditions are favourable.

The scale of production could further explain the contrasting results obtained from an increase in crop diversity. Parcels in tropical cool areas are considerably smaller than those in tropical warm areas by approximately two acres. This difference in cultivable land area translates into an important difference in the number of crops being cultivated per acre which is significantly higher in tropical cool areas (2.53 crops per acre versus 1.73 in tropical warm areas), and which suggests, ceteris paribus, that parcels in tropical cool areas may be effectively constrained in their capacity to add more crops to their production portfolios. The role of scale effects is explored in greater detail in the next sub-section.

Table 9. Diversity and gender on log gross margins per acre: non-linear specification

	(1) Crops/acre	**(2) Traditional crops/acre**	**(3) Shannon**	**(4) Berger-Parker**	**(5) Margalef**	**(6) Simpson**
A. Parameter Estimates						
Diversity	4.83	3.18	5.62	-0.01	-0.29	-54.38
	(0.00)	(0.00)	(0.00)	(0.97)	(0.00)	(0.00)
Diversity^2	0.01	0.01	0.00	0.00	0.00	2.70
	(0.00)	(0.58)	(0.83)	(0.54)	(0.42)	(0.16)
Female manager	53.82	32.65	-35.71	92.13	18.26	-8.53
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.47)
Diversity*Female	-24.42	-13.57	14.94	-27.69	-0.33	1.51
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.92)
Diversity^2*Female	0.92	0.18	0.05	-0.01	0.00	2.73
	(0.46)	(0.27)	(0.36)	(0.74)	(0.18)	(0.36)
B. Marginal effects						
1% change on gross margins	-17.5%	-9.3%	23.2%	-24.2%	-45.2%	-41.1%
Confidence intervals	[-21.0, -13.7]	[-12.5, -5.8]	[17.9, 28.7]	[-27.1, -21.3]	[-52.8, -36.3]	[-49.5, -31.3]
N	1480	1474	1480	1273	1461	1468

Notes: p-values in parentheses below parameter estimates.

Whether crop diversity on female parcels is potentially maximized in tropical cool areas (and not yet maximized in tropical warm areas) suggests a non-linearity may underlie the relationship between diversity and agricultural productivity. The presence of nonlinearities can be tested in an additional estimation for the diversity indices in which a squared term is included in the specification[30], results of which are reported in Table 9. The marginal effects do not reveal any new trends following the inclusion of the squared term. The parameter estimates based upon the squared terms are insignificant across all six estimations and the magnitude of the marginal effects of a one per cent increase in crop diversity, remains comparable to that of the overall impacts reported in Table 6.

5c. Scale effects

One mechanism that may be underlying the role of gender in a study involving production profiles and diversity is the inherent inequality in land access across gender, referred to in Section 3c. This issue has been partially addressed by analysing gross margins in per-acre terms, and utilizing spatial measures of crop diversity. If, however, scale effects influence the cropping decision by permitting greater diversity on larger parcels, then it is necessary to estimate the relationship between diversification, gender and productivity by parcel size. In order to explore these scale effects, the sample is divided into small and large holders (see Table 10, whereby small parcels are in the bottom quartile of the parcel land distribution (of no more than 1.23 acres), and large parcels comprise all parcels in the top quartile (effectively those greater than 4.94 acres in size[31]). While female-managed parcels represent 34 per cent of smallholders and 20 per cent of large-holders, mixed-gender parcels respectively account for 50.4 to 59.2 per cent of small and large-holders. Parcels under male management represent the remainder.

Table 10. Descriptive statistics, by parcel size (2009)

	Small (37.9%)	**Large** (25.4%)	**T-test p**
Parcel characteristics			
Female manager (%)	0.34	0.20	**0.00**
Parcel size (acres)	0.87	10.27	**0.00**
Slope (%)	12.11	7.07	**0.00**
Elevation (m)	1413	1209	**0.00**
Mean annual temperature (°C)	21	22	**0.00**
Uni-modal rainfall (%)	0.75	0.67	**0.01**
Inputs (% using)			
Hired labour	0.24	0.54	**0.00**
Organic fertilizer	0.19	0.16	0.24
Chemical fertilizer	0.07	0.05	0.42
Pesticides	0.15	0.20	**0.03**
Used improved seeds	0.07	0.20	**0.00**
Diversity indicators			
Number of crops cultivated	2.21	4.76	**0.00**
Traditional crops	2.03	3.88	**0.00**
Improved variety	0.18	0.88	**0.00**

[30] The implementation of the control function approach with a nonlinearity in the endogenous variable is addressed following Wooldridge (2010), in which the nonlinear term is instrumented using the set of continuous instruments, transformed by the same nonlinearity, in this case the squared term.
[31] Quartiles based upon 2009 parcel area.

Margalef	0.34	0.49	**0.00**
Shannon	1.35	5.05	**0.00**
Berger-Parker	2.24	4.28	**0.00**
Simpson	0.54	0.73	**0.00**
Main crops produced			
Beans/peas	0.45	0.71	**0.00**
Maize	0.31	0.67	**0.00**
Cassava	0.24	0.65	**0.00**
Banana	0.40	0.54	**0.00**
Sweet potato	0.18	0.34	**0.00**
Groundnut	0.08	0.26	**0.00**
Coffee	0.14	0.23	**0.00**

Note: Bold denotes significance of at least 90% confidence.

The results in Table 11, Panels I and II, demonstrate how gender and crop diversity effects differ according to the small/large-holder typology. For small parcels (Panel I), significant marginal effects are observed for four of the six indices (the Margalef and number of traditional crops produced are not significant). Positive effects emerge for the number of crops per acre, the Shannon and Berger-Parker indices, yielding an increase in productivity that ranges from 5.7 to 25.3 per cent; however only the first two of these indices is precisely measured. A one per cent increase in the Simpson index instead leads to a 52 per cent drop in agricultural productivity for female managed parcels, though the effect is significant over a broad range of values.

On large parcels (Panel II), significant results are observed for five of the six diversity indices, and once again reflecting the same direction of effects as in the overall results. Only the Shannon index is associated with an increase in agricultural productivity, which is in addition, precisely measured as compared to the broad confidence bands around the negative effects reported for the Simpson, Margalef and count indices. Since the effects are so loosely estimated for those indices, it suffices to state that for female producers on large parcels, increasing crop diversity through an expansion of the portfolio, or improvements in richness or proportional abundance does not generate productivity gains. The results indicate that on large female-managed land parcels, the main avenue towards increased productivity sourced in crop diversity is through improvements in the equitable distribution of land across crops. If production covariance across crops is discounted, this finding suggests that the size of the crop portfolio is less important than ensuring that production risk is equally spread across the members of the portfolio.

The contrasting results between small and large parcels illustrate the potentially different nature of production profiles across land size. As indicated in Table 10, the average levels of crop diversity on female parcels for each group present a first indication of such differences. Women on small parcels are cultivating land with a greater intensity than those on larger parcels, as observed by comparing the number of crops per acre. However, larger parcels are characterised by greater diversity in terms of equitable distribution of land over crops, as given by the higher scores on the four spatial indices when compared with smaller parcels.

Table 11. Diversity and gender on log gross margins per acre: by parcel size

	(1) Crops/acre	(2) Traditional crops/acre	(3) Shannon	(4) Berger-Parker	(5) Margalef	(6) Simpson
			I. SMALL PARCELS (BOTTOM QUARTILE)			
A. Parameter Estimates						
Diversity	-1.26	0.07	3.32	21.05	-1.38	-35.38
	(0.01)	(0.85)	(0.06)	(0.01)	(0.75)	(0.00)
Female manager	-22.77	6.02	10.64	36.17	11.35	3.26
	(0.03)	(0.50)	(0.12)	(0.15)	(0.01)	(0.78)
Diversity* Female	8.84	1.02	2.24	1.49	0.52	-38.19
	(0.00)	(0.57)	(0.36)	(0.85)	(0.94)	(0.02)
B. Marginal effects						
Effect 1% change on gross margins	7.9%	1.1%	5.7%	25.3%	-0.86%	-52.1%
Confidence intervals	[3.6, 12.3]	[-2.0, 4.2]	[1.2, 10.5]	[11.7, 40.6]	[-12.4, 12.2]	[-63.0, 39.6]
2009 Female diversity	3.83	3.77	1.49	2.12	0.34	0.56
‘000 USh equiv.	13.9	1.9	10.1	44.6	-1.5	-91.8
N	1070	1061	1070	893	1048	1059
			II. LARGE PARCELS (TOP QUARTILE)			
A. Parameter Estimates						
Diversity	-26.33	-24.86	1.40	-2.31	-26.94	-55.85
	(0.00)	(0.01)	(0.01)	(0.00)	(0.00)	(0.00)
Female manager	11.14	19.57	-68.52	-53.13	15.60	31.66
	(0.04)	(0.14)	(0.00)	(0.06)	(0.20)	(0.28)
Diversity* Female	-17.75	-59.58	14.29	6.42	-32.45	-44.11
	(0.02)	(0.05)	(0.00)	(0.07)	(0.16)	(0.22)
B. Marginal effects						
Effect 1% change on gross margins	-21.69%	-33.47%	93.52%	12.78%	-23.34%	-51.89%
Confidence intervals	[-44.9, -24.8]	[-74.5, -27.4]	[11.4, 22.8]	[-1.8, 11.0]	[-63.2, -17.2]	[-82.5, -22.4]
2009 Female diversity	0.55	0.48	4.21	2.93	0.45	0.73
‘000 USh equiv.	-13.8	-22.1	6.6	1.6	-17.4	-24.5
N	881	881	881	830	880	880

Notes: p-values in parentheses below parameter estimates.

Taking both observations into consideration, smaller parcels may report greater diversity per unit of land, but it appears that it is more likely that they are specializing in one crop that receives a disproportionate share of the parcel land, and marginally cultivating two or three other crops. Conversely, female managers of large parcels, due to a greater disposition of land, are likely to produce considerably fewer crops per parcel, but not due a practice of crop specialization per se, but because more land can be dedicated to each crop. In practice, larger parcels managed by women cultivate approximately 4.8 crops, while their counterpart on smaller parcels produces only 2.2 crops over the whole parcel.

Of great relevance is the extent to which each cropping system is profitable, as significant differences are also observed on this front with respect to land size. Female smallholders report a gross margin per acre of 132,314 USh, whereas female large-holders obtain only about one-fifth of that value per acre (33,368 USh). At the parcel level, looking at producers overall across agro-ecological zone, the trend is reversed with large holders earning nearly four times the total parcel gross margin of small holders; however, it is valuable to note that despite producing fewer crops and with a less equitable land distribution, female small-holders are not undercut by their access to land. The selection of the crop portfolio is thus highlighted since the value of production will depend on the quantity of harvest obtained and the market price of the crop.

5d. Robustness

Whereas the estimations of the previous section present evidence of the utilization of crop diversity levels as an adaptation strategy for female producers in Uganda, it remains to be understood how specific crop choice may influence the resulting level of agricultural productivity on the parcel. Empirical applications of the Simpson index in industrial economics indicate the inclusion of component shares as additional explanatory variables allows for better interpretation the effect of each contributing factor (Vigdor, 2002).

Following that approach, the estimation with the Simpson index is re-run for the overall sample and by agro-ecological zones with the area share of the 48 crops used in its construction. This estimation generates results that are consistent with previous findings in that an increase in the Simpson index on female-managed land is associated with a negative effect on the parcel gross margin. Inclusion of the area shares does not affect the relationship, which remains negative and significant at -48.2 per cent (Table 12, Panel A), with confidence bands overlapping those observed in Table 6. Examination of the parameter estimates for each of the crop shares[32] demonstrates that all but 11 crops generate a significant negative effect on gross margins. Those that are not significant include banana (sweet; beer; food), pineapples, papaya, ginger, coco yam, sweet potato, soya bean, sesame, and mango.

Since multicollinearity issues may affect the interpretation of the crop shares estimates, an alternative approach for exploring the effect of cultivating specific crops is pursued. Instead of including crop shares in the specification, crop group cultivation dummies are included as additional explanatory variables. The crop groups considered include: bananas; beans/pulses;

[32] Results not reported; available upon request.

maize; sweet potato; sorghum; cassava; groundnuts; coffee; millet; fruits/vegetables; other grains; cash crops; oil seeds; and roots/tubers. Results from these additional estimations on all six diversity indices, reported in Panel B of Table 12, demonstrate trends in the marginal effects similar to what was observed for tropical warm areas of Uganda. Increasing the count or Shannon indices is associated with productivity gains, whereas increases in the remaining indices are generally associated with productivity losses for female-managed parcels. The large marginal effect for the Margalef index suggests multicollinearity may persist in that specification.

Table 12. Marginal effects from estimations with crop-specific covariates

	(1) Crops/acre	**(2) Traditional crops/acre**	**(3) Shannon**	**(4) Berger-Parker**	**(5) Margalef**	**(6) Simpson**
A. Component shares						
1% change on gross margins	…	…	…	…	…	-48.2%
Confidence intervals	…	…	…	…	…	[-56.2, -38.8]
B. Crop group dummies						
1% change on gross margins	2.8%	2.8%	21.9%	-20.4%	-74.1%	-48.0%
Confidence intervals	[2.0, 3.6]	[2.0, 3.6]	[17.1, 26.9]	[-24.1, -16.5]	[-78.9, -68.2]	[-54.6, -40.5]
N	3266	3257	3266	2925	3242	3252

The parameter estimates on the crop group cultivation dummies[33] vary in sign and significance depending on the diversity index, however, certain crops are revealed as generally contributing to greater agricultural productivity while others generating overall negative effects. Among the crops associated with agricultural gains are bananas, cassava, coffee, and roots/tubers, whereas those generating marginal losses are beans/pulses, maize and groundnuts. Cultivation of sweet potato, sorghum, millet, horticulture crops, cash crops, oil seeds and other grains generates ambiguous effects across estimations.

These findings demonstrate that most crops associated with traditional or subsistence agriculture in Uganda, such as bananas and cassava, are not exclusively associated with less productive agriculture. At the same time, in line with expectations, the cultivation of coffee, a higher value crop, does contribute to greater marginal returns to agriculture. The ambiguous effect for cash crops and fruits/vegetables is likely due to the relatively low overall extent of their cultivation in Uganda, as well as to regional differences that might favour/hamper their production.

[33] Not reported; available upon request.

5e. Underlying motives for diversity

Until this point, the analysis has sought to describe the relationship between gender, crop diversity and productivity, but has not fully illustrated the potential underlying motivations for crop diversity. One key motivation that is considered in the context of climate change in the literature review is diversification of crops as diversification of risk. As described in Section 2b, defining a crop portfolio that is sufficiently varied can protect producers against crop failure, if the production covariance between crops is relatively low. Whereas the data does not permit a straightforward test of risk diversification, it is possible to look at risk management in order to gauge whether risk matters for crop diversity. Columns (A) of Table 13 present the estimation results for parcels in households that did and did not experience an agricultural shock in the previous five years.

A separate channel through which crop diversity may arise is that of labour demand and supply. Crops can be more or less intensive in their labour requirements due to a range of factors. Some of these factors include the intensity of land preparation activities and how harvest tasks are best performed. Producers may therefore select crops to align with labour requirements, or labour availability, factors that may rely on the presence of functioning labour markets, disposable income for engaging workers, as well as individual time and effort constraints that impede family labour from being sufficient to meet household production needs. In order to probe this channel, results are compared across parcels that do and do not hire in labour in columns (B) of Table 13.

Finally, biological causes underlying crop diversity can be linked to prevention or management of disease, as well as crop rotation practices that are associated with maintaining and restoring the nutrient composition of cultivatable land. The management of disease risk can be analysed through estimations of parcels using and not using pesticides (column C in Table 13). Crop rotation is not explicitly asked in the questionnaire; however, given the prevalence of parcel manager gender switching over time and the documented prevalence of gendered crops, it is possible that parcel manager gender changes may be linked to crop rotation across parcels within households. While this cannot be formally confirmed, if we assume it is the case, the crop rotation channel can be tested by running the estimation on the subsample of parcels for which parcel manager gender is constant and that for which it changes across rounds. Results from these estimations appear in columns (D) of Table 13.

Although these comparisons are relatively simple and may only provide evidence of correlation rather than causality, they do portray how crop diversification differs under various conditions and provide insight as to why crop portfolio diversification may take place. Furthermore, even if not all parameter estimates in Table 13 are significant, it is worthwhile to observe the opposite trends that emerge for each situation pair. Among parcels in households that were exposed to shocks, crop diversity generates productivity gains among female producers, whereas a negative relationship is observed for those parcels in households who were not exposed to agricultural shocks. While not a causal relationship, this outcome suggests that there is a positive correlation between vulnerability to agricultural shocks and the utilization of crop diversity to manage such vulnerability. Households that are seemingly less vulnerable to agricultural shocks instead benefit more from crop specialization.

Table 13. Causes of crop diversification

	A. Agricultural shock		B. Hired labour		C. Pesticide use		D. Parcel manager gender	
	Yes	No	Yes	No	Yes	No	Const-ant	Chang-ing
Parameter Estimates								
Diversity	3.10	1.60	3.05	-2.36	5.36	-2.64	-1.00	-0.61
	(0.05)	(0.00)	(0.40)	(0.00)	(0.16)	(0.00)	(0.07)	(0.35)
Female manager	15.72	-1.57	6.84	-28.90	-9.15	-33.67	-	-4.55
	(0.15)	(0.79)	(0.43)	(0.00)	(0.74)	(0.00)	-	(0.35)
Diversity*Female	5.17	-3.43	-5.24	7.42	-11.30	5.96	-0.25	1.39
	(0.16)	(0.01)	(0.09)	(0.00)	(0.26)	(0.02)	(0.91)	(0.62)
N	1613	1653	1305	1974	491	2784	2254	1025

Notes: p-values in parentheses below parameter estimates.

Regarding the use of hired labour, female-managed parcels that produced with hired labour are less likely to utilize crop diversity to increase productivity. This relationship may have to do with the fact that the use of hired labour by female producers is indicative of being relatively better off economically, perhaps less focused on subsistence production and more so in market-oriented production. The opposite, positive, effect for female parcels that do not hired in labour indicates a trade-off between crop diversity and the use of more specialized factors of production. This presence of such a trade-off is supported by the same set of trends for female producers that do and do not use pesticides on their land. Among pesticide-users, diversification is negatively associated with productivity, whereas non-users experience productivity gains from diversification. Finally, no evidence of crop rotation as an influential factor in the gender-diversity relationship is observed using the proxy of parcels with changing versus constant manager gender.

6. Discussion and Conclusions

While the implications of and responses to climate change are increasingly explored in the context of developing countries, the role of gender in agricultural adaptation strategies has been largely ignored. Twenty years of economic research have documented agricultural productivity differentials across male and female producers, highlighting differences in access to inputs and assets as fundamental obstacles to closing the gender gap in agriculture. Although a number of adaptation strategies have high entry or implementation costs (i.e. irrigation, non-farm diversification, migration, etc.) adapting to increasing variability by adjusting the level of crop diversity is arguably more accessible to producers facing liquidity, asset, or other relevant constraints, the main conditions being farmer experience or knowledge, and potentially access to seed markets or traders, both of which have the potential to be accessed through formal and informal mechanisms.

This paper has sought to fill the knowledge gap with respect to the use of crop diversity among female producers and its implications for agricultural production outcomes and food security. Focusing on rural producers in Uganda and using a nationally representative household panel survey with agricultural production data at the parcel level, the role of agricultural decision-maker gender in selecting the level of crop diversity is isolated in a control function estimation (Wooldridge 2010) of a parcel-level measure of agricultural productivity. Various measures of crop diversity are utilized in efforts to test the robustness of the results to variable choice and to explore the different facets of portfolio diversity. Estimates are also obtained for specific characterizations of Uganda's agro-ecological zones, and for subsamples of small and large producers, given key differences in land access across gender that may affect the scale of production and corresponding production strategies.

6a. Overall findings

The analysis largely finds that productivity is negatively influenced by higher levels of crop diversity for female agricultural decision-makers. While the magnitude of the main effect varies across specifications, this result is robust across five of the six measures of crop diversity and holds for estimations on the overall sample as well as for tropical-cool areas of Uganda. For producers in tropical-warm areas, the relationship is not unambiguously negative. Instead, for three of the six indices, a positive relationship is found such that female parcels that increase their level of crop diversity will obtain greater returns to their production portfolio.

Taking the scale of production into account, differentiating producers according to parcel size, also demonstrates varying direction and magnitude of effects, highlighting a greater sensitivity of the estimation to the selection of the crop diversity variable. Among small-holders, neither crop diversity nor gender are systematically significant, results emerging only for two of the six indices, of similar magnitudes but of opposite signs. For the large-holder sample, four of the six indices reveal a significant relationship with gender in explaining gross margins; however, results are also of differing signs. The results from this set of estimations is informative in highlighting the different characteristics of crop diversity captured by each index, while also pointing to the different ways in which crop diversity is relevant for land constrained versus unconstrained producers.

6b. Gender effects

Motivated by a rich set of descriptive evidence of the important productivity gap faced by female producers relative to male producers, the analysis was successful in providing robust empirical evidence of that gap and the gendered effects of changes to parcel-level crop diversity. The production and productivity gap was estimated at approximately 30 per cent, with female-managed land generating less output overall and per acre than male or mixed-managed land. This gap raised the question of the extent to which crop diversity can contribute to narrowing gender differences in Ugandan agriculture, especially since female producers are likely to be negatively affected from climatic changes and variability, given documented differences in access to assets and inputs, and given female capacity to adapt under constraints linked to parallel economic and domestic responsibilities.

Various levels of complexity underlie an analysis of gender, crop diversity and agricultural productivity, having to do with unobserved factors such as the household level designation of members to the parcel-manager role, societal norms regarding access to land according to gender, ethnographic issues surrounding the selection of the crop portfolio, and how that portfolio's components relates to its size. The econometric specification allowed a number of these issues to be addressed through the fixed effects within transformation, which removes time-invariant unobserved heterogeneity; however, the variability in parcel-manager gender over time indicated that the household decision-making process is fluid, subject to labour availability, exposure to shocks, and potentially to agricultural production practices that interact with gender roles. This time-variant unobserved heterogeneity was addressed with the control function approach, allowing the gender dimension of crop diversity to be isolated.

The analysis revealed a strong, significant relationship between productivity and the interaction of gender and crop diversity. Two main findings emerge from the analysis. First and foremost, increasing female-managed crop diversity from the perspective of evenness (the Shannon index) contributes positively to agricultural productivity on female-managed land. This finding was robust across agro-ecological zones and regardless of the scale of production, indicating that a more equitable land distribution among female-managed parcels is favourable for the net returns to production.

It is valuable to note that a simplified notion of evenness can be extracted from the Berger-Parker index as it reports the inverse of the maximum area share dedicated to a single crop. The smaller the value of that maximum area share, the more likely an even distribution is implemented on the parcel. Despite this interpretation of the Berger-Parker index, it only moves in the same direction as the Shannon index for the sub-sample of small parcels, generating an effect that is positive and significantly larger than that of the Shannon index. Reducing the "dominance" of a single crop under limited land resources is thus important for improving agricultural productivity on female land and suggests that a production risk management strategy that favours productivity gains may optimize land use by seeking a more equitable distribution of land across cultivars. This strategy undoubtedly relies on a complementary set of crops within a portfolio, a subject in which this paper did not delve, but that would provide even greater insight regarding how crop diversity is used in practice.

Second, the potential for greater crop portfolio richness to benefit female agricultural productivity depends on agro-ecological conditions and the scale of production. Whereas richness as conveyed by the count and Margalef indices are negatively associated with gross margins per acre for female parcels in the overall sample, in some instances, the count indices are found to increase female agricultural productivity. This result is specific to tropical warm areas of Uganda and for the sub-sample of smallholders, which are surprisingly characterised by considerably different production conditions. Parcels in tropical warm areas are generally large (4.9 acres), located on flat terrain, at lower altitudes and with milder long run temperatures, whereas smallholder parcels fall into the bottom quartile of land area, are located on moderate slopes, at relatively higher altitudes and subject to relatively cooler temperatures. Finding a similar effect of increasing the richness of crop diversity for female-managed land in two substantially different contexts indicates that while agro-ecological conditions and available land resources may be important criteria for understanding productivity effects, other factors, potentially related to the specific cultivars being produced within crop portfolios may be equally relevant.

In practice, while there is overlap in the crops cultivated on small parcels and in tropical warm areas, the main crops are not the same, banana and beans/peas being the most prevalent smallholder crops, while cassava, maize and beans/peas representing the most often produced crops in tropical warm areas. The question that arises thus relates to the specific choice of a new crop when crop diversity as richness is increased and the extent to which that new crop will interact favourably with the rest of the female-managed crop portfolio so to increase productivity. This question is increasingly relevant in the context of climate change as farmers adapt the components of their production portfolios, adopting new crops and crop varieties in response to changing temperature and rainfall patterns. The value of the current analysis and variables is therefore limited in the climate change context since this question cannot be answered, highlighting an important drawback of the crop diversity indices as de facto "black boxes" regarding the agronomic content of any crop portfolio.

6c. Understanding crop diversity

A clear observation from the full analysis is the non-substitutability of one crop diversity index for another. The results obtained from each specification demonstrated that each index is effectively capturing a different aspect of crop diversity, despite the fact that each index is increasing in diversity, and that for the spatial indices, three of the four are sensitive both to the number of crops cultivated and the extent to which parcel area is evenly distributed across crops. This outcome was not found to be related to the nonlinear behaviour potentially underlying each index; at a parcel level, introducing squared terms to the analysis negligibly affected the estimation of marginal effects.

The correlation between indices, reported in Table 14 fails to provide insight to the different outcomes obtained in terms of the sign and/or magnitude of the marginal effects. Although most of the spatial indices are significantly correlated ($p<.01$), the magnitude of their correlation varies considerably between indices, with most index pairs reporting a correlation below 30 per cent. The first exception is for the Simpson and Margalef indices, for which a correlation coefficient of 0.50 is observed, an outcome that is consistent with the estimation results given the general consistency in the sign and large magnitude of their respective marginal effects across estimations[34]. With the Margalef index representing richness of the crop portfolio and the Simpson index conveying proportional abundance of the portfolio, the rationale behind the strong correlation is not immediately obvious. However, if proportional abundance is interpreted as portfolio *heterogeneity* (Smale, 2006), then it becomes clear that the Simpson index is more strongly capturing the richness rather than the evenness of the crop portfolio. This assertion is supported by the significant correlations observed between the Simpson and Margalef indices and both of the count indices, which also represent portfolio richness. There is no significant relationship observed between the count indices and the Shannon and Berger-Parker indices.

[34] Except for Table 11, in which the Margalef index was not significant.

The Shannon and Margalef indices are even more strongly related, reporting a correlation coefficient of 0.70. This outcome is less intuitive given that the Shannon index was consistently associated with positive productivity effects, and the Margalef with negative effects. In the context of the marginal effects, the Shannon index appears to more strongly convey the evenness of the crop portfolio than its richness; however, in the context of the different aspects of crop portfolio diversity, the strong relationship between these two indices suggest that evenness and richness may move together in contributing to greater diversity. This interpretation is in line with the finding presented in Section 3c that the spatial indices are maximized under evenness and with the addition of crops to the portfolio.

Table 14. Correlation between diversity indices

	Number of crops	Number traditional crops	Margalef	Shannon	Berger-Parker	Simpson
Number of crops	1.00	…	…	…	…	…
Number traditional crops	0.99*	1.00	…	…	…	…
Margalef	0.44*	0.43*	1.00	…	…	…
Shannon	0.02	-0.00	0.70*	1.00	…	…
Berger-Parker	0.03	0.02	0.20*	0.20*	1.00	…
Simpson	0.07*	0.08*	0.50*	0.28*	0.25*	1.00

Note: * denotes $p<0.01$.

The different aspects of crop diversity thus become essential for interpreting the results of the analysis in terms of agricultural productivity, particularly in light of contrasting results across indices. Given that the Shannon index was unambiguously associated with positive productivity outcomes for female parcels, the importance of distributing the crop portfolio across the parcel area becomes essential, particularly in light of the relatively low prevalence of pesticide use across the full sample. Distributing parcel area evenly across crops can serve as a mechanism to protect overall output from the spread of agricultural pests and disease (Smale, 2006). Conversely, concentrating cultivation in one crop can make the overall parcel harvest vulnerable to the success of that crop's productivity.

Introducing additional richness to the crop portfolio is not necessarily associated with productivity gains, as observed from the overall results. However, the productivity effects of increasing the size of the crop portfolio are instead subject to the choice of index used to measure crop diversity, as well as locational and scale factors. In terms of the choice of index, the count and Margalef indices both represent portfolio richness. For the former, the number of crops per acre is captured, whereas for the latter, the number of crops per log acre is represented. This difference in the construction of the indices has important implications for modelling the diversity-productivity relationship. Whereas both indices address across-parcel scale differences by scaling the size of the portfolio according to land area, the Margalef index benefits from the logarithmic transformation to deal with extremely large values in the parcel size distribution. However, the construction of the Margalef index is subject to the caveat that parcels one acre in size will receive a log area of zero, and those below one acre will generate a negative index. Since by definition the index is constrained to be equal or greater than zero, this creates an estimation problem for dealing with extremely small parcels. The per-acre count indices are not affected by this estimation problem, which could render the estimates generated with the count indices more reliable. In practice, this is likely the case, given the substantial fluctuation in the Margalef index marginal effects across estimations, which is not observed to the same extent for the count indices, with the exception of the estimations for the large landholding sub-sample. At the same time, the magnitude of the marginal effects from the Margalef and count indices move in the same direction across estimations, yielding at minimum consistent the direction of the correlation between richness and productivity on female-manage parcels.

6d. Final words

Despite the constraints faced by this analysis in terms of isolating the role of key variables inherently affected by issues of endogeneity and complexities in their interpretation, it was nonetheless possible to narrow in on the different aspects of the relationship between crop diversity and agricultural productivity among female producers in Uganda, enabling one aspect of food security to be explained in the context of agro-diversity. The role of agricultural productivity is highly relevant for sustaining food security among a largely rural population, and one that is dependent on the success of the agricultural sector in order to maintain consumption. It is thus valuable to expand the knowledge base regarding factors that contribute to or detract from agricultural productivity gains.

As indicated in the descriptive statistics, anywhere from 44 to 65 per cent of harvested crops were allocated to household consumption in 2009 and 2010, indicating the degree of dependence at a household level on its production for consumption. Maintaining, or even increasing productivity, is therefore an essential component of responding to household food security needs. The role of gender in this response is critical with female parcels dedicating a larger share of their harvest to household consumption than male or mixed-managed parcels. Whether that relationship is due to the nature of the crop portfolio (female parcels being more likely to produce staple rather than high-value crops), or due to other factors that limit market access, was not identified in this paper although differences in inputs, technology and capital were accounted for in the analysis. As such, extensions to the analysis presented in this paper could look beyond traditional market access constraints and explore the role of other sources of diversity that may complement or challenge the crop diversity-productivity relationship. These could include agricultural diversity into livestock, fisheries or forestry, or livelihoods diversity into non-agricultural activities, migration, and domestic tasks. Diversification into this compendium of activities is also gender-sensitive and may have implications for parcel productivity.

In the context of Uganda where, regardless of gender, production of staple crops is widespread, the role of additional crop diversity and how it interacts with gender is of central interest, especially if that diversity can contribute to improved agricultural outcomes. While the role of increasing crop diversity for female producers did not explicitly emerge as positive or negative, the magnitude of the effects was large across specifications, indicating that changes in crop diversity, measured in its different forms, can be powerful in contributing to higher or lower productivity for female parcels. The important contribution made by female-managed parcels to household consumption must therefore be considered in policies that affect crop choice and the shift between mono- versus multi-cropping regimes. What does emerge as incontestable evidence regards the gains from a more equitable land distribution over a given multi-crop portfolio.

In its analysis of gender, crop diversity and productivity, this paper shed light on the complexities and possibilities underlying the definition of crop diversity. Using a standard count definition as a starting point, other approaches for capturing diversity were explored in an attempt to specify a more precise notion of diversity that captures scale and distributional effects. The entropy indices were insightful, demonstrating that the definition of diversity must be carefully constructed in order to capture the information of interest. Given that results were not always consistent across different measures of diversity, conclusions drawn must factor in the underlying differences between indices, especially if policy recommendations are to be drawn from them. Whether the entropy indices are more valuable than a standard county index of diversity remains to be established. The interpretation of the latter is undeniably easier; however, the utility of factoring in additional dimensions of production diversity remains an attractive feature that may be best exploited with complementary information pertaining to the contents of production portfolios.

In order to further narrow in on the relationship between crop diversity and productivity, future research must delve deeper into the specific crops selected for cultivation on female versus non-female managed parcels and relate specific cropping regimes to the established measures of crop diversity. This will shed greater light on the mechanisms underlying the contrasting results related to different aspects of crop diversity as presented in this paper. Such research should also take steps towards more clearly identifying the interactions between reported crop combinations, as conditioned on producer gender, and the implications for agricultural production. More nuanced analyses at the micro-level, that continue to place emphasis on producer heterogeneity, will be fundamental to establishing with even greater confidence the importance of agro-diversity on the agricultural production aspect of food security, which will inevitably be challenged under climate changed-induced variability.

Appendix Tables

Table A1. Agricultural production zones of Uganda

Zone	Rainfall	Main crops	Livestock cultivation	Elevation/ Vegetation
(1) Banana-coffee	Regular, annual	Banana, coffee, maize, sweet potatoes	Minor	Forest-savannah; pastures
(2) Banana-millet-cotton	Unstable	Millet, sorghum, maize	In dry areas	Moist, moderate biomass
(3) Montane	High, regular	Banana, sweet potatoes, cassava, Irish potatoes, coffee, wheat, barley	Yes; fed crop residue	Higher elevation
(4) Teso	Bimodal rainfall; long dry season	Millet, maize sorghum, oil seed crops, cotton	Yes, mixed with crop production; crop residues used	Moist grass savannah, short grassland,
(5) Northern	Moderate bimodal in southern areas; Low unimodal in northernmost areas	Finger millet, sesame, cassava, sorghum, tobacco, cotton	Pastoralist, seminomadic cattle herding	Grassland
(6) West Nile	Similar to Northern, more rain at higher elevations	Mixed cropping; tobacco and cotton cash crops	Limited	Sub-humid zone, moist grassland
(7) Pastoral	Low annual rainfall		Nomadic extensive grazing; mixed herds	Short grassland

Note: Information obtained from Mwebaze (2006).

Table A2. Sets of instrumental variables, Z_{iht}

Diversity Specification	Diversity instruments	Gender instruments	Interaction instruments
Number of crops/acre	▪ educational attainment of parcel manager	▪ coffee price in previous year ▪ rice price in last quarter ▪ maize price in last quarter	▪ household structure shock in last year
Number of traditional crops/acre	▪ educational attainment of parcel manager	▪ coffee price in previous year ▪ rice price in last quarter ▪ maize price in last quarter	▪ household structure shock in last year
Shannon	▪ educational attainment of parcel manager	▪ coffee price in previous year ▪ rice price in last quarter ▪ maize price in last quarter	▪ household structure shock in last year
Berger-Parker	▪ educational attainment of parcel manager	▪ coffee price in previous year ▪ rice price in last quarter ▪ maize price in last quarter	▪ household structure shock in last year
Margalef	▪ educational attainment of parcel manager ▪ price shock in last year ▪ groundnut price in last year ▪ seed vendor present in community	▪ coffee price in previous year ▪ rice price in last quarter ▪ maize price in last quarter	▪ climate shock to agriculture in last year ▪ household structure shock in last year
Simpson	▪ educational attainment of parcel manager ▪ household is credit constrained	▪ coffee price in previous year ▪ rice price in last quarter ▪ maize price in last quarter	▪ climate shock to agriculture in last year ▪ household structure shock in last year

Table A3. Descriptive statistics of covariates, X_{iht}

	2009					2010				
	(1) Female	(2) Male	(3) Mixed	p (1-2)	p (1-3)	(4) Female	(5) Male	(6) Mixed	p (4-5)	p (4-6)
Slope (%)	8.79	8.90	9.91	0.85	**0.03**	9.76	10.12	9.63	0.60	0.81
Irrigated	0.01	0.02	0.03	0.69	0.12	0.04	0.03	0.03	0.41	0.11
Improved seeds	0.08	0.19	0.13	**0.00**	**0.00**	0.05	0.15	0.11	**0.00**	**0.00**
Intercropped	0.56	0.58	0.55	0.47	0.85	0.57	0.59	0.60	0.54	0.25
KM to nearest main road	7.78	8.80	8.58	**0.04**	**0.02**	7.26	9.30	8.49	**0.00**	**0.00**
KM to nearest major market	29.67	31.16	30.29	0.22	0.47	29.25	28.87	31.11	0.77	**0.03**
Head gender (female=1)	0.68	0.06	0.08	**0.00**	**0.00**	0.68	0.06	0.10	**0.00**	**0.00**
Head age (years)	49.86	43.42	44.67	**0.00**	**0.00**	47.93	43.52	46.10	**0.00**	**0.02**
Dependency ratio	2.45	1.90	1.53	0.12	**0.00**	2.61	1.96	1.74	0.16	**0.00**
Non-agricultural wealth index	0.00	0.08	0.14	0.27	**0.01**	-0.05	0.11	0.09	**0.02**	**0.00**
% income from transfers	0.17	0.06	0.043	**0.00**	**0.00**	0.16	0.08	0.05	**0.00**	**0.00**

Note: Weighted averages reported. P-values indicate the result of the t-test of difference in means between the indicated columns. Significant differences highlighted in bold text.

Table A4. Full results, overall sample

	N crops/acre	N trad. crops/acre	Shannon	Berger Parker	Margalef	Simpson
Diversity	4.92	3.26	5.68	0.00	-29.84	-50.82
	0.00	0.00	0.00	0.99	0.00	0.00
Female manager	54.59	33.30	-35.88	91.74	18.24	-7.52
	0.00	0.00	0.00	0.00	0.00	0.52
Diversity*Female	-24.81	-13.89	15.10	-27.62	-32.56	-2.46
	0.00	0.00	0.00	0.00	0.00	0.86
Residuals (1)	-4.85	-3.19	-5.68	0.00	31.35	52.20
	0.00	0.00	0.00	0.99	0.00	0.00
Residuals (2)	-54.54	-33.31	35.92	-91.71	-18.34	7.81
	0.00	0.00	0.00	0.00	0.00	0.51
Residuals (3)	24.76	13.87	-15.13	27.58	32.25	1.90
	0.00	0.00	0.00	0.00	0.00	0.89
Intercropping on parcel	5.14	2.61	-26.83	9.97	14.34	8.82
	0.00	0.00	0.00	0.00	0.00	0.00
Slope	-1.19	-0.79	-0.60	-0.11	0.37	0.15
	0.00	0.00	0.00	0.62	0.00	0.31
Irrigation	-3.57	-2.21	-6.07	4.70	1.04	-2.28
	0.00	0.01	0.00	0.00	0.15	0.00
Improved seed use	7.30	2.45	-6.76	4.49	3.57	-0.53
	0.00	0.00	0.00	0.00	0.00	0.31
Km to nearest major road	-0.33	-0.16	0.34	0.22	0.63	-0.02
	0.25	0.57	0.30	0.46	0.02	0.95
Km to nearest major market	0.18	0.18	-0.75	1.43	0.25	0.28
	0.09	0.09	0.00	0.00	0.09	0.20
Female head	-3.50	-5.72	4.53	-14.31	-1.36	6.28
	0.01	0.00	0.00	0.00	0.23	0.00
Age head	-0.44	-0.34	-0.11	-0.50	-0.13	0.02
	0.00	0.00	0.01	0.00	0.01	0.78
Dependency ratio	0.17	0.07	0.13	-0.23	-0.10	-0.09
	0.00	0.03	0.00	0.00	0.00	0.02
Non-agricultural wealth index	3.47	2.31	-1.47	1.30	1.22	0.45
	0.00	0.00	0.00	0.00	0.00	0.05
Share of hh income from transfers	8.89	6.22	3.07	-5.91	2.49	0.70
	0.00	0.00	0.00	0.00	0.01	0.36
Constant	20.95	17.63	37.15	-19.31	0.81	28.11
	0.00	0.00	0.00	0.00	0.88	0.00
Number observations	3266	3257	3266	2925	3242	3252

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The FOODSECURE project in a nutshell

Title	FOODSECURE – Exploring the future of global food and nutrition security
Funding scheme	7th framework program, theme Socioeconomic sciences and the humanities
Type of project	Large-scale collaborative research project
Project Coordinator	Hans van Meijl (LEI Wageningen UR)
Scientific Coordinator	Joachim von Braun (ZEF, Center for Development Research, University of Bonn)
Duration	2012 - 2017 (60 months)
Short description	In the future, excessively high food prices may frequently reoccur, with severe impact on the poor and vulnerable. Given the long lead time of the social and technological solutions for a more stable food system, a long-term policy framework on global food and nutrition security is urgently needed. The general objective of the FOODSECURE project is to design effective and sustainable strategies for assessing and addressing the challenges of food and nutrition security. FOODSECURE provides a set of analytical instruments to experiment, analyse, and coordinate the effects of short and long term policies related to achieving food security. FOODSECURE impact lies in the knowledge base to support EU policy makers and other stakeholders in the design of consistent, coherent, long-term policy strategies for improving food and nutrition security.
EU Contribution	€ 8 million
Research team	19 partners from 13 countries

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This project is funded by the European Union
under the 7th Research Framework Programme
(theme SSH) Grant agreement no. 290693