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Research Paper 419

AFRICAN ECONOMIC RESEARCH CONSORTIUM
CONSORTIUM POUR LA RECHERCHE ÉCONOMIQUE EN AFRIQUE

Bringing Rigour and Evidence to Economic Policy Making in Africa

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AERC Research Paper 419
African Economic Research Consortium, Nairobi
March 2021

THIS RESEARCH STUDY was supported by a grant from the African Economic Research Consortium. The findings, opinions and recommendations are those of the author, however, and do not necessarily reflect the views of the Consortium, its individual members or the AERC Secretariat.

Published by: The African Economic Research Consortium
P.O. Box 62882 - City Square
Nairobi 00200, Kenya

ISBN 978-9966-61-117-8

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List of abbreviations and acronyms

FASID	Foundation for Advanced Studies on International Development
GRIPS	National Graduate Institute for Policy Studies
IFPRI	International Food Policy Research Institute
NPA	National Planning Authority
OB	Operation Barga
RePEAT	Research on Poverty, Environment and Agricultural Technology
SSA	Sub-Saharan African countries
SSM	Sample Selection Model
TPM	Two Part Model
UBOS	Uganda Bureau of Statistics
WFP	World Food Programme

Abstract

This study uses household-, parcel- and plot-level data to analyse the effect of land tenure insecurity and land fragmentation on crop choice. We use formal land titling as a proxy for de jure land rights, and the perceived transfer rights over parcels as a proxy for de facto land rights. Using a two-part model, the study shows that both de jure and de facto land rights significantly increase the likelihood of planting perennial commercial crops, and also increase the hectares allocated to commercial crops. The results also show that when the rights to land are weak (i.e., no land titling and no transfer rights), farmers tend to grow annual crops. Land fragmentation affects more the choice of, and land allocation to, perennial crops than it does for other crop categories. Overall, the results suggest that there is a need for policies and laws that strengthen land tenure security, either through formal land titling or strengthening informal land rights, to promote the production of perennial and other commercial crops.

Key words: Land tenure insecurity; Land fragmentation; Crop choice; Uganda.

1. Introduction

Land is a major pillar of national development and source of livelihood for most developing countries which rely on agriculture (Lawry et al., 2017; Bugri, 2008). Therefore, factors that impede effective utilization of land have serious implications on economic development and poverty. Land tenure insecurity and land fragmentation are major factors that are prevalent in most sub-Saharan African countries (SSA).

Land tenure insecurity is blamed on the communal nature of tenure systems in most SSA countries (see Oladele et al., 2011; Bugri, 2008; Sjaastad & Bromley, 1997), while land fragmentation is caused by population explosion and practices of equal inheritance among siblings (Ali et al., 2015). Empirical evidence shows that tenure insecurity reduces investment in land, and impedes efficient land allocation, which in turn affects agricultural productivity (Besley, 1995; Deininger & Jin, 2006; Goldstein & Udry, 2008; Fenske, 2011; Bellemare, 2013; Mwesigye & Matsumoto, 2016). Farmers are less likely to invest in land if they are not sure of recouping the benefits from the investment in future. Land tenure insecurity also affects portfolio choice of crops. A study by Voors et al. (2012), on land insecurity in Burundi, found that households with land disputes had lower shares of cash crops grown in total production.

Land fragmentation is another factor that affects land use and agricultural performance. Land fragmentation is mainly caused by partible inheritance and population growth. Fragmentation raises the cost of land in borders and of labour in moving among fragments (Eastwood et al., 2010). Land fragmentation leads to increased travel times, more boundary waste, non-feasible small-scale unproductive investments, and increased supervision costs of labour, which negatively impact on-farm activities (Monchuk et al., 2010). It, therefore, follows that addressing tenure insecurity and land fragmentation challenges would help boost agricultural performance in most sub-Saharan African countries. Both tenure insecurity and land fragmentation are endogenous and their net effect on agricultural productivity is ambiguous a priori. Farmers can invest in land to enhance tenure security especially if that investment can reduce expropriation risk (Place & Otsuka, 2002; Deininger & Jin, 2006). In addition, farmers can acquire more parcels of land to diversify crops, and to reduce the likelihood of losing the entire land, especially in areas where land tenure insecurity is high. Therefore, it is important to control for tenure insecurity when examining the agricultural impacts of land fragmentation and vice versa.

Tenure security is a matter of public concern in Uganda. Land in the country is increasingly getting scarce, largely propelled by the rapid population growth rate. Indeed, the country's population growth rate is second in SSA after Niger (Uganda Bureau of Statistics [UBOS], 2016; World Bank, 2018)[1]. Due to land scarcity, land fragmentation has increased, mostly in regions with high population density. Fragmentation of land has attracted government attention, indicated by the president's repeated calls to farmers to consolidate family land and work as groups, rather than sub-dividing it among the children into small fragmented parcels, so as to aid agricultural commercialization. The current agricultural sector strategic plan (2015/16 to 2019/20) intends to promote commercialization of prioritized agricultural commodities, especially among smallholder farmers because most of them (about 69%) are still stuck in subsistence production (World Food Programme and National Planning Authority [WFP & NPA], 2017). The plan to promote agricultural commercialization is justifiable as it is one of the critical drivers of poverty reduction and welfare improvement. As such, it is important to understand whether and how land tenure insecurity and land fragmentation can affect commercialization of agriculture in Uganda, through crop choice.

The rest of the study is organized as follows. In the next section, we provide the context of the land tenure arrangements and the existing land policy and strategies in Uganda. In section three, we provide a survey of the related literature on land tenure. Section four presents the measurement indicators for land fragmentation, crop choice and tenure security. The data and descriptive statistics, and the estimation methodology, are provided in sections five and six, respectively. Section seven presents the results, while section eight concludes.

2. Uganda's land tenure systems, fragmentation and policy frameworks

Land is the most important factor of agricultural production in Uganda and its security enhances food and nutrition security (World Food Programme and National Planning Authority [WFP & NPA], 2017). Land tenure security[2] is especially critical for poor people living in rural areas and depending on agriculture for their livelihood. In Uganda, over 78% of the total population live in rural areas (Uganda Bureau of Statistics [UBOS], 2016) and agriculture employs about 75% of the rural labour force.

Land is scarce, with the average holding estimated at 1.1 hectares per household, and farmers largely practise subsistence farming. Transforming the sector into commercialized agriculture would require increased land investment to enhance crop intensification, and the production of commercial crops. However, there are still low levels of technology adoption in the country. For example, in 2014, 85% of farmers reported that they did not use fertilizers and planted local seed, while about 6.5% of farmers combined fertilizers and improved seed, suggesting very low levels of intensification. Evidence indicates that tenure insecurity has affected agriculture productivity in Uganda (Deininger & Castagnini, 2006; Mwesigye & Matsumoto, 2016). Thus, it is important that farmers gain secure access to land to encourage land investment and increased productivity, because this reduces vulnerability to hunger and poverty.

There are four legally recognized land tenure regimes in Uganda (freehold, leasehold, customary and Mailo), with varying levels of tenure security and land rights (The 1995 Constitution of Uganda). Customary tenure is the dominant system, constituting about 80% of the total land in Uganda. A study by Mwesigye et al. (2017) showed that this tenure regime is evolving from communal to private land ownership due to rural-to-rural migrations and population pressure. In communities where the land rights are more privatized, individuals have full rights to sell and bequeath land without seeking approval from the extended family or clan members. In other communities where private land rights are weak, individuals are required to seek the approval of clan heads or other extended family members before transferring land; where land rights are purely communal, transfer rights are restricted. Therefore, the customary tenure regime contains private and communal elements (Businge, 2002).

Mailo is another land tenure system in Uganda. In central Uganda (Buganda kingdom), the colonialists introduced the Mailo tenure system where land, about 19,600 square miles, was divided into mile blocks (hence Mailo) and given to chiefs

and other officials with their titles in the Buganda kingdom through the Buganda Agreement of 1900 (West, 1965; Rugadya, 1999). Former peasants who were cultivating the land never got a share and instead became tenants, obliged to pay rent to title holders. Since then, a landlord-tenant relationship has been created. Landlords own titles, but tenants have usufruct rights. Since the tenants have been on the land for long, they consider it theirs, which creates overlapping rights, and has catalysed land disputes (Deininger & Castagnini, 2006). To enhance tenants land rights, the government, through the 1998 Land Act and 2010 Amended Land Act, stipulated that tenants that have been on land for 12 years cannot be evicted by their landlords without full compensation. In addition, the Acts state that if the landlords want to sell land, they should give the priority to current tenants. The laws have thus strengthened the land rights of both tenants and occupants on Mailo land (Republic of Uganda, 1998; 2010). Studies have found that the registration of land under the Mailo tenure system has not improved investment in land (Deininger & Ali, 2008). This suggests that the overlapping land rights created by the Mailo tenure system offset the security that comes with land registration. While other land tenure arrangements have revolved around customary land, the Mailo land tenure has not changed much, and is still characterized by landlords with full rights, and tenants and occupants with limited rights.

Land rights are most secure under freehold and leasehold tenure systems, which account for the smallest share of land in Uganda.[3] These two tenure regimes grant land titles to owners, which increase tenure security. Individual farmers enjoy full rights, such as transfer rights, rights to bequeath and to give, and the right to use land as collateral. Under freehold, land is held in perpetuity and the owner is issued with a title. In leasehold, the same full rights are exercised as in freehold up to the expiration of a lease, usually 49 ord 99 years.

In 2013, the Government of Uganda formulated a National Land Policy to address land access and tenure security issues. The policy provides a framework for articulating the role of land in national development, land ownership, distribution, utilization, alienability, management and control of land (Republic of Uganda, 2013). The policy maintains and recognizes the four tenure systems (customary, freehold, leasehold and Mailo) as enshrined in Uganda's constitution. However, as earlier noted, the most predominant system (customary) does not fully guarantee tenure security to the occupants since their rights to transfer the land are restricted. Thus, by analysing the consequences of restricted land transfer rights (a form or cause of tenure insecurity), the study findings can inform the review of the National Land Policy and strategies.

Furthermore, the National Land Policy recognizes that excessive land fragmentation is a common practice, especially in the densely populated areas such as Kigezi highlands, and is believed to negatively affect agricultural production potential. The policy identifies strategies to institute public education on the consequences of land fragmentation and sensitize the public on the value of land as a wealth producer and a factor of production. Therefore, this study strongly contributes to the attainment of this

strategy by generating research-based evidence on the impact of land fragmentation on investment in agriculture.

Land tenure insecurity has been identified as one of the key causes of low agricultural production and productivity in Uganda. It is said to affect investments on land, especially investments in long-term high value crops such as coffee (WFP & NPA, 2017). Land tenure insecurity exists in Uganda because institutions that have to deal with land administration and land disputes have remained weak (Mwesigye et al., 2017). Land tenure insecurity is a source of conflict within families, and between groups and communities. Land conflicts render land inaccessible for production and yet resolution in the high court takes quite a long time and is costly.

Given that land tenure security is of high relevance to the policy debate and land fragmentation is increasingly high, our study seeks to answer the following research questions, among others:

- Is crop choice (between annual and perennial commercial crops) influenced by land tenure security and land fragmentation?

- Is the production intensity of adopting commercial crops (proportion of land allocated to a specific crop category) affected by land tenure security and land fragmentation?

Objectives of the study

The overarching objective of this study is to examine whether land tenure security and fragmentation impact on agricultural commercialization through crop choice in Uganda.

Hypotheses

We use the two key indicators of land rights and tenure security to derive our hypotheses. These are de jure land rights, which are derived from the ownership of formal land titles, and de facto land rights, which are derived from community-specific norms and practices regarding land use, land rights and tenure security. These informal arrangements shape individuals' perceptions about the form of rights they possess over the land they occupy such as land transfer rights (see Bellemare, 2013; Besley, 1995). The study empirically tests the following null hypotheses:

- Land titling has no differential effect on the choice between perennial commercial and other crop types, and on the production intensity.

- There is no differential effect of perceived land transfer rights on the choice between perennial, commercial and other crop types, and on the production intensity.

- Land fragmentation has no differential effect on the choice and production intensity between perennial, commercial and other crop types.

3. Literature review

The challenge of land tenure insecurity is not unique to Uganda but occurs in several other countries. While in some countries (such as Burkina Faso, Ethiopia, India and Ghana) the impact of land tenure insecurity on agricultural commercialization and productivity has been studied, in the case of Uganda, empirical evidence on the same remains scanty.

One of the earliest attempts to examine the link between land tenure insecurity and investment incentives was by Besley (1995). The author looked at six categories of de facto land rights in Ghana—the right to sell, rent, gift, mortgage, pledge or bequeath. He found that having land rights (secure tenure) significantly matters for investment in trees; an extra right with approval from lineage raises the probability of investing in trees by 2.5%.

Banerjee et al. (2002) studied the effect of the Operation Barga (OB) programme on agricultural productivity in the Indian state of West Bengal. The OB programme offered incumbent tenants security of tenure and regulated the share of output that was paid as rent—tenants were given the right to claim a higher share of output. Following the launch of the OB programme, there was significant improvement in terms of tenants' contracts and more secure tenure. Analysis based on district-level data revealed that the Operation Barga programme had a positive and significant effect on agricultural productivity; 28% of the increase in agricultural productivity in West Bengal state was attributed to implementation of the OB programme.

In another study, Banerjee and Iyer (2005) investigated investment and agricultural productivity differences between landlord and non-landlord areas in India. Landlord areas are associated with higher tenure insecurity—landlords set terms for the tenants. The investigations revealed large significant differences in measures of agricultural investment and productivity between landlord and non-landlord areas. For example, non-landlord areas had a 24% higher proportion of irrigated area, 43% higher levels of fertilizer use and a 27% higher proportion of rice area under high-yielding varieties.

More recent literature has revealed that the impact of land tenure insecurity sometimes varies by type of land-related investment. When Deininger and Jin (2006) assessed the link between tenure security and land productivity-enhancing investments, they found that insecure tenure significantly encouraged tree planting but discouraged terracing (a soil erosion control measure). Ali et al. (2011) provide

strong evidence indicating that tenure insecurity negatively affects agricultural commercialization. Farmers with limited land transfer rights and perceived tenure insecurity tend to minimize the share of land allocated to the production of perennial crops such as coffee and eucalyptus. A study by Lovo (2016) analysed the impact of tenure insecurity on adoption of soil conservation measures in Malawi. The author focused on two main sources of tenure insecurity; informal short-term tenancy contracts and customary gender-biased inheritance. She found that tenure insecurity reduces the probability of investing in soil conservation measures. Linkow (2016) estimated the impact of land tenure insecurity on agricultural productivity in Burkina Faso. The author found that tenure insecurity in form of perceived risk of land conflict or expropriation reduces agricultural productivity by at least 8.9%. This means there would be substantial productivity gains if the tenure security of farming households is guaranteed (Linkow, 2016).

Land fragmentation is linked to agricultural commercialization through its effects on agricultural productivity and technical efficiency. Tan et al. (2010) used number of plots, average plot sizes and average distance of plots to the homestead to measure land fragmentation, and analysed the impact on rice producers' technical efficiency in Southeastern China. The authors found that land fragmentation strongly reduces farmers' technical efficiency. Additional evidence from Northwestern Ethiopia indicates that land fragmentation reduces farm profitability (Gashaw et al., 2017). However, other studies have found that fragmentation is productivity enhancing, stimulates crop diversification and reduces food insecurity. For example, Ali et al. (2019) found that, while fragmentation increases the time required to move between a household's parcels, this does not appear to affect overall technical efficiency on the farm in Rwanda. Fragmentation rather reduced the incidence of crop shocks and increased yields and productive efficiency. Also, a study by Ciaian et al. (2018) found that land fragmentation stimulates significantly more diversification for subsistence farm households than for market-oriented households. In addition, Knippenberg et al. (2018) analysed the effect of land fragmentation in Ethiopia and found that it reduces food insecurity through mitigating the adverse effects of low rainfall.

Overall, existing empirical studies have examined the link between tenure security and agricultural productivity and land-related investments. A few have analysed the impact of land fragmentation on agricultural productivity and profitability but the results are inconclusive. For example, while land fragmentation had a positive effect on production efficiency and productivity in Rwanda, it was found to negatively affect technical efficiency in Ethiopia and China. In this study, apart from the aforesaid linkages, we assess jointly the impact of land tenure insecurity and land fragmentation on agricultural commercialization.

4. Measurements and indicators

Tenure security measures

We use tenure security as a general term that captures the various ways in which households and individuals can have secure rights to land, including formal land titles and more informal types of tenure security. We analyse how both de jure and de facto rights to land influence farmers' choice of which crops to grow. De jure rights are mainly derived from formal land titling and registration. While titling has been the focus of land policy reforms, empirical studies have found mixed results regarding whether titling enhances tenure security and increases agriculture performance. For example, studies by Bellemare (2013) and Jacoby and Minten (2007) found no effect of formal land titles on agriculture productivity in Madagascar. In addition, a study by Atwood (1990) argues that titling may not be security enhancing especially if it conflicts with community-level land use practices. On the other hand, land formalization has been found to enhance agriculture performance in Ethiopia (Deininger et al., 2011). Due to these mixed results, Lawry et al. (2017) recommended the need for further research on interregional differences and on the role of customary tenure arrangements.

The de facto rights are derived from community-specific customary norms and practices regarding land use, land rights and tenure security. Therefore, de facto land rights capture landowners' subjective perceptions of what they can and cannot do with their plots. If farmers can transfer their land without seeking for approval, and bequeath or use land as collateral, then their right to land is more secure. Empirical studies have found a positive effect of the informal customary land rights on agriculture productivity (see Bellemare, 2013; Besley, 1995). It thus follows that whether formal or informal land rights enhance agriculture performance depends on the land owners' perceptions about whether their land rights are secure. This study uses land titling as an indicator of formal land rights, and land transfer rights as measures of de facto or informal land rights. We use the three levels of perceptions about the rights to transfer land: whether a farmer can transfer land without any approval, whether the farmer needs approval to transfer land, or whether they have no transfer rights at all.

Measure of land fragmentation

Land fragmentation is a spatial phenomenon which depends on many parameters such as holding size, number of parcels belonging to the holding, size of each parcel, shape of each parcel, the spatial distribution of parcels, and distance to parcels (Blarel et al., 1992; Kadigi et al., 2017). For this study, we use Simpson Index to measure land fragmentation because it is sensitive to both size of parcels and number of parcels. There are a number of studies which have used Simpson Index as an indicator of land fragmentation (see Ciaian et al., 2018; Knippenberg et al., 2018; Ali et al., 2015; Monchuk et al., 2010; Blarel etal., 1992). In addition to Simpson Index, we use walking time (in minutes) from the homestead to the parcel to capture the time costs of land fragmentation.

The Simpson Index takes the following form:

$$SI = 1 - \frac{\sum_{i=1}^{n} A_i^2}{A^2} \tag{1}$$

Where, SI = the Simpson Index; i refers to individual plot, A_i = the area of the i^{th} plot, and $A = \sum_{i=1}^{n} A_i$ is the total sum of individual plot areas, while A is the total land holding in hectares. A value of zero indicates complete land consolidation (one parcel only), while a value of one is approached by holdings of numerous parcels of equal size. However, because the Simpson Index is sensitive to dispersion and the size of the parcels as well as to their number, we also use the number of parcels as an alternative fragmentation measure. A similar approach was used by Blarel et al. (1992).

Measures of different crops grown by the farmer

This study examines the relationship between land tenure security, land fragmentation and different kinds of crops grown, specifically the choice between annual crops and commercial perennial crops. The annual crops considered in this study include legumes and cereals such as beans, soya beans and maize. The other annual crops include rice and vegetables. The perennial commercial crops include Uganda's traditional export crops such as coffee, cotton and tea, and root tubers such as cassava. We also categorize bananas as perennial crops because of their long maturity period. While annual crops can be planted and harvested in one season, the perennials take long to mature and require a significant investment. We also capture trees as long-term perennials. Trees can be planted on a commercial scale, in which case they are affected by the land rights, and on a very small scale purposely to enhance tenure security. Studies have found that farmers plant trees to enhance their rights over land (Place & Otsuka, 2002). Therefore, the relationship between land rights and tree planting is unknown a priori.

5. Data and descriptive statistics

Data

This study utilizes household-, parcel- and plot-level data collected as part of the Research on Poverty, Environment and Agricultural Technology (RePEAT) surveys from rural Uganda from 2003 to 2015. The sample for the RePEAT survey builds upon a research project on policies for improved land management in Uganda, conducted by the International Food Policy Research Institute (IFPRI) and Makerere University from 1999 to 2001 (Pender et al., 2004). The latter involved a survey of 107 villages selected from two-thirds of the regions in Uganda, including the more densely populated areas and areas that were free from wars in the southwest, central, east and parts of northern Uganda and representing seven of the nine major farming systems of the country. Because of insecurity in the north and northeastern parts of the country, villages in this region were excluded from the surveyed samples. Within the study region, villages (the lowest administrative units) were selected using a stratified random sample, with the stratification based on development domains defined by the different agro-ecological and market access zones, and differences in population density.

The RePEAT survey covers 94 villages which are the smallest administrative units in Uganda.[4] From each village, ten households were randomly selected to make a total of 940 sample households (Yamano et al., 2004). The RePEAT surveys were jointly conducted by Makerere University, the Foundation for Advanced Studies on International Development (FASID), and the National Graduate Institute for Policy Studies (GRIPS) in 2003, 2005 and 2009, and by Makerere University and GRIPS in 2012/2013 and 2015.

RePEAT surveys captured information on household characteristics, land tenure and tenancy arrangements, land titling and documentation, different forms of land use and land transfer rights, crops produced and land allocation to each crop. The survey was extended to Nothern and Northeastern Uganda in 2015, and therefore the latest survey phase covered all regions of Uganda.

RePEAT panel surveys have suffered from attirition over the years. The sample in 2003 was 940 households, but reduced to 936 households in 2005 and, hence, the attrition rate was 0.4%. In 2012, the panel sample size reduced to 778 households, resulting in an attrition rate of 17%. In 2015, the original panel sample reduced further to 609, and the attrition rate rose to 35%. In 2012 and 2015, the households that could not be traced were randomly replaced by their previously neighbouring households.

In addition, the 2015 survey expanded the scope to include the northern region. This study utilizes the 2003 and 2012 data because it captured the land rights and tenure security variables which are key for our analysis. The focus of the analysis is land tenure security, land fragmentation and crop choice. Accordingly, information on land tenure systems, tenancy arrangements, titling and transfer rights form the core of this study. However, the 2005 panel round missed information on land tenure systems, and as a result, we drop this data set.

Descriptive statistics

Table 1 presents the trends in household characteristics from 2003 to 2012. The average land holding increased from 2.16 hectares in 2003 to 2.86 hectares in 2012. This increase might be explained by the fact that households acquired more parcels. Indeed, the number of operated parcels increased from 2.6 in 2003 to 3.2 in 2012, and the difference is statistically significant at 1%. The Simpson Index (a measure of land fragmentation) is also consistent with the statistics on the number of parcels. The index increased from 0.35 in 2003 to 0.43 in 2012, suggesting an increase in land fragmentation.

Table 1: Household characteristics

Variable	2003		2012		ttest: 2012-2003
	MEAN	SD	MEAN	SD	
Total land holding (ha)	2.16	2.87	2.86	6.48	0.70(0.005)**
Number of parcels	2.62	2.14	3.20	2.19	0.58(0.000)***
Simpson Index	0.35	0.30	0.43	0.29	0.08(0.000)***
Female headed household (1/0)	0.004	0.06	0.002	0.04	-0.002(0.316)
Age of the household head	45.52	14.80	54.40	14.08	8.89(0.000)***
Household head's years of schooling	5.67	3.84	5.63	4.12	-0.04(0.8953)
Family size in adult equivalent unit	7.34	4.39	9.50	4.00	2.15(0.000)***
Total assets value in USD (1 US$=1,994 UGx in 2003)	124	291	542	1014	419(0.000)***
Per capita consumption expenditure (US$)	100	106	338	202	238(0.000)***
Number of households	778		778		

Source: Authors' computations using RePEAT panel data set. *** is significant at 1%, ** at 5%, and * at 10%.
P-Values are in parentheses.
Note that the value of assets is in constant prices using 2003 exchange rate as a base.

Other household characteristics that changed between 2003 and 2012 are the age of the household head, which increased from 45 to 54 years. The diffrerence matches the gap between the two surveys, confirming the balanced panel that we use in the analysis. The household heads' schooling years did not change, while the household family size reduced by almost 1 member, suggesting that some family members left the households, either to start their own families or to live independently. However, the family size in adult equivalent units increased between the two survey periods.

This indicates that, on average, more household members were of adult age in 2012 than they were in 2003.

Over the two survey rounds, households became wealthier both in terms of asset values and per capita household consumption expenditure. The average value of assets was US$124 in 2003 and it increased almost five-fold to US$542 in 2012. As a result, consumption expenditure per capita (using adult equivalent) significantly increased from US$100 per person in 2003 to US$338 per person in 2012.

Table 2 presents parcel characteristics. While the number of parcels operated by the households and thus land fragmentation increased (see Table 1), the average distance (minutes) to parcels remained the same at 18 minutes between 2003 and 2012. With regard to land rights, the proportion of titled parcels did not significantly change over the survey period. In 2003 and 2012, 4% and 5% of parcels were titled, respectively. The statistics, however, show that informal land rights have improved over time. The proportion of parcels where farmers have full transfer rights increased during the survey periods. In 2003, farmers reported to have sale rights without consulting anyone for over 62% of the parcels they operated, and this significantly increased to 72% in 2012. Accordingly, the proportion of parcels over which farmers have no rights to sell reduced from 21% to 16% between 2003 and 2012. In addition, the percentage of parcels over which farmers need approval from the clan or extended family member to sell also decreased from 17% to 12% between 2003 and 2012. These statistics indicate that de facto land rights are improving over time, while de jure rights are still weak in Uganda.

Table 2: Parcel characteristics: Accessibility, land rights and tenancy arrangements

Variable	2003		2012		ttest: 2012-2003
	MEAN	SD	MEAN	SD	
Distance to parcel (minutes)	17.78	47.04	17.80	33.00	0.02(0.988)
De jure rights: Land title (1/0)	0.04	0.20	0.05	0.22	0.01(0.115)
De facto land rights: Variable takes 1 if HH has:					
Rights to sell parcel	0.62	0.49	0.72	0.45	0.10(0.000)***
Has no right to sell	0.21	0.41	0.16	0.37	-0.05(0.000)***
Can sell with approval	0.17	0.37	0.12	0.32	-0.05(0.000)***
Tenancy arrangement: Takes 1 if the HH is:					
Owner	0.80	0.40	0.74	0.44	-0.05(0.001)***
Occupant	0.13	0.34	0.08	0.27	-0.05(0.000)***
Tenant	0.07	0.26	0.18	0.38	0.10(0.000)***
Mode of land acquisition: Variable takes 1 if parcel was:					
Purchased	0.44	0.50	0.48	0.50	0.04(0.019)**
Inherited	0.43	0.49	0.38	0.49	-0.04(0.004)**
Rented-in	0.08	0.27	0.09	0.29	0.01(0.135)
Borrowed-in	0.01	0.11	0.04	0.20	0.03(0.000)***
Number of parcels	2,039		2,057		

Source: Authors' computations using RePEAT panel data set. *** is significant at 1%, ** at 5%, and * at 10%. P-Values are in parentheses.

In terms of tenancy arrangements, the percentage of parcels that are owned by farmers reduced from 80% in 2003 to 74% in 2012, while the percentage of land over which farmers are tenants increased significantly during the same period, from 7% to 18%. This suggests that land markets are improving and farmers can access land through renting. Indeed, land purchase as a mode of land acquisition increased, while inheritance decreased over the study period.

Table 3 presents the statistics on the crops grown by the surveyed households. The crop analysis is at the plot-level. There can be many plots in one parcel and farmers can grow different crops on different plots under the same parcel. For this analysis, crops were cartegorized into short-term perennial commercial crops such as coffee, cotton, root tubers (such as cassava) and bananas; annual crops such as legumes and cerelas, vegetables and rice; and long-term perennial trees.

Table 3: Crops grown in Uganda between 2003 and 2012

Variable	2003		2012		2012-2003
	MEAN	SD	MEAN	SD	
Perennial commercial crops					
1 if traditional export crops are grown	0.05	0.22	0.13	0.34	0.08(0.000)***
1 if root tubers are grown	0.22	0.41	0.23	0.42	0.01(0.063)*
1 if bananas are grown	0.19	0.40	0.09	0.28	-0.11(0.000)***
Overall proportion of plots with perennial crops	0.46	0.50	0.45	0.50	-0.02(0.061)*
Annual crops					
1 if legumes and cereals are grown on a plot	0.50	0.50	0.48	0.50	-0.02(0.061)*
1 if rice is grown	0.00	0.01	0.01	0.09	0.01(0.000)**
1 if vegetables are grown	0.02	0.12	0.02	0.13	0.00(0.227)
1 if seasonal fruits are grown	0.00	0.05	0.00	0.05	0.00(0.872)
1 if animal feed is grown	0.00	0.08	0.00	0.04	0.00(0.0002)***
1 if sim sim is grown	0	0	0.00	.05	-0.00(0.001)***
Overall proportion of plots with annual crops	0.53	0.50	0.51	0.50	-0.01(0.382)
Overall proportion of plots with trees	0.01	0.13	0.03	0.18	0.02(0.000)***
Land allocated to each crop category in hectares					
Perennial/commercial crops (ha)	0.39	0.86	0.28	0.60	-0.11(0.000)***
Annual crops (ha)	0.30	0.56	0.29	0.54	-0.01(0.077)*
Trees (ha)	0.02	0.31	0.01	0.17	0.00(0.284)
Number of plots	5,417		7,514		

Source: Authors' computations using RePEAT data set.
Notes: There can be more than one plot in one parcel and hence the number of plots can be greater or equal to the number of parcels. Traditional export crops include coffee, tea, cotton and sugarcane.

For all the survey rounds, annual crops were the most grown, followed by perennial crops and trees, respectively. For example, in 2003, short-term perennial crops were grown on 46% of the plots, while annual crops were grown on 52% of the plots. Trees were only grown on 2% of the plots. Comparing the years reveals that the proportion of plots on which perennial crops are grown declined by 2 percentage points between 2003 and 2012, while those on which annual crops are grown remained the same. The trees take a very small percentage of land (about 2%) but the allocation has increased over time.

Table 3 also presents the land allocated to these crop cartegories in hectares. Consistent with the percentage of parcels allocated to perennial crops, the area (ha) reduced significantly from 0.39ha in 2003 to 0.28ha in 2012. The hectares allocated to annual crops slightly reduced from 0.3ha to 0.29ha while that allocated to trees reduced from 0.2ha to 0.1ha. The overall decline in land allocated to the three crop cartegories might be explained by population pressure and the resulting land scarcity.

Looking at specific crops as of 2012, legumes and cereals were the most grown crops (on 48% of the parcels), followed by root tubers (on 23% of land), traditional export crops (on 13% of parcels) and bananas (on 9% of land).

6. Estimation methodology

The effects of land tenure security and fragmentation on crop choice and production intensity

We use a double-hurdle model (two-part model) to examine how land tenure security and fragmentation influence crop choice, specifically the likelihood of growing a crop type, and the intensity of production, using land allocated to a crop as an indicator. The use of double-hurdle is motivated by the fact that farmers are sequentially faced with two production choices. The first choice is what kind of crops to grow. The second choice is, conditional on the choice of crops to grow (whether perennial commercial crops, annual crops or trees), how much land should be allocated. It thus follows that the land allocated to a given crop cartegory is zero if the crop is not grown.

An econometric concern for modelling the production choice and intensity is that not all households grow a specific crop type, hence the land allocated to a given crop type for no-growers is zero. Thus, the distribution of the observations for land allocated to a given crop type exhibits a large number of cases lumped at zero, and then a distribution of cases greater than 0, exhibiting a large positive skew, which can create problems for standard ordinary least squares (OLS) regression. Thus, we use Cragg's (1971) double-hurdle model, a bi-variate generalization of the Tobit model which, unlike Tobit, allows the decisions about whether to grow sugarcane and how much area to plant it on to be determined by different processes.

In the TPM (two-part model), we observe an outcome y, which is either zero or greater than zero. Therefore, TPM is prefered when the zeros are observed, meaning that there is no missing data on those who choose not to participate. Other related specifications such as sample selection models (SSM) are used when we do not observe zeros because the non-participants are not surveyed and there is missing data, hence we only have potential zeros (Madden, 2008). For example, when we examine the effect of education on wages, we do not observe wages for those out of the work force. SSM is used in this case to model the potential wages of those that are not working. In this study, we observe the land allocated to different crop categories. When a certain crop is not grown, the land allocated to it is zero, and when it is grown, the land allocated takes a value greater than zero. Therefore, practically, TPM is the best model for our current data structure.

In the TPM, we observe an outcome y which is either zero or greater than zero. Using the notation in Wooldridge (2010, section 17.6) and (Drukker, 2017), the observed y is given by;

$$y = s.w \tag{1}$$

Where,

$$s = \begin{cases} 1 & if \quad X\alpha + \mu > 0 \\ 0 & otherwise \end{cases} \tag{2}$$

Where, s is a variable that takes either zero or not zero depending on the farmers' choice to grow a crop category, and w is a variable which takes non-zero outcomes when $s = 1$. Therefore, $w = X\alpha + \mu$. Drukker (2017) showed that TPM works well even when we do not impose conditional mean independence and allow that, $E[w|\mathrm{x}, \mathrm{s}] \neq E[w|\mathrm{x}]$.

For this analysis, y is a semi-continuous variable for the land allocated to different crop types - commercial, annual crops and trees. This outcome variable takes 0 if a given crop type is not grown, and is greater than 0 if the land is allocated to a crop type. Meaning that we observe the land allocated to commercial crops when there is a decision to grow commercial crops.

The two-part model is estimated by a Probit model for the probability of observing a positive value of y along with generalized mixed models on the sub-sample of positive observations. The two parts are a model for the binary response variable and a model for the outcome variable that is conditioned on the binary response. We estimate the following regression equation:

$$y_{pi} = \alpha + \gamma TS_{pi} + \varphi SI_i + \vartheta M_{pi} + \partial X_i + \varepsilon_{pi} \tag{3}$$

where TS_{pi} is a tenure security measure, and we use de jure and de facto land rights as indicators. In one specification, TS_{pi} is a dummy that takes 1 if the household i has a title over parcel p. In a different specification, TS_{pi} is a dummy that takes 1 if a household has full transfer rights over the parcel p, or has transfer rights with approval, and 0 if the household has no rights at all. We conduct a parcel-level analysis because land rights, and hence tenure security, vary across parcel owned by the same household.

SI is the Simpsons Index which measures land fragmentation at a household-level and ranges from 0 to 1. It takes 0 if a household has one parcel and 1 if it has infinite parcels. The index captures the number of parcels and their relative sizes. M_{ip} is a vector of parcel characteristics such as distance to the parcel in minutes. X_i is a vector of household characteristics, including household head's age, square of age, gender, years of schooling, family size, and value of household assets (in Uganda shillings), and ε_{ip} is the idiosyncratic error term that is assumed to be normally distributed.

Robustness checks

Heckman sample selection (HSS) model

The key assumption for using TPM is that the error terms for participation and area allocated to a crop category are independent. However, there is an alternative simplifying assumption to independence, known as first hurdle dominance, i.e., that the decision to grow a crop category dominates the area allocation decision (see Madden, 2008). This implies that the observed zero land allocated to each crop does not arise from a standard corner solution but represents a separate discrete choice.

From Equation 2, first hurdle dominance implies that $P(y > 0 \mid s = 1) = 1$ and $g(y|y > 0, s = 1) = g(y|s = 1)$. If we allow for the possibility of dependence between the disturbance terms, we apply the Heckman sample selection model (HSS) and the likelihood function is:

$$\prod_{0}[1 - p(\mu > -\alpha' X)] \prod_{+} p(\mu > -\alpha' X) g(y|\mu > -\alpha' X) \tag{4}$$

For robustness checks, we estimate Equation 3 using the HSS model.

Estimation using fixed effects

We also apply the household fixed effects (FE) model for robustness checks. This model exploits the panel structure of the data used. The statistics show significant changes in de facto land rights, specifically the right to transfer land without and with approval. We thus use the FE model to examine the within household changes in land rights and how this affects the amount of land allocated to each crop. This model, however, does not adjust for the sequential nature of participation and land allocation decisions. In addition, as indicated in the statistics (see Table 2), the percentage of titled parcels did not change over the two periods. This suggests that the FE model may not be

applied to model the effect of change in titling on the choice of crops. Therefore, we only use FE to examine the effect of de facto land rights on land allocated to different crop categories using the following equation;

$$y_{pit} = \alpha + \gamma TS_{pit} + \varphi SI_{it} + \vartheta M_{pit} + \partial X_{it} + \varepsilon_{pit} \quad (5)$$

where, t refers to time period and other variables are as specified in Equation 3.

7. Estimation results

This section presents the results generated using TPM as the main estimation methodology, and selection and fixed effects models for robustness checks. Throughout the analysis, data for 2003 and 2012 is pooled. We could have used only 2012 data but there was a 17% attrition rate, which reduced the number of sample households from 940 in 2003 to 778 in the 2012 survey.

Land tenure security and fragmentation effect on crop choice and production intensity

Table 4 presents TPM results on the effect of formal land titling, which grants farmers de jure land rights (proxy for tenure security), and land fragmentation on crop choice. The table presents estimation results for the determinants of whether to grow commercial perennial crops, annual crops or trees, with land titling and land fragmentation as variables of interest. In addition, the table presents the results on how land titling and fragmentation influences land allocation (in hectares) to each of the three crop categories. Specifications (1) and (2) show how land titling and fragmentation influence the choice and intensity of perennial crop growing. Specifications (3) and (4) show the same for annual crops while specifications (5) and (6) present the results on the determinants of growing trees.

The results show that there are heterogeneous effects of titling on crop choice. Titling positively affects the production of perennial crops but not annual crops and trees. There is a significantly high likelihood of growing perennial commercial crops on titled parcels compared to those that are not titled. Having a title is associated with 28% higher likelihood of growing perennial commercial crops compared to untitled parcels. In addition, the land allocated to perennial commercial crops is 0.36 hectares higher if the parcel is titled, significant at 1%, compared to untitled parcels. Regarding annual crops, the results show that there is a 25% less likelihood of growing annual crops on titled parcels compared to the untitled ones. The results also show no effect of land titling on the area allocated to annual crops. In addition, there is a 19% less likelihood of growing trees on titled parcels compared to untitled ones. However, for those that grow trees, land titling enhances the land allocated to trees.

These findings are consistent with our hypothesis that land tenure security affects

more the production of perennial commercial crops than it does annual crops and trees. Perennial commercial crops require a large investment whose return comes after a long time compared to annual crops. Therefore, farmers are more likely to allocate titled and secure land to the production of perennial commercial crops and less secure land to production of annual crops, which have a short maturity period of about three months. The result on the titling effect of tree planting shows that those with titles are less likely to grow trees. This is consistent with past studies, which show that trees are planted to enhance tenure security suggesting that when the farmers' tenure is secured through titling, they do not grow trees. However, if the farmer decides to grow trees, tenure security is key in determining the intensity of tree production.

The results also show that land fragmentation hurts more the production of perennial commercial crops, than it does annual crops and trees. We find that a one percentage point change in land fragmentation measure is associated with a 23% lower likelihood of growing perennial crops, and 0.63 less hectares allocated for the same crops. On the other hand, land fragmentation increases the likelihood of growing annual crops but reduces the land allocated to the same crop. In addition, land fragmentation reduces the likelihood of growing trees but has no effect on the land allocated to trees. Land fragmentation increases monitoring costs and thus discourages the production of valuable crops. Also, land fragmentation curtails land investment by increasing the associated costs, and reducing land sizes to support mechanization. However, land fragmentation increases crop diversification, especially for annual crops like beans, which do not need significant investment. This might explain why land fragmentation increases the production of annual crops.

In addition, the results show that distance to parcel influences crop choice. A one-minute increase in the distance to parcel is associated with a 0.2% less likelihood of growing perennial commercial crops and 0.00245 less hectares of land allocated to perennial crops. However, the distance to the parcel increases both the likelihood and land allocated to annual crops. In addition, the distance only reduces the likelihood of growing trees but has no effect on the hectares allocated to trees. Distance, just like land fragmentation, increases the monitoring costs. In addition, the longer the parcel distance is from the homestead, the higher the likelihood of food theft. This thus discourages the production of valuable commercial crops.

Other factors influencing crop choice are: age of the household head and the age squared, schooling level of the household head, family size, assets and land size. The results show that young household heads are significantly more likely to grow perennial commercial crops, and fewer annual crops. However, as households age, the likelihood and intensity of growing commercial perennial crops reduce significantly as they switch to annual crops. This might be because perennial commercial crops require a lot of investment and labour, which only young households can afford. As expected, those with larger land holdings allocate more land to the production of all crops.

Table 4: Land titling and fragmentation effect on crop choice and production intensity

	Commercial Crops		Annual Crops		Trees (Long-Term)	
	Choice 0/1	Area (ha)	Choice 0/1	Area (ha)	Choice 0/1	Area (ha)
	(1)	(2)	(3)	(4)	(5)	(6)
Land title (1/0)	0.280***	0.356***	-0.254***	0.0514	-0.193*	0.754**
	(5.583)	(8.086)	(-5.028)	(1.344)	(-1.706)	(2.187)
Simpson Index	-0.227***	-0.633***	0.289***	-0.589***	-0.380***	0.109
	(-5.642)	(-15.97)	(7.182)	(-21.92)	(-4.373)	(0.398)
Distance to parcel (minutes)	-0.00223***	-0.00242***	0.00288***	0.000405**	-0.0118***	-0.00341
	(-5.128)	(-5.432)	(6.576)	(2.016)	(-5.641)	(-0.614)
Age of household head (years)	0.0116**	0.0148***	-0.0136***	-0.00696**	0.0146	0.0300
	(2.298)	(2.891)	(-2.703)	(-2.117)	(1.263)	(0.835)
Household head's age squared	-0.000103**	-9.88e-05**	0.000116**	8.10e-05***	-9.26e-05	-0.000275
	(-2.218)	(-2.089)	(2.498)	(2.663)	(-0.896)	(-0.868)
Household head years of schooling	0.000319	0.00205	-0.00179	0.0113***	0.0121*	-0.00453
	(0.106)	(0.690)	(-0.594)	(5.537)	(1.925)	(-0.256)
Female headed household (1/0)	0.0284	-0.336	0.0377	-0.218		
	(0.0858)	(-1.058)	(0.114)	(-1.004)		
Family size	0.00196	0.0207***	-0.00309	0.0305***	0.00578	-0.0231
	(0.740)	(8.095)	(-1.172)	(16.90)	(1.010)	(-1.186)
Total assets value in USD	4.84e-05***	3.10e-06	-4.48e-05***	5.16e-06	-2.08e-05	3.87e-05
	(3.517)	(0.262)	(-3.253)	(0.493)	(-0.602)	(0.310)
Total land in hectares	-0.000918	0.0266***	0.000852	0.0183***	-0.00193	0.0938***
	(-0.382)	(10.87)	(0.355)	(11.72)	(-0.369)	(3.283)
Constant	-0.301**	0.346***	0.310**	0.574***	-2.520***	0.389
	(-2.412)	(2.740)	(2.490)	(7.081)	(-8.426)	(0.404)
Year dummies	Y	Y	Y	Y	Y	Y
Observations	12,557	12,557	12,557	12,557	12,542	12,542

Notes: Robust z-statistics in parentheses. *** is significant at 1%, ** at 5%, and * at 10%.

One of the pathways through which land fragmentation affects agriculture is increasing travel time between parcels and hence increasing monitoring and management costs (Eastwood et al., 2010; Monchuk et al., 2010). Indeed, Table 4 indicates that while distance to the parcel reduces the production of commercial perennial crops, it increases the likelihood of planting annual crops and the intensity of allocation. Table 5 interacts titling and distance to the parcel to establish whether the effect of distance on crop choice varies by parcel titling status. The results show that distance reduces the likelihood of producing perennial crops and the intensity of production on untitled parcels, but titling attenuates the effect of distance on production of perennial crops. Indeed, the results show that the likelihood of producing commercial crops is significantly high on titled parcels even when the distance increases. We also find no significant effect of distance on the intensity of producing commercial perennial crops on titled plots.

In specifications (3) and (4) of Table 5, we show how the interaction of parcel titling and distance to parcel affect the production of annual crops. The results indicate that distance enhances the likelihood and intensity of growing annual crops on untitled parcels. However, we found that there is a significantly less likelihood of growing annual crops on titled parcels even when the distance increases. This suggests that when there is tenure security, the choice and production intensity of perennial crops remain high irrespective of distance. In addition, the choice and land allocation remain low. Also, distance has no effect on choice and intensity of growing trees. The rest of the results are similar to those in Table 4.

This study also examined whether some of the demographic characteristics interact with formal land titling to influence crop choice. Table A1 (in the appendix) reports the estimation results where land titling was interacted with education level of the household head. The results show that education level weakly affects the likelihood and intensity of any of the crop categories. However, interacting education level and land titling reveals that education reduces the likelihood of producing commercial crops when the parcel is titled, but increases the intensity of producing the same crop type. This implies that when the educated farmers have titles, they allocate land to other crops and not perennial commercial crops; but those who choose to grow perennial commercial crops allocate more land. Also, the results show that education level leads to an increase in the likelihood of growing annual and the intensity of producing the same crop when the land is titled. Therefore, while education alone may not affect farmers' choice of crops, land titling influences the most educated farmers to allocate more land to production of all crop categories.

Table 5: Land rights effects on crop choice and production intensity: Interacting land title and distance to parcel

Variables	Commercial Crops		Annual Crops		Trees (Long-Term)	
	Choice 0/1	Area (ha)	Choice 0/1	Area (ha)	Choice 0/1	Area (ha)
	(1)	(2)	(3)	(4)	(5)	(6)
Land title (1/0)	0.257*** (4.997)	0.371*** (8.214)	-0.225*** (-4.361)	0.0578 (1.478)	-0.158 (-1.329)	0.808** (2.274)
Distance to parcel (minutes)	-0.00263*** (-5.513)	-0.00209*** (-4.214)	0.00337*** (7.012)	0.000449** (2.152)	-0.0116*** (-5.553)	-0.00328 (-0.590)
Tile*Distance to parcel (minutes)	0.00241** (2.106)	-0.00162 (-1.479)	-0.00291** (-2.539)	-0.000585 (-0.779)	-0.0246 (-0.776)	-0.0857 (-0.639)
Simpson Index	-0.222*** (-5.530)	-0.636*** (-16.02)	0.283*** (7.047)	-0.589*** (-21.92)	-0.376*** (-4.324)	0.120 (0.437)
Age of household head (years)	0.0115** (2.277)	0.0148*** (2.900)	-0.0135*** (-2.679)	-0.00693** (-2.108)	0.0145 (1.258)	0.0298 (0.829)
Household head's age squared	-0.000103** (-2.201)	-9.90e-05** (-2.094)	0.000115** (2.478)	8.07e-05*** (2.654)	-9.19e-05 (-0.890)	-0.000274 (-0.864)
Household head years of schooling	0.000443 (0.147)	0.00191 (0.645)	-0.00194 (-0.645)	0.0113*** (5.528)	0.0120* (1.913)	-0.00492 (-0.278)
Female headed household (1/0)	0.0295 (0.0888)	-0.335 (-1.054)	0.0365 (0.110)	-0.218 (-1.005)		
Family size	0.00208 (0.786)	0.0207*** (8.079)	-0.00324 (-1.227)	0.0304*** (16.87)	0.00592 (1.034)	-0.0222 (-1.139)
Total assets value in USD	4.86e-05*** (3.533)	2.86e-06 (0.242)	-4.50e-05*** (-3.270)	5.22e-06 (0.499)	-1.99e-05 (-0.582)	3.79e-05 (0.304)
Total land in hectares	-0.00164 (-0.676)	0.0272*** (10.97)	0.00171 (0.705)	0.0184*** (11.71)	-0.00211 (-0.400)	0.0941*** (3.289)
Constant	-0.295** (-2.363)	0.342*** (2.706)	0.303** (2.432)	0.573*** (7.064)	-2.521*** (-8.431)	0.385 (0.400)
Year dummies	Y	Y	Y	Y	Y	Y
Observations	12,557	12,557	12,557	12,557	12,542	12,542

Notes: Robust z-statistics in parentheses. *** is significant at 1%, ** at 5%, and * at 10%.

Table 6 reports the effect of de facto land rights, measured by perceived rights to transfer land either with or without approval, on crop choice and production intensity. In the analysis, having no rights to sell is the reference category. The results are consistent with those of the effect of formal titling on crop choice and production intensity. There is a significantly higher likelihood (14%) of growing perennial commercial crops on parcels over which the owners have full transfer rights compared to those over which there are no sale rights at all. In addition, there is more land (0.23ha) allocated to perennial crops if a farmer has full sale rights over the parcel. The results, however, show that having full rights to sell a parcel do not affect the size of land allocated to both annual crops and trees, but only affects the likelihood. There is a 17% lower likelihood of planting annual crops if the farmer has full sale rights over the parcel compared to those parcels where there are no such rights.

The second level of de facto land rights is relatively weak, having a right to sell but with approval from the extended family or clan. The results show that these relatively weak rights positively affect the likelihood of growing perennial commercial crops, compared to having no rights at all but the size of the coefficient is smaller than that of having full rights. There is a 7% higher likelihood of planting perennial crops and 0.20 more hectares allocated to the same crops if the farmer can sell the parcel with approval compared to no sale rights at all. Like with full rights, there is a lower likelihood of growing annual crops if the farmer can sell the parcel with approval compared to no rights at all. These findings suggest that farmers choose to grow annual crops on the parcels over which they have no full rights and whose tenure security is weak. The results also show that there is a high likelihood of growing trees on parcels over which farmers have sale rights with approval compared to those where they have no sale rights at all, but we find no effect on the land allocated to trees. These results confirm our hypothesis that, like de jure land rights emanating from land titling, de facto land rights enhance the production of perennial commercial crops, than it does for annual crops and trees.

Table 6: De facto land rights effect on crop choice and production intensity

Variables	Commercial Crops		Annual Crops		Trees (Long-Term)	
	Choice 0/1	Area (ha)	Choice 0/1	Area (ha)	Choice 0/1	Area (ha)
	(1)	(2)	(3)	(4)	(5)	(6)
[a]De facto land rights						
1 if a farmer has a right to sell the parcel without approval	0.136*** (4.350)	0.225*** (7.087)	-0.172*** (-5.484)	-0.00420 (-0.207)	0.306*** (3.527)	0.0828 (0.286)
1 if a farmer has a right to sell a parcel with approval	0.0747* (1.860)	0.200*** (4.936)	-0.122*** (-3.034)	0.0776*** (2.951)	0.404*** (4.064)	-0.100 (-0.314)
Simpson Index	-0.267*** (-6.664)	-0.689*** (-17.35)	0.330*** (8.221)	-0.588*** (-22.02)	-0.389*** (-4.457)	0.0525 (0.188)
Distance to parcel (minutes)	-0.00208*** (-4.753)	-0.00230*** (-5.151)	0.00267*** (6.074)	0.000420** (2.079)	-0.0108*** (-5.234)	-0.00391 (-0.697)
Age of household head	0.00960* (1.893)	0.0127** (2.478)	-0.0113** (-2.236)	-0.00625* (-1.891)	0.0131 (1.130)	0.0329 (0.910)
Household head's age squared	-8.99e-05* (-1.922)	-8.55e-05* (-1.804)	0.000101** (2.154)	7.62e-05** (2.500)	-8.24e-05 (-0.796)	-0.000304 (-0.953)
Household head years of schooling	0.00226 (0.754)	0.00524* (1.769)	-0.00364 (-1.217)	0.0116*** (5.753)	0.0116* (1.857)	-0.00140 (-0.0784)
Female headed household (1/0)	0.0723 (0.218)	-0.222 (-0.697)	-0.0260 (-0.0783)	-0.211 (-0.973)		
Family size	0.000881 (0.333)	0.0190*** (7.426)	-0.00188 (-0.714)	0.0303*** (16.79)	0.00489 (0.853)	-0.0211 (-1.069)

continued next page

Table 6 Continued

Variables	Commercial Crops		Annual Crops		Trees (Long-Term)	
	Choice 0/1	Area (ha)	Choice 0/1	Area (ha)	Choice 0/1	Area (ha)
	(1)	(2)	(3)	(4)	(5)	(6)
[a]De facto land rights						
Total assets value in USD	4.95e-05***	6.00e-06	-4.66e-05***	7.40e-06	-1.61e-05	1.76e-05
	(3.592)	(0.505)	(-3.374)	(0.707)	(-0.473)	(0.137)
Total land in hectares	0.000418	0.0289***	-0.000219	0.0186***	-0.00339	0.103***
	(0.176)	(11.90)	(-0.0925)	(12.03)	(-0.610)	(3.606)
Constant	-0.313**	0.269**	0.342***	0.542***	-2.751***	0.242
	(-2.486)	(2.107)	(2.724)	(6.636)	(-9.008)	(0.243)
Year dummies	Y	Y	Y	Y	Y	Y
Observations	12,557	12,557	12,557	12,557	12,542	12,542

Notes: Robust z-statistics in parentheses. *** is significant at 1%, ** at 5%, and * at 10%.
a The reference category is farmer has no right to sell.

Robustness checks

The foregoing section presents the results from two-part model (TPM). In this subsection, we check for the robustness of our results by applying the Heckman sample selection (HSS) and fixed effects methods. As discussed in the foregoing, SSM addresses endogeneity concerns but is suitable in cases where we do not observe the true zero. TPM, on the other hand, is recommended when the true zero is observed for non-adopters (in this case, zero land allocation is observed for farmers who did not grow a given crop type). In addition, studies have shown that TPM also addresses endogeneity concerns. Nonetheless, in this subsection we present the results of HSS and check whether they are related to those of TPM. Studies have shown that TPM and SSM results are largely similar in terms of signs and significance, but with variations in magnitudes (Madden, 2008).

The results from the Heckman sample selection analysis (see tables A2 and A3 in the appendix) are similar to those of TPM. For example, Table A2 shows that having a title over a parcel is associated with a 27% higher likelihood of planting perennial commercial crops. Also, Table A2 results show that there is a 26% and 20% less likelihood of growing annual crops and trees, respectively, on titled parcels compared to untitled ones. The results on land fragmentation are consistent with those of TPM which show that land fragmentation affects more the choice of, and land allocation to, perennial crops than it does for other crops. An increase in the Simpson Index by one percentage point is associated with a 22% lower likelihood of growing perennial crops.

Table A3 presents the HSS results on the crop choice effects of de facto land rights. The results show that there is a high likelihood of growing perennial crops on parcels over which farmers have full sale rights, or sale rights with approval than the parcels over which farmers have no such rights at all. In addition, there is a significantly less likelihood of producing annual crops on parcels to which farmers have transfer rights whether with or without approval, compared to those over which they have no transfer rights at all.

In Table A4 (in the appendix), we test for robustness using fixed effects modelling framework on the determinants of intensity of adoption. Consistent with other estimation methods, the results show that transfer rights significantly increase the size of land allocated to commercial crops and trees, but significantly reduces the size of land allocated to annual crops. The results on land titling are weak because there are fewer titled plots, which lead to power size issues when we run fixed effect models.

8. Conclusion and policy recommendations

This study examines the effect of land tenure security and land fragmentation on crop choice and production intensity in Uganda using household-, parcel- and plot-level data for 2003 and 2012. We use formal land titling as a proxy for de jure land rights, and land transfer rights as an indicator of informal or de facto land rights. These two measures indicate land tenure security. The two-part model estimates show that having a title significantly increases the likelihood of growing perennial commercial crops, and the land allocated to their production. However, the findings show that there is a lower likelihood of growing annual crops on the titled parcels, suggesting that when farmers have land rights, they substitute annual crops with perennial commercial crops. The results show no effect of land titling on the land allocated to annual crops and trees. When land titling is interacted with the distance to parcel, the results show that farmers grow more commercial crops and fewer annual crops on the titled parcels even when the distance increases. In addition, the results show no effect of distance on the size of land allocated to commercial and annual crops when parcels are titled.

Consistent with the results on de jure land rights, the results also show that transfer rights (both with and without approval) increase the likelihood of growing perennial commercial crops and the size of land allocated to these crops. The transfer rights weakly affect the production of annual crops and trees, as they have no effect on the land allocated to these crops.

Regarding land fragmentation, the results reveal that the Simpson Index is negatively and significantly associated with a low likelihood of growing commercial crops and a reduction in the land allocated to perennial commercial crops. The Simpson Index, however, is positively associated with the likelihood of growing annual crops but negatively associated with the land allocated to annual crops. We do not find any impact of the Simpson Index on the land allocated for trees. These results suggest that land fragmentation affects more the production of perennial commercial crops than it does other crops.

The results have key policy implications. First, they suggest that land tenure security affects more the production of commercial crops, which need significant investment compared to annual crops and trees. Therefore, to promote the production of commercial crops, there is a need for policies and strategies that enhance tenure security through titling and registration, and other interventions to privatise land

rights. Secondly, the results show that both formal (tilting) and informal (de facto) land rights enhance the choice of, and land allocated to, perennial commercial crops. This means that simple and less costly interventions that improve farmers' land rights and security perceptions would go a long way in promoting the production of commercial crops. The Government of Uganda has implemented similar interventions through the 1998 Land Act that prohibits displacement of tenants and bona fide occupants on Mailo land without compensation. Similar interventions can be implemented on customary land to enhance transfer rights.

Notes

1. According to World Bank data (2018), Uganda's population growth rate is 3.7% and second in sub-Saharan Africa, after Niger, whose population grew at 3.8% per annum in 2018. Other countries with a growth rate above 3% in SSA include Equatorial Guinea (3.7%), Angola (3.3%), Burundi (3.2%), Democratic Republic of Congo (3.2%), Chad (3.0%) and Tanzania (3.0%) (World Bank, 2018).

2. Liversage & Mangiafico (2015) define land tenure security as people's ability to control and manage land, use it, dispose of its produce and engage in transactions, including transfers.

3. A parcel is considered to be in freehold if the owner has a title. Titling and leasing are still rare in Uganda because of the high costs of surveying and demarcation that are involved in obtaining a land title.

4. We use village to mean Local Council 1, the lowest administrative unit in Uganda.

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Appendix

Table A1: Land rights effects on crop choice and production intensity: Interaction of title and household head years of schooling using TPM

Variables	Commercial Crops		Annual Crops		Trees (Long-Term)	
	Choice 0/1	Area (ha)	Choice 0/1	Area (ha)	Choice 0/1	Area (ha)
	(1)	(2)	(3)	(4)	(5)	(6)
Land title (1/0)	0.500***	0.211**	-0.485***	-0.112	-0.165	-0.623
	(4.812)	(2.382)	(-4.624)	(-1.374)	(-0.714)	(-0.990)
Simpson Index	-0.228***	-0.632***	0.290***	-0.589***	-0.380***	0.000631
	(-5.663)	(-15.95)	(7.207)	(-21.93)	(-4.372)	(0.00230)
Distance to parcel (minutes)	-0.00225***	-0.00239***	0.00290***	0.000405**	-0.0118***	-0.00245
	(-5.176)	(-5.369)	(6.628)	(2.020)	(-5.642)	(-0.443)
Age of household head	0.0114**	0.0150***	-0.0135***	-0.00684**	0.0146	0.0322
	(2.265)	(2.923)	(-2.670)	(-2.080)	(1.262)	(0.905)
Household head age squared	-0.000102**	-0.000101**	0.000114**	7.97e-05***	-9.25e-05	-0.000306
	(-2.177)	(-2.129)	(2.457)	(2.621)	(-0.895)	(-0.976)
Household head years of schooling	0.00226	0.000364	-0.00379	0.0102***	0.0123*	-0.0171
	(0.726)	(0.118)	(-1.220)	(4.899)	(1.901)	(-0.939)
Title*Head years of schooling	-0.0267**	0.0204**	0.0266**	0.0307***	0.00867	0.156**
	(-2.309)	(2.006)	(2.285)	(3.483)	(0.344)	(2.435)
Female headed household (1/0)	0.0323	-0.339	0.0337	-0.220		
	(0.0973)	(-1.067)	(0.101)	(-1.015)		

continued next page

Table A1 Continued

Variables	Commercial Crops		Annual Crops		Trees (Long-Term)	
	Choice 0/1	Area (ha)	Choice 0/1	Area (ha)	Choice 0/1	Area (ha)
	(1)	(2)	(3)	(4)	(5)	(6)
Family size	0.00180	0.0208***	-0.00294	0.0306***	0.00575	-0.0187
	(0.683)	(8.147)	(-1.114)	(16.95)	(1.004)	(-0.968)
Total assets value in USD	4.20e-05***	2.93e-06	-3.69e-05***	-4.59e-06	-2.17e-05	3.47e-05
	(3.055)	(0.248)	(-2.684)	(-0.424)	(-0.629)	(0.282)
Total land in hectares	-0.00122	0.0269***	0.00116	0.0185***	-0.00195	0.101***
	(-0.507)	(10.95)	(0.483)	(11.83)	(-0.373)	(3.551)
Constant	-0.307**	0.351***	0.316**	0.576***	-2.521***	0.402
	(-2.457)	(2.777)	(2.537)	(7.110)	(-8.427)	(0.421)
Year dummies	Y	Y	Y	Y	Y	Y
Observations	12,556	12,556	12,556	12,556	12,541	12,541

Notes: Robust z-statistics in parentheses. *** is significant at 1%, ** at 5%, and * at 10%.

Table A2: Land rights effects on crop choice and production intensity: Estimation using Heckman sample selection (HSS)

Variables	Commercial Crops		Annual Crops		Trees (Long-Term)	
	Area allocated	Selection equation	Area allocated	Selection equation	Area allocated	Selection equation
	(1)	(2)	(3)	(4)	(5)	(6)
Land title (1/0)	1.916	0.273***	0.157*	-0.258***	2.179	-0.195*
	(0.430)	(5.452)	(1.892)	(-5.112)	(0.239)	(-1.721)
Simpson Index	-1.958	-0.223***	-0.712***	0.294***	2.868	-0.377***
	(-0.517)	(-5.542)	(-8.120)	(7.325)	(0.163)	(-4.342)
Distance to parcel (minutes)	-0.0165	-0.00222***	-0.000287	0.00289***	0.0853	-0.0118***
	(-0.409)	(-5.107)	(-0.526)	(6.595)	(0.151)	(-5.638)
Age of household head	0.0832	0.0114**	-0.00169	-0.0139***	-0.0771	0.0143
	(0.416)	(2.247)	(-0.323)	(-2.750)	(-0.111)	(1.243)
Household head age squared	-0.000710	-0.000101**	3.62e-05	0.000118**	0.000409	-9.08e-05
	(-0.397)	(-2.174)	(0.780)	(2.535)	(0.0910)	(-0.879)
Household head years of schooling	0.00550	0.000493	0.0119***	-0.00158	-0.0942	0.0123*
	(0.196)	(0.164)	(5.009)	(-0.525)	(-0.164)	(1.954)
Female headed household (1/0)	-0.145	0.0320	-0.238	0.0426		-4.280
	(-0.0500)	(0.0964)	(-0.945)	(0.128)		
Family size	0.0336	0.00209	0.0316***	-0.00287	-0.0662	0.00591
	(0.776)	(0.791)	(14.37)	(-1.089)	(-0.235)	(1.034)
Total assets value in USD	0.150	0.0244***	0.0108	-0.0223***	0.0599	-0.00570
	(0.374)	(3.530)	(1.308)	(-3.226)	(0.187)	(-0.331)

continued next page

Table A2 Continued

Variables	Commercial Crops		Annual Crops		Trees (Long-Term)	
	Area allocated	Selection equation	Area allocated	Selection equation	Area allocated	Selection equation
	(1)	(2)	(3)	(4)	(5)	(6)
Total land in hectares	0.0217	-0.000840	0.0179***	0.000856	0.108	-0.00192
	(0.847)	(-0.350)	(9.784)	(0.357)	(0.895)	(-0.366)
Constant	-8.759	-0.298**	0.949***	0.311**	24.14	-2.516***
	(-0.338)	(-2.387)	(3.527)	(2.499)	(0.160)	(-8.415)
Lambda (Mills)		9.158		-0.619		-8.386
		(0.352)		(-1.487)		(-0.158)
Year dummies	Y	Y	Y	Y	Y	Y
Censored Observations	6,843	6,843	6,098	6,098	12,247	12,247

Notes: Robust z-statistics in parentheses. *** is significant at 1%, ** at 5%, and * at 10%.

Table A3: De facto land rights and fragmentation effect on crop choice and production intensity: Estimation using HSS

Variables	Commercial Crops		Annual Crops		Trees (Long-Term)	
	Area allocated	Selection equation	Area allocated	Selection equation	Area allocated	Selection equation
	(1)	(2)	(3)	(4)	(5)	(6)
[a]De facto land rights						
1 if a farmer has a right to sell the parcel without approval	0.691	0.136***	0.0630	-0.172***	-1.004	0.306***
	(0.481)	(4.344)	(1.175)	(-5.501)	(-0.137)	(3.526)
1 if a farmer has a right to sell a parcel with approval	0.442	0.0710*	0.128***	-0.128***	-1.519	0.400***
	(0.575)	(1.768)	(2.718)	(-3.188)	(-0.158)	(4.027)
Simpson Index	-1.575	-0.263***	-0.727***	0.336***	1.409	-0.385***
	(-0.579)	(-6.560)	(-7.002)	(8.374)	(0.154)	(-4.419)
Distance to parcel (minutes)	-0.00973	-0.00207***	-0.000204	0.00268***	0.0354	-0.0108***
	(-0.424)	(-4.735)	(-0.385)	(6.090)	(0.133)	(-5.231)
Age of household head	0.0446	0.00934*	-0.00189	-0.0116**	-0.0134	0.0127
	(0.442)	(1.842)	(-0.381)	(-2.290)	(-0.0420)	(1.103)
Household head age squared	-0.000385	-8.79e-05*	3.77e-05	0.000103**	-9.99e-06	-8.01e-05
	(-0.406)	(-1.879)	(0.839)	(2.198)	(-0.00484)	(-0.774)
Household head years of schooling	0.0136	0.00238	0.0130***	-0.00346	-0.0429	0.0118*
	(0.460)	(0.796)	(5.158)	(-1.159)	(-0.152)	(1.889)
Female headed household (1/0)	0.0371	0.0755	-0.205	-0.0219		-4.072
	(0.0206)	(0.228)	(-0.819)	(-0.0661)		

continued next page

Table A3 Continued

Variables	Commercial Crops		Annual Crops		Trees (Long-Term)	
	Area allocated	Selection equation	Area allocated	Selection equation	Area allocated	Selection equation
	(1)	(2)	(3)	(4)	(5)	(6)
[a]De facto land rights						
Family size	0.0228	0.00104	0.0309***	-0.00166	-0.0388	0.00505
	(1.319)	(0.392)	(14.62)	(-0.629)	(-0.314)	(0.881)
Total assets value in USD	0.0937	0.0248***	0.0123	-0.0232***	0.0194	-0.00359
	(0.377)	(3.590)	(1.406)	(-3.354)	(0.159)	(-0.211)
Total land in hectares	0.0301**	0.000433	0.0187***	-0.000237	0.115	-0.00339
	(2.397)	(0.183)	(10.41)	(-0.100)	(1.267)	(-0.610)
Constant	-4.927	-0.309**	0.902***	0.346***	12.52	-2.744***
	(-0.310)	(-2.455)	(3.264)	(2.752)	(0.151)	(-8.991)
Lambda (Mills)		5.186		-0.615		-4.048
		(0.327)		(-1.387)		(-0.148)
Year dummies	Y	Y	Y	Y	Y	Y
Observations	6,843	6,843	6,098	6,098	12,247	12,247

Notes: Robust z-statistics in parentheses. *** is significant at 1%, ** at 5%, and * at 10%.
a The reference category is farmer has no right to sell.

Table A4: De facto land rights effect on production intensity: Estimation using fixed effects model

	Dependent variable is the area (hectares) allocated to the production of the following crop categories					
	Commercial crops	Annual crops	Trees	Commercial crops	Annual crops	Trees
	(1)	(2)	(3)	(4)	(5)	(6)
Land title (1/0)	-0.0496	0.0606*	0.0225*			
	(-0.859)	(1.783)	(1.729)			
[a]De facto land rights						
1 if a farmer has a right to sell the parcel without approvals				0.0971***	-0.0488***	0.0148***
				(6.061)	(-3.425)	(2.809)
1 if a farmer has a right to sell a parcel with approval				0.104***	-0.0346*	0.0156***
				(4.732)	(-1.796)	(2.960)
Distance to parcel (minutes)	-0.000897***	0.000818***	-9.53e-05***	-0.000770***	0.000757***	-7.81e-05***
	(-4.742)	(4.498)	(-3.093)	(-4.348)	(4.256)	(-2.834)
Constant	0.391***	0.302***	0.0168***	0.310***	0.342***	0.00590
	(37.20)	(38.22)	(4.164)	(22.97)	(25.48)	(1.152)
HH and year FE	Y	Y	Y	Y	Y	Y
Observations	12,745	12,745	12,745	12,745	12,745	12,745
R-squared	0.297	0.267	0.094	0.298	0.268	0.094

Notes: Robust t-statistics in parentheses. *** is significant at 1%, ** at 5%, and * at 10%.
[a] The reference category is farmer has no right to sell.

Mission

To strengthen local capacity for conducting independent, rigorous inquiry into the problems facing the management of economies in sub-Saharan Africa.

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