Land Market Frictions and Structural Transformation in Uganda*

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Abstract

This paper examines how land market frictions can impede structural transformation. Using a sectoral choice model calibrated to Uganda, it simulates the effects of land market reforms in a low-income setting with complex and overlapping land tenure systems. Results show that reforms—expanding land titling and eliminating land usurpation—raise agricultural production by 14.2 percent and total output by 5.6 percent. These gains arise not only from productivity improvements in agriculture but also from reduced risk of income loss through usurpation, which facilitates labor out-migration from agriculture. Additional counterfactual simulations show that the marginal impact of land market reforms are greater when the economy suffers from labor mobility frictions, agricultural productivity is suppressed by climate shocks, or the demand composition is distorted in favor of agricultural goods by relatively large subsistence requirements.

Keywords: Structural Change, Land Use, Productivity Growth, Labor Mobility.

JEL classification: J43, J60, O11, O4

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1 Introduction

Structural transformation is a defining characteristic of economic development. A significant body of literature has explored the reallocation of productive factors across sectors during economic growth, primarily focusing on sectoral productivity differentials and labor mobility frictions. Recently, however, attention has shifted towards the influence of land market institutions on the structural transformation processes, especially in developing countries. This paper contributes to this emerging field by utilizing a quantitative discrete sectoral choice model with labor and land market frictions calibrated to Uganda. This framework enables us to disentangle the effects of land market frictions in low-income settings and assess their role in hindering structural transformation and, by extension, development.

Our central hypothesis is that frictions in land markets, often stemming from poorly defined ownership or user rights, can impede development through two channels. First, weak property rights can reduce productivity-enhancing investments due to diminished appropriability, directly lowering agricultural productivity—an effect previously highlighted by Besley (1995) and Banerjee & Iyer (2005). In a closed economy, or when trade costs are high, this can increase equilibrium employment in agriculture. Second, weak property rights enable usurpation, further trapping landowners and the non-landowners in agriculture, driven by fears of losing income or the opportunity for appropriation. These effects are likely more pronounced in low-income countries with complex or ambiguous land tenure systems. However, how significant are they relative to other barriers against labor mobility?

To examine these ideas, we employ a quantitative discrete choice model with two sectors, agriculture and non-agriculture. While production in agriculture utilizes both land and labor, non-agriculture uses labor only. Households can respond to changes in expected income, net of any transition costs, by changing sectors. We distinguish between two types of households: those who own land and those who do not. With the possibility of land rentals, households compare expected income streams associated with working in different sectors. Working in agriculture, landowners receive the proceeds of their agricultural production, while non-landowners earn the same but net of the rental rate for the land. In comparison, when working in non-agriculture, landowners can earn wages and rental incomes, whereas non-landowners earn only wages. However, the households' discrete choice problem is complicated by frictions in the land market. With imperfectly enforced property rights, when landowners are away, working in non-agriculture, their land can be usurped by others, characterized by a conventional matching mechanism.

We calibrate this model for Uganda, a country with a particularly rich context for exploring the economic consequences of land market frictions. Uganda's land tenure system, shaped by colonial-era boundaries and subsequent reforms, has led to diverse patterns of land ownership and use. These patterns and their impact on agricultural practices are extensively documented in the Ugandan National Panel Surveys, which cover eight waves from 2009 to 2019. These surveys provide detailed data on income sources, land ownership, crop production, input usage, farming practices, output, and sales at the parcel level for approximately 3000 households per wave. On average, 76 percent of all parcels are cultivated by owners, 12 percent are usurped, and the remainder is cultivated by non-owners with the owner's agreement[1]. Usurpation is more common in certain tenure systems (leasehold

[1] The usurpation refers to the situation where a non-landowner uses a land without owner's authorization or without rent payment. During data collection, each farmer cultivating land they own must indicate

and mailo), and usurped plots exhibit lower productivity, even after controlling for land tenure type.

To isolate the role played by land market frictions in hindering structural transformation, we analyze the marginal impact of land market reforms which eliminates usurpation and assigns titles to all landowners, under different conditions. This includes a baseline, which is calibrated to Uganda, and several hypothetical situations including a climate shock scenario which reduces the productivity of all lands by a third, a labor market reform scenario, which eliminates labor mobility frictions for entering non-agriculture sector, and a homothetic model scenario, which shuts down the demand composition channel (Engel effect) by gradually removing the subsistence level of consumption requirements.

Our results provide important insights into the role that land market reforms can play in developing economies. First, land market reforms can be an effective instrument for boosting aggregate productivity. In Uganda, eliminating land market frictions could increase GDP by 5.6 percent and agricultural productivity by 17.5 percent in the baseline scenario. Second, the marginal impact of land market reforms is magnified when agricultural productivity suppressed by climate shocks. The GDP impact of land market reforms increases to more than 8 percent, and agricultural productivity impact increases to 19.3 percent, when a climate shock reduces the productivity of all land types by a third. Third, the marginal impact of land market reforms on real economic activity are also higher when labor mobility frictions are prevalent. The GDP impact of land market reforms decreases to 5.1 percent and the agricultural productivity impact decreases to 17.2 percent, when the reforms are undertaken in an environment without labor frictions for entering non-agriculture sector. Finally, we also show that the marginal impact of land market reforms increase in the degree of non-homotheticity, e.g., the subsistence level of consumption.

Our findings contribute to a rapidly growing literature on the role played by land market inefficiencies in structural change and economic development. Among this literature, Chen (2017) shows that economies with a higher proportion of untitled land experience lower agricultural productivity, a result that reinforces the earlier findings. Others, including Giles & Mu (2018), Adamopoulos et al. (2022), and Chari et al. (2021), show that land reforms in rural China, which allowed farmers to lease their land, led to a redistribution of land toward more productive farmers and an increase in agricultural employment. Similarly, Gottlieb & Grobovšek (2019) suggest that lifting communal land tenure restrictions boosted GDP and reduces agricultural employment in Ethiopia. Adamopoulos & Restuccia (2020) show that imposing a ceiling on land holdings and redistributing above-ceiling lands to landless and smallholder households in Philippines reduced average farm size and agricultural productivity. In addition, Beg (2021) finds that the digitization of rural land records in Pakistan increased the likelihood that landowners rented out their land and transitioned to non-agricultural occupations. Finally, De Janvry et al. (2015) show that delinking land use from land rights through the issuance of ownership certificates led to substantial adjustments in both labor and land allocations in Mexico.

While the existing studies employ two-sector general equilibrium models that differentiate between titled and untitled land, our treatment of structural transformation is based on a richer categorization of agricultural land in terms of ownership and land use patterns, which aligns well with empirical data in a complex developing country context. For in-

whether they possess a formal or informal document certifying ownership of the land. In addition, those who do not own land must report whether they obtained the owner's permission to use the land and whether they pay rent. Since responses are confidential and cannot be used for prosecution in accordance with statistical laws, households that usurp land are less exposed to retaliation.

stance, the closest studies to our analysis, Ngai et al. (2019) and Adamopoulos et al. (2024) are concerned with the economic consequences of land insecurity in China. However, the nature of this insecurity is quite different from those observed in less developed countries, such as usurpation under ambiguous and overlapping land tenure systems. Our analysis builds on these earlier studies by constructing a simple and tractable model of structural change, calibrated to analyze the role of land market frictions in less developed country settings, while considering other shocks and frictions like climate shocks and labor mobility barriers in a simultaneous manner. Therefore, this paper also contributes to the literature on barriers to labor mobility and structural change, which includes a large volume of recent studies such as Lee & Wolpin (2006), Hayashi & Prescott (2008), Lagakos & Waugh (2013), Adamopoulos & Restuccia (2014), Raurich et al. (2015), Hobijn et al. (2018), Herrendorf & Schoellman (2018), Porzio et al. (2022), Cheremukhin et al. (2017), Buera & Kaboski (2009), and Alonso-Carrera & Raurich (2018) that are primarily concerned with the role of labor market frictions in structural change.[2]

The paper proceeds as follows. The next section presents the background of the paper, including the complex nature of Uganda's land tenure system and the data used for our calibrations. Section 3 presents the model. Section 4 describes the calibration procedure and the model fit. Section 5 discusses baseline simulations, and the counterfactual experiments performed to assess the impact of land market reforms on labor reallocation, welfare, and GDP. Section 6 presents additional counterfactual results including partial land market reforms, homothetic preferences, and alternative specifications of agricultural plot productivity. Section 7 concludes.

2 Background

Uganda is a landlocked country in East Africa who shares borders with the Democratic Republic of Congo, Kenya, Rwanda, South Sudan, and Tanzania. Its landscape is characterized by rolling hills, fertile plains, dense rainforests, and remarkable biodiversity. Notably, the country's access to Lake Victoria—the largest lake in Africa and a source of the Nile—further solidifies its moniker as "The Pearl of Africa".

Despite its natural wealth, however, Uganda remains a low-income, agrarian economy. Roughly two-thirds of the workforce is employed in agriculture, though the sector contributes less than a quarter of the country's total value added. Agriculture is divided into cash crop farming and subsistence agriculture, a division reminiscent of the country's colonial past. Cash crop farming, which accounts for about one-fifth of farmland and a quarter of agricultural labor, focuses on export commodities like coffee, tea, and tobacco. In contrast, subsistence agriculture, which employs the majority of rural land and labor, produces domestically consumed staples such as matoke, cassava, and maize.

Recent policy analyses, including World Bank (2022), attribute the lack of a more rapid structural transformation in Uganda to several factors. Those include a weak pull from non-agricultural sectors, major frictions in the form of high job search costs and barriers to mobility, and market imperfections such as for land, which render upfront investments (e.g., in human capital) for sectoral transition unaffordable under credit constraints. It is in this context that we focus on the role of land market distortions in explaining the relatively slow structural transformation in Uganda.

[2]The economic significance of land tenure characteristics is not limited to developing countries. For example Bahrami et al. (2025) analyze the role of land tenure in driving the adoption of conservation practices in the US.

Table 1: Description of sample

Wave	2009	2010	2011	2013	2015	2018	2019
Number of household	2976	2716	2850	3119	3305	3242	3098
% of landowners	47.77	51.39	47.57	54.68	51.66	43.40	45.46
% of workers in agriculture	49.67	49.09	53.39	53.01	54.20	42.91	40.45
% of non-rented land	54.95	26.99	66.07	57.44	46.06	55.70	56.18

2.1 Data

Our primary source of data is the Uganda National Panel Survey (UNPS), which provides a representative sample of Ugandan households. The UNPS was conducted in eight waves (2005, 2009, 2010, 2011, 2013, 2015, 2018, and 2019),[3] and each wave surveys approximately 3000 households (ranging from 2716 to 3305). With high attrition rate and re-sampling, and without the possibility of parcel-level tracking over time, we limit attention to exploring conditional correlations between agricultural outcomes and land utilization statute in a repeated cross-section framework.

Of particular relevance to our analysis is the primary source of household income, as reported by the survey for the past 12 months. Income categories include subsistence farming, commercial farming, wage employment, non-agricultural enterprises, property income, transfers, remittances, organizational support, and others. We classify a household as agricultural if its main income source is either subsistence or commercial farming. Accordingly, the proportion of agricultural households in the sample declined from 50 percent in 2009 to 40 percent in 2019.

The UNPS also includes an agricultural module that captures detailed information on land ownership, crop production, input usage, farming practices, output, and sales at the parcel level. This module is completed by households that cultivated crops during the second cropping season of the previous year or the first cropping season of the current year, as well as those that raised livestock or poultry in the past 12 months. Across the survey waves, the share of households engaged in crop farming varied from 75.6 percent at the minimum to 89.7 percent at the maximum, with up to 2.8 percent additional households involved in livestock production. While the number of parcels per household remained stable, average plot size decreased steadily, from 3.78 acres in 2005 to 1.79 acres in 2019, reflecting a remarkably high population growth. It should be noted that parcel identifiers are not maintained across waves, preventing longitudinal tracking of specific plots.

2.2 Land utilization and productivity

A key feature of our analysis is the impact of land utilization on agricultural productivity. When future returns on productivity-enhancing efforts cannot be fully captured—due to incomplete property rights, for instance—land users may underinvest in such efforts. The agricultural module of the UNPS allows us to explore these potential effects by examining the relationship between land utilization status and productivity.

Across survey waves, approximately 76 percent of the parcels are cultivated by their owners, a rate that has remained relatively stable. Among these owners, 80 percent lack

[3] Each wave was conducted over a two calendar-year period; we denote the waves by the first year of their implementation.

Table 2: Correlation between land utilization statute and agricultural outcomes

	Log of production (UShs)			Log of profit (UShs)		
	(1)	(2)	(3)	(4)	(5)	(6)
Land ownership						
Owner no doc.	**-0.266*****	**-0.215*****	**-0.226*****	**-0.260*****	**-0.217*****	**-0.226*****
	(0.019)	(0.022)	(0.022)	(0.021)	(0.023)	(0.024)
Rented	**-0.381*****	**-0.293*****	**-0.302*****	**-0.432*****	**-0.330****	**-0.350*****
	(0.026)	(0.029)	(0.029)	(0.028)	(0.031)	(0.031)
Tenant no rent	**-0.450*****	**-0.339*****	**-0.343****	**-0.457*****	**-0.349*****	**-0.354****
or usurped	(0.019)	(0.029)	(0.029)	(0.028)	(0.031)	(0.044)
Log size of land	0.587***	0.576***	0.577***	0.576***	0.566***	0.566***
	(0.007)	(0.008)	(0.008)	(0.008)	(0.009)	(0.008)
Log size of hh	0.132***	0.170***	0.177***	0.155***	0.190***	0.199***
	(0.012)	(0.013)	(0.013)	(0.013)	(0.014)	(0.014)
Type of parcel	No	Yes	Yes	No	Yes	Yes
Topography	No	Yes	Yes	No	Yes	Yes
Land quality	No	Yes	Yes	No	Yes	Yes
Read & write	No	No	Yes	No	No	Yes
FE year	No	No	Yes	No	No	Yes
N	28001	23188	22762	27220	22619	22208
R^2	0.230	0.244	0.250	0.210	0.225	0.230

Standard errors in parentheses. ***p < 0.01, **p < 0.05, *p < 0.1.
Notes: Model: columns (1)–(3): parcel level, dependent variable: log-agricultural income (in Uganda Shillings). Columns (4)–(6): parcel level, dependent variable: log-agricultural profit (in Uganda Shillings). All the data have been weighted in these regressions.

formal ownership documentation, comprising 60 percent of all parcels surveyed. These self-reported figures align with earlier estimates.[4] The remaining 24 percent of parcels are cultivated by non-owners: about half are leased, where owners receive payment, while another fifth (5 percent of all parcels) are used with the owner's consent but without payment. Notably, about a third (nearly 12 percent of all parcels) are cultivated without the owner's permission (usurped).

To assess the impact of land utilization on productivity, we examine parcel-level agricultural output (columns 1-3) and profits (columns 4-6) in Table 2. The analysis controls for land size, household characteristics such as household size and literacy, as well as parcel topography and land quality. The type of parcel captures if the plot is sand loam, sandy clay loam, or black clay while parcel topography reveals if the parcel is hilly, flat, slope, or valley. The variable land quality indicates if the soil quality is good, fair, or poor. Moreover, Read & write indicates if the head of household is able to read and write. All the data have been weighted in these regressions[5].

[4] For instance, USAID (2010) suggests that about 15 to 20 percent of land ownership in Uganda is attributable through documentation.

[5] As the analysis relies on nationally representative Living Standards Measurement Study (LSMS) data, all regressions are weighted using the survey sampling weights provided in the dataset to obtain unbiased population-level inferences. These weights correct for the complex survey design, including unequal probabilities of selection and stratification, and ensures that the estimated coefficients are representative at the

Compared to parcels farmed by documented owners (the omitted category), other land utilization statuses consistently exhibit lower productivity and profitability. For instance, usurped parcels generate 29.6 percent lower output and 31.8 percent lower profits than those with documented ownership, even after controlling for all relevant factors (columns 3 and 6, respectively). These effects are similar across specifications.

2.3 A land tenure conundrum

While the data suggest a strong correlation between land utilization patterns and agricultural productivity across all parcels, this observation may be affected by a specific form of omitted variable bias known as Simpson's Paradox. Land utilization types may be clustered within unobserved subgroups alongside productivity, which could cause the correlation between observed characteristics to disappear or even reverse within these subgroups. For example, Banerjee & Iyer (2005) show that India's colonial demarcation of land tenures has shaped productivity to date, with lands where the actual cultivators received land tenure performing better despite not exhibiting ex-ante heterogeneity. In Uganda, a complex and overlapping land tenure system can provide a similarly plausible mechanism.

Uganda currently has four land tenure systems: freehold, leasehold, mailo, and customary. The freehold system represents a modern property rights framework, where owners' rights to exclusion and transfer are typically recognized with a title, and the land is registered. In our sample, 40 percent of all parcels fall under this system. The leasehold system assigns exclusion rights for a specified period (e.g., 99 years) and comprises the 4 percent of the parcels in the UNPS. Mailo is a unique system in Uganda where land is owned, sometimes with official titles, but long-standing tenants' user rights are also recognized. These tenants pay rent to use the land and can bequeath it to their offspring, but they cannot sell or transfer it to others without the landowner's consent. Approximately 3 percent of parcels in our sample are classified as mailo. Finally, the customary system defines user rights in a communal manner, with specific rules varying across regions and ethnic groups. This is the largest tenure group in our sample, representing 52 percent of parcels. The remaining 1 percent of plots are under other systems.

Land utilization patterns in Uganda vary significantly by tenure type (Figure 1). For example, ownership with a title is significantly more common in the freehold system (24.3 percent of freehold lands, about 9.9 percent of all plots in the sample) compared to the customary system (8.02 percent of the customary land and 4.2 percent of all plots). Usurpation rates are similarly higher in the freehold system (13.42 percent of freehold lands and 5.4 percent of all plots) than in the customary system (9.78 percent of customary lands and 5.1 percent of all plots). Interestingly, the less common leasehold and mailo systems show even higher usurpation rates, at 25.72 percent (1 percent of all sample) and 19.07 percent (0.6 percent of all sample), respectively.

Whether land tenure systems inherently shape agricultural productivity is not immediately clear. However, there is anecdotal evidence suggesting that the genesis of Uganda's land tenure systems may be linked to productivity differences. For example, the British introduced the freehold system in Uganda's central region in 1900, an area often regarded as having the country's most fertile agricultural lands (Lastarria-Cornhiel, 2003). In contrast, northern regions, with a hotter and drier climate, have largely remained under the customary tenure system.

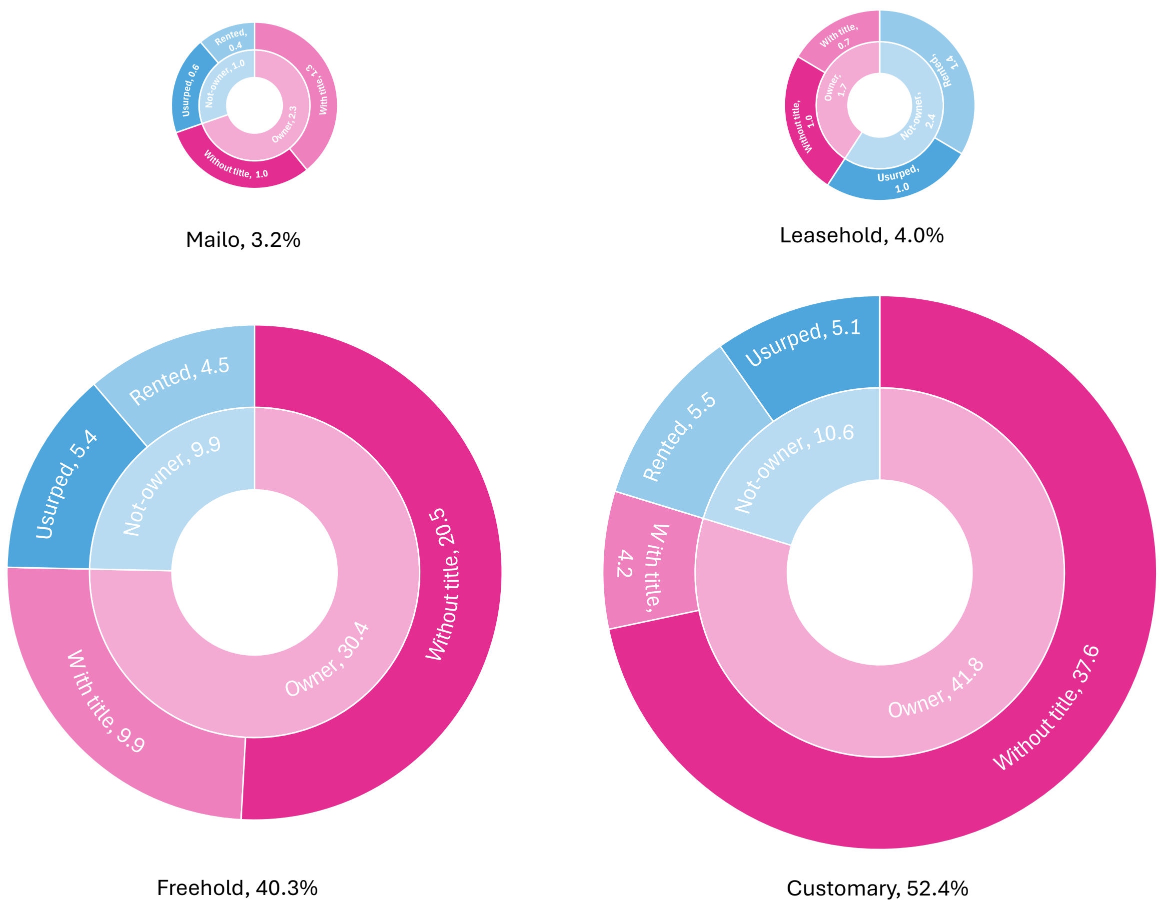
population level.

Table 3: Land ownership statute and productivity relationship across land tenure systems

	Log of production (UShs)			
	(1)	(2)	(3)	(4)
Land utilization				
Owner no doc.	**-0.226*****		**-0.051****	**0.081*****
	(0.022)		(0.022)	(0.028)
Rented	**-0.303*****		**-0.205*****	**-0.236*****
	(0.030)		(0.030)	(0.040)
Usurped or no rent	**-0.343*****		**-0.282*****	**-0.351*****
	(0.029)		(0.033)	(0.038)
Tenure system				
Leasehold		**-0.181*****	**-0.120*****	0.073
		(0.038)	(0.038)	(0.095)
Mailo		0.051	0.054	**0.159****
		(0.046)	(0.046)	(0.076)
Customary		**-0.572*****	**-0.580*****	**-0.410*****
		(0.016)	(0.018)	(0.046)
Others		**-0.242** ***	-0.097	0.024
		(0.068)	(0.069)	(0.724)
Land utilization × Tenure system				
Owner no doc. × Leasehold				-0.082
				(0.119)
Owner no doc. × Mailo				-0.172
				(0.111)
Owner no doc. × Customary				**-0.305*****
				(0.050)
Rented × Leasehold				**-0.279****
				(0.118)
Rented × Mailo				**-0.300****
				(0.151)
Rented × Customary				0.056
				(0.065)
Usurped or no rent × Leasehold				-0.116
				(0.122)
Usurped or no rent × Mailo				0.009
				(0.128)
Usurped or no rent× Customary				**0.153****
				(0.078)
Log size of land	**0.577*****	**0.608*****	**0.593*****	**0.595*****
	(0.008)	(0.007)	(0.008)	(0.008)
Log size of hh	**0.177*****	**0.181*****	**0.175*****	**0.174*****
	(0.013)	(0.013)	(0.013)	(0.013)
N	22757	22744	22744	22744
R^2	0.250	0.285	0.289	0.294

Standard errors in parentheses. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.
Notes: Model: columns (1)–(4): parcel level, dependent variable: log-agricultural income (in Uganda Shillings). All the data have been weighted in these regressions. In these regressions, we control for type of parcel, parcel topography, land quality, capacity of the head of household to read & write.

Figure 1: Tenure system and land utilization patterns



Notes: Figure sizes (areas) proportional to the sample weights. Numbers denote the share of land use category in the entire sample. The "other" category, comprising 1.06 percent of the sample, is excluded.

To evaluate concerns about Simpson's Paradox, we examine whether the average productivity impact of land utilization patterns is driven by selection into different tenure systems. Table 3 presents the marginal effects of land utilization patterns, controlling for tenure systems. The omitted categories for land utilization and tenure variables are "owner with documents" and "freehold," respectively. Columns 1 and 2 report the average effects of land utilization and tenure, both showing the expected negative effects. For instance, usurped parcels are, on average, 34.3 percent less productive than parcels operated by owners with documents (column 1), and parcels under customary tenure are 57.2 percent less productive than freehold parcels (column 2). Column 3 presents the results when controlling for both land utilization and tenure. With smaller but significant and negative coefficients, the average effects are qualitatively preserved. Finally, column 4 introduces interaction terms, with usurped parcels as the primary variable of interest. The negative joint effects indicate that usurped parcels are less productive than parcels operated by owners with documents across all tenure systems. In light of these observations, we conclude that land use patterns drive parcel productivity in Uganda, which is consistent with the evidence from other country studies discussed earlier.

3 Model

We consider a representative household model in a closed economy with two sectors: agriculture (a) and non-agriculture (n). There are two types of households distinguished by land ownership: non-landowners (type 1), who do not possess land, and landowners (type 2) who do possess it[6]. Both types of households can choose to work in either sector. Landowners engaged in agriculture use their own land for cultivation. In contrast, non-landowners wishing to work in agriculture must either rent land or usurp land left idle by landowners who choose to work in the non-agricultural sector. Households employed in the non-agricultural sector earn wage income.

3.1 Endowments

The household is composed of a unit-mass continuum of members. Each household member is endowed with one unit of productive time that is supplied inelastically in one of the two sectors. The economy comprises a mass L_1 of non-landowners and L_2 of landowners. The economy is endowed with T units of land, which is shared equally among the landowners.

3.2 Preferences and sectoral choice

To account for labor mobility barriers, we incorporate costs that directly affect the welfare of each household type upon choosing their sector of employment. This approach mirrors the concept of mobility frictions introduced in Artuç et al. (2010) in a static setting.

When a type i worker is employed in sector k, the resulting utility is

$$\mathbb{V}_{i,k}(\epsilon_k) = \frac{V_{i,k}}{\psi_{i,k}\,\epsilon_k} \tag{1}$$

where $i \in \{1, 2\}$ for workers from non-landowner and landowner households respectively, $k \in \{a, n\}$ for agriculture and non-agriculture sectors, and $\psi_{i,k}$ is the utility cost varying across types of workers and sectors. These utility costs may capture transportation costs, the cost to acquire the skills necessary to work in each sector, and all other factors that may impede allocation of labor across sectors, exclusive of the land market frictions. The utility costs prevent wage equalization across sectors, and can make one sector more difficult to enter despite having higher wages. We will normalize the costs in agriculture to $\psi_{i,a} = 1$. Thus, the costs in the non-agricultural sector $\psi_{i,n}$ capture the gains or losses in utility that a type i worker faces if they decide to work in the non-agricultural sector. As demonstrated subsequently, applying these frictions directly on welfare is equivalent to applying it to income given the structure of the preference function we use in this work. ϵ_k is a random utility component, representing idiosyncratic tastes for working in sector k and is drawn independently from a Weibull distribution[7] with shape parameter θ.

The parameter θ controls the dispersion of individual utility cost in each sector, with a smaller θ implying more dispersion in the utility cost across individuals in sector k and a higher θ meaning less dispersion. The term $V_{i,k}$ refers to the welfare that a type i household

[6] With data limitations, we are unable to conduct the analysis in a dynamic framework that captures sectoral transitions or accounts for each member's decisions—which restricts the analysis to a representative agent framework. Similarly, with the vast majority of land being held by a single household member, modeling intra-household land allocation among members is not feasible.

[7] It is possible to define the problem using Gumbel distribution after a log transformation, or using Frechet distribution isomorphically.

working in sector k and is determined by a utility function that encapsulates both income and non-income factors, reflecting the comprehensive welfare impact of their employment decision. Specifically, the utility function for a worker of the type i employed in sector k can be represented as

$$V_{i,k} = (c_{i,k,a} - \bar{c}_a)^{\eta} (c_{i,k,n} + \bar{c}_n)^{1-\eta}, \tag{2}$$

where, $c_{i,k,j}$ denotes the consumption of sector j final good, $\bar{c}_a > 0$ refers to the subsistence consumption requirement of agricultural goods, and η is a preference weight for the agricultural good and $\bar{c}_n > 0$ refers to home production of non-agricultural good. This nonhomothetic specification allows us to capture the demand-driven drivers of structural transformation, the Engel's Law[8].

The budget constraint facing the type i household working in sector k is

$$p_a c_{i,k,a} + p_n c_{i,k,n} = I_{i,k}, \tag{3}$$

where p_a, p_n are the prices of agriculture, and non-agricultural goods respectively, and $I_{i,k}$ is the income of type i household working in sector k. We assume the nonagricultural good is the numeraire, with its price normalized to one.

The sectoral choice problem thus reduces to choosing the sector that delivers the highest value of $\mathbb{V}_{i,k}(\epsilon_k)$. Maximization of the utility function in equation (2) subject to the budget constraint in equation (3) leads to the following optimal conditions:

$$c_{i,k,n} + \bar{c}_n = \frac{1-\eta}{\eta} p_a (c_{i,k,a} - \bar{c}_a). \tag{4}$$

At the optimum, the expression of $V_{i,k}$ is

$$V_{i,k} = \eta^{\eta}(1-\eta)^{1-\eta} \frac{(I_{i,k} - p_a\bar{c}_a + \bar{c}_n)}{p_a^{\eta}}, \tag{5}$$

and the probability $\pi_{i,k}$ of type i household to operate in the sector k is

$$\pi_{i,k} = \Pr\left[\mathbb{V}_{i,k}(\epsilon_k) = \max_{j=a,n}\left\{\mathbb{V}_{i,j}(\epsilon_j)\right\}\right]. \tag{6}$$

Manipulating equation (6) and using Weibull distribution proprieties, we obtain

$$\pi_{i,k} = \frac{\left(\frac{V_{i,k}}{\psi_{i,k}}\right)^{\theta}}{\left(\frac{V_{i,a}}{\psi_{i,a}}\right)^{\theta} + \left(\frac{V_{i,n}}{\psi_{i,n}}\right)^{\theta}}. \tag{7}$$

Equation (7) implies a log-linear relationship in the ratio of probabilities of a type i worker to choose agricultural to non-agricultural sector, the relative income, and the relative utility cost[9],

$$\log\left(\frac{\pi_{i,n}}{\pi_{i,a}}\right) = \theta\left[\log\left(\frac{V_{i,n}}{V_{i,a}}\right) - \log\left(\frac{\psi_{i,n}}{\psi_{i,a}}\right)\right], \tag{8}$$

[8]The calibration and resolution of the model take into account the fact that the consumption of each household type in agricultural goods $c_{i,k,a}$ exceeds subsistence consumption $\bar{c}_a$.

[9]Also notice that this specification produces qualitatively similar labor allocation patterns to models where mobility costs directly reduce monetary income. The effects would be identical under homothetic preferences (i.e., $\bar{c}_a = \bar{c}_n = 0$).

which has an intuitive explanation. A worker chooses to work in the nonagricultural sector if can earn relatively more income there and if the utility costs of working there are relatively low. Moreover, with a low θ, i.e., a high-cost dispersion across workers, large changes in the relative income are needed to induce workers to switch sectors. On the other hand, a higher θ, i.e., a small utility cost dispersion, implies that only small changes in the relative income are needed to induce workers to switch sectors.

Finally, the total labor supply in sector k is provided by:

$$H_k = \pi_{1,k}L_1 + \pi_{2,k}L_2.$$

3.3 Production

Non-agricultural goods are produced competitively by labor (only input) using the constant returns to-scale technology

$$Y_n = A_n H_n,$$

where A_n is the productivity parameter and H_n is the total labor input in the non-agriculture sector. Given that the non-agriculture good is the numeraire, perfect competition ensures that

$$w_n = A_n.$$

The agricultural good is produced by households operating in the agriculture sector. The production function of a household $h \in H$ operating on the plot $p \in P$ is given by

$$y_h(p) = A_p z_h^{\alpha}, \quad 0 < \alpha < 1$$

where z^h is the size of land cultivated by the single producer h, $y_h(p)$ is output and A_p is agricultural technology[10]. We assume that the productivity A_p of the plot p equals a product of two factors:

$$A_p = S(p) \cdot \bar{A}, \tag{9}$$

where $S(p)$ depends on the statute of the plot[11]. $\bar{A}$ is the component of productivity depending on other factors including climate change. We assume that

$$S(p) = \begin{cases} 1 & \text{if the plot } p \text{ is operated by the owner with ownership document} \\ \gamma_1 & \text{if the plot } p \text{ is operated by the owner without ownership document} \\ \gamma_2 & \text{if the plot } p \text{ is rented} \\ \gamma_3 & \text{if the plot } p \text{ is usurped} \end{cases} \tag{10}$$

where $0 < \gamma_j \leq 1,\ j = 1,\, 2,\, 3$. This range is consistent with facts shown in Tables 2 and 3 in the previous section and can be because compared to a producer who operates on his land, a producer who rents or usurps land will prefer short-cycle crops to long-cycle crops, even though the latter may be more profitable. Furthermore, a producer who usurps land does not practice a long-term fertilization technique because the parcel can be withdrawn at any time by the landowner.

[10] Ngai et al. (2019) use a similar production function for a single farmer in China.

[11] Recall that the different statutes of the plot are: operated by an owner with a document, operated by an owner without a document, rented and usurped.

3.4 Land utilization

A landowner may or may not have a document attesting to their ownership. We denote by δ the share of landowners with a document. We assume that this probability is exogenous. A worker who does not own land and chooses to work in agriculture can either rent or usurp land from landowners working outside the agricultural sector. We model the rental or usurpation decision as follows: The mass of land not utilized by the landowners is equal to $\pi_{2,n}T$, and the mass of non-landowners seek to rent or usurp land is equal to $\pi_{1,a}L_1$. There are some non-landowners who will choose to usurp land. If they are matched to a land they can usurp, they can use it without paying a fee. If not, they have to rent it from owners. The mass of non-landowners who can successfully usurp land is determined by a standard matching function:

$$\widetilde{L} = \kappa \left(\pi_{2,n}T\right)^{\vartheta} \left(\pi_{1,a}L_1\right)^{1-\vartheta},$$

where κ is the matching efficiency and ϑ is the share of initially idle land in the matching technology. Then, the probability of usurpation[12] is equal to

$$\tau = \frac{\widetilde{L}}{\pi_{1,a}L_1},$$

which implies that

$$\tau = \kappa \left(\pi_{2,n}T\right)^{\vartheta} \left(\pi_{1,a}L_1\right)^{-\vartheta}, \tag{11}$$

where $0 \leq \tau \leq 1$. A sufficient condition for this requirement to be satisfied is that the productivity parameter κ meets the following condition:

$$\kappa \leq \max_t \left(\frac{\pi_{1,a,t}L_1}{\pi_{2,n,t}T}\right)^{\vartheta}.$$

We adhere to this condition during calibration.

3.5 Household income

A land market exists where those landowners who do not utilize their plots can rent them to non-landowners seeking agricultural employment. Transactions in this market occur exclusively for rental plots. However, non-landowners have an alternative option too: instead of participating in the formal rental market, they may try to usurp land. Specifically, they can directly cultivate plots owned by individuals working outside agriculture, bypassing formal arrangements. As introduced earlier, a non-landowner can succeed in usurping land from out-of-sector landowners with probability τ. Consequently, the expected agricultural income for a non-landowner household engaging in cultivation is given by:

$$I_{1,a} = \tau p_a \gamma_3 \bar{A} z^{\alpha} + (1-\tau)\left(p_a \gamma_2 \bar{A} z^{\alpha} - rz\right) \tag{12}$$

[12] Notice that, it is not possible to distinguish between different probabilities of usurpation based on ownership types in the UNPS as the reports of usurped land come from the usurpers themselves, who may not know whether the rightful owner possesses a property. Although formal property titles are designed to secure tenure, empirical evidence—including *Report of the Public Inquiry into Land Usurpation* (2014), Stein & Cunningham (2015), Mueller (2022), and Levien (2018)—demonstrates that even titled land can be vulnerable to usurpation or disputes in certain institutional contexts while Hombrados et al. (2015) shows that households with land titles do not feel substantially more tenure secure in Tanzania.

where z is the size of land used and r is the rental rate of the land. Maximizing with respect to z yields

$$r = \frac{\alpha}{1-\tau}\left[\tau\gamma_3 + (1-\tau)\gamma_2\right] p_a \bar{A} z^{\alpha-1}. \tag{13}$$

As non-landowners are assumed to be homogeneous, the solution of z is identical choices of across this group. Then, under the market clearing conditions, z equals the aggregate land area managed by landowners engaged in non-agricultural activities, divided by the total number of non-landowners employed within the agricultural sector. Consequently, the relationship can be formalized as:

$$z = (1-\pi_{2,a})\frac{T}{\pi_{1,a}L_1}, \tag{14}$$

where $\pi_{i,k}$ denotes the probability that type i household works in sector k.

Combining equations (12), (13) and (14) yield,

$$I_{1,a} = (1-\alpha)\left[\tau\gamma_3 + (1-\tau)\gamma_2\right] p_a \bar{A}\left(\frac{1-\pi_{2,a}}{\pi_{1,a}}\frac{T}{L_1}\right)^{\alpha}, \tag{15}$$

and

$$r = \frac{\alpha}{1-\tau}\left[\tau\gamma_3 + (1-\tau)\gamma_2\right] p_a \bar{A}\left(\frac{1-\pi_{2,a}}{\pi_{1,a}}\frac{T}{L_1}\right)^{\alpha-1}. \tag{16}$$

A non-landowner household working in the non-agriculture sector derives its income from wages. Thus,

$$I_{1,n} = w_n. \tag{17}$$

We now turn to the income of landowners. Recall that each landowner is endowed with one unit of time, which is allocated entirely to operating own land if the household chooses to work in agriculture. Landowners may or may not have a document attesting to their ownership of the plot. They know the title status of their land prior to making their sectoral choice. Let δ denote the share of landowners with such a document. Given that each landowner holds a plot of size T/L_2, the income of a representative landowner household working in crop production is:

$$I_{2,a} = \left[\delta + (1-\delta)\gamma_1\right] p_a \bar{A}\left(\frac{T}{L_2}\right)^{\alpha}. \tag{18}$$

If instead the landowner household chooses to work outside the agricultural sector, it rents out its land with probability $1-\tau$. The expected income of a landowner working in the non-agricultural sector is therefore:

$$I_{2,n} \quad = \quad w_n + (1-\tau)r\frac{T}{L_2}. \tag{19}$$

3.6 Equilibrium

Equilibrium in this model can be summarized as a collection of consumptions $\{c_{i,k,j},\ i=1,2;\ j,k=a,n\}$, probabilities $\{\pi_{i,k},\ i=1,2;\ k=a,n\}$, incomes $\{I_{i,k},\ i=1,2;\ k=a,n\}$, decisions of land utilization $\{\tau\}$ and prices $\{w_n,\ p_a\}$, such that given prices: (i) the collection of consumptions, probabilities, and incomes solve the utility maximization problem i.e (3), (4), (5), and (7) hold; (ii) collection of incomes and probabilities solve the profit maximization final goods producer in each sector i.e (15), (16), (17), (18), and (19), (iii) probabilities and decisions of land utilization respect the matching process describes by (11), and (iii) all markets clear:

$$\textit{Labor market: } H_a + H_n = L_1 + L_2.$$

$$\textit{Goods market: } Y_j = \sum_{i=1,2} \sum_{k=a,n} L_i \pi_{i,k} c_{i,k,j}, \quad j = a, n,$$

where

$$\begin{aligned} Y_a &= \pi_{1,a} L_1 \left[\tau\gamma_3 + (1-\tau)\gamma_2\right] \bar{A} z^{\alpha} + L_2 \pi_{2,a} \left[\delta + (1-\delta)\gamma_1\right] \bar{A} \left(\frac{T}{L_2}\right)^{\alpha}, \\ Y_n &= H_n A_n = (\pi_{1,n} L_1 + \pi_{2,n} L_2) A_n. \end{aligned}$$

Land market: The land market clears, as we have assumed that all agricultural land T is held by landowners and that all land not used by landowners is used by non-landowners wishing to work in agriculture.

Welfare. We define the welfare of each household type U_i as follows:

$$U_i = \Gamma\left(1 - \frac{1}{\theta}\right) \left[\left(\frac{V_{i,a}}{\psi_{i,a}}\right)^{\theta} + \left(\frac{V_{i,n}}{\psi_{i,n}}\right)^{\theta}\right]^{\frac{1}{\theta}}.$$

where $\Gamma(\cdot)$ is the gamma function. We provide the details of this derivation in the Appendix. The economy's aggregate welfare is

$$\mathcal{U} = L_1 U_1 + L_2 U_2.$$

Having normalized the population size to 1, aggregate GDP is still equivalent to GDP per worker:

$$Y = p_a Y_a + Y_n.$$

4 Quantitative analysis

In this section, we first describe the calibration procedure. Then, we present a baseline simulation. We end with the results of counterfactual experiments conducted to assess the quantitative importance of land market frictions in driving sectoral labor share, GDP, and welfare under different circumstances, i.e., the baseline environment, under climate shocks, and when labor mobility frictions for entering into non-agriculture sector are eliminated.

4.1 Calibration

Our model has several exogenous time-varying series and parameters for which we need to specify values. Our calibration strategy involves choosing some parameters based on a priori information and finding the rest as part of the solution of the model to match aggregate farming data in the benchmark economy. These parameters can be separated into three groups: preference parameters, sector choice function parameters, and production parameters.

Preference parameters: The preferences parameters that we have to calibrate are: $\{\eta,\ \bar{c}_a,\ \bar{c}_n,\ \psi_{1,a},\ \psi_{2,a},\ \psi_{1,n},\ \psi_{2,n}\}$. We follow the literature and set η equal to the long-run agricultural employment share. In advanced countries, the share of employment in agriculture is about 5 percent, so we set $\eta = 0.05$. We assume that $\bar{c}_a$ and $\bar{c}_n$ are constant. We also assume that they are all positive, which implies that the income elasticity of the agricultural good is smaller than one while the income elasticity of the non-agricultural good is higher than one which is consistent with the stylized fact in the development literature. We choose $\bar{c}_a$ such that $\bar{c}_a/y_a$ match at the initial year the ratio between the income of agricultural households whose main source of income is subsistence agriculture and the income of all agricultural households, which is 0.68 at first date[13]. Moreover, we choose $\bar{c}_n$ such that the model can replicate the contribution of agriculture to the total household wealth at the initial date, which is equal to 35%. We normalize the values of $\psi_{1,a} = \psi_{2,a} = 1$, meaning that the calibrated values $\psi_{i,n}$ at a given period represent the utility costs or gains for a type-i household to switch from agriculture to the non-agricultural sector. We calibrate $\psi_{i,n}$ to reflect the share of each type of worker employed in the agricultural sector in the first period, which yields $\psi_{i,n} > 1$. Table 4 summarizes the value of parameters as well as the targeted moments.

Function of sectoral choice parameters: We begin by the parameter of the Weibull distribution θ. Lagakos & Waugh (2013) assume a variation in individual productivity in non-agricultural work and agricultural work and uses micro-level wage data from the United States of America to calibrate the value of θ at the sectoral level. They found $\theta_a = 5.3$ in agriculture and $\theta_n = 2.7$ in the non-agriculture sector. We set $\theta = 4$. As a robustness check, we have conducted sensitivity analyses with another value in this range. The main results are largely unaffected.

Land and production parameters: The list of parameters for this group is: L_1, L_2, ϑ, κ, δ, α, γ_1, γ_2 and γ_3. We normalize the size of households to one in each period. Therefore, L_1 represents the shares of households that do not own land. The time-averaged share of agricultural households owning land is 48.8 percent, implying that the share of those without land ownership is 51.2%[14]. We therefore set L_1 to 0.51 and L_2 to 0.49. We calibrate the matching function elasticity parameters ϑ, and κ by minimizing the distance between the observed share of non-rented land and the model-implied usurpation rate described in equation (11). Specifically, we solve the following problem:

$$(\vartheta,\ \kappa) = \arg\min \sum_t \left[\tau_t - \kappa \left(\pi_{2,n,t} T_t\right)^{\vartheta} \left(\pi_{1,a,t} L_{1,t}\right)^{-\vartheta}\right]^2,$$

where $L_{1,t}$ is the share of non-landowner in the economy at time t, while $\pi_{1,a,t}$ and $\pi_{2,n,t}$ are respectively the share of landowner working in agriculture and landowner working in nonagriculture at time t. T_t is the mean on land size and τ_t denotes the share of land used without rent payment at time t. Table 4 shows the results found.

[13] We also obtain the same result using profit instead of nominal production value.

[14] Some households both own land and cultivate land they do not own. To classify these households into one of the two ownership categories, we implement the following procedure: We first compute the average landholding size for (i) households without land ownership and (ii) households with land ownership. Next, we calculate the ratio of these two averages (non-owners' average to owners' average). For households with mixed ownership status, we compare their ratio of operated-but-not-owned land to owned land against this threshold: If the ratio exceeds the threshold, the household is classified as non-landowner. If the ratio is below or equal to the threshold, the household is classified as landowner.

Table 4: Parametrization

Parameters		Value	Target/Label
Technology	L_1	0.52	Share of non-landowner household
	L_2	0.48	Share of landowner household
	κ	0.47	Share of land usurped
	ϑ	0.13	Share of land usurped
	α	0.57	Land income share
	δ	0.23	Share of plot hold by owners with title
	γ_1	0.77	Productivity gap across land use statute
	γ_2	0.70	Productivity gap across land use statute
	γ_3	0.66	Productivity gap across land use statute
	$\bar{A}_0$	1.62e(-4)	Initial productivity of land with title
	$A_{n,}$	1.00	Initial productivity in nonagriculture
	g_a	5.98	Growth rate of prod. of land with title (in %)
	g_n	6.13	Growth rate prod. in nonagriculture (in %)
Preferences			
	$\bar{c}_a$	1.03e(-4)	Subsistence income share
	$\bar{c}_n$	1.15	Agriculture value added share
	η	0.05	Long run labor share in agriculture
	θ	4	Take in literature
	$\psi_{1,n}$	1.45	Labor shares of non-landowners
	$\psi_{2,n}$	1.81	Labor shares of landowners

Across all the land operated by landowners, only 22.8 percent of the parcel's ownership is backed by a title deed. Therefore, we fix the probability that each landowner of a parcel has a document δ to 0.23. We also set the parameter of returns to scale at the farm level α to 0.57 which is the coefficient of the log of land size in column (3) of Table 4, in which we regress the log of production on several independent variables including the log of land size, and land characteristics[15]. The productivity gap parameters γ_j for each parcel status are set equal to one minus the coefficient of the dummies of that status in the regression in column (3) in Table 2. We also verified the share of title lands, the share of usurped lands depended on the quality of the lands. We find the same rate of usurpation in both subsets. This suggests that this inefficiency in the land market is not dependent on the quality of the plots.

Time varying exogenous variables: The solution of the model relies on several exogenous variables, including time series of land T, and sectoral productivity $\bar{A}$ and A_n. The variable T is measured as the average farm size for each period. Between 2009 and 2019, the average parcel size declined from 2.35 acres to 1.43 acres. The calibration of $\bar{A}$ and A_n proceeds in three steps. First, we estimate sectoral productivities using survey data. Specifically, $\bar{A}$ denotes the agricultural productivity of land operated by landowners with documents, while A_n represents the productivity in the non-agricultural sector. From the model's production technology, the productivity of each parcel operated by a titled

[15] Alternatively, we compute the land-income share α in agriculture directly from the data by taking the ratio of total land income and total income. We also obtain $\alpha = 0.58$.

household h is given by:

$$\bar{A}^h = \frac{Inc_a^h}{n^h p_a {z^h}^\alpha},$$

where Inc_a^h is the nominal value of agricultural output produced by household h, n^h is the household size, and z^h denotes the land area cultivated. The average agricultural productivity $\bar{A}$ is then obtained by averaging $\bar{A}^h$ across all landowner households with a title. We compute productivity in the non-agricultural sector, A_n, as the average per capita non-agricultural income among households engaged exclusively in non-agricultural activities:

$$A_n = \frac{1}{H_n} \sum_{h \in H_n} \frac{Y_n^h}{n^h},$$

where Y_n^h denotes the nominal non-agricultural income of household h, n^h is the household size, and H_n is the total number of non-agricultural households in the sample. It is important to recall that the price of the non-agricultural asset has been normalized to one.

In the second step, we normalize all productivity measures by dividing them by the initial value of agricultural productivity A_n obtained in the first step. In the third step, we construct the full time series of productivity for each sector using the calibrated initial levels and the corresponding sector-specific growth rates. These initial productivity values and growth rates are reported in Table 4.

4.2 Model fit

Table 5 provides a comparison between the observed values and those predicted by the baseline model for the proportions of each type of worker operating in agriculture, as well as the proportion of land that is either usurped or used without the payment of rent. It is important to recall that the model was not calibrated to match only the initial employment shares of each type of worker. Nevertheless, this table demonstrates that the baseline model's predictions are closely aligned with the actual data despite a few differences.

5 Counterfactual experiments and the main results

To isolate the role played by land market frictions in explaining structural transformation, in this subsection, we conduct three counterfactual experiments using the baseline model. The first mimics a land market reform scenario, where land usurpation is eliminated ($\tau = 0$) and universal land titling is introduced ($\delta = 1$). The second experiments repeats the same exercise in a hypothetical environment where agricultural productivity is reduced by a third as a result of climate shocks. This allows us to derive preliminary conjectures regarding how constraining land market frictions may become under a changing climate or in countries who suffer from lower agricultural productivity than Uganda. Finally, the third experiment repeats the same land reform scenario in an environment where labor mobility frictions are eliminated, ($\psi_{i,n} = 1$). This helps us explore the complementarity between land and labor market reforms in low income settings. Table 6 shows the results for all three scenarios.

Land market reforms, which comprise extending title coverage to all land and eliminating the likelihood of usurpation, leads to a 17.53 percent increase in average agricultural productivity (Y_a/H_a) in the baseline simulations. Higher productivity in agriculture reduces the relative price of the agricultural good through general equilibrium mechanisms (including a demand substitution effect known as the Engel's Law). Moreover, at the

Table 5: Baseline model fit: Data vs baseline predictions

	H_a		$\pi_{1,a}$		$\pi_{2,a}$		τ	
	Data	Model	Data	Model	Data	Model	Data	Model
2009	49.67	51.40	31.38	34.02	68.93	69.60	53.74	56.77
2010	49.09	49.80	31.43	32.37	64.73	68.04	34.74	57.17
2011	53.39	48.21	34.68	30.79	71.76	66.44	65.46	57.57
2013	53.01	45.09	35.80	27.86	67.19	63.14	57.69	58.34
2015	54.20	42.11	36.92	25.27	70.02	59.74	51.26	59.06
2018	42.91	37.93	30.04	22.02	59.72	54.58	51.86	59.97
2019	40.45	36.62	24.37	21.11	58.87	52.87	53.73	60.23

Notes: Table presents the values in data and baseline prediction of values of H_a: agriculture employment, $\pi_{1,a}$: probability of agriculture employment by non-landowners, $\pi_{2,a}$: probability of agriculture employment by landowners τ: probability of land usurpation, p_a: relative price of agriculture good, divided by the initial value.

margin, a reduced likelihood of usurpation also incentivizes out-migration from agriculture for both types of households. This effect operates through a reduced risk of losing rental income for landowners and reduced prospects for rent-free farming in the case of non-landowner households. In equilibrium, the likelihood of agricultural employment decreases by 0.61 percentage points for landowners ($\pi_{1,a}$) and by 1.88 percentage points for non-landowner households ($\pi_{2,a}$). Despite the reduced work force, agricultural output (Y_a) increases by 14.15 percent thanks to the sizable increase in productivity and, with the 2.3 percent increase in non-agricultural sector driven by labor inflows, the total output in the economy (GDP) increases by 5.59 percent.

Next, we evaluate the impact of land market reforms in a hypothetical scenario featuring a climate-driven reduction in agricultural productivity, affecting all land utilization types. To do this, we begin by introducing a 32 percent reduction in agricultural productivity across all land types[16]. The magnitude of the shocks is borrowed from the main specification of Costinot et al. (2016) and Artuç et al. (2024), who utilize the impact of future climate based on projections of the United Nations' Intergovernmental Panel on Climate Change (detailed projections for Uganda and other countries are available from The Food and Agriculture Organization's Global Agro-Ecological Zones database). The second column in Table 6 shows the results for this scenario.

Compared to the baseline, the marginal effects of land market reforms are more pronounced in the climate shock scenario. The reforms boost agricultural productivity by 19.34 percent and reduce agricultural employment by 2.41 percentage points. Compared to the baseline, the labor outflow from agriculture increases more for landowners—by 2.61 percentage points—than for non-landowners, who experience an increase of 2.13 percentage points. With greater productivity growth in agriculture and greater labor outflow from the sector, the total GDP impact of land market reforms under the climate shock reaches 8.07 percent, which also exceeds that of the baseline.

[16] This counterfactual exercise differs from the one that involves varying the value of δ. Specifically, a change in $\bar{A}$ affects the productivity of all agricultural land, whereas a change in δ only influences the productivity of land cultivated by landowners holding a formal property title.

Table 6: The marginal impact of land market reforms ($\tau = 0$, $\delta = 1$) by scenario

	Effects in the baseline	**Under a climate shock**	**Labor market reform** ($\psi_{i,n} = 1$)
$\Delta H_a(p.p.)$	-1.26	-2.41	-2.49
$\Delta \pi_{1,a}(p.p.)$	-1.88	-2.13	-4.18
$\Delta \pi_{2,a}(p.p.)$	-0.61	-2.61	-0.72
$\Delta Y_a(\%)$	14.15	13.34	7.88
$\Delta Y_n(\%)$	2.30	4.71	3.67
$\Delta GDP(\%)$	5.59	8.07	5.13
$\Delta Y_a/H_a(\%)$	17.53	19.34	17.17
$\Delta U_1(\%)$	3.06	7.49	5.28
$\Delta U_2(\%)$	0.17	-2.04	-0.07
$\Delta U(\%)$	1.60	2.30	2.33

Notes: Results for average values of those obtained in each year of the study period. $\Delta H_a(p.p.)$: agriculture employment, $\Delta \pi_{1,a}(p.p.)$: probability of agriculture employment by non-landowners, $\Delta \pi_{2,a}(p.p.)$: probability of agriculture employment by landowners, $\Delta Y_a(\%)$: agriculture output, $\Delta Y_n(\%)$: non-agriculture output, $\Delta GDP(\%)$: gross domestic product, and $\Delta Y_a/H_a(\%)$: per-capita output in agriculture (productivity), $\Delta U_1(\%)$: welfare of non-landowners, $\Delta U_2(\%)$: welfare of landowners and $\Delta U(\%)$: aggregate welfare. Counterfactual results are measured based on the predictions of the baseline model in the first column, the model results under climate shock in the second column, and the model results under without labor frictions in the third column. Climate shock refers to a scenario where agricultural land productivity ($\bar{A}$) is reduced by 32 percent.

Finally, in the third column of Table 6, we evaluate the marginal impact of land market reforms under another hypothetical scenario where labor mobility frictions for entering non-agriculture sector are eliminated ($\psi_{i,n} = 1$). This helps us explore the potential complementarity between land market and labor mobility frictions in developing countries, both of which are prevalent across low-income economies. Results exhibit a weak complementary relationship between land market frictions and labor mobility frictions as far as the impact on GDP is concerned. That is, the marginal impact of land market reforms is relatively smaller in the absence of labor mobility frictions. To see this, first note that labor outflows from agriculture are greater for both worker types with no labor mobility frictions (4.18 percentage points for non-landowners and 0.72 percentage points for landowner households). This reflects a greater sensitivity of labor mobility to productivity differentials between sectors under labor mobility reform scenario. This yields a smaller positive impact of land market reforms on agricultural output (7.88 percent), and a smaller impact on overall GDP (5.13 percent).

6 Extensions

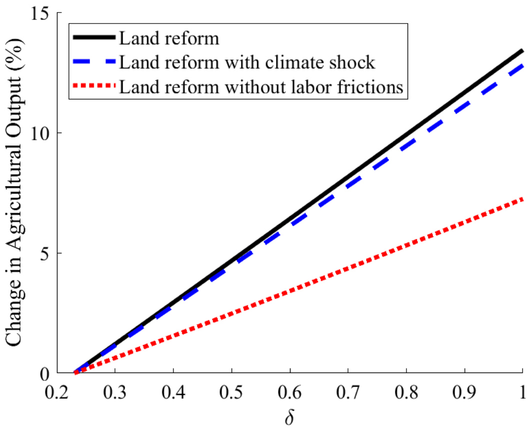
In this section, we run two sets of exercises to further elaborate on the mechanisms that drive the economic impact of implementing land market reforms in a low income country setting. First, we extend our main results by considering a continuum of reforms which partially remove land market frictions. Second, to pin down the demand-side mechanisms that may be driving results in a general equilibrium in a closed economy, we relax the non-homotheticity assumption and simulate a model with homothetic preferences. Third, we use productivity values for different land types as directly observed from the data.

6.1 Partial reform in land markets

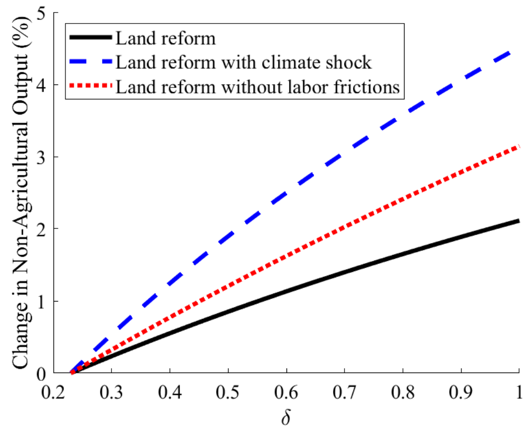
Our main results suggest that land market reforms can play a significant role as part of development policy agendas. The impact of these reforms on output is more pronounced when other factors like a climate-driven decrease in agricultural productivity or labor mobility barriers are more prevalent. However, eliminating all land market frictions completely in a swiping land reform may be challenging in many developing countries. Thus, we next consider the two key policy component of land market reforms in a continuum. Figures (2) and (3) show the marginal impact of expanding land title coverage ($\delta : 0.23 \rightarrow 1$) and reducing usurpation ($\kappa : 0.47 \rightarrow 0$) separately and in a progressive manner across the three scenarios discussed above.

Figure 2: The marginal impact of expanding land title coverage ($\delta : 0.23 \rightarrow 1$)

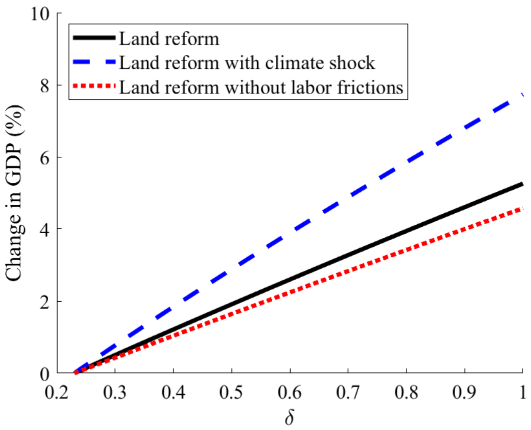
(a) Agricultural output



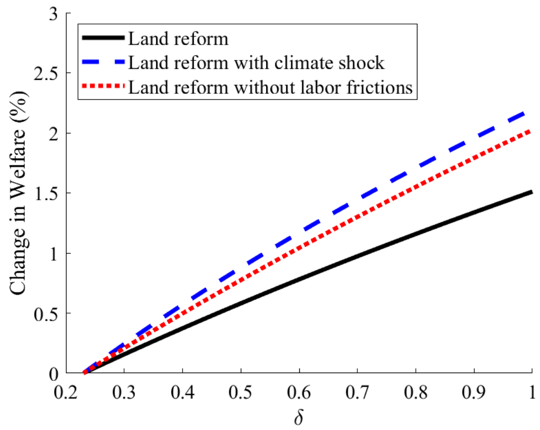
(b) Non-agricultural output



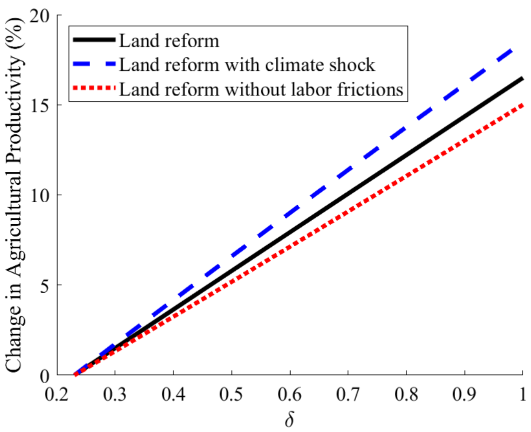
(c) Total output (GDP)



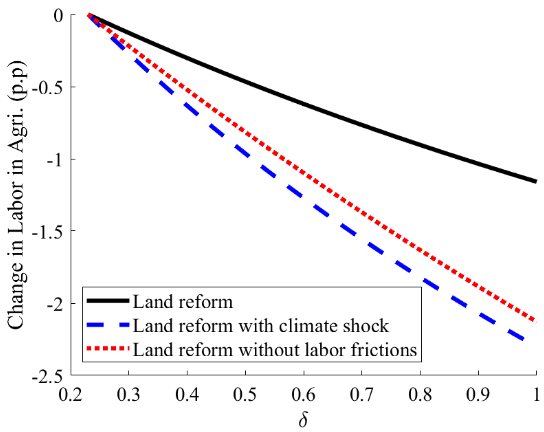
(d) Aggregate welfare



(e) Agricultural productivity

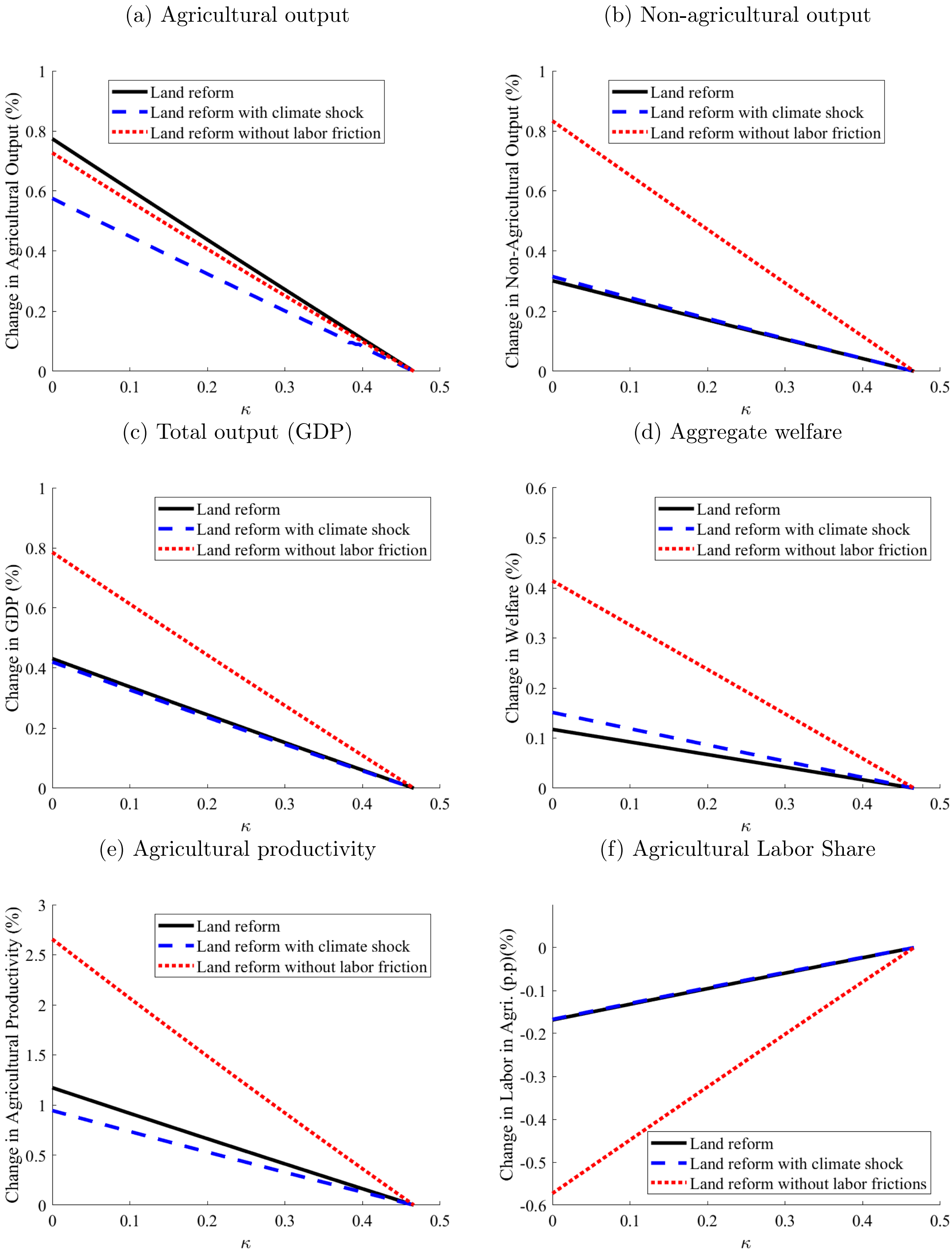


(f) Agricultural Labor Share



Note: The figure presents the impact on welfare, sectoral and aggregate output, of a gradual increase in the share δ of workers holding land titles, from its baseline value of 23 percent to 100 percent. We do that in the baseline model, in the model with climate shock, and in the model without labor mobility frictions.

Figure 3: The marginal impact of reducing usurpation ($\kappa : 0.47 \to 0$)



Note: The figure presents the impact on welfare, sectoral and aggregate output, of reducing land usurpation. To do so, we progressively lower the parameter κ in the usurpation matching function from its baseline value of 0.47 to zero. This leads to a gradual reduction in the usurpation probability τ toward zero. We do that in the baseline model, in the model with climate shock, and in the model without labor mobility frictions.

Table 7: Agriculture labor share data vs models

	Data	Model				
		Baseline	*Climate Shock*	*Labor market reforms*	*No Engel effect*	*Alternative productivity*
2009	49.67	51.40	55.03	36.31	7.48	50.07
2010	49.09	49.80	53.45	34.98	7.48	48.62
2011	53.39	48.21	51.88	33.71	7.48	47.19
2013	53.01	45.09	48.77	31.30	7.48	44.44
2015	54.20	42.11	45.77	29.08	7.47	41.86
2018	42.91	37.93	41.51	26.04	7.47	38.35
2019	40.45	36.62	40.17	25.11	7.47	37.28

Note: Table reports actual (data) and predicted agricultural labor shares for the baseline model, the model with climate shocks, the model with labor market reforms, i.e., $\psi_{ik} = 1$, the model with homothetic preferences, i.e., $\bar{c}_a = 0$ and $\bar{c}_s = 0$, and the model where the land productivity is taken directly from the data. The last two models were not recalibrated.

The policy continuum exercise sheds some additional light on our main results. First, the marginal impact of both expanding land title coverage and reducing usurpation are monotonic between the initial calibrated value and the final level (the universal titling and no usurpation). This is true for all three scenarios (baseline, under climate shock, and without labor mobility friction). Wile both expanding the land title coverage and reducing usurpation have almost linear effects on key economic indicators, the former policy's impact is weakly concave and that of the latter is weakly convex. Second, the rank order of the land market reform's marginal impact across scenarios does not change by the magnitude of the reform. For example, the marginal impact of expanding land title coverage on GDP (Panel c in 2) is greatest in the climate change scenario, and this is through for all values of $\delta \in (0.23, 1)$. This can be seen from figures as the only time the impact lines cross is at the initial equilibrium. Third, while reducing the usurpation risk has a sizable impact across all indicators analyzed, the bulk of the impact comes from expanding the title coverage, which affects directly the productivity of plots as discussed earlier. Importantly, however, reducing usurpation plays a relatively more prominent role in the scenario with no labor mobility frictions (red dotted lines in Figure (3)).

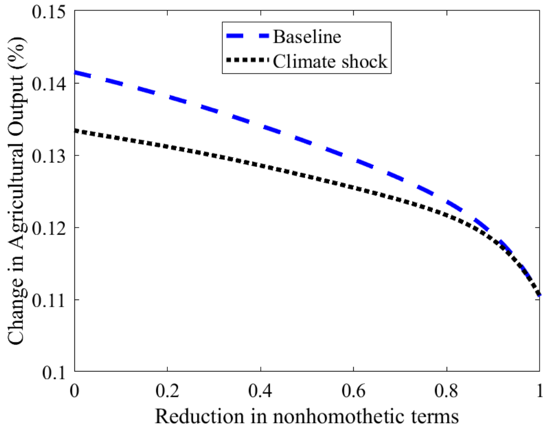
6.2 Homothetic preferences

With non-homothetic preferences in our main specification, any increases in income will shift the composition of demand in favor of the non-agricultural sector. This provides a demand-induced mechanism for structural transformation, known as the Engel's Law (Matsuyama 2019). In the case of labor market reforms in this paper, this demand side mechanism reinforces the reallocation of labor directly as a result of the income increase generated by productivity increases in our simulations. Therefore, as our second extension of the main results, we investigate the relative importance of this demand side mechanism in driving our results. To do this, we simulate the model by gradually reducing non-homothetic terms, $\bar{c}_a, \bar{c}_n \to 0$, and observe the changes.

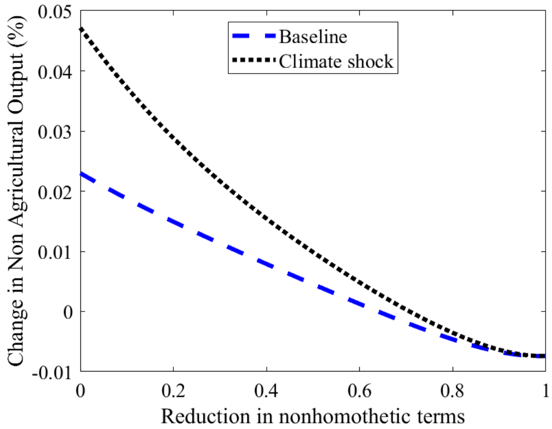
Figure 4 shows the marginal impact of land market reforms as the non-homotheticity assumption is gradually relaxed for both the baseline model and the model under climate shock. In both cases, the presence of non-homothetic terms $\bar{c}_a$ and $\bar{c}_n$ generally magnify the the marginal impact of the land market reforms. As the non-homothetic terms are gradually dampened (moving right on the horizontal axis), the marginal impact of land market reforms on sectoral and total output subsides and the labor transition out of agriculture diminishes in both the baseline model and the model with climate shock. While these effects are monotonic, they are not linear. Similarly, while the marginal impact of the land market reforms increase in non-homothetic terms, the sign of these effects are generally preserved except for the panel for employment in agriculture (Panel f) which switches from a labor outflow to labor inflow as non-homothetic terms are reduced gradually.

Figure 4: The marginal impact of land market reforms under weakening non-homotheticity $(\bar{c}_a, \bar{c}_n \to 0)$: Baseline model vs. the model with climate shock

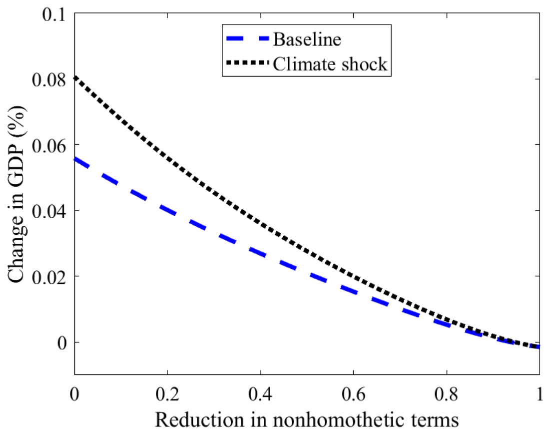
(a) Agricultural output



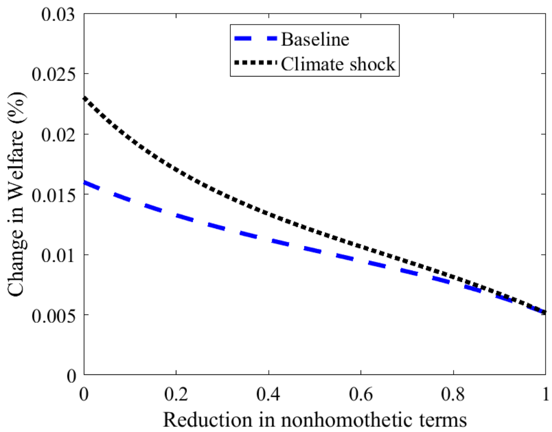
(b) Non-agricultural output



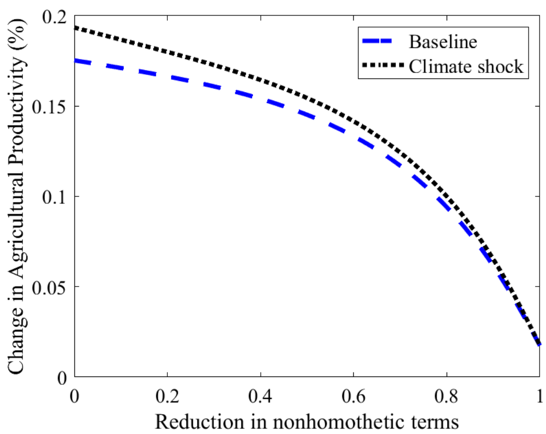
(c) Total output (GDP)



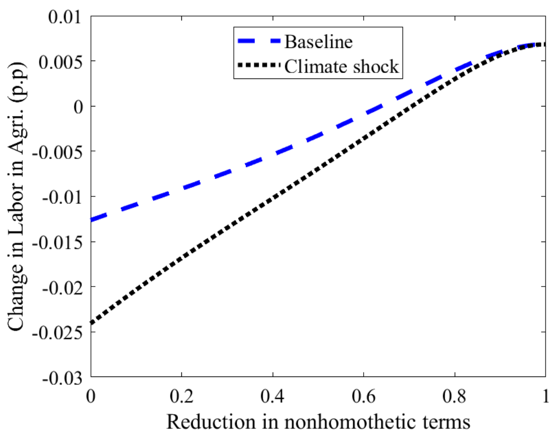
(d) Aggregate welfare



(e) Agricultural productivity



(f) Agricultural Labor Share



Note: Figure presents the impact on welfare, sectoral and aggregate output, of gradually reducing no-homotheticity in preferences $(\bar{c}_a, \bar{c}_n \to 0)$ in the baseline model and in the model with climate shock.

Table 8: Marginal impact of land market reforms with alternative specification for productivity

	Effects in the baseline	**Under a climate shock**	**Labor market reform** ($\psi_{i,n} = 1$)
$\Delta H_a(p.p.)$	-0.91	-1.78	-1.27
$\Delta \pi_{1,a}(p.p.)$	-1.81	-2.29	-3.64
$\Delta \pi_{2,a}(p.p.)$	0.04	-1.24	1.20
$\Delta Y_a(\%)$	10.74	10.20	5.84
$\Delta Y_n(\%)$	1.54	3.26	1.75
$\Delta GDP(\%)$	3.80	5.59	3.07
$\Delta Y_a/H_a(\%)$	13.45	14.96	11.57
$\Delta U_1(\%)$	1.92	4.10	2.88
$\Delta U_2(\%)$	0.40	-0.67	0.19
$\Delta U(\%)$	1.17	1.62	1.42

Notes: The values presented in this table are average values of those obtained in each year of the study period. The row are changes in $\Delta H_a(p.p.)$: agriculture employment, $\Delta \pi_{1,a}(p.p.)$: probability of agriculture employment by non-landowners, $\Delta \pi_{2,a}(p.p.)$: probability of agriculture employment by landowners,$\Delta Y_a(\%)$: agriculture output, $\Delta Y_n(\%)$: non-agriculture output, $\Delta GDP(\%)$: gross domestic product, and $\Delta Y_a/H_a(\%)$: per-capita output in agriculture (productivity), $\Delta U_1(\%)$: welfare of non-landowners, $\Delta U_2(\%)$: welfare of landowners and $\Delta U(\%)$: aggregate welfare. Changes are measured in comparison with the predictions of the baseline prediction of each framework.

Importantly, Figure 4 also shows that results converge between the baseline model and the model under climate shock asymptotically as $\bar{c}_a, \bar{c}_n \to 0$. Notice that the main difference between the baseline model and the model with climate change is the 32 percent gap in initial productivity in all land types. Simulations in Figure 4 suggest that as non-homothetic terms become negligibly small, this initial gap does not affect how land market reforms shape productivity, labor transition, and output across sectors on the margin. Therefore, we conclude this extension by learning that not only the Engel effect magnifies our main results as far as the marginal impact of land market reforms is concerned, it also drives a wedge between the effectiveness of policy reforms under different initial conditions.

6.3 Alternative specification for the productivity of land

In our modeling framework, we use the productivity parameters γ_i obtained from regression analysis, which capture productivity differentials between various land types and land operated by titled landowners. As our third extension, we reconduct the analysis using instead the average productivity of each land type as directly observed in the data. The productivity of each land type is computed following the same procedure used to calibrate $\bar{A}$, as described earlier in the calibration section. Table 7 shows the simulated labor share of agriculture across all models and the actual data. Table 8 shows the marginal impact of land market reforms under the baseline, climate shock, and labor market reform scenarios.

In all scenarios, results are qualitatively similar between our main specification and the alternative specification for the productivity of agricultural plots. The positive impact of land market reforms on agricultural productivity, agricultural output, and GDP are preserved across all scenarios. However, the magnitudes of these effects are relatively smaller with the alternative productivity specification by about a third. The only sign reversal in economic activity occurs in the case of landowners, whose agricultural employment decrease for the baseline and labor market scenarios in the main specification, but increase with the alternative productivity specification. However, these changes are not large enough to change the sign of total employment in agriculture, which decreases in all scenarios and specifications under land market reforms.

7 Conclusion

This paper investigates the critical role played by land market frictions in shaping structural transformation and economic development. To do this, we use a quantitative discrete sectoral choice model calibrated to a low-income country setting with complex and overlapping land tenure systems in Uganda. We are primarily interested in analyzing the economic consequences of weak property rights in the land market under different conditions. Our data allows us to account for the productivity suppressing and mobility reducing effects of weak property rights, which operate through low appropriability of investments in land and the risk or opportunity of usurpation, respectively.

Our counterfactual experiments suggest that land market inefficiencies can play an important role in hinder development in low income countries. A land market reform that assigns titles to all landowners and eliminates usurpation could boost Uganda's GDP by 5.6 percent. Under a climate-induced reduction in agricultural productivity, the GDP impact of the land market reforms exceeds 8 percent. Although these gains are manifested primarily through a direct increase in agricultural productivity, the risk of income loss through usurpation also plays an important role. Additional counterfactual simulations show that the marginal economic impact of labor market reforms is greater when the economy also suffers from high labor market frictions and under a high degree of non-homotheticity in preferences, which tilts demand composition in favor of the agricultural sector. These experiments suggest that in low income countries that suffer from multiple frictions and distortions, land market reforms can play an important role in the country's development strategy.

Our findings complement earlier studies by highlighting the importance of secure land rights for agricultural productivity and labor mobility, extending the analysis to specific challenges faced by low-income countries such as Uganda. By incorporating a more nuanced treatment of land ownership and use patterns, and investigating the mechanisms that drive the economic impact of these patterns, this study helps to make progress in understanding how land market frictions interact with broader structural change dynamics.

References

Adamopoulos, T., Brandt, L., Chen, C., Restuccia, D. & Wei, X. (2024), 'Land Security and Mobility Frictions', *The Quarterly Journal of Economics* **139**(3), 1941–1987.

Adamopoulos, T., Brandt, L., Leight, J. & Restuccia, D. (2022), 'Misallocation, selection, and productivity: A quantitative analysis with panel data from china', *Econometrica* **90**(3), 1261–1282.

Adamopoulos, T. & Restuccia, D. (2014), 'The size distribution of farms and international productivity differences', *The American Economic Review* **104**(6), 1667–1697.

Adamopoulos, T. & Restuccia, D. (2020), 'Land reform and productivity: A quantitative analysis with micro data', *American Economic Journal: Macroeconomics* **12**(3), 1–39.

Alonso-Carrera, J. & Raurich, X. (2018), 'Labor mobility, structural change and economic growth', *Journal of Macroeconomics* **56**, 292–310.

Artuç, E., Chaudhuri, S. & McLaren, J. (2010), 'Trade shocks and labor adjustment: A structural empirical approach', *American Economic Review* **100**(3), 1008–1045.

Artuç, E., Porto, G. & Rijkers, B. (2024), 'Crops, conflict and climate change', *Mimeo: World Bank* .

Bahrami, S., Rad, M. R. & Nayga Jr, R. M. (2025), 'Land tenure and conservation in agriculture: Evidence from united states farm-level data', *Land Use Policy* **153**, 107534.

Banerjee, A. & Iyer, L. (2005), 'History, institutions, and economic performance: The legacy of colonial land tenure systems in india', *American Economic Review* **95**(4), 1190–1213.

Beg, S. (2021), 'Digitization and development: Property rights security, and land and labor markets', *Journal of the European Economic Association* **20**(1), 395–429.

Besley, T. (1995), 'Property rights and investment incentives: Theory and evidence from ghana', *Journal of Political Economy* **103**(5), 903–937.

Buera, F. J. & Kaboski, J. P. (2009), 'Can Traditional Theories of Structural Change Fit the Data?', *Journal of the European Economic Association* **7**(2-3), 469–477.

Chari, A., Liu, E. M., Wang, S.-Y. & Wang, Y. (2021), 'Property rights, land misallocation, and agricultural efficiency in china', *The Review of Economic Studies* **88**(4), 1831–1862.

Chen, C. (2017), 'Untitled land, occupational choice, and agricultural productivity', *American Economic Journal: Macroeconomics* **9**(4), 91–121.

Cheremukhin, A., Golosov, M. J., Guriev, S. M. & Tsyvinski, A. (2017), 'The industrialization and economic development of Russia through the lens of a neoclassical growth model', *The Review of Economic Studies* **84**(2).

Costinot, A., Donaldson, D. & Smith, C. (2016), 'Evolving comparative advantage and the impact of climate change in agricultural markets: Evidence from 1.7 million fields around the world', *Journal of Political Economy* **124**(1).

De Janvry, A., Emerick, K., Gonzalez-Navarro, M. & Sadoulet, E. (2015), 'Delinking land rights from land use: Certification and migration in mexico', *American Economic Review* **105**(10), 3125–49.

Giles, J. & Mu, R. (2018), 'Village political economy, land tenure insecurity, and the rural to urban migration decision: evidence from china', *American Journal of Agricultural Economics* **100**(2), 521–544.

Gottlieb, C. & Grobovšek, J. (2019), 'Communal land and agricultural productivity', *Journal of Development Economics* **138**, 135–152.

Hayashi, F. & Prescott, E. C. (2008), 'The depressing effect of agricultural institutions on the prewar japanese economy', *Journal of Political Economy* **116**(4), 573–632.

Herrendorf, B. & Schoellman, T. (2018), 'Wages, Human Capital, and Barriers to Structural Transformation', *American Economic Journal: Macroeconomics* **10**(2), 1–23.

Hobijn, B., Schoellman, T. & Vindas, A. (2018), 'Structural transformation by cohort', *Unpublished manuscript, Arizona State University* .

Hombrados, J. G., Devisscher, M. & and, M. H. M. (2015), 'The impact of land titling on agricultural production and agricultural investments in tanzania: a theory-based approach', *Journal of Development Effectiveness* **7**(4), 530–544.

Lagakos, D. & Waugh, M. E. (2013), 'Selection, agriculture, and cross-country productivity differences', *American Economic Review* **103**(2), 948–80.

Lee, D. & Wolpin, K. I. (2006), 'Intersectoral labor mobility and the growth of the service sector', *Econometrica* **74**(1), 1–46.

Levien, M. (2018), *Dispossession without Development: Land Grabs in Neoliberal India*, Oxford University Press.

Matsuyama, K. (2019), 'Engel's Law in the Global Economy: Demand-Induced Patterns of Structural Change, Innovation, and Trade', *Econometrica* **87**(2), 497–528.

Mueller, B. (2022), 'Property rights and violence in indigenous land in brazil', *Land Use Policy* **116**, 106063.

Ngai, L. R., Pissarides, C. A. & Wang, J. (2019), 'China's mobility barriers and employment allocations', *Journal of the European Economic Association* **17**(5), 1617–1653.

Porzio, T., Rossi, F. & Santangelo, G. (2022), 'The human side of structural transformation', *American Economic Review* **112**(8), 2774–2814.

Raurich, X., Sánchez-Losada, F. & Vilalta-Bufí, M. (2015), 'Knowledge misallocation and growth', *Macroeconomic Dynamics* **19**(7), 1540–1564.

Report of the Public Inquiry into Land Usurpation (2014), Technical report, Independent Joint Anti-Corruption Monitoring and Evaluation Committee. Translated from Dari.

Stein, H. & Cunningham, S. (2015), 'Land grabbing and formalization in africa: A critical inquiry'.

World Bank (2022), *Growth, trade, and transformation: A Country Economic Memorandum for Uganda*, The World Bank.

Appendix

A. Construction of agriculture price and production and profit

The aggregated price is constructed using the sales data. We exclude the sales data from the years 2009 and 2015 due to their poor quality. To obtain the price per kilogram of each crop under each condition/state, we proceed as follows: First, we convert all sold quantities into kilograms. To do this, we use the kilogram conversion factor for each crop in each condition/state. Given the significant disparity in conversion factors within the data, we use the median conversion factor for each plant in each condition/state. Once the quantities are converted into kilograms, we divide the sales amounts by the quantity to obtain the sales price per kilogram for each crop in each condition/state for each sales row in data. The data obtained for a product in a given condition are also highly variable from one household to another and across survey waves. We take the median to obtain the price per kilogram of each plant in each condition/state. It is important to note that the price does not vary over time because, given the exclusion of the years 2009 and 2015, we have aggregated the prices at the level of the entire sample. We use these prices to calculate the production value for each year. To do this, we use the conversion factor to convert production into kilograms and use the price of each good in each condition/state to convert the produced quantities into monetary value. We subtract the various costs reported by the household from this production to obtain the profit.

We obtain the aggregate price in agriculture p_a as follows:

$$p_{a,t} = \sum_{c,\,j} \frac{Inc^c_{k,t}}{Inc_{a,t}} p^c_{j,t}, \tag{A.1}$$

where p^c_j denotes the price of one kilogram of crop j in condition c and Inc^c_j is the income generate by sale of agricultural good j in condition c and Inc_a is the total agriculture income at period t which expression is given by

$$Inc_a = \sum_{c,\,j} Inc^c_j. \tag{A.2}$$

A.2 Derivation of expected welfare U_i

Recall that the welfare of a type i household working in sector is $k \in \{a, n\}$ to maximize utility:

$$\mathbb{V}_{i,k}(\epsilon_k) = \frac{V_{i,k}}{\psi_{i,k}\epsilon_k},$$

where: ϵ_k is an idiosyncratic shock drawn independently from a Weibull distribution with shape parameter θ and scale 1. The cumulative distribution function (CDF) of ϵ_k is:

$$F_{\epsilon_k}(x) = 1 - e^{-x^\theta}, \quad x \geq 0.$$

Noting that the random variable $z_k = 1/\epsilon_k$ follows a Fréchet distribution with shape θ and scale 1. The household's maximized utility is:

$$U_i = \max\left(\frac{V_{i,a}}{\psi_{i,a}} z_a, \frac{V_{i,n}}{\psi_{i,n}} z_n\right).$$

Let's define the new random variable:

$$X_k = \frac{V_{i,k}}{\psi_{i,k}} z_k.$$

Since z_k is Fréchet-distributed, X_k is also Fréchet-distributed with:

$$F_{X_k}(x) = \exp\left(-\left(\frac{x}{\lambda_k}\right)^{-\theta}\right), \quad \text{with} \quad \lambda_k = \frac{V_{i,k}}{\psi_{i,k}}.$$

The maximum $U_i = \max(X_a, X_n)$ has the CDF:

$$F_{U_i}(u) = F_{X_a}(u) F_{X_n}(u) = \exp\left(-u^{-\theta}\left(\lambda_a^\theta + \lambda_n^\theta\right)\right).$$

This is the cumulate distribution function of a Fréchet distribution with scale parameter $\left(\lambda_a^\theta + \lambda_n^\theta\right)^{1/\theta}$.

Therefore, the expected value of a Fréchet variable U_i with shape θ and scale λ is:

$$\mathbb{E}[U_i] = \lambda\, \Gamma\left(1 - \frac{1}{\theta}\right),$$

where $\Gamma(\cdot)$ is the gamma function. Substituting λ yields:

$$U_i = \left[\left(\frac{V_{i,a}}{\psi_{i,a}}\right)^\theta + \left(\frac{V_{i,n}}{\psi_{i,n}}\right)^\theta\right]^{1/\theta} \Gamma\left(1 - \frac{1}{\theta}\right).$$