The Mystery of Land Rights: Explorations on Informal Institutions in Ghana*

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Abstract

Informal institutions often persist even when governments expand formal alternatives. Evidence from Ghana's rollout of land registration offices shows that improved access to statutory land institutions did not significantly increase the adoption of formal agricultural land rights. Instead, formalization appears to be constrained by village chiefs. To interpret these findings, we develop a model linking land markets to informal risk-sharing networks, in which chiefs' power limits the take-up of formal land rights. While partial adoption of land rights generates sizeable welfare gains by improving consumption insurance and the efficiency of land reallocations, full formalization can unravel informal insurance networks. The persistence of informality may therefore reflect a rational response to the value of local cooperation.

Keywords: Agriculture, land security, misallocation, risk sharing

JEL Codes: Q12, Q18, O11

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1 Introduction

Why do many developing countries persist with informal land institutions? This puzzle lies at the heart of the literature in development economics that follows the logic of Coase [1960] and documents that well-defined property rights over agricultural land are consistently linked to increased investment, higher agricultural productivity, and enhanced economic growth.[1] Yet, sub-Saharan Africa stands out for its strikingly low levels of formal land documentation, despite pronounced productivity gaps and the potential economic benefits of formalization.

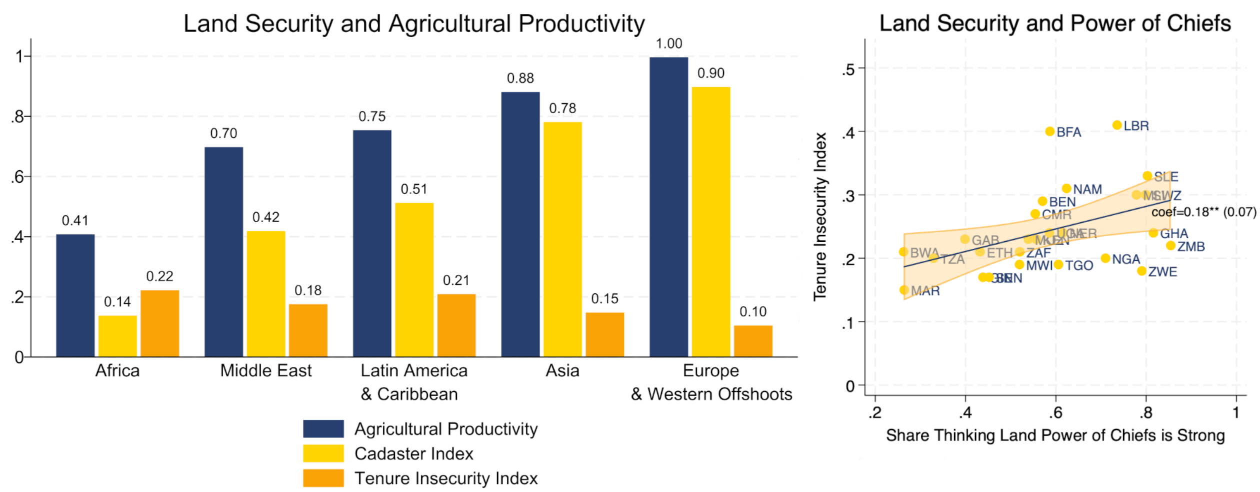


Figure 1: Agricultural landscape in Africa and the world

Note: Agricultural productivity is measured as yields from Adamopoulos and Restuccia [2022], is normalized relative to the average in "Europe & Western Offshoots" and is constructed as a regional-average weighted by countries' population size. Cadaster Index is from D'Arcy et al. [2024]. Tenure Insecurity Index (for rural areas) is the 2020 value from PRIndex. "Share Thinking Land Power of Chiefs is Strong" is the share of Afrobarometer's (round 8) respondents thinking that traditional authorities have some or a lot (as opposed to little or none) of influence over local land allocations.

The left panel of Figure 1 illustrates this paradox clearly: regions with a higher formal land security provided by the public cadastral system [D'Arcy et al., 2024], show substantially higher agricultural productivity. In contrast, Africa, with the lowest cadaster coverage, exhibits the lowest agricultural yields. Notably, tenure insecurity in this region is more than double of that in developed western countries, suggesting that improving land security through formalization of agricultural land rights could unlock significant economic poten-

[1] See for instance Feder et al. [1988], Besley [1995], Deininger and Jin [2006], Goldstein and Udry [2008]. Going beyond agriculture, De Soto [2000] argues that the growth of developed countries was possible due to adoption of formal and unified legal property systems.

tial. These observations can be especially puzzling in light of the many efforts by African governments and international organizations to formalize land tenure and expand statutory alternatives to customary systems across Sub-Saharan Africa [Boone, 2019].

This paper uses the case study of Ghana to shed light on this mystery of low land rights take-up. Exploiting the recent nationwide rollout of land registration offices aimed at boosting the adoption of formal land rights, we find that access to formal institutions has not been a constraining factor. Consistent with suggestive evidence in the right panel of Figure 1, we argue that the concentration of power over local land markets among traditional authorities (village chiefs) constitutes a significant barrier to formalization of land rights. These chiefs, whose source of authority pre-dates modern formal institutions and hinges on controlling communal land, often resist reforms that threaten to diminish their influence [Abubakari et al., 2018, 2020]. In our empirical analysis of Ghana, we construct a Chief Power Index (CPI) that captures the historically rooted importance of traditional authorities in conducting local land transaction. We show that villages with a higher value of this index have a significantly lower share of land with formal land rights.

Moving beyond, or –as we will argue– rather parallel to, those constraining factors, we provide novel evidence on consumption risk sharing benefits of formal land rights. Using an extended version of consumption smoothing test of Townsend [1994], we show that the transmission of idiosyncratic income shocks to consumption is lower in villages with higher average degree of land rights. This result also holds when exploiting within-village variation in land rights over time, and is consistent with a suggestive IV exercise that instruments average land rights with the Chief Power Index. Likewise, we find that the cross-sectional ratio of within-village consumption-to-income dispersion [Attanasio and Ríos-Rull, 2000] tends to decrease when the formality of land markets increases.

In order to further interpret these findings and shed more light on both the constraining factors and the causal effects of land rights, we develop a dynamic model where, as in our empirical setting, the level of formal land rights is chosen by the village planner-chief. Agricultural output is produced using labor and land, that is allocated in previous period ("time-to-build") and is subject to land adjustment costs. Importantly, the model features endogenous, self-enforcing cooperation over land and risk sharing, the extent of which is pinned down in equilibrium through the limited commitment constraints. We assume that households are free to leave the cooperation arrangement at any instance and that land rights strengthen a household's fallback position outside the arrangement by improving the security of its baseline customary land entitlement and by reducing the land adjustment costs in the outside formal market. The model's parameters are identified using reduced-form evidence combined with the simulated method of moments. Among others, we target the empirical distribution of CPI across villages, the impact of CPI on the take up of land rights and the average degree of consumption smoothing. Given the lack of plausibly exogenous variation that would separately identify land adjustment costs and village productivity fundamentals conditional on land-rights take-up, we model Total Factor Productivity (TFP) heterogeneity explicitly and estimate both the land-reallocation cost and the TFP-distortion parameters via indirect inference, matching cross-village patterns in land-market fluidity, TFP dispersion, and land-rights adoption. This approach captures persistent heterogeneity and prevents land-rights take-up from mechanically absorbing all cross-village variations in both persistent productivity and fluidity of land reallocations.

The estimated model confirms that broader adoption of formal land rights can yield sizable welfare gains. In counterfactual simulations that remove the power of chiefs over local land markets, land-rights take-up rises by about 50% relative to baseline and generates a welfare improvement equivalent to roughly a 3% permanent increase in consumption, relative to full informality. While land rights improve the efficiency of land allocation across households, this channel raises average consumption by only about 2%. Instead, consistent with our empirical evidence, land rights primarily operate by strengthening informal risk-sharing arrangements, improving insurance against idiosyncratic productivity shocks by up to 50%. At the same time, the model delivers a key –and potentially counterintuitive– insight: an exogenous push of land rights to full formality can unravel informal cooperation over land and insurance transfers, exposing the community to excessive consumption fluctuations and less efficient allocation of both labor and land, generating a welfare loss equivalent to an approximately 20% permanent reduction of consumption on average.

We therefore show that, rather than outright resistance to modernization, the persistence of informal land institutions in Ghana and similar contexts may well reflect a rational, adaptive response to complex economic realities. Understanding this delicate balance—between securing formal rights and preserving informal social protections—is crucial for designing effective policies that can sustainably enhance land security and economic development without inadvertently dismantling critical local institutions.

Literature review. Our paper falls within the recent macro-development literature reviewed by Buera et al. [2021]. Work of [Caselli, 2005], [Restuccia et al., 2008], [Vollrath, 2009] and [Gollin et al., 2014] documenting large agricultural productivity gaps in developing countries has sparked a lot of interest in understanding the reasons behind these gaps.[2] A rich literature suggests that these gaps can be linked to frictions and missing property rights in agricultural land markets [Besley, 1995, Goldstein and Udry, 2008]. Papers by [Chen, 2017, Chari et al., 2021, Adamopoulos et al., 2022, Chen et al., 2022, 2023] attribute misallocation in agriculture to the absence of formal land markets. We contribute with a novel empirical and quantitative evidence that although adoption of some formality is beneficial as argued in the above papers, informal institutions may be a constrained-efficient feature of an incomplete market environment. A similar point, although through a different mechanism, is made in concurrent work of Manysheva [2022] applying an Aiyagari-type of economy to understand sluggish take-up of land rights in Tanzania.

By emphasizing the role of social norms and informal institutions, our work relates to the literature integrating those margins –prevalent in traditional villages– into the study of economic development [Platteau, 2015]. In the absence of formal insurance markets, [Townsend, 1994] and [Udry, 1994] find that informal insurance networks in rural India and Nigeria significantly enhance consumption smoothing. Evidence in [Brasselle et al., 2002] shows that increased formal land rights in Burkina Faso have generated limited productivity improvements, suggesting that informal institutions do provide important land allocation functions, as is similarly argued in [Gottlieb and Grobovšek, 2019]. [Gollin and Udry, 2021] find that upon accounting for unobserved heterogeneities and measurement error, the measured efficiency of land markets in Tanzania and Uganda is greatly improved. Consistent with these studies, we argue that informal rural institutions can partially compensate for the lack of

[2] [Mazur and Tetenyi, 2024] show that some of these gaps may be constrained-efficient due to micro-level transaction costs and associated food security considerations.

well-developed formal markets and that a significant share of beneficial effects of land rights arises through broader local economy interactions (like risk sharing networks in our case).

Our argument for rational persistence of informal institutions, even in the absence of chiefs' power, relies on off-equilibrium analysis requiring a formal theory. Theoretical papers by [Carter, 1987] and [Baland and Francois, 2005] analyze the insurance properties stemming from output sharing of collective agriculture without considering direct transfers through informal insurance networks. [Delpierre et al., 2019] study theoretically agricultural output sharing in a static model of voluntary risk sharing with fixed land endowments. Our work complements those papers with a theoretical model allowing for dynamic interactions between the risk sharing and land allocations.

The theoretical model employed is an extension of the dynamic risk-sharing framework with two-sided limited commitment due to Kehoe and Levine [1993] and Kocherlakota [1996]. Ligon et al. [2002] provided the first application of that model to village economies in India. Attanasio and Rıos-Rull [2000], Thomas and Worrall [2007], Krueger and Perri [2006] and Ábrahám and Laczó [2018] study impacts of different public or private insurance programs on risk sharing against idiosyncratic shocks. Morten [2019], Meghir et al. [2022] and Mazur [2023] extend this class of models by interactions of the risk sharing institution with margins of migration and investments into irrigation. We analyze interactions between risk sharing and land markets, and show the importance of accounting for how statutory reforms affect the functioning of these institutions through their impact on the outside option.

The rest of the paper is organized as follows. In Section 2, we briefly introduce the institutional setting in Ghana. In Section 3, we describe our data sources, measurement and provide initial suggestive evidence. The main empirical results on the roll-out of registration offices and power of chiefs, and the impact of land rights on risk sharing are in Section 4. Section 5 introduces the theoretical framework, Section 6 describes the structural estimation and Section 7 presents the quantitative results. We conclude in Section 8.

2 Statutory and customary land institutions in Ghana

Land management in Ghana combines statutory and customary practices that interact and overlap, creating a dynamic institutional framework. Despite numerous post-colonial reforms, customary land norms have remained widely accepted regardless of national politics [Woodman, 2003]. The Constitution of 1992 formally recognized customary land ownership provided it does not violate state law [Kline et al., 2019], and customary groups are permitted to manage Alternative Dispute Resolution (ADR) programs mediating community disputes.

Under customary norms, land belongs either to "Stool lands" (southern Ghana, matrilineal inheritance) or "Skin lands" (northern Ghana, patrilineal inheritance), both symbols of chieftainship, signifying the centrality of customary rules in rural land governance. Consistent with the collectivist foundations of African law [Driberg, 1934], land belongs to the community, village or family but never to the individual [Daniels, 1996].[3] As a result, heads of extended families and traditional leaders hold extensive authority over land matters.

An important feature of customary land governance is its balancing of the efficiency–equity considerations emphasized in the literature [Turpin, 1963, Ollennu et al., 1962]. On the one hand, land is treated as a communal resource to which members retain residual claims, limiting permanent alienation and helping preserve access within the community. On the other hand, customary rules often require land to remain in active use, with unused land reverting to the stool, family, or other communal authority for reallocation. In this sense, customary tenure can simultaneously provide social protection and support productive land use.

A significant milestone in the formalization of land rights in Ghana was the launch of the Land Administration Project (LAP) in 2003, a long-term initiative aimed at addressing major weaknesses in the country's land administration system and regulatory framework. The project was implemented in two phases: LAP-1 (2003–2008) and LAP-2, which commenced in 2008. Its primary objective was to facilitate land registration and enhance legal security of tenure [Alhola and Gwaindepi, 2024]. One of the key outcomes of the project was the

[3] "There is a Ghanaian saying to the effect that there is no land without an owner" [Daniels, 1996].

decentralization of land administration services from Accra to regional and district levels, achieved through the expansion of Land Commission offices (LCs) and the establishment of Customary Land Secretariats (CLSs) across the country. By the conclusion of LAP's first phase, 10 Land Commission offices had been established, and by the end of 2016, a total of 81 Customary Land Secretariats were in operation.

Land Commission offices and Customary Land Secretariats play distinct yet complementary roles in Ghana's land governance. LCs, as statutory bodies, oversee formal land registration, titling, and dispute resolution under national law, aiming to streamline bureaucratic processes and enhance tenure security. In contrast, CLSs operate within customary frameworks, sometimes under the authority of traditional leaders, with the goal of documenting and managing communal land allocations. Established under the LAP, CLSs were designed to bridge formal and informal systems by recording customary land transactions and reducing ambiguities in ownership, ultimately facilitating the procedures towards registration of formal land rights. The relative influence of statutory land institutions and customary authorities depends on the degree of centralization in local land governance. As documented by Abubakari et al. [2018], some areas are characterized by highly centralized systems in which chieftaincy is closely tied to land custody, while others are more decentralized in relying on local clans and families in the allocation of land.

A further institutional feature relevant to our modelling is that virtually all formally registered land rights in Ghana take the form of leaseholds rather than freehold titles [Abubakari et al., 2018]. This reflects both the constitutional prohibition on freehold grants from stool land and the administrative practice of the Lands Commission, whose operational manual sets upper limits on lease terms and provides no procedures for perpetual individual ownership. Upon expiry, land reverts to the allodial holder, the stool or family, rather than remaining with the individual. This fiduciary obligation, enshrined in Article 36(8) of the 1992 Constitution, further empowers and constitutionally requires custodians of stool, skin, and family lands to reallocate land that is no longer serving the benefit of the community. Taken together, these features imply that formal land rights are inherently conditional on customary rules. We return to this point when motivating modelling choices in our structural model (Section 5).

3 Data, measurement and descriptive evidence

For the empirical analysis, we draw on the ISSER–Northwestern–Yale Long-Term Ghana Socioeconomic Panel Survey (GSPS) [Osei et al., 2022], which provides nationally representative data covering all ten regions of Ghana. The survey spans three waves (2009/2010, 2013/2014, and 2017/2018), during which 5,009 households across 334 enumeration areas were interviewed. To focus on rural dynamics, we restrict the sample to non-urban households that own and cultivate land, yielding a main estimation sample of 3,870 household-wave observations across 200 villages in 95 administrative districts. The sample construction is described in detail in Appendix A.1. In addition to the household-level data, we use the GSPS community questionnaire on local institutions, and GPS coordinates of the surveyed households to construct complementary spatial variables. In what follows, we describe construction of the main variables used in our analysis and provide some first descriptive evidence. Table A.2 reports summary statistics for the main variables used.

3.1 Measurement of key variables

Land rights

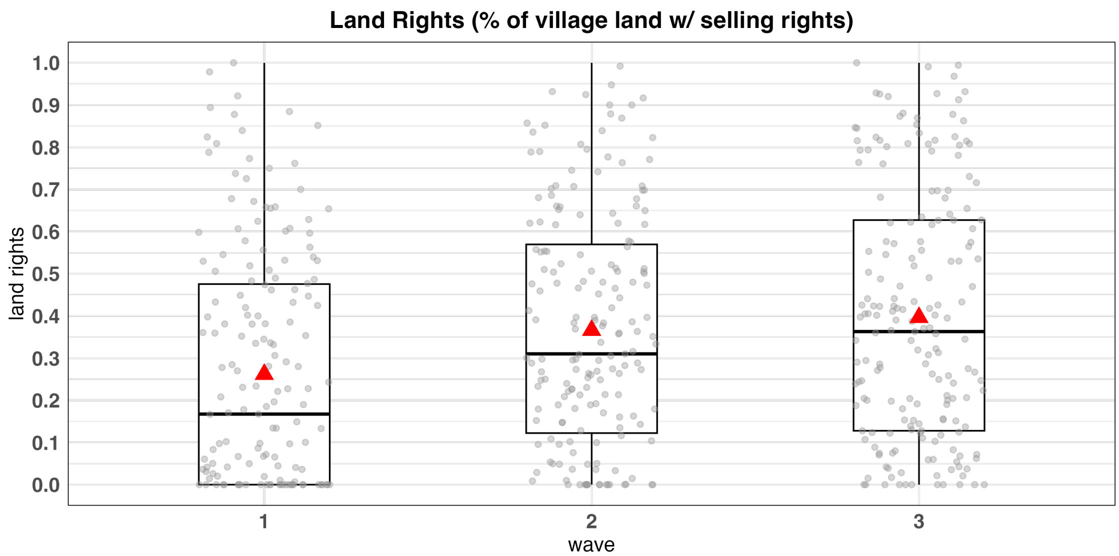
To capture land rights, we use plot-level data from the GSPS, which records whether the current user of each parcel has the right to sell or to use it as collateral for a bank loan. We construct a binary indicator at the plot level:

$$\text{land-rights}_{p,t} = \begin{cases} 1, & \text{if the user can sell or sell and collateralize the plot} \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

We then aggregate to the village level by computing the acreage-weighted share of plots with selling rights:

$$\text{land-rights}_{v,t} = \sum_{p \in (v,t)} \left(\text{selling-rights}_{p,t} \cdot \frac{\text{area}_{p,t}}{\sum_{p' \in (v,t)} \text{area}_{p',t}} \right) \tag{2}$$

where p indexes plots, v the village, and $\text{area}_{p,t}$ is the size of the plot in acres. This measure captures the prevalence of formal land security within each village at time t. Figure 2 shows the distribution of village-level land rights across the three waves, highlighting a notable increase from around 25% in wave 1 to around 40% in wave 3, alongside substantial heterogeneity across villages.



Note: The figure shows the boxplot with distribution of village-level land rights — measured as the acreage-weighted share of plots with formal selling rights defined in (2) — across the three waves. The red triangle indicates the wave mean. The three horizontal lines indicate the 25th percentile, the median and the 75th percentile.

Figure 2: Land rights over time

Distance to land administration offices

Using GPS coordinates from the GSPS, we define the origin point as the centroid of each rural village and construct three distance measures to the nearest land administration office: (i) Euclidean distance, (ii) driving distance via Google Maps, and (iii) a composite measure that uses the distance to the nearest CLS if one exists within a 5 km radius of the village, and the distance to the nearest LC otherwise.[4] The 5 km threshold reflects the fact that CLSs typically serve the customary land areas in their immediate surroundings. Figure 3 shows the locations and opening times of LCs and CLSs.

[4]We thank Benjamin Quaye from Accra's Land Commission for sharing the data on locations and opening times of LCs and CLSs.

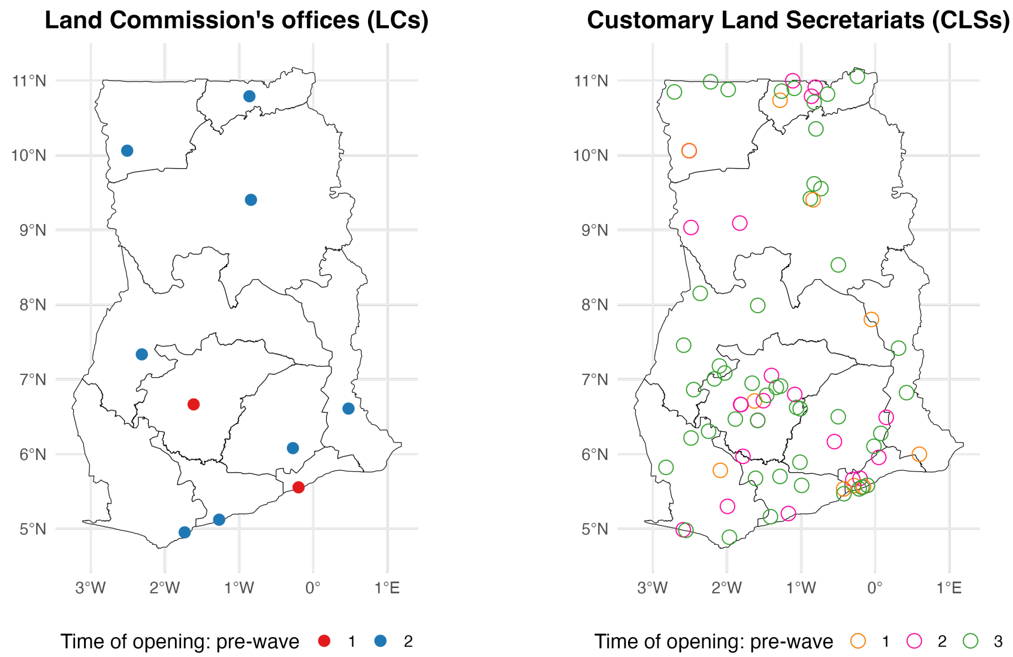


Figure 3: Spatial distribution of Land Commission offices (LCs) and Customary Land Secretariats (CLSs) and their time of opening

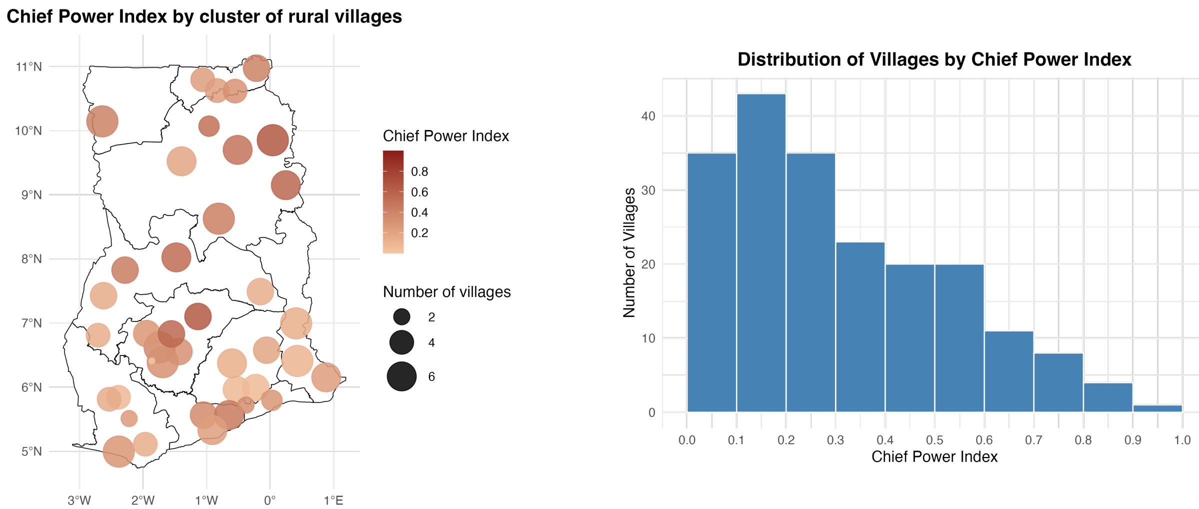
Note: Classification of an office being "opening pre-wave 1" indicates we treat it as open in wave 1 (2009/10) of GSPS data, "opening pre-wave 2" as opened between waves 1 (2009/10) and 2 (2013/14) of GSPS data etc. All LC offices, apart from ones in Accra and Kumasi, were opened in regional capitals of Ghana following enactment of the Lands Commission Act, 2008 (Act 767). We classify those LCs as *opened and operational* between waves 1 and 2.

Chief Power Index

To quantify the degree of centralization in land governance, we draw on responses to the GSPS community survey question: *"What are the main system(s) of obtaining land to own in this community?"*. We create an index between 0 and 1 classifying a village as more centralized if the (averaged over waves) share of responses referring to chieftaincy-owned or Tendaamba[5] systems is higher, and as more decentralized if more answers report that land is primarily obtained through family inheritance, individual arrangements, purchase, or rental. See Appendix A.8 for construction details. Figure 4 illustrates the spatial variation and

[5]Historically, Tendaamba are clan leaders or earth priests vested with spiritual and administrative authority over communal land. They oversee land allocation, mediate disputes, and ensure adherence to customary norms, acting as intermediaries between communities and ancestral spirits tied to the land. This system is inherently centralized, as land rights are vested in the Tendaamba rather than individuals or families, and decisions require their approval [Ubink, 2008].

distribution of the index across the 200 rural villages in our sample.



Note: Left panel: to preserve the anonymity of survey locations, the map displays clusters formed from 200 rural villages. Cluster sizes reflect the number of villages in each group and colors indicate the average Chief Power Index within each cluster. Right panel: distribution of the Chief Power Index across the 200 villages.

Figure 4: Spatial distribution of Chief Power Index

Our identifying variation in CPI is best viewed as predetermined rather than contemporaneously generated. Abubakari et al. [2018] and Abubakari et al. [2020] show that in Ghana there exists a strong distinction between historically entrenched centralized land-governance systems, where chiefs or Tendaamba retain strong authority over land custody, and more decentralized systems, where land allocation relies more heavily on clans and families. Moreover, the authors trace these differences to historically evolved governance structures and show that they continue to shape the practical organization of land administration and registration across regions of Ghana. Our CPI is constructed precisely from these underlying modes of land access.

As a further evidence, Table A.4 in Appendix A.8 shows that village fixed effects account for 59% of the variation in CPI, while common wave effects contribute virtually nothing. This combination of institutional history and persistence over almost 10 years of the GSPS sample supports interpreting CPI as a slow-moving measure of local institutional centralization, predetermined with respect to the more recent expansion of statutory land administration.

Income and consumption

We measure income as the net monetary value of agricultural production in the major agricultural season, combining crop sales revenues with the market value of home-consumed production and subtracting production costs (seeds, tractor services, hired labour, and transportation). See Appendix A.2 for full construction details.

Consumption is measured as the sum of four non-durable expenditure components: deseasonalized food consumption, clothing and footwear, fuels, and other items. Since food consumption is the only component recorded on a monthly basis, we deseasonalize it using a wave-region normalization approach that removes month and region fixed effects to account for the different agricultural seasons experienced by northern and southern Ghana, and then annualize the deseasonalized figure (see Appendix A.5).

Both income and consumption measures are deflated to 2009 prices using the World Bank CPI (see Appendix A.6), and expressed in per capita terms using an adult-equivalent household size following Townsend [1994] (see Appendix A.7). Both measures are winsorized at the 1% level within each wave. Full construction details are provided in Appendix A.4.

3.2 Descriptive evidence

Four key patterns emerge from the descriptive evidence on land access, land rights, and informal risk-sharing in rural Ghana. All figures are reported in Appendix B.

First, land transfers are almost exclusively informal and occur within extended families (Figure B.1): inheritance and free allocation dominate, while formal sales are virtually absent. Although chiefs appear to play a limited *direct* role, their influence operates *indirectly* through extended families and customary tenure systems, as supported by Figure 1 in the introduction, where more than 80% of respondents report chiefs playing an important role in rural land allocations, and by Figure 4 documenting a significant share of villages in GSPS sample with a high value of the CPI.

Second, despite the informality of land transfers, household landholdings change substantially over time (Figure B.2), pointing to active informal reallocation mechanisms. Village-level land rights also fluctuate considerably across villages and over time (Figure B.3), suggesting weak and fluid institutional enforcement that is consistent across all administrative regions.

Third, household savings are negligible relative to consumption (Figure B.4), underscoring the need for alternative risk-coping mechanisms. Most loans come from relatives or neighbours and typically require no collateral (Figure B.5), suggesting that informal mutual insurance arrangements embedded in social networks are the primary mechanism through which households cope with risk.

4 Empirical analysis

Our empirical analysis has two objectives. First, we study why formal land rights remain limited despite the expansion of statutory land institutions. We distinguish between an *access* explanation, according to which households fail to formalize because land offices are too costly to reach, and a *local-governance* explanation, according to which formalization is constrained by centralized customary control over land. To test the access channel, we exploit the rollout of Land Commission offices and Customary Land Secretariats, which generated time variation in villages' proximity to statutory institutions. To test the local-governance channel, we use cross-village variation in the Chief Power Index, a slow-moving measure of land-governance centralization described in Section **??**. The comparison is central to our argument: if proximity to statutory institutions does not affect formalization, while historically rooted variation in local land governance does, the evidence points to customary institutional constraints rather than statutory access as the main barrier to land-rights take-up.

Second, we study whether land rights affect village economies through informal insurance. We estimate an extended version of the Townsend [1994] consumption-smoothing test and ask whether the pass-through of idiosyncratic income shocks to consumption is lower in villages with stronger land rights. These results motivate the structural model in Section 5.

Our panel regressions include relevant unit and time fixed effects that absorb unobserved time-invariant heterogeneity and changes in aggregate conditions. As the GSPS contains only three survey waves, spaced several years apart, the panel structure is too coarse to capture high-frequency serial dependence. For this reason, we cluster standard errors at the district $\times$ wave level for village-wave panel specifications and at the village $\times$ wave level for the household-level Townsend regression, allowing for arbitrary dependence within those cells. For cross-sectional village-level specifications, where the identifying variation is across villages within districts, we cluster at the district level.

4.1 Determinants of land rights take-up

We examine two potential determinants of land rights take-up: proximity to land administration offices and the degree of traditional chiefs' power in local land governance. Both factors relate directly to the ease with which households can formally register land.

Leveraging the quasi-experimental variation in villages' distance to land administration offices generated by the roll-out of LCs and CLSs under the LAP, we estimate the following specification:

$$\text{land-rights}_{v,t} = \beta \cdot \log(\text{distance-to-LC/CLS}_{v,t}) + \mu_v + \mu_{d,t} + \varepsilon_{v,t} \tag{3}$$

where distance-to-LC/CLS refers to the driving distance from village v to the nearest CLS if one exists within a 5 km radius, and to the nearest LC otherwise. Village and district-by-time fixed effects μ_v and $\mu_{d,t}$ control for unobserved village characteristics and aggregate shocks. The relative influence of LCs and CLSs, however, depends on the degree of centralization in local land governance [Abubakari et al., 2018]. To capture this variation, we use the Chief Power Index described in Section 3 and estimate the following cross-sectional specification:

$$\overline{\text{land-rights}}_v = \beta \cdot \text{Chief-Power-Index}_v + \mu_d + \varepsilon_v \tag{4}$$

Table 1 presents the results. The exogenous reductions in distance to the nearest land administration office show no significant impact on land rights take-up across all three distance specifications (columns 1–3). In contrast, the Chief Power Index has a strong negative and significant effect on average land rights (column 4): a one-unit increase in the Chief Power Index is associated with a reduction in average land rights of approximately 74% of the sample mean. This result aligns with Abubakari et al. [2018], who argue that more centralized land governance structures contribute to an implementation gap between legal provisions and the services actually delivered in practice.

	Dependent variable:			
	land-rights$_{v,t}$ Time-varying land rights			$\overline{\text{land-rights}}_v$ Average land rights
	(1)	(2)	(3)	(4)
log(driving-distance-to-LC/CLS$_{v,t}$)	−0.009			
	(0.024)			
log(driving-distance-to-LC$_{v,t}$)		−0.014		
		(0.038)		
log(driving-distance-to-CLS$_{v,t}$)			0.004	
			(0.027)	
Chief Power Index$_v$				−0.253**
				(0.102)
Mean of Dep. Variable	0.347	0.347	0.347	0.340
Unit of analysis	Vil	Vil	Vil	Vil
Unit FE	Yes	Yes	Yes	No
Time FE	No	No	No	No
District FE	No	No	No	Yes
District × Time FE	Yes	Yes	Yes	No
F-stat	0.06	0.06	0.01	5.25
Observations	556	556	556	200

Note: Cols. 1–3 report driving distances to land administration offices in kilometers, computed via Google Maps. Col. 1: driving distance to the nearest CLS if one is located within a 5 km radius of the village; otherwise, driving distance to the nearest LC. Col. 2: driving distance to the nearest LC. Col. 3: driving distance to the nearest CLS. The sample drops from 565 to 556 village-wave observations due to missing driving distances for 9 village-wave observations. Col. 4 reports the cross-sectional relationship between the Chief Power Index and average land rights. Standard errors are clustered at the district × wave level for cols. 1–3 and at the district level for col. 4. Robustness checks using Euclidean distance measures are reported in Appendix C.1.

Table 1: Access to formal institutions, land power of traditional authorities and land rights

Importantly, the CPI coefficient is identified from comparisons across villages within the same district. District fixed effects absorb broad differences in regional administration, legal environment, market access, state capacity, and district-level social structure, including trust, ethnic composition, and cooperative norms to the extent that these are shared within districts. The estimated relationship is therefore driven by relatively local differences in the centralization of customary land governance, rather than by broad regional differences in statutory institutions or social organization.

Another potential concern is that CPI may proxy for other village-level characteristics that also shape the demand for formal land rights. We examine two such alternatives. The first is population density, which captures land scarcity and demographic pressure; the second is ethnic fractionalization, which captures one dimension of social heterogeneity that may affect trust, coordination, and the enforcement of customary norms. If CPI were simply proxying for these broader social or demographic factors, its coefficient should attenuate once they are included. Instead, Table C.2 in Appendix C.2 shows that neither population density nor ethnic fractionalization is statistically significant, either individually or jointly, while the CPI coefficient remains negative and significant throughout. This supports the interpretation that the relevant variation is tied to the centralization of customary land governance rather than to land scarcity or ethnic heterogeneity alone. Details on the construction of these controls are provided in Appendices A.9 and A.10.

4.2 Impact of land rights on risk sharing

We now turn to the empirical analysis of the interaction between land rights and informal institutions at the village level. Our primary objective is to understand how land rights influence informal risk-sharing mechanisms among predominantly farming households. We exploit the panel structure of our dataset to estimate an extended version of the Townsend [1994] consumption smoothing test, assessing both the extent to which farmers are able to smooth consumption in rural Ghana and the role of land rights in shaping mutual insurance:

$$\begin{aligned} \log(c_{i,t}) = \beta_1 \cdot \log(y_{i,t}) + \beta_2 \cdot \log(y_{i,t}) \cdot \text{land-rights}_{v,t} \\ + \beta_3 \cdot \text{land-rights}_{v,t} + \beta_4 \cdot \log(c_{v,t}) + \mu_i + \mu_t + \varepsilon_{h,t} \end{aligned} \tag{5}$$

where $c_{i,t}$ and $y_{i,t}$ are per capita consumption and income of household i at time t, and μ_i, μ_t are household and time fixed effects. Village-level consumption[6] controls for aggregate

[6] Of every household but household i.

shocks. The key coefficients are β_1, capturing the sensitivity of consumption to idiosyncratic income shocks with lower values implying better risk-sharing, and β_2, capturing whether land rights reduce that sensitivity. We consider specifications with (i) time-varying land rights, (ii) time-invariant average village-level land rights, and (iii) average land rights instrumented by the Chief Power Index.

As a complementary measure, following Attanasio and Rıos-Rull [2000], we construct a village-wave risk-sharing ratio:

$$\mathrm{RS}_{v,t} = 1 - \log\left(\frac{\mathrm{Var}_{i\in v}(c_{i,t})}{\mathrm{Var}_{i\in v}(y_{i,t})}\right) \tag{6}$$

where higher values indicate greater risk-sharing, and estimate:

$$\log(\mathrm{RS}_{v,t}) = \beta_1 \cdot \text{land-rights}_{v,t} + \mu_v + \mu_{d,t} + \varepsilon_{v,t} \tag{7}$$

Our estimates reveal three main findings. First, households smooth consumption to a significant degree: the elasticity of consumption with respect to idiosyncratic income shocks is small and statistically significant across all specifications. Second, land security enhances informal insurance: the coefficient on the interaction between income and village-level land rights is negative and significant throughout, suggesting that stronger land rights improve risk-sharing capacity within villages. Third, average household consumption is significantly higher in villages with more secure land tenure, pointing to potential productivity gains. Column (4) shows consistent evidence that land rights are positively correlated with the cross sectional risk-sharing ratio.

Finally, we verify that the improvement in risk-sharing does not operate through a self-insurance channel. Regressing household savings on land rights at the household-wave, village-wave, and village cross-section levels yields uniformly insignificant coefficients, as does a regression of the Chief Power Index on average village savings. This confirms that the mechanism operates through informal mutual insurance arrangements within village networks rather than through individual savings accumulation, consistent with the descriptive evidence in Figure B.4 and the formal results in Appendix C.4.

	Dependent variable:			
		$\log(c_{i,t})$		$\log(\text{RS})_{v,t}$
	Time-varying land rights	Average land rights	IV — Average land rights	Time-varying land rights
	(1)	(2)	(3)	(4)
$\log(y_{i,t})$	0.068***	0.075***	0.080***	
	(0.011)	(0.014)	(0.017)	
land-rights$_{v,t}$	0.302**			1.578*
	(0.129)			(0.939)
$\log(c_{v,t})$	0.653***	0.657***	0.657***	
	(0.040)	(0.041)	(0.041)	
$\log(y_{i,t}) \times$ land-rights$_{v,t}$	−0.059***			
	(0.022)			
$\log(y_{i,t}) \times \overline{\text{land-rights}}_v$		−0.074**		
		(0.033)		
$\log(y_{i,t}) \times \widehat{\overline{\text{land-rights}}}_v$			−0.089*	
			(0.046)	
Unit of analysis	HH	HH	HH	Vil
Unit FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	No
District × Time FE	No	No	No	Yes
Observations	3,870	3,870	3,870	536

Note: Standard errors are clustered at the village × time level for cols. 1–3 and at the district × time level for col. 4. Column 3: average land rights instrumented by the Chief Power Index.[7] Since the Chief Power Index is time-invariant and village-specific, it is fully absorbed by household fixed effects and cannot be used directly in a standard IV framework. We therefore implement the procedure manually by substituting predicted values from a first stage regression of average land rights on the Chief Power Index into the Townsend specification. See Appendix C.3 for details. Column 4: 29 village-wave observations dropped due to villages appearing with only 1 household.

Table 2: Impact of land rights on risk sharing

5 Model of land and risk sharing

In this section, we develop a dynamic stochastic village economy that can rationalize the empirical findings documented above. Figure 5 summarizes the timeline of events.

In period 0, before the dynamic game starts, the planner chooses the degree ψ of formal land titles. At any later point in time, households interact in the *cooperation allocation* over the allocation of land used to produce agricultural output and over risk sharing. The degree of this cooperation is pinned down by the value of the (off-equilibrium) outside option attainable by reverting to *self-insurance outside option* where land is traded in the formal market. The period-0 choice of ψ_v links all these margins.

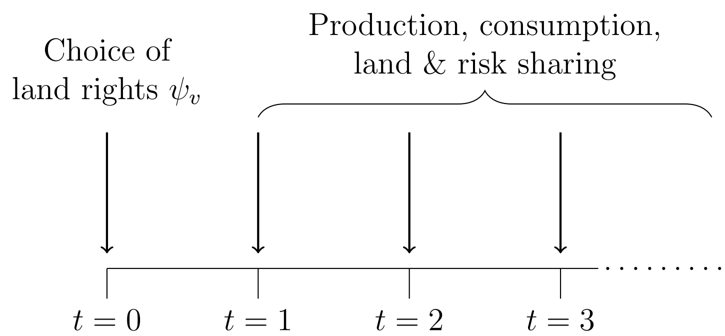


Figure 5: Timeline of decisions and activities in a village economy

5.1 Environment

Time is discrete and the economy is populated by V island villages. Each village v is inhabited by a planner and two ex-ante homogeneous infinitely-lived risk-averse households denoted by $i \in \{1, 2\}$.

Period t=0: choice of formal land rights

In period 0, the village v planner (traditional chief) chooses once for all the level of formal land rights $\psi_v \in [0, 1]$ to maximize the expected utilitarian Social Welfare Function (SWF) given by:

$$\max_{\psi_v} \quad \mathbb{E}_t V_{v,1}^{SWF}(x_{v,1}; \psi_v) - \delta_1 \cdot \mathcal{P}_v \cdot \psi_v^{\delta_2} \tag{8}$$

where $\mathbb{E}_t V_{v,1}^{SWF}(x_{v,1}; \psi_v)$ denotes the equally-weighted expected utility of both households in village v from period $t = 1$ onwards. Parameter $\mathcal{P}_v \in [0, 1]$ is our theoretical counterpart of the empirical Chief Power Index. Technically, it governs the one-off quadratic disutility to the planner from land formalization (e.g. discounted present value of rents lost due to giving up power over land). Parameters δ_1, δ_2 are common across all villages and govern average and curvature of the disutility. The choice of ψ_v determines the functioning of the local economy, as we describe below.

Period $t \geq 1$: allocation of land, production & consumption

At any point in time t, household i derives utility from consumption and disutility from working, according to function:

$$u(c_{i,t}) - v(h_{i,t}) = \log(c_{i,t}) - \eta_0 \frac{h_{i,t}^{1+\eta_1}}{1+\eta_1}$$

where $h_{i,t} \in [0,1]$ denotes labor hours, η_1 governs the Frisch elasticity of labor supply and η_0 is a shift parameter of the labor disutility function.

In every period, household produces crop output using amount of land $z_{i,t}$ (chosen in period $t-1$, "time-to-build") and self-provided labour hours $h_{i,t}$ (chosen in t) as inputs in the following production function:

$$y_{i,t} = A_v \phi_t \theta_{i,t} h_{i,t}^{\alpha_h} z_{i,t}^{\alpha_z} \tag{9}$$

where we assume decreasing returns to scale ($\alpha_h, \alpha_z \in (0,1)$ and $\alpha_h + \alpha_z \in (0,1)$). We let the idiosyncratic productivity be driven by a persistent process θ and aggregate productivity by an i.i.d. shock ϕ. In the quantitative implementation, we approximate these continuous processes with finite-state Markov chains with transition matrices π_ϕ and π_θ.

Villages are ex-ante heterogeneous due to differences in A_v, the village-specific total factor productivity (TFP) normalized to 1 on average and given by:

$$A_v = \frac{\exp(-a \cdot \mathcal{P}_v)}{\mathbb{E}\exp(-a \cdot \mathcal{P}_v)} \tag{10}$$

where $\mathcal{P}_v$ is the same village-specific friction that drives the disutility of planner from formal land rights.

The dependence of village TFP on P_v reflects our interpretation of the Chief Power Index as a historically rooted measure of local land-governance centralization, rather than as a pure shifter of chiefs' private cost of formalization. The same institutional environment that leads traditional authorities to resist land-rights formalization may also distort local production, for instance by affecting land allocation, investment incentives, or the scope for gains from trade across households. Allowing A_v to vary with P_v is therefore deliberately conservative: it prevents the model from attributing all cross-village differences in productivity and land-market fluidity mechanically to land-rights take-up.

As households are ex-ante homogeneous, each begins with an equal customary land entitlement, $z_{1,0} = z_{2,0} = 0.5$. We interpret this as the household's *inherent* family- or stool/skin-based claim under customary tenure.

In every period, the land can be reallocated between households subject to the "fixed supply" constraint:

$$z_{1,t} + z_{2,t} = 1. \tag{11}$$

Importantly, land reallocations are frictional and subject to the quadratic adjustment cost. In the cooperative allocation, we assume that these frictions are independent of ψ_v chosen and that each household with land-state $z_{i,t}$ and choice $z_{i,t+1}$ has to bear the following cost:

$$\frac{\kappa}{2}\left(z_{i,t+1} - z_{i,t}\right)^2. \tag{12}$$

We interpret this term as capturing real resource and coordination costs of reallocating land within the village economy, such as search, bargaining, and enforcement frictions embedded in customary relations.

By contrast, in the outside option each household's corresponding adjustment cost is assumed to depend negatively on ψ_v:

$$(1 - \psi_v)\frac{\kappa}{2}\left(z_{i,t+1}^{out} - z_{i,t}^{out}\right)^2. \tag{13}$$

This asymmetric specification is motivated by the institutional setting in Ghana. Within-village land reallocations are typically mediated through customary relations and local co-operation, so the associated adjustment costs reflect frictions that persist even when formal rights become more prevalent. By contrast, in the (off-equilibrium) outside option, land is assumed to be transacted in a formal market where land rights improve a household's ability to rely on statutory institutions. We therefore let ψ_v directly reduce land-market frictions only in the outside option, while –as we will explain below– affecting the cooperative allocation indirectly through the limited commitment constraints.

5.2 Outside option: self-insurance in a formal land market

The outside option assumes that households do not participate in the customary arrangement, i.e. do not participate in an informal risk sharing network, but trade land in the formal market. Hence, the only way for households to smooth consumption is by trading their current land endowment or adjusting their labor hours.

Formally, given the degree of land rights ψ_v, the value of the outside option for household i with current state $x_{i,t} = (z_{i,t}^{out}, \phi_t, \theta_{i,t})$ that deviates from the contract, reads:

$$V_{i,t}^{out}(x_{i,t};\psi_v) = \max_{\{c_{i,t}^{out}, h_{i,t}^{out}, z_{i,t+1}^{out}\}} u(c_{i,t}^{out}) - v(h_{i,t}^{out}) + \beta \mathbb{E}_t V_{i,t+1}^{out}(x_{i,t+1};\psi_v) \tag{14}$$

$$\text{subject to :}$$

$$c_{i,t}^{out} + q_{z,t} z_{i,t+1}^{out} + (1-\psi_v)\frac{\kappa}{2}\left(z_{i,t+1}^{out} - z_{i,t}^{out}\right)^2 \leq A_v \phi_t \theta_{i,t} \left(h_{i,t}^{out}\right)^{\alpha_h} \left(z_{i,t}^{out}\right)^{\alpha_z} + q_{z,t} z_{i,t}^{out} \tag{15}$$

We describe the main ingredients of this allocation step by step. First, households participate in the formal land market where they can trade land at current price $q_{z,t}$ that is pinned down in equilibrium but taken as given by households. Apart from the adjustment cost, households retain the full proceeds from any sales of their land holdings.

Second, the period-0 planner's choice of land rights ψ_v has a direct impact on the outside option through the dependence of adjustment costs on ψ_v, as in (13). The greater is the level of land rights chosen, the lower are the adjustment costs associated with land transactions in the formal market.

Third, the optimal labor supply choice $h_{i,t}^{out}$ satisfies the following standard First Order Condition (FOC) equating the marginal benefit of a marginal increase in labour (weighted by the marginal utility of consumption) with the marginal disutility of labour:

$$\frac{v'(h_{i,t}^{out})}{u'(c_{i,t}^{out})} = \alpha_h A_v \phi_t \theta_{i,t} (h_{i,t}^{out})^{\alpha_h - 1} (z_{i,t}^{out})^{\alpha_z} \tag{16}$$

Fourth, the FOC governing the optimal land choice $z_{i,t+1}^{out}$ induces the following asset pricing equation:

$$q_{z,t} + \kappa(1-\psi_v)(z^{out}_{i,t+1} - z^{out}_{i,t}) = \beta\,\mathbb{E}_t\,\frac{u'(c^{out}_{i,t+1})}{u'(c^{out}_{i,t})}\Bigg[\alpha_z A_v \phi_{t+1}\theta_{i,t+1}(h^{out}_{i,t+1})^{\alpha_h}(z^{out}_{i,t+1})^{\alpha_z-1} + q_{z,t+1} + \kappa(1-\psi_v)(z^{out}_{i,t+2} - z^{out}_{i,t+1})\Bigg] \tag{17}$$

Optimal land holdings for next period are chosen such that the marginal cost of an additional unit of land bought at price $q_{z,t}$, inclusive of the adjustment cost incurred, is equalized with its expected marginal benefit. The latter is given by the next period's expected marginal increase in the crop output due to additional unit of land, in the capital value of land and the marginal change in the reference level for future adjustment costs (all weighted by the stochastic discount factor). Importantly, the equilibrium price $q_{z,t}$ has to be such that $z_{i,t} \in [0,1]\ \forall i$ and the market clearing condition $z_{1,t} + z_{2,t} = 1\ \forall t$ holds.

5.3 First best benchmark

We proceed with the description of the first best (FB) benchmark, where the limited commitment friction is absent. We use this allocation as the benchmark for the limited-commitment distortions characterized below.

Assuming that the planner of village v attaches constant Pareto weights λ_i to each household, she assigns consumption, land and labour to maximize the objective function (18) subject to the resource constraint (20) and the fixed land supply constraint (21):

$$V^{FB}_t(x_t) = \max_{\{c^{FB}_{i,t}, z^{FB}_{i,t+1}, h^{FB}_{i,t}\}} \sum_{i=1}^{2} \lambda_i \Big(u(c^{FB}_{i,t}) - v(h^{FB}_{i,t})\Big) + \beta \mathbb{E}_t V^{FB}_{t+1}(x_{t+1}|x_t) \tag{18}$$

$$\text{subject to :} \tag{19}$$

$$\sum_{i=1}^{2} c^{FB}_{i,t} + \frac{\kappa}{2}\sum_{i=1}^{2}\left(z^{FB}_{i,t+1} - z^{FB}_{i,t}\right)^2 \leq \sum_{i=1}^{2} A_v \phi_t \theta_{i,t}(h^{FB}_{i,t})^{\alpha_h}(z^{FB}_{i,t})^{\alpha_z} \tag{20}$$

$$z^{FB}_{1,t} + z^{FB}_{2,t} = 1 \tag{21}$$

$$z^{FB}_{i,t},\ h^{FB}_{i,t} \in [0,1]$$

Notice that the degree of formal land rights ψ_v is irrelevant under the first best. This is a direct consequence of the fact that the planner is assumed to be benevolent with perfect enforcement power (in particular, she does not have to respect the limited commitment constraints described below). The associated current state vector is denoted by $x_t = (z_{1,t}, z_{2,t}, \theta_{1,t}, \theta_{2,t}, \phi_t)$. For brevity, we postpone description of the FOCs to the section on the LRS allocation below.

5.4 Land and risk sharing with limited commitment

Given the degree of land security ψ_v chosen at $t = 0$, the planner of village v allocates consumption, land, and labour in every period $t \geq 1$ to maximize the social welfare function. The resulting land-and-risk-sharing (LRS) arrangement must be both feasible and self-enforcing: at every date, each household must weakly prefer remaining in the cooperative arrangement to deviating to the outside option.

To capture the links between decisions made within cooperation and the outside option, we make the following assumption:

Assumption 1 (Separation rule). *In the period of deviation ($t = t_{dev}$), the household enters outside option with the following land holdings:*

$$z^{out}_{i,t_{dev}} = \psi_v \cdot z_{i,0} + (1 - \psi_v) \cdot z^{LRS}_{i,t} \tag{22}$$

Thus, the deviating household enters self-insurance with a landholding equal to a convex combination of its customary baseline entitlement, $z_{i,0} = 0.5$, and the amount of land assigned to it within the cooperative land-and-risk-sharing arrangement, $z^{LRS}_{i,t}$. A higher degree of land security ψ_v places greater weight on the household's own baseline land claim upon deviation.

We further assume, as is standard in limited-commitment environments, that deviation is punished by permanent exclusion from future village cooperation and reversion to the self-insurance outside option. This amounts to restricting attention to subgame-perfect self-enforcing arrangements in which the continuation value after deviation is given by the outside option.

Formally, the planner solves the following problem:

$$V_{v,t}^{LRS}(x_{v,t};\psi_v) = \max_{\{c_{i,t},z_{i,t+1},h_{i,t}\}_{i\in\{1,2\}}} \sum_{i=1}^{2} \lambda_{i,t}^{LRS}\Big(u(c_{i,t}) - v(h_{i,t})\Big) + \beta\mathbb{E}_t V_{v,t+1}^{LRS}(x_{v,t+1};\psi_v) \tag{23}$$

subject to the feasibility constraint,

$$(\zeta_t^{LRS}) \qquad \sum_{i=1}^{2} c_{i,t} + \frac{\kappa}{2}\sum_{i=1}^{2}\left(z_{i,t+1}^{LRS} - z_{i,t}^{LRS}\right)^2 \leq A_v\phi_t \sum_{i=1}^{2}\theta_{i,t}h_{it}^{\alpha_h} z_{i,t}^{\alpha_z} \tag{24}$$

and the limited commitment constraint for each household:

$$(\mu_{i,t}^{LRS}) \qquad \mathbb{E}_t\Big[\sum_{t'=t}^{\infty}\beta^{t'-t}\Big(u(c_{i,t'}^{LRS}) - v(h_{i,t'}^{LRS})\Big)\Big] \geq V_{i,t}^{out}\Big(\underbrace{\psi_v \cdot 0.5 + (1-\psi_v)\cdot z_{i,t}^{LRS}}_{\equiv z_{i,t_{dev}}^{out}:\text{ land upon deviation}}, \theta_{i,t}, \phi_t; \psi_v\Big)\ \forall i, x^t \tag{25}$$

where ζ and μ denote the Lagrange multipliers associated with the relevant constraints, and we assume that initially $\lambda_{i,0}^{LRS}(x_0) = 1\ \forall i$.

Furthermore, notice the right-hand side of the dynamic participation constraints (25) where Assumption 1 enters: upon deviation from the LRS cooperation, the deviator departs the cooperation with $\psi_v \cdot 0.5 + (1-\psi_v)\cdot z_{i,t}^{LRS}$ units of land. This constraint reflects the assumed timing of the model: deviations at any time t are considered before the new land assignment becomes operative, and so before production takes place.

5.5 Characterization and properties of the cooperative allocation

Optimality conditions. For a given state of the village economy v with permanent productivity A_v with current state vector $x_t = (z_{1,t}^{LRS}, z_{2,t}^{LRS}, \phi_t, \theta_{1,t}, \theta_{2,t}, \lambda_{1,t-1}^{LRS}, \lambda_{2,t-1}^{LRS})$, the allocation can be characterized using the following set of optimality conditions:[8]

$$c: \quad \zeta_t^{LRS} = u'\left(c_{i,t}^{LRS}\right) \cdot \left(\lambda_{i,t-1}^{LRS} + \mu_{i,t}^{LRS}\right) \tag{26}$$

$$h: \quad \frac{v'(h_{i,t}^{LRS})}{u'(c_{i,t}^{LRS})} = \alpha_h A_v \phi_t \theta_{i,t} (h_{i,t}^{LRS})^{\alpha_h - 1} (z_{i,t}^{LRS})^{\alpha_z} \tag{27}$$

$$\begin{aligned} z': \quad & -\lambda_{1,t}^{LRS} u'(c_{1,t}^{LRS}) \kappa \Delta z_{1,t+1}^{LRS} + \beta \mathbb{E}_t \Big[\lambda_{1,t+1}^{LRS} u'(c_{1,t+1}^{LRS}) \big(MPZ_{1,t+1}^{LRS} + \kappa \Delta z_{1,t+2}^{LRS} \big) - \mu_{1,t+1}^{LRS} D_{1,t+1}^{out} \Big] \\ & = -\lambda_{2,t}^{LRS} u'(c_{2,t}^{LRS}) \kappa \Delta z_{2,t+1}^{LRS} + \beta \mathbb{E}_t \Big[\lambda_{2,t+1}^{LRS} u'(c_{2,t+1}^{LRS}) \big(MPZ_{2,t+1}^{LRS} + \kappa \Delta z_{2,t+2}^{LRS} \big) + \mu_{2,t+1}^{LRS} D_{2,t+1}^{out} \Big] \end{aligned} \tag{28}$$

where:

$$\Delta z_{i,t+1}^{LRS} \equiv z_{i,t+1}^{LRS} - z_{i,t}^{LRS}, \tag{29}$$

$$MPZ_{i,t+1}^{LRS} \equiv \alpha_z A_v \phi_{t+1} \theta_{i,t+1} \big(h_{i,t+1}^{LRS}\big)^{\alpha_h} \left(z_{i,t+1}^{LRS}\right)^{\alpha_z - 1}, \tag{30}$$

$$D_{1,t+1}^{out} \equiv \frac{\partial V_{1,t+1}^{out}}{\partial z_{1,t+1}^{LRS}}, \tag{31}$$

$$D_{2,t+1}^{out} \equiv \frac{\partial V_{2,t+1}^{out}}{\partial z_{2,t+1}^{LRS}} \frac{\partial z_{2,t+1}^{LRS}}{\partial z_{1,t+1}^{LRS}}. \tag{32}$$

Pareto weights with limited commitment. As the RHS of FOC (26) suggests, with limited commitment, $\lambda_{i,t}^{LRS}$ become the co-state Pareto weights attached to each household's current value function [Marcet and Marimon, 2019]. These Pareto weights are updated along the economy's history such that no household departs from the cooperation. In other words, LRS allocation is characterized by no default in equilibrium. Mathematically, they are updated by adding the current value of the Lagrange multiplier $\mu_{i,t}^{LRS}(x_t)$ on the limited commitment constraints (25) to the last period's Pareto weight $\lambda_{i,t-1}^{LRS}(x_{t-1})$, i.e. the co-state transition rule satisfies:

$$\lambda_{i,t}^{LRS}(x_t) = \lambda_{i,t-1}^{LRS}(x_{t-1}) + \mu_{i,t}^{LRS}(x_t) \tag{33}$$

[8] Appendix D describes the numerical implementation of the land FOC for solving the model.

Consumption sharing rule. After combining the c-FOCs (26) for both households, the optimal consumption sharing rule reads:

$$\frac{u'(c_{1,t}^{LRS})}{u'(c_{2,t}^{LRS})} = \frac{\lambda_{2,t-1}^{LRS} + \mu_{2,t}^{LRS}}{\lambda_{1,t-1}^{LRS} + \mu_{1,t}^{LRS}} \tag{34}$$

A direct implication of (33) is that individual Pareto weights are updated only when individual limited commitment constraint are binding, i.e. whenever $\mu_{i,t}^{LRS} > 0$. Thus, the planner will update the split of total resources devoted for consumption between the two households only in periods of binding limited commitment constraints such that no household breaks out of the cooperation.

First best. In the FB benchmark, the limited commitment constraints are absent, i.e. $\mu_{i,t} = 0\ \forall i, t$. Therefore, Pareto weights are constant at the level of $\lambda_1 = \lambda_2 = 1\ \forall i, t$ and –from (34)– we have perfect consumption insurance against idiosyncratic shocks: $c_{1,t}^{FB} = c_{2,t}^{FB}\ \forall t$. Then, the land FOC (28) tells us that the FB-planner equalizes marginal products of land net of adjustments costs incurred, all expressed in marginal utility terms.

Consumption & land dynamics in limited commitment. The degree of risk sharing is pinned down by the tightness of the enforcement constraints. In particular, the ability of the planner to provide consumption insurance to both households is an increasing function of the distance between the (inside) value of cooperation and the (outside) value of deviating in the enforcement constraints of both households.

The land allocation is also distorted relative to the first best due to the endogenous impact of within-contract land allocation $z_{i,t+1}$ on the *next period's* value of outside option. Because $\frac{\partial V_{i,t+1}^{out}(x_{t+1})}{\partial z_{i,t+1}^{LRS}} > 0\ \forall i$, the planner distorts land assignments $z_{i,t+1}^{LRS}$ away from the first best by tilting future land toward the household whose future continuation participation constraint is expected to be less binding. Hence, current land assignments matter for future enforcement, even though they do not enter the current deviation value directly.

Land rights & limited commitment. Land rights ψ_v do not affect the cooperative allocation directly through the quadratic adjustment cost in (12). Their role is instead to shift the outside option and thereby alter the enforcement constraints.

Two distinct channels are at work. First, through the separation rule (22), a higher ψ_v changes the landholding carried into deviation. Holding fixed all other state variables and abstracting from the direct effect of ψ_v on formal-market adjustment costs, a higher ψ_v raises the outside option of a household with $z_{i,t}^{LRS} < z_{i,0}$ and lowers it for a household with $z_{i,t}^{LRS} > z_{i,0}$. Intuitively, stronger land rights place greater weight on the household's baseline customary entitlement and less weight on the amount of land currently assigned within cooperation. Second, ψ_v lowers land-market adjustment costs in the outside option, as in (13), which raises deviation values for both households.

To understand the equilibrium implications, consider the state that will also serve as our running example in the quantitative section: at date t, household 2 enters the period with a relatively large landholding from past period but a low realization of idiosyncratic productivity, while household 1 enters with relatively little land but a high realization of idiosyncratic productivity. Given the persistence of idiosyncratic shocks and the time-to-build nature of land, productive efficiency calls for reallocating land toward household 1 for production in period $t + 1$.

The timing is important for understanding how land rights affect this decision. Deviation at date t occurs before current production and before the new land assignment $z_{i,t+1}^{LRS}$ becomes operative. Hence, the participation constraints at t depend on the landholding state variable $z_{i,t}^{LRS}$, not on next period's land allocation. In the state considered here, household 2 is currently land-rich relative to its baseline entitlement, while household 1 is currently land-poor. Through the separation-rule channel, a higher degree of land rights ψ_v therefore lowers the current deviation value of household 2 and raises that of household 1. Put differently, stronger land rights relax the current participation constraint of the unproductive but land-rich household, while tightening that of the productive but land-poor household.

This asymmetry is precisely what allows stronger land rights to sustain larger reallocations inside cooperation. Because household 2 is the current donor of land, the relaxation of its participation constraint makes it easier for the planner to withdraw land from that household and reassign it toward household 1. At the same time, the planner internalizes that the choice of $z_{2,t+1}^{LRS}$ affects continuation values through next period's outside option, as reflected in the $D_{i,t+1}^{out}$ terms in (28). Hence, the effect of ψ_v on cooperative land reallocation is fundamentally dynamic: stronger land rights do not reduce the direct adjustment cost in (12), but they can nonetheless increase the equilibrium fluidity of land reallocations by relaxing the relevant enforcement constraint on the side of the household from which land is being taken.

At the same time, a higher ψ_v also improves the outside option by lowering formal-market adjustment costs, and it raises the current deviation value of the productive but land-poor household through the separation rule. If these forces become too strong, the planner must compensate both households more aggressively to keep them in the arrangement, and eventually the participation constraints can become jointly too tight to satisfy. Thus, stronger land rights may initially support more efficient land reallocation and better risk sharing, but sufficiently high levels of formalization can unravel the cooperative arrangement altogether.

Constrained efficiency with limited commitment. For any fixed degree of land rights ψ_v and given primitives of the outside option, the LRS allocation characterized above is constrained efficient: it solves the planner's problem over the set of feasible and self-enforcing allocations, taking as given the outside option and the associated enforcement constraints. At the same time, the period-0 choice of ψ_v shifts this constrained-efficient frontier by changing the deviation technology faced by households, as described above. From this perspective, the planner's ex-ante choice of ψ_v is a constrained-efficient choice over the enforcement environment itself, net of the land registration costs in equation (8).

5.6 On decentralization of the planner's allocation

Thus far, our analysis has focused on a constrained-efficient planner's allocation of land reallocation and risk sharing within village economies. In a pure endowment economy with idiosyncratic risk and limited commitment, Alvarez and Jermann [2000] show that such allocations can be decentralized using state-contingent Arrow-Debreu securities together with borrowing limits. Extending this insight to a production economy with capital accumulation, Abraham and Carceles-Poveda [2006] show that decentralization additionally requires state-contingent taxes on capital positions.

Our environment is closer to the latter case, but differs in two important respects: land is in fixed aggregate supply, and deviation is governed by the land-separation rule in Assumption 1. Accordingly, an analogous decentralized implementation of the cooperative allocation would likely involve equilibrium land prices together with state-contingent taxes or wedges on land trades within the cooperative arrangement, so as to replicate the planner's Euler equation under limited commitment. A separate ingredient is needed to capture enforcement. Because the land claim retained after deviation is governed by the separation rule in (22), a decentralized counterpart of our model would also require an institutional settlement rule specifying what land claim survives upon exit from cooperation.

This interpretation fits naturally with the institutional setting discussed in Section 2. In rural Ghana, formal land rights typically take the form of leaseholds rather than perpetual freehold ownership, and land ultimately remains conditional on customary authority. Accordingly, the decentralized counterpart of our model is best interpreted not as trade in permanent land ownership, but as trade in land-use claims or rentals. The same institutional features also provide support for Assumption 1: stronger formal rights naturally increase the weight placed on the household's baseline customary entitlement upon deviation, rather than protecting the full amount of land temporarily controlled within the cooperative arrangement. This is further supported by Abubakari et al. [2018], who document that formal land rights in Ghana take the form of leaseholds negotiated between the chief as allodial holder and the household as lessee, and by Ubink [2008], who show that formalisation through leaseholds strengthens the chief's residual authority over land, so that what formal rights protect upon breakdown is the household's underlying customary entitlement rather than the full amount of land it may have been controlling. This is consistent with the idea that, when cooperation breaks down, what survives is the household's underlying customary claim rather than its entire within-cooperation allocation.

Finally, it is important to stress that the outside option is not itself the decentralization of the cooperative LRS arrangement, even when $\psi_v = 1$. Rather, it is a competing self-insurance environment that determines households' deviation values and thereby disciplines the set of self-enforcing cooperative allocations.

6 Structural estimation

We estimate our model using the GSPS data combined with related evidence in the literature. First, we pin down the block of parameters that can be determined directly from household- and village-level data or from standard values in the literature (the output elasticities α_z, α_h, the idiosyncratic θ and aggregate ϕ productivity processes, and the curvature η_1 of the labour disutility).

The second block contains the vector Θ of six parameters that are chosen internally within the model using the simulated method of moments (SMM): β governing time preferences, η_0 - the level of labour disutility, κ - land adjustment costs, δ_1, δ_2 - the level and curvature of registration costs, and a - the extent of village heterogeneity in productivity. The algorithm chooses jointly the values of these six parameters $\hat{\Theta}$ so as to minimize the distance between six model-generated moments and their empirical counterparts. Formally:

$$\hat{\Theta} = \arg\min_{\Theta} \left(m^{data} - m^{model}(\Theta)\right)' \Omega^{-1} \left(m^{data} - m^{model}(\Theta)\right),$$

To ensure comparability between the model and the data, we construct a simulated dataset from the stochastic steady state distribution that mirrors the GSPS sample structure: observations are retained every four model periods to match the gaps between survey waves, synthetic panels contain three observations only, villages of different productivity levels are weighted to reproduce the empirical Chief Power Index distribution in Figure 4, and the same variable definitions and regression specifications are applied to the simulated data as in the empirical analysis. The reported model moments are then averaged across repeated Monte Carlo draws of this synthetic short panel.

Since some of our targeted moments come from household-wave regressions, while others are based on cross-sectional village-level regressions, we account for common sampling variation of our moments using standard bootstrapping. The resulting 6×6 variance-covariance matrix across moments, which accounts for within-village dependence across households and waves as well as cross-moment correlation, is reported in Appendix C.6. Given this, we compute standard errors for the internally calibrated parameters using the standard GMM sandwich formula.

Finally, although the equilibrium of the model is highly nonlinear and, in general, one parameter may affect multiple moments, our method of moments strategy explicitly associates the most informative moments with particular groups of parameters.

Table 3 summarizes all externally chosen and internally estimated parameters. Table 5 presents the empirical fit of our model. Tables C.4 - C.6 in Appendix C.5 contain tables with estimation results referenced below.

6.1 Parameters chosen externally

Production function. We assume output elasticities of land and labour of $\alpha_z = 0.40$ and $\alpha_h = 0.35$, as per the estimated household-level Cobb-Douglas production function:

$$\log(y_{i,t}) = \underbrace{\alpha_z}_{=0.40^{***}} \cdot \log(land_{i,t}) + \underbrace{\alpha_h}_{=0.35^{***}} \cdot \log(labour_{i,t}) + \mu_i + \mu_t + \varepsilon_{i,t} \tag{35}$$

where $y_{i,t}$ is agricultural income, μ_i are household fixed effects, and μ_t are time fixed effects.[9]

Idiosyncratic productivity process. Following the production-function estimation, we proxy the time-varying household-level productivity using:

$$\xi_{i,t} = \hat{\mu}_i + \hat{\varepsilon}_{i,t},$$

which we assume to follow a standard AR(1) process:

$$\xi_{i,t} = \underbrace{\rho_\xi}_{=0.23^{***}} \cdot \xi_{i,t-1} + \varepsilon^{\xi}_{i,t}.$$

We feed the estimated persistence of $\rho_\xi = 0.23$ and innovation's standard deviation of $\sigma_{\varepsilon^\xi} = 1.58$ into the Rouwenhorst's method yielding a discretized two-state Markov chain θ used in the model, which we normalize to 1 on average and assume to be perfectly negatively correlated across households (i.e. $\theta_{i,t} = 1 - \theta_{-i,t}$).

[9]Our estimates are close to those of Gollin and Udry [2021] for Uganda using the IV estimator for the correlated random-coefficients model.

Aggregate productivity process. We assume that the aggregate productivity ϕ_t follows a symmetric two-state i.i.d. process with mean normalized to 1. We set the support of ϕ so that $\text{Var}(\log \phi_t)$ equals to the average within-village time-series dispersion of log demeaned village consumption: $\frac{1}{V}\sum_{v=1}^{V} \text{Var}_t\left(\log\left(\frac{c_{v,t}}{\bar{c}_v}\right)\right) = 0.21$ (see Appendix A.12 for details).

Labour disutility. We set the curvature of labour disutility to $\eta_1 = 2.0$, which corresponds to a Frisch elasticity of labour supply equal to 0.5, in line with standard values used in the literature (Bick et al. [2022], Heathcote et al. [2017]).

6.2 Parameters chosen internally

Time preferences. In the model, higher patience relaxes the dynamic participation constraints and deepens risk sharing. We therefore choose $\beta = 0.87$ so that the model matches the average consumption elasticity w.r.t. idiosyncratic income shocks of $\hat{\beta}^{c,y} = 0.05$ from the baseline Townsend test:

$$\log(c_{i,t}) = \alpha + \underbrace{\beta^{c,y}}_{=0.05^{***}} \cdot \log(y_{i,t}) + \beta^{c_v,y} \cdot \log c_{v,t} + \gamma_i + \gamma_t + \epsilon_{i,t} \tag{36}$$

Labor disutility. The labour disutility shifter $\eta_0 = 8.6$ is chosen to match the mean share of household's discretionary time spent working in agriculture. To compute it, we first sum the total hours spent across all stages of agricultural production by all types of labour (family, communal or hired) during the major agricultural season. Then, we compute per capita labor hours by dividing the total hours by the number of adults in the households with a discounted weight of adult females of 0.46 to account for their domestic and care time commitments, as documented in Gottlieb et al. [2024].[10] Assuming the total discretionary time endowment for work of 5 days per week of 16 hours per day for 365 days, we target the average share of time worked in agriculture of $\bar{h} = 0.27$, which is close to the evidence for Ghana in Bick et al. [2022] (see Appendix A.11 for details on the construction of labour hours).

[10] Our assumed factor corresponds to the share of total work time spent in market work (which includes subsistence farming), as opposed to time spent in domestic and care services, by married women documented in Figure 1 of Gottlieb et al. [2024] based on the 2009 Ghana Time Use Survey.

Land registration costs. In the model, δ_1 governs the overall level of the one-off cost of formalization and therefore determines the average take-up of land rights across villages. Thus, we pin down the value of shifter $\delta_1 = 62.0$ by targeting the average level of land rights in the data, $\bar{\psi} = 0.34$.

Parameter	Interpretation	Value	Target/source
		Externally calibrated	
(α_z, α_h)	output shares	$(0.40, 0.35)$	CD production function
$(\rho_\theta, \sigma_{\varepsilon_\theta})$	idiosyncratic productivity	$(0.23,\ 1.58)$	AR(1) on $\xi_{i,t} = \hat{\mu}_i + \varepsilon_{i,t}$
$(\rho_\phi, \sigma^2_\phi)$	aggregate productivity	$(0.00,\ 0.21)$	i.i.d. and $\frac{1}{N_v}\text{Var}\left(\log \frac{c_{v,t}}{\bar{c}_v}\right)$
η_1	work disutility curvature	2.0	Frisch elasticity $= 0.5$
		Internally calibrated	
β	discount factor	0.87 (0.01)	Coeff. $\hat{\beta}^{c,y} = 0.05$ in (36)
η_0	work disutility shifter	8.60 (0.90)	avg. labour supply $\bar{h} = 0.27$
δ_1	registration cost shifter	62.00 (12.01)	avg. land rights $\bar{\psi} = 0.34$
δ_2	registration cost curvature	5.95 (0.63)	Coeff. $\hat{\beta}^{\bar{\psi},\mathcal{P}} = -0.25$ in (4)
κ	land adjustment cost	1.47 (1.44)	Coeff. $\hat{\beta}^{LFI,\bar{\psi}} = 0.98$ in (38)
a	TFP heterogeneity	0.30 (0.14)	Coeff. $\hat{\beta}^{TFP,\bar{\psi}} = 0.95$ in (39)

Table 3: Calibration summary

Note: For the internally calibrated parameters, standard errors are reported in parentheses below point estimates and are computed using the usual GMM sandwich formula, $\widehat{\text{Var}}(\hat{\Theta}) = \left(\hat{G}'\hat{W}\hat{G}\right)^{-1}\hat{G}'\hat{W}\hat{\Omega}\hat{W}\hat{G}\left(\hat{G}'\hat{W}\hat{G}\right)^{-1}$, where $\hat{G}$ is the numerical Jacobian of the six targeted model moments with respect to the six internally calibrated parameters, evaluated at the estimated parameter vector using finite differences, $\hat{\Omega}$ is the 6×6 bootstrap variance-covariance matrix of the empirical moments, and $\hat{W}$ is the identity weighting matrix. Reported standard errors are the square roots of the diagonal elements of $\widehat{\text{Var}}(\hat{\Theta})$.

The curvature parameter $\delta_2 = 5.95$ is identified using the cross-sectional regression of average land rights on the Chief Power Index, reported earlier in the main text. In the model, δ_2 controls how sharply the cost of formalization increases with ψ, and therefore disciplines how sensitive land-rights take-up is to differences in local land-power centralization.

Land adjustment costs and TFP heterogeneity. Given the centrality of land-rights' take-up on our model's equilibrium and in absence of plausibly exogenous variations that separately shift land adjustment costs and TFP fundamentals, conditional on land-rights take-up, we resort to indirect inference for estimating κ and a.

Intuitively, κ governs how costly it is to reallocate land across households, and thus shapes the response of equilibrium land holdings to changes in land security. Since we assume a common κ across villages, heterogeneity in $A_v = \exp(-a \cdot P_v)$ that depends on the institutional environment gives the model enough flexibility to absorb persistent village-level heterogeneity while still preserving a disciplined interpretation of the land-rights channel. Assuming homogeneous village TFP together with a common κ would make the model empirically too restrictive, as it would force cross-village differences in land fluidity and productivity to be absorbed mainly by land-rights take-up. Allowing A_v to vary relaxes this restriction by recognizing that the same reallocation cost is easier to absorb in more productive villages.

To implement this strategy, we construct the empirical village-level measure of TFP, A_v, as the village average household fixed effect from regression (35). Furthermore, we define a village-level *Land Fluidity Index (LFI_v)* as follows:

$$LFI_v = \frac{1}{T} \sum_{h \in v} \sum_{t \in \{1,2\}} \left(\frac{\text{land}_{i,t+1}}{2 \cdot \frac{\text{village-land}_{v,t+1}}{N_{v,t+1}}} - \frac{\text{land}_{i,t}}{2 \cdot \frac{\text{village-land}_{v,t}}{N_{v,t}}} \right)^2 \tag{37}$$

where we normalize land of household i in wave t by $2 \cdot \frac{\text{village-land}_{v,t}}{N_{v,t}}$, i.e. by the average per-household land supply in village v at time t, so that LFI_v can directly correspond to our model where total land supply is normalised to 1 and we have $N = 2$ households per village.

Given those, the land adjustment cost $\kappa = 1.47$ is identified by matching the empirical cross-sectional relationship between land rights and land fluidity:

$$\log(LFI_v) = \overline{\text{land-rights}}_v + \mu_d + \varepsilon_{v,t} \tag{38}$$

The parameter $a = 0.30$ is identified by matching the empirical cross-sectional relationship between land rights and village TFP:

$$\log(A_v) = \overline{\text{land-rights}}_v + \mu_d + \varepsilon_{v,t} \tag{39}$$

Table 4 reports these two moments. Results suggest that a 1 percentage-point increase in land rights is associated with about a 0.98% increase in LFI_v and a 0.95% increase in A_v.

Dependent variable:	$\log(LFI_v)$	$\log(A_v)$
$\overline{\text{land-rights}}_v$	0.983**	0.952**
	(0.470)	(0.422)
District FE	Yes	Yes
Observations	188	200
R^2	0.618	0.749

Notes: The dependent variable in column (1) is the village-level land fluidity index, constructed from changes in household landholdings across survey waves and normalized by average village land. The dependent variable in column (2) is village TFP, measured as the average of household fixed effects from the Cobb-Douglas production function estimated at the household level. In both columns, the regressor is average village land rights. Standard errors clustered at the district level are reported in parentheses. The sample size of villages in col (1) drops by 12 villages due to either different households appearing across waves or single wave appearance.

Table 4: Land rights, land fluidity, and village productivity

Moment	**Identifies**	**Data**	**Model**
Townsend coeff. $\hat{\beta}^{c,y}$ in (36)	β	0.05	0.08
Avg. labour supply $\bar{h}$	η_0	0.27	0.29
Avg. land rights $\bar{\psi}$	δ_1	0.34	0.36
CPI coeff. $\hat{\beta}^{\bar{\psi},\mathcal{P}}$ in (4)	δ_2	−0.25	−0.25
LFI coeff. $\hat{\beta}^{LFI,\bar{\psi}}$ in (38)	κ	0.98	0.98
TFP coeff. $\hat{\beta}^{TFP,\bar{\psi}}$ in (39)	a	0.95	1.06

Table 5: Simulated method of moments: fit of the model

7 Quantitative analysis

With the calibrated model in hand, we now quantify the effects of land rights on village-level allocations and welfare. Unless stated otherwise, the figures in this section refer to a village with $\mathcal{P}_v = 0.1$. When we plot value or policy functions, these are evaluated at a particular state in which household 2 enters the period with a high landholding and low idiosyncratic productivity, while household 1 enters with a low landholding and high productivity. Given the persistence and negative correlation of idiosyncratic shocks, this is a state in which productive efficiency calls for reallocating land toward household 1 in the next period. We use this state as an illustrative benchmark for understanding the mechanism. Appendix D contains the analogous figures for a village with $\mathcal{P}_v = 1.0$.

Land rights, enforcement, and breakdown of cooperation

Figure 6 illustrates the crux of our model's mechanism: as land rights ψ_v increase, the planner can –up to some level of ψ_v– sustain cooperation with smaller limited-commitment distortions. The key reason is that a higher degree of land rights changes the continuation values in the participation constraints (25): in the state considered here, higher land rights reduce the amount of land available to the land-rich household 2 upon deviation, and so weaken incentives for doing so. This effect arises in our limited-commitment environment as, although that household's current productivity θ is low, their outside option is relatively high (especially at low levels of ψ_v), as they have relatively more of land that is demanded by the other more productive household. Thus, the relaxation of limited commitment distortions improves both land and labour allocation.

While this mechanism is presented here for one particular state, it is a more general feature of the model. The middle panel confirms the latter by showing that the average relative Pareto weight $\frac{\lambda_{1,t}}{\lambda_{2,t}}$ moves towards 1 (the First Best level) as ψ_v rises. Since the consumption-sharing rule and the law of motion of Pareto weights govern the shadow value of reallocating resources across households, lower Pareto-weight distortions translate directly into smaller distortions in the z'-FOC (28) of the LRS problem. The right panel confirms this: the expected land-allocation limited commitment distortion of household 2 falls sharply with ψ_v.

At the same time, as ψ_v becomes sufficiently large, for the mirror image of reasons why the deviation incentives of household 2 decline, the outside option of the land-poor but highly productive household 1 becomes increasingly attractive. Because of this, the planner must compensate both households more aggressively to keep them in the contract, and eventually both participation constraints become binding. Once this threshold is crossed, cooperation can no longer be sustained and the economy collapses to the outside option. Thus, higher land rights first relax the relevant limited-commitment distortions, but beyond a point they unravel the very insurance arrangement they were helping to improve.

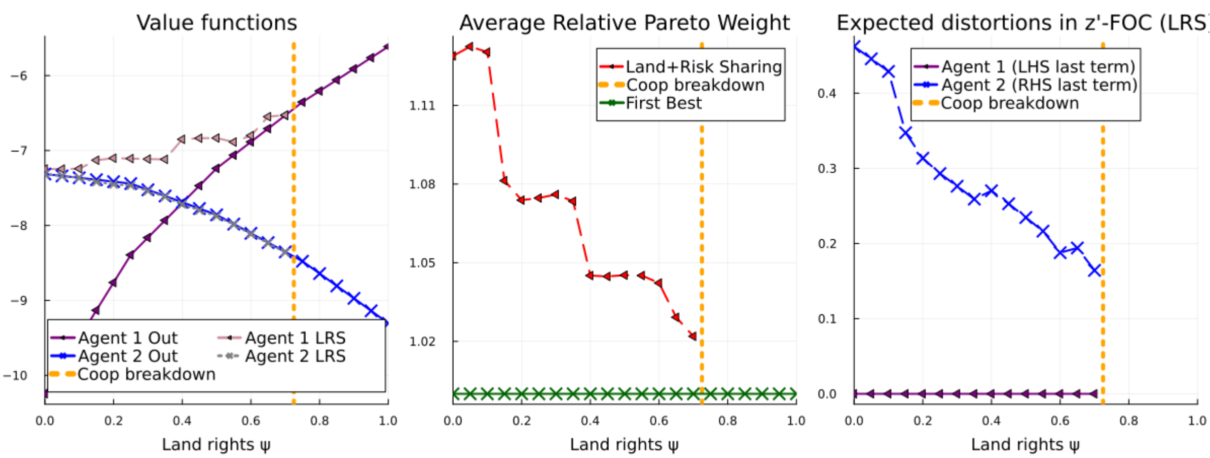


Figure 6: Impact of land rights on sustainability of cooperation

Note: The left panel shows the value functions of households in LRS and self-insurance allocations. The right panel shows expected distortions in z' FOC (28). In both cases, the current state of household 2 is low productivity and high land endowment from previous period. Household 1 is more productive and starts with low land from the previous period. The middle panel uses long-run model simulations to show average relative Pareto weight $\frac{\lambda_{2,t}^{LRS}}{\lambda_{1,t}^{LRS}}$.

Land assignments, misallocation, and excess fluidity

Figure 7 turns to land allocations. The left panel shows that, in the state considered here, the LRS planner assigns slightly more land to the more productive household 1 than under the First Best. This apparent "over-reallocation" is the direct implication of the land Euler equation with limited commitment (28), in which future land assignments affect not only marginal products and adjustment costs, but also next period's participation constraints through the outside option. Assigning "excessive" amount of land to household 1 simultaneously raises output and reduces the future outside option of household 2 by lowering the amount of land that can be taken away upon deviation. In this sense, land becomes an enforcement device in addition to being a productive input.

As such, this mechanism may generate *excess fluidity* of land markets relative to the First Best. Indeed, while the middle panel shows that the correlation between current household's land assignment and productivity rises with ψ_v towards First Best, the right panel shows that the Land Fluidity Index not only rises towards the First Best level as ψ_v rises, but at some point even exceeds it. This happens precisely because the planner uses land reallocations both to improve productive efficiency and to relax the enforcement problem. Nonetheless, these results confirm that –although the land adjustment costs in cooperation are assumed invariant to ψ_v (unlike in the self-insurance outside option)– higher land rights do generate more land reallocations through relaxation of limited commitment constraints.

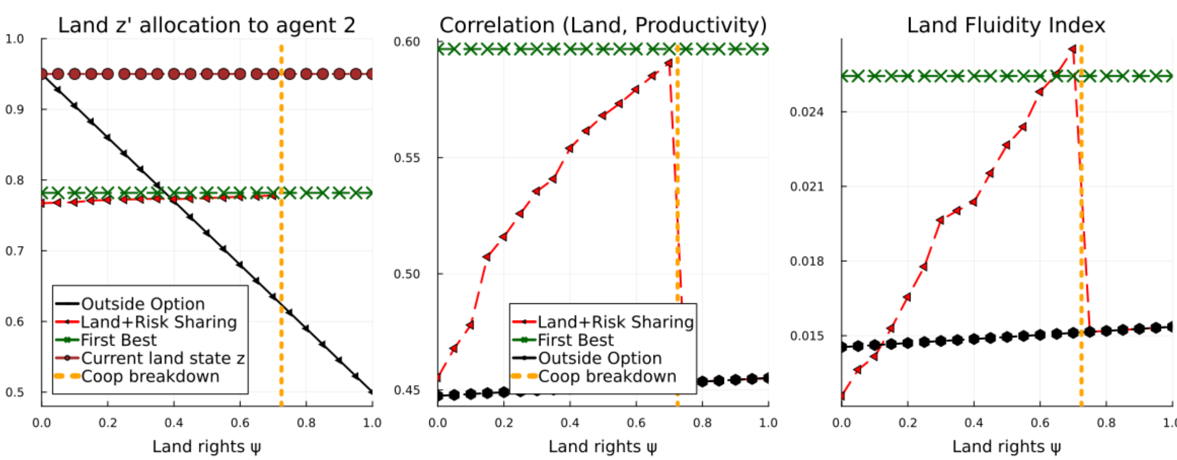


Figure 7: Impact of land rights on land dynamics

Note: The left panel shows the current land state $z_{2,t}$ of household 2, the optimal $z_{2,t+1}$ policy function in LRS and FB, and the implied amount of land available to household 2 upon deviating. The current state of household 2 is low productivity and high land endowment from previous period. Household 1 is more productive and starts with low land from the previous period. The middle and right panels use long-run model simulations to show correlation between land z and productivity θ, and the Land Fluidity Index implemented as equivalent of (37): $LFI_v = \frac{1}{T}\sum_{i\in\{1,2\}}\sum_{t=1}^{T}(z_{i,t+1}-z_{i,t})^2$.

Labour, consumption, and informal insurance

Figure 8 shows the consequences of land rights for the dynamics of labour and consumption. As land rights increase, the more efficient land assignment feeds into more efficient labour choices made according to FOC (27). The upper-left panel shows that the correlation between individual labour hours and current landholdings rises substantially toward the First Best benchmark. Similarly, the upper-right panel shows that the dispersion of village labour input falls, indicating improved labour smoothing approaching the First Best levels. Hence, the planner uses the improved enforcement environment not only to reallocate land more efficiently, but also to align labour more closely with productive opportunities.

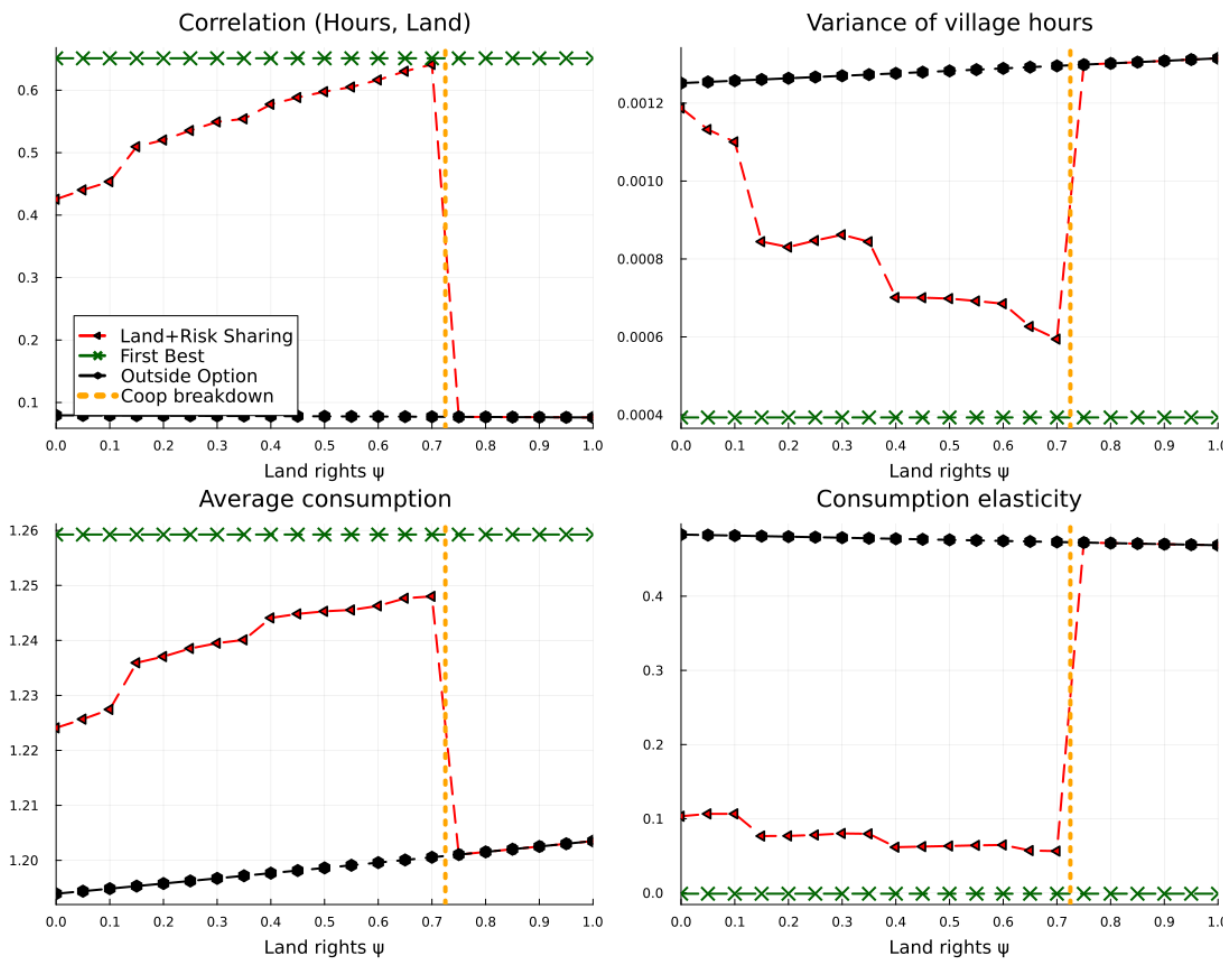


Figure 8: Impact of land rights on labour hours and consumption

Note: The four panels use long-run model simulations to show correlation between individual labour hours $h_{i,t}$ and landholdings $z_{i,t}$, variance of total village hours $h_{1,t} + h_{2,t}$, average consumption $0.5 \cdot (c_{1,t} + c_{2,t})$ and consumption elasticity from baseline Townsend consumption smoothing test.

The lower panels show the consequences for consumption dynamics. While implementing the maximum sustainable degree of land rights raises average consumption by up to modest 2%, the elasticity of consumption with respect to idiosyncratic income falls markedly by approximately 50%. As such, we find that the main gains from agricultural land rights may not come so much from higher output, but rather from a stronger ability of the village to cooperate over other relevant margins – in our case, risk sharing. Consistent with this interpretation, when we run the extended Townsend regression on simulated data, we obtain an income coefficient of 0.10 and an interaction coefficient on income and land rights of −0.07, close to the empirical estimates reported in Table 2. The collapse point is again visible in all panels: once the participation constraints can no longer be satisfied jointly, the economy discretely switches to the outside option, with significantly less efficient labour allocation, weaker consumption (self-)insurance, and lower level of consumption.

Welfare effects of land rights

Before discussing our results, we clarify distinction between two welfare objects involved. The first is village welfare conditional on a given degree of land rights ψ_v, which we measure in consumption-equivalent terms using the expected life-time value from entering the arrangement in period 1: $\mathbb{E}_0 V_{v,1}^{SWF}(x_{v,1}; \psi_v)$. The second pins down the "chief-optimal" degree of land rights in period-0 objective function (8), which equals the latter welfare measure netted out of the one-off land registration cost $\delta_1 \mathcal{P}_v \psi_v^{\delta_2}$. The first object isolates the allocative and insurance consequences of implementing a given ψ_v. The second determines the ex-ante choice of ψ_v by the planner-chief.

Figure 9 plots village welfare conditional on implementation of a given degree of land rights ψ_v, measured in consumption-equivalent terms relative to the baseline $\psi_v = 0$ and excluding the one-off registration-cost term in equation (8). Welfare initially rises with ψ_v, as stronger land rights relax the relevant enforcement distortions and improve both land allocation and risk sharing. In the village considered here, moving from $\psi_v = 0$ to $\psi_v = 0.35$ raises village welfare by an amount equivalent to roughly a 2% permanent increase in consumption. These gains are large relative to the modest rise in average consumption shown in Figure 8, indicating that improved insurance, rather than higher output alone, is quantitatively important.

Village welfare gains from land rights continue to rise beyond the chief's preferred choice and reaches its maximum at an interior value around $\psi_v = 0.7$, where the gain is equivalent to about a 3.3% permanent increase in consumption. Beyond that point, however, the co-operative arrangement can no longer be sustained and the economy switches discretely to the outside option, causing welfare losses equivalent up to a 20% reduction in consumption. Thus, our model suggests that rural societies in developing countries with weak-state environment may rationally choose to stop short of complete formalization because it would risk destroying the gains from other important margins of informal cooperation.

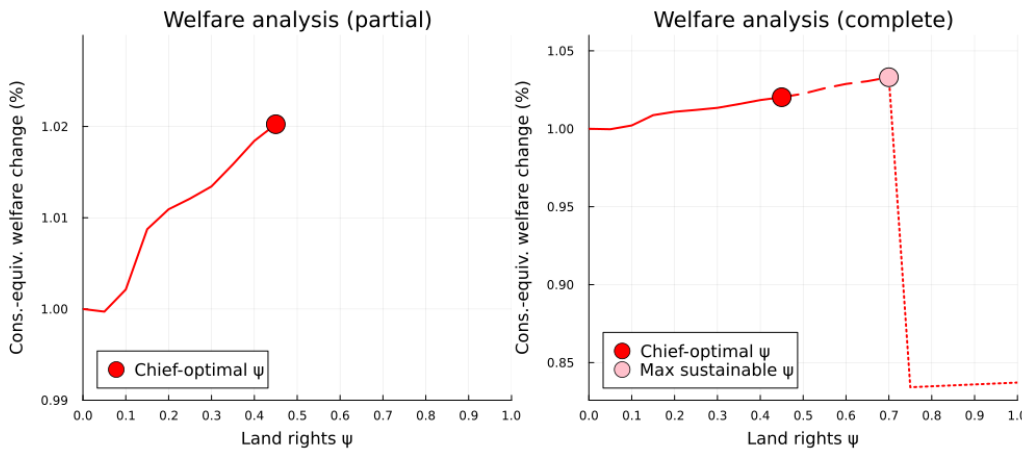


Figure 9: Effects of land rights ψ_v on village welfare

Note: Welfare is measured in consumption-equivalent terms from $E_0 V_{v,1}^{SWF}(x_{v,1}; \psi_v)$ relative to $\psi_v = 0$, excluding the registration costs. The red marker denotes the chief-optimal choice of ψ_v once registration costs are taken into account.

Finally, a comment on importance of heterogeneity in TFP is due. Given the assumed log-preferences, the substitution and income effects induced by heterogeneity in TFP and chosen land rights wash out. Figure C.1 in Appendix D confirms this by showing that most results for village with $\mathcal{P}_v = 1.0$ are quantitatively similar to the ones discussed here. There is, however, one key difference that villages with higher TFP are characterized not only by higher level of chief-optimal level of land rights, but also by a higher upper bound on the maximum sustainable degree of formality. The reason is that a higher A_v increases the surplus from coordinated land reallocation and risk sharing relative to autarky, while making the common land-adjustment cost less burdensome in resource terms, thereby relaxing the participation constraints relative to villages with lower A_v.[11]

Interaction between frictions and institutions

Table 6 compares the baseline land and risk sharing allocation against a number of other allocations. The first best removes the limited-commitment constraints altogether. The self-insurance allocation corresponds to the outside option, in which households do not cooperate and instead rely only on own production and decentralized land trading in the formal market. The two remaining counterfactuals retain the planner structure and the same limited commitment environment, but shut down one margin of cooperation at a time. In land sharing only, the planner can reallocate land subject to limited commitment, but direct consumption transfers are shut down, so consumption equals own output net of land adjustment costs. In risk sharing only, the planner can transfer consumption subject to limited commitment, but land is fixed at $z_i = 0.5$ in every period.

The comparison with the first best isolates the quantitative importance of enforcement constraints. Relative to the baseline joint land-and-risk-sharing allocation, the first best raises welfare by 1.4%, increases average consumption by 3%, and improves the alignment of land and labour with productivity, as seen in the higher correlations between land and productivity and between land and labour. The fact that these gains are positive but modest indicates that the constrained-efficient cooperative arrangement already captures a substantial fraction of the attainable surplus.

The remaining comparisons reveal strong interaction effects between the two cooperative margins. The baseline with joint land and risk sharing dominates the other alternatives. Eliminating only the land-sharing margin while preserving mutual insurance (*risk sharing only*) generates a relatively small welfare loss of 1.2%, even though, by construction, land can no longer move toward the more productive household. By contrast, eliminating state-contingent insurance transfers while preserving only cooperative land reallocation (*land*

[11] From the identification point of view, these results do not invalidate the importance of TFP heterogeneity for absorbing persistent cross-village differences in productivity and the effective resource cost of land-reallocation. Conversely, these results imply that the main land-rights mechanism is robust (up to the assumption of log-preferences), while TFP heterogeneity prevents the model from attributing too much of the observed cross-village variation in productivity and land fluidity to land-rights differences alone.

Model	Avg c	c elast.	Avg h	Corr(z,θ)	Corr(z,h)	Welfare
land & risk sharing	0.61	0.04	0.29	0.53	0.54	—
first best	0.63	0.00	0.29	0.60	0.65	+1.4%
land sharing only	0.57	1.00	0.34	0.49	-0.48	-48.9%
risk sharing only	0.59	0.09	0.30	–	–	-1.2%
self-insurance	0.60	0.28	0.30	0.45	0.08	-18.2%

Table 6: Measuring interactions between institutions and frictions

Note: Results are reported for respective allocations from the village with $\mathcal{P}_v = 0.1$ and chief-optimal $\psi_v = 0.45$. The column "c elast." reports the elasticity of consumption with respect to idiosyncratic income, measured from the baseline Townsend regression run on simulated data for the corresponding allocation. The welfare column reports consumption-equivalent changes in expected utilitarian welfare relative to the baseline land-and-risk-sharing allocation. For each alternative allocation, the reported number is the uniform percentage change in consumption that makes households indifferent between that allocation and the baseline, evaluated at the symmetric initial state and taking expectations over future productivity realizations. Correlations in "risk sharing only" allocation are not defined as z is fixed.

sharing only) is extremely costly: welfare falls by 48.9%, average consumption declines by 7%, and the consumption elasticity rises to 1, implying full pass-through of idiosyncratic income shocks to consumption. This confirms that the insurance margin is quantitatively more important for welfare than land reallocation on its own.

The comparison between *land sharing only* and *self-insurance* is also informative. Even though self-insurance features no state contingent transfers, it delivers substantially higher welfare than land sharing only. The reason is that, in the outside option, households can still trade land in the formal market and use land as a smoothing asset, whereas in the land-sharing-only allocation they neither receive state-contingent transfers nor benefit from decentralized self-insurance through private land trading. In this sense, land as a marketable asset provides a non-trivial amount of self-insurance. Nevertheless, self-insurance remains far inferior to the baseline joint allocation because it forgoes the gains from efficient risk sharing.

8 Concluding discussion

Why do informal land institutions persist even when governments expand formal alternatives? Using the case of Ghana, this paper argues that the answer lies not only in barriers to formalization, but also in the value of the informal arrangements that formalization may displace. Exploiting the nationwide rollout of Land Commission offices and Customary Land Secretariats, we show that improved proximity to statutory land institutions did not, by itself, significantly increase the take-up of formal agricultural land rights. Instead, the centralization of authority over land in the hands of traditional leaders emerges as a powerful predictor of low formalization. At the same time, we document that villages with stronger land rights exhibit better consumption smoothing, indicating that land rights affect not only land-market outcomes, but also broader local institutional environment - in our case, the functioning of local risk sharing networks.

To interpret these findings, we develop a dynamic village economy in which a planner-chief chooses the degree of land rights and households participate in a self-enforcing cooperation over land reallocation and risk sharing. A higher degree of land formalization affects the outside option of households by reducing frictions in the formal land market and altering the amount of land a household can retain upon deviation. This generates a non-monotone trade-off. On the one hand, greater formalization can relax limited-commitment constraints, improve the allocation of land and labour, and strengthen informal risk sharing. On the other hand, once land rights become sufficiently strong, the outside option becomes attractive enough that cooperation unravels. Quantitatively, our model implies that greater adoption of land rights can generate welfare gains of up to 3% in consumption-equivalent terms, with a substantial share of these gains operating through improved consumption insurance. However, when land rights become excessive and cooperation collapses, the resulting welfare losses are equivalent to roughly a 20% fall in consumption.

A central implication of the paper is therefore that the benefits of land formalization in weak state environments cannot be assessed by looking at land misallocation alone. More broadly, we argue that informal institutions persist not simply because they block modernization, but because they continue to perform economically valuable functions in settings where formal markets and formal insurance remain incomplete. Policies aimed at strengthening land rights should therefore be designed jointly with institutions that can replace the insurance and enforcement services currently provided by customary systems. Otherwise, reforms that improve formal tenure on paper may weaken the very local arrangements that sustain welfare in practice.

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A Data Appendix

A.1 Sample Construction

The sample is drawn from the Ghana Socioeconomic Panel Survey (GSPS), conducted jointly by Yale-EGC and the University of Ghana-ISSER across three waves (2009, 2014, 2019). Table A.1 summarises the sequential restrictions applied to arrive at the main estimation sample.

Step	Observations	Reason
All HHs across 3 waves	7,152	Starting sample
Drop communities with $<$ 4 HHs	6,746	
Drop obs. with $C, Y \leq 0$	3,989	
Drop missing district (id2)	3,955	
Drop HHs with zero agr. labour hours	3,904	Focus on farming HHs
Drop villages with missing selling rights	3,894	Townsend sample
Restrict to strictly positive land	3,870	Main estimation sample
Village $\times$ wave observations	565	170 villages $\times$ 3 waves + 25 villages $\times$ 2 waves + 5 villages $\times$ 1 wave
Unique villages	200	

Table A.1: Sample construction

A.2 Agricultural Income

We construct net agricultural income as the difference between gross agricultural revenues and production costs, deflated to 2009 prices and winsorized at the 1% level within each wave.

Gross agricultural revenues. We combine two sources of revenue data. The first is crop sales revenues, directly reported by households that sold part of their harvest to the market. The second is the market value of production, which assigns a monetary value to the entire harvest — including the portion retained for home consumption — by multiplying harvested quantities by local crop prices. Our gross revenue measure takes the maximum of the two when both are available, and uses whichever is non-missing otherwise. This ensures that households that sell their entire harvest are valued at market prices, while households that retain a larger share of production are valued at the market equivalent of their total output.

Crop prices. Prices are constructed from two sources: community survey price data (available for waves 1 and 3) and market prices derived from crop sales transactions (available for waves 2 and 3). For wave 1 we rely entirely on community survey prices. For wave 2, community survey price data are unavailable and we rely on market prices as the sole source. For wave 3 we construct a composite price as the mean of the two sources where both are available, and use whichever is available otherwise. To maximize price coverage across all crop-unit combinations, we apply a hierarchical imputation procedure: prices are first assigned at the community level, then at the district level, then at the region level, and finally at the national level, with each level serving as a fallback when the finer level is missing. At each level we use the mean price at the community level and the median at the district, region and national levels.

Production costs. We subtract four categories of production costs reported by households: seeds, tractor services, hired labour, and transportation. All cost components are deflated to 2009 prices prior to subtraction.

Final measure. Net agricultural income is defined as:

$$y_{i,t} = \max(\text{crop-sales}_{i,t},\ \text{harvest-value}_{i,t}) - \text{costs}_{i,t} \tag{1}$$

where all components are deflated to 2009 prices using the World Bank CPI (see Appendix A.6). The resulting measure is winsorized at the 1% level within each wave to limit the influence of outliers, and expressed in per capita terms using the household size adjustment described in Appendix A.7.

A.3 Summary Statistics

Table A.2 reports summary statistics for the main variables used in the analysis. The sample consists of 3,870 household-wave observations drawn from 200 villages across three waves (2009, 2014, 2019). Statistics are reported at the level of observation at which each variable is defined (household-wave, village-wave, or village).

name	median	mean	sd	min	max
Land rights (village-wave)	0.290	0.343	0.295	0.000	1.000
Average Land rights (village)	0.327	0.340	0.205	0.000	0.893
Farm size (hh-wave)	5.000	7.552	8.194	0.019	92.960
Consumption per capita (hh-wave)	669.855	866.891	765.001	10.154	13011.231
Income per capita (hh-wave)	209.329	4032.168	21404.867	0.056	379944.521
Household size (adult equivalent)	3.630	3.793	2.108	0.520	15.550
Chief Power Index (village)	0.265	0.315	0.226	0.000	1.000
Village TFP	-0.050	-0.034	0.896	-2.656	2.387

Table A.2: Summary statistics

All variables are deflated to 2009 prices and winsorized at the 1% level within each wave. Per capita quantities are computed by dividing household-level values by a composite, age-adjusted measure of household size following Townsend [1994] (see Appendix A.7). Consumption is the total value of household non-durable consumption, defined as the sum of the value of food purchased, home-produced, and received as gifts or transfers, net of food given away, plus expenditures on clothing, fuel, and other items. Income is net agricultural income, defined as the market value of the harvest net of production costs. Income is highly right-skewed and the median is the more informative statistic. The gap between median per capita consumption (GHS 670) and median per capita agricultural income (GHS 209) reflects several factors. First, income is highly right-skewed — the mean is driven by a small number of households with very large harvests, and the median is the more informative statistic. Second, consumption includes the value of home-produced food at market prices, while income nets out production costs, creating a mechanical wedge for subsistence households who consume most of what they produce. Third, the income measure captures only agricultural earnings, excluding off-farm activities and transfers; the gap narrows substantially when total household income is used instead (median per capita total income: GHS 402). Fourth, food consumption is collected with a short recall period and is generally better measured than agricultural income, which relies on recall of an entire season and is subject to larger measurement error and underreporting. This pattern is consistent with the broader evidence on rural Sub-Saharan Africa [De Magalhães and Santaeulàlia-Llopis, 2018]. Farm size is in acres. Land rights are measured as the acreage-weighted share of villages plots with formal selling rights, averaged across households in the village. Village TFP is derived from the Cobb-Douglas production function estimation described in Appendix C.5.

A.4 Consumption

We construct household consumption as the sum of four non-durable expenditure components: food, clothing and footwear, fuels, and other items. All components are recorded in nominal current-year prices and deflated to 2009 prices using the World Bank CPI (see Appendix A.6).

Food consumption. The food consumption module covers 85 distinct items and records, for each item, the value of own-produced and consumed food, purchased food, and food received as gifts, net of food given as gifts. Since food consumption is the only component recorded on a monthly basis, we deseasonalize it first using Method 3 described in Appendix A.5, and then annualize the deseasonalized monthly figure by multiplying by 12.

Clothing and footwear. The clothing module records annual expenditures on 11 clothing and footwear items separately for children, elderly, male adults, and female adults. Total clothing expenditure is the sum across all demographic groups and all items.

Other items. The other items module records annual expenditures on 32 non-food, non-clothing items including ceremonies, vehicles, and household repairs. Total other expenditure is the sum across all items. This module also includes gifts and remittances, which we retain in the consumption aggregate as they represent transfers that are part of normal consumption behaviour in this context.

Fuels. The fuels module records annual expenditures on 10 fuel items, distinguishing between home-produced or collected fuels (e.g. crop byproducts, firewood) and purchased fuels (e.g. electricity, gasoline). Total fuel expenditure is the sum of both components.

Final measure. Total consumption is the sum of deseasonalized and annualized food consumption, clothing, other items, and fuels, all deflated to 2009 prices:

$$c_{i,t} = \text{food}_{i,t}^{\text{deseas}} + \text{clothing}_{i,t} + \text{other}_{i,t} + \text{fuels}_{i,t} \tag{2}$$

The resulting measure is winsorized at the 1% level within each wave to limit the influence of outliers, and expressed in per capita terms using the household size adjustment described in Appendix A.7.

A.5 Consumption Deseasonalization

Food consumption is the only component of total consumption recorded on a monthly basis. To account for seasonal variation in reported food consumption, we deseasonalize it using the following procedure.

Step 1. For each wave w and region r (northern vs. southern Ghana),[12] compute the wave-region mean of food consumption:

$$\bar{c}_{w,r} = \frac{1}{N_{w,r}} \sum_{i \in (w,r)} c_{i,w,r} \tag{3}$$

Step 2. Express each household's food consumption as a share of the wave-region mean:

$$\tilde{c}_{i,w,r} = \frac{c_{i,w,r}}{\bar{c}_{w,r}} \tag{4}$$

Step 3. Estimate the seasonal component as the fitted values from a regression of the household shares on month and region dummies:

$$\tilde{c}_{i,w,r} = \sum_{m=1}^{12} \gamma_m \mathbf{1}_m + \delta \cdot \mathbf{1}_{\text{north}} + u_{i,w,r} \tag{5}$$

The predicted values $\hat{s}_{i,w,r}$ from this regression serve as the seasonal component.

The regression is estimated on the pooled sample across all three waves, imposing a common seasonal pattern across waves. Wave-level variation in consumption levels is absorbed prior to estimation through the normalization by the wave-region mean in Step 1, which ensures that the month fixed effects capture within-wave seasonal fluctuations rather than cross-wave trends.

The estimated seasonal component ranges from 0.77 to 1.28, confirming that all predicted values are strictly positive and that the deseasonalization does not distort the sign of consumption. The mean of exactly 1.0 is expected by construction.

Step 4. Deseasonalize food consumption by dividing by the estimated seasonal component:

$$c^{\text{ds}}_{i,w,r} = \frac{c_{i,w,r}}{\hat{s}_{i,w,r}} \tag{6}$$

The deseasonalized monthly food consumption is then annualized by multiplying by 12 and deflated to 2009 prices. Total consumption is constructed as the sum of annualized deseasonalized food consumption and the remaining non-food components, clothing, other

[12] The two parts of the country experience different agricultural seasons: the north has a single season (May–September), while the south has a major season (April–July) and a minor season (September–November).

expenditures, and fuel, which are already reported on an annual basis and require no deseasonalization. The resulting measure is winsorized at the 1% level within each wave.

A.6 Deflation

We deflate nominal income and consumption using the Consumer Price Index (CPI) reported by the World Bank, with 2009 as the base year. Specifically:

$$\text{Value}_{2009} = \text{Value}_{\text{nominal}} \times \frac{\text{CPI}_{2009}}{\text{CPI}_w} \tag{7}$$

where $\text{CPI}_{2009} = 90.3$, $\text{CPI}_{2014} = 150.21$, and $\text{CPI}_{2019} = 278.5$.

A.7 Per Capita Measures

Per capita income and consumption are computed by dividing household-level values by a composite, age-adjusted measure of household size following the methodology of Townsend [1994], which assigns different weights to household members based on age and gender to account for differential consumption needs: adult males (1.0), adult females (0.9), boys aged 13–18 (0.94), girls aged 13–18 (0.83), children aged 7–12 (0.67), children aged 4–6 (0.52), toddlers aged 1–3 (0.32), and infants (0.05).

A.8 Chief Power Index: Construction Details

The Chief Power Index (CPI) is constructed from responses to the community-level survey question: *"What are the main system(s) of obtaining land to own in this community?"*, for which respondents report up to three systems ranked by prevalence. We classify each reported system as centralized or decentralized according to Table A.3.

System	Type
Family owned, patrilineal	Decentralized
Family owned, matrilineal	Decentralized
Tendana system	Centralized
Chieftaincy owned, patrilineal	Centralized
Chieftaincy owned, matrilineal	Centralized
Personal arrangements	Decentralized

Table A.3: Classification of land systems

Each system is coded $s_k = 1$ if centralized and $s_k = 0$ if decentralized. The CPI is then constructed as a rank-weighted average of the reported systems, where the weights depend on the number of systems reported by respondent i in village v and wave t:

$$\text{CPI}_{i,v,t} = \begin{cases} 0.5\, s_1 + 0.3\, s_2 + 0.2\, s_3 & \text{if three systems reported} \\ 0.6\, s_1 + 0.4\, s_2 & \text{if two systems reported} \\ s_1 & \text{if one system reported} \end{cases} \tag{8}$$

The index ranges from 0 to 1, with higher values indicating more centralized land allocation. The question was asked in each wave of GSPS and the number of respondents varies between 1-4. Thus, we construct final index as an average over all individual responses over all waves:

$$\text{CPI}_v = \frac{1}{N^{w_v}} \cdot \underbrace{\sum_{t=1}^{N^{w_v}} \frac{1}{N^{r_{v,t}}} \sum_{i=1}^{N^{r_{v,t}}} \text{CPI}_{i,v,t}}_{=CPI_{v,t}} \tag{9}$$

where $N^{r_{v,t}}$ is the number of respondents to the CPI-question in village-wave v, t, and N^{w_v} is the number of waves in which the question was asked in village v. The implied histogram is in the right panel of Figure 4.

To support the interpretation of the Chief Power Index as a stable long-run institutional variable rooted in pre-colonial governance structures, we decompose its variation into between-village and within-village components by estimating:

$$\text{CPI}_{v,t} = \mu_v + \mu_t + \varepsilon_{v,t} \tag{10}$$

with and without wave fixed effects μ_t. Table A.4 reports the results.

	Dependent variable: $\text{CPI}_{v,t}$	
	(1)	(2)
Village FE	Yes	Yes
Wave FE	No	Yes
Observations	513	513
R^2	0.591	0.593

Note: The sample covers 200 villages across up to 3 waves, yielding a maximum of 565 village-wave observations. The sample reduces to 513 because 52 village-wave observations have no CPI data available from the community survey i.e. no respondent answered the question in that village-wave.

Table A.4: Chief Power Index: persistence and stability

Village fixed effects alone explain 59% of the total variation in the Chief Power Index. Adding wave fixed effects increases the R^2 by only 0.002, indicating that common time variation across survey waves accounts for virtually none of the remaining variation. Together, these results suggest that the Chief Power Index is driven primarily by persistent between-village differences rather than by aggregate time-varying shocks, consistent with its roots in historically persistent local governance structures and customary norms. This lends support to our interpretation of the Chief Power Index as a slow-moving, predetermined measure of institutional centralization in the empirical and structural analysis.

A.9 Population Density

We construct a village-level measure of population density using gridded population data for Ghana from the WorldPop dataset for 2015, retrieved from the Energy Data portal.[13] The dataset is provided in GeoTIFF raster format at a spatial resolution of approximately 100m $\times$ 100m. We first aggregate the raster to 1km $\times$ 1km resolution by summing population values across each 10×10 block of cells. We then project construct a 5km circular buffer around each village centroid. Population density is measured as the average number of people per km^2 across all 1km grid cells falling within the buffer, capturing the demographic pressure surrounding each village. Since the population data refer to 2015, we treat this as a time-invariant village-level characteristic.

A.10 Ethnic Fractionalization Index

We construct a village-wave level measure of ethnic fractionalization using individual-level data on self-reported ethnicity from the GSPS roster and background sections, which are available for all three waves. The survey records ethnicity at a fine-grained level, distinguishing over 50 ethnic groups in Ghana. We classify these into eight broader ethnic categories following the standard classification used in the Ghanaian census: Akan, Ga-Dangbe, Ewe, Guan, Gurma, Mole-Dagbani, Grusi, and Mande.

The ethnic fractionalization index (EFI) for village v at time t is computed using the standard Herfindahl-based measure:

$$\text{EFI}_{v,t} = 1 - \sum_{e} \left(\frac{n_{e,v,t}}{N_{v,t}} \right)^2 \tag{11}$$

where $n_{e,v,t}$ is the number of individuals belonging to ethnic group e in village v at time t, and $N_{v,t}$ is the total number of individuals surveyed in that village-wave. The index ranges from 0 (complete homogeneity: all individuals belong to the same ethnic group) to 1 (complete heterogeneity). In the regression of average land rights on the Chief Power Index and additional controls (Appendix C.2), we use the village-level average of $\text{EFI}_{v,t}$ across waves, treating it as a time-invariant village characteristic.

A.11 Labour Hours Construction

Total agricultural labour hours are constructed from the plot-level labour input questions of the GSPS across all three waves. Hours are summed across all production stages and labour types (family, communal, casual, hired) during the major agricultural season. Children are excluded from the calculation throughout.

[13]Available at: https://energydata.info/dataset/ghana-population-density-2015.

Throughout the analysis we use the fixed hours assumption: $\bar{h} = 7.67$ hours per day, applied uniformly across all waves, stages and labour types. Total hours for each labour type are computed as:

$$\text{tot-hrs} = \text{days} \times \text{workers} \times 7.67 \tag{12}$$

Wave 1 reports labour inputs separately for the major and minor seasons, each broken down into four production stages: (1) clearing and land preparation, (2) ploughing, planting, chemical application and weeding, (3) harvesting, and (4) post-harvest processing. Only the major season is used, as this is when the bulk of agricultural production takes place. Waves 2 and 3 do not distinguish between major and minor seasons and ask about the last farming season only.

Women's labour discount. Women's labour hours are discounted by a factor $d_w = 0.46$ to account for differences in time allocation. All women's hours (family, communal, casual and hired) are multiplied by this factor.

Per capita labour supply. Adjusted household size is computed as the sum of adult equivalent units within the household, excluding members that are away and part of another household:

$$\text{hhsize}_{i,t} = \sum_{j \in i} w_j, \quad w_j = \begin{cases} 1 & \text{if adult man (age} > 18) \\ d_w & \text{if adult woman (age} > 18) \\ 0 & \text{if child (age} \leq 18) \end{cases} \tag{13}$$

In cases where the adjusted household size equals zero, the standard household size is used as a fallback. The per capita share of time devoted to agricultural work is then:

$$h_{i,t} = \frac{\text{tot-hrs-fixed}_{i,t}}{\text{hhsize}_{i,t} \times 5 \times 52 \times 16} \tag{14}$$

where the denominator corresponds to 5 days/week × 52 weeks/year × 16 active hours/day. The resulting $h_{i,t}$ serves as the labour supply moment in the SMM estimation, with a sample mean of 0.267.

A.12 Village-level consumption volatility

We construct a measure of village-level consumption volatility used as the aggregate productivity moment in the SMM estimation. For each village v, village-wave specific mean consumption $c_{v,t}$ is computed as the average household consumption across all households in village v at time t. We then normalise by the village-specific mean across waves $\bar{c}_v = \frac{1}{T}\sum_t c_{v,t}$ and compute the within-village variance of the log-normalised consumption:

$$\sigma^2_{c,v} = \text{Var}_t\left(\log\left(\frac{c_{v,t}}{\bar{c}_v}\right)\right) \tag{15}$$

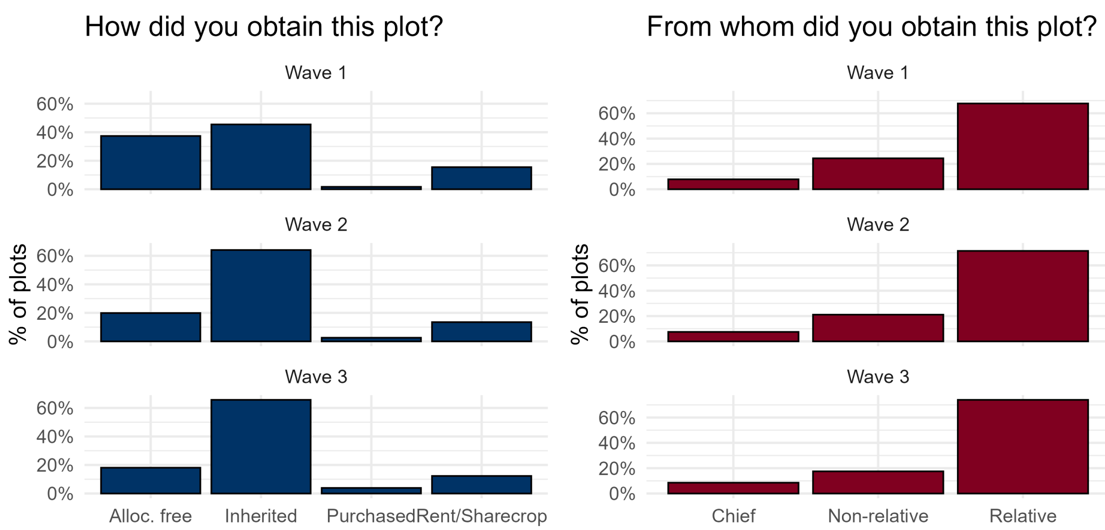
The final statistic is the average of $\sigma^2_{c,v}$ across all villages:

$$\overline{\sigma^2_c} = \frac{1}{V}\sum_v \text{Var}_t\left(\log\left(\frac{c_{v,t}}{\bar{c}_v}\right)\right) \tag{16}$$

The estimated value of this statistic is 0.207, which is used to discipline the size of aggregate productivity fluctuations in the model.

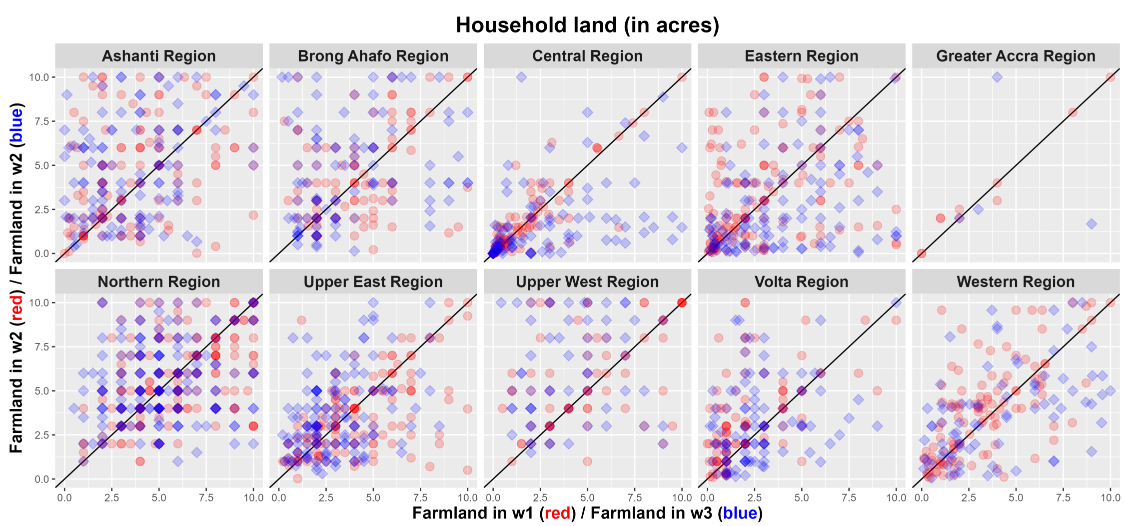
B Figures

B.1 Land Access and Transfers



Note: The figure shows the distribution of land access sources across the three waves. Waves 1, 2 and 3 combined.

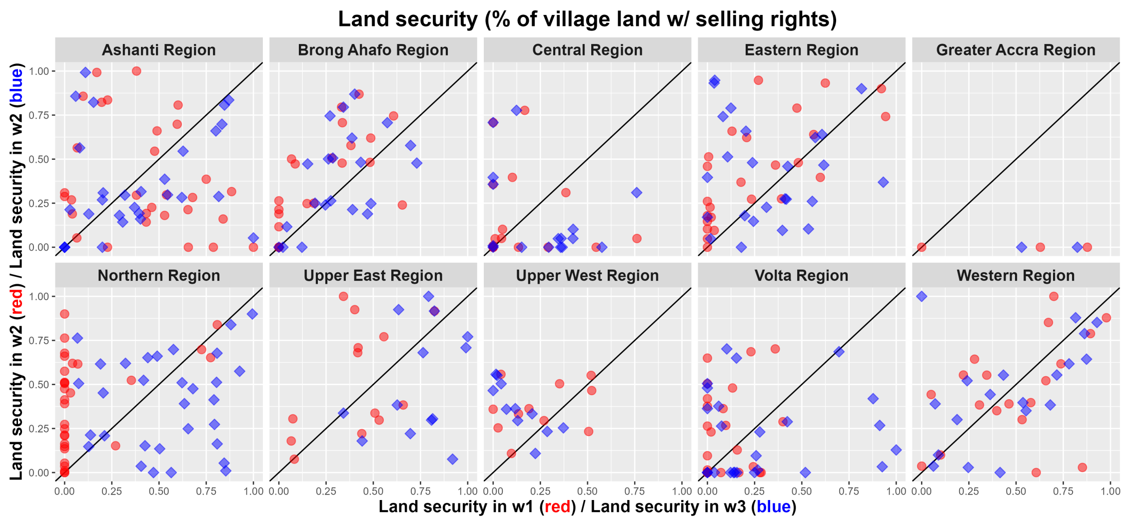
Figure B.1: Sources of land access in rural Ghana



*Note:*The figure shows the distribution of changes in household landholdings across waves.

Figure B.2: Household landholdings over time

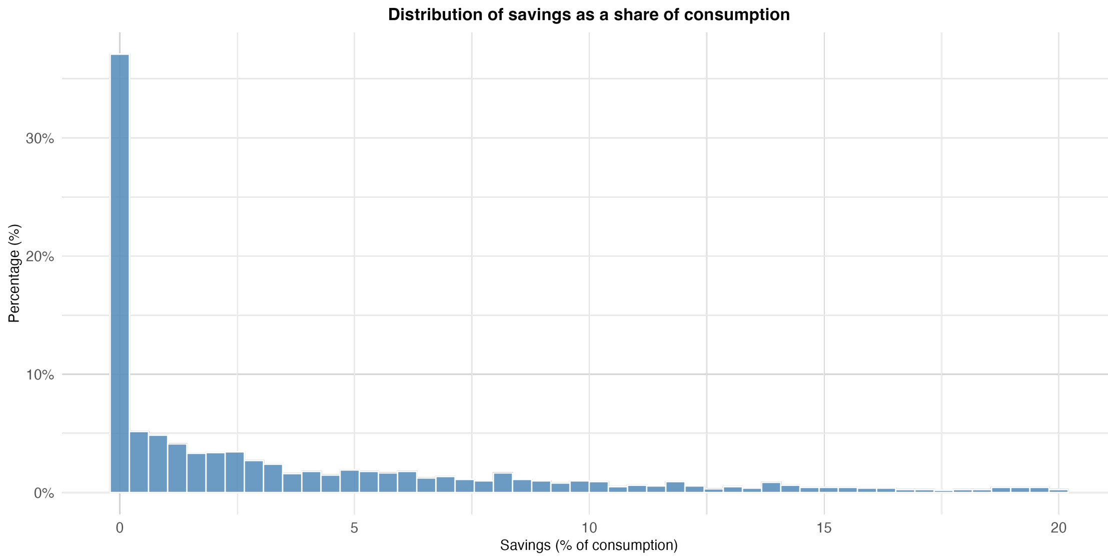
B.2 Land Rights Dynamics



Note: Each panel shows wave 2 land security (y-axis) against wave 1 (red circles) and wave 3 (blue diamonds). Points above the 45° line indicate an increase in land security relative to wave 2.

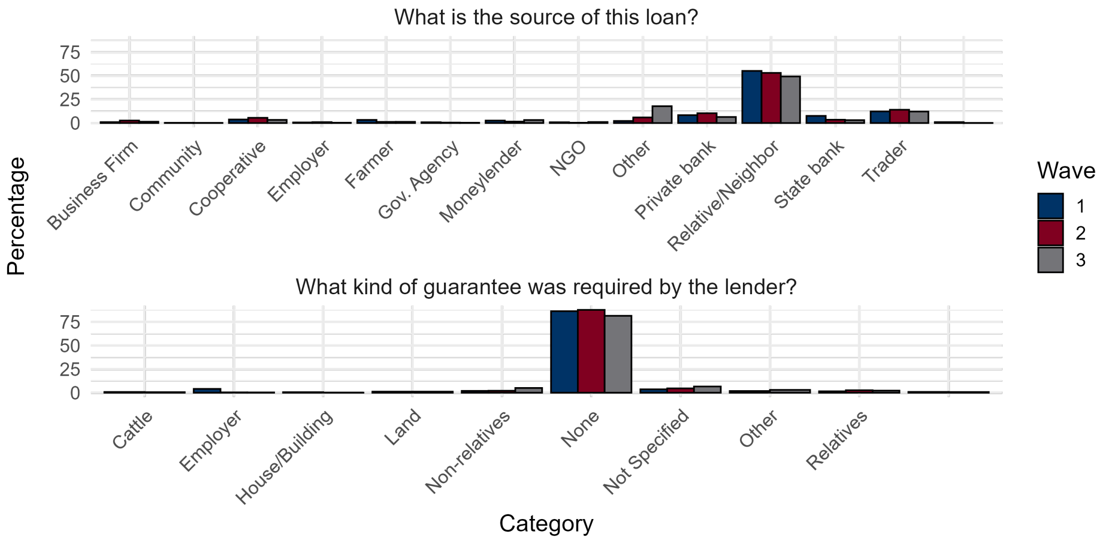
Figure B.3: Land rights across villages and regions

B.3 Informal Risk-Sharing



Note: The figure shows the distribution of average household savings as a share of consumption, averaged across the three waves, for the estimation sample of 3,870 household-wave observations. Total household savings are computed as the sum of savings held at home and savings held in a banking institution, *susu*, or other savings society, aggregated across all savings accounts reported by the household. Households reporting missing savings are treated as non-savers and assigned zero savings. This is supported by the very small number of households reporting explicit zero savings across all three waves (7, 34, and 23 in waves 1, 2, and 3 respectively), suggesting that non-savers are captured by missing values rather than explicit zeros. The sample is restricted to households with an average savings share between 0 and 20% of consumption, covering approximately 85% of the estimation sample.

Figure B.4: Distribution of savings as a share of consumption



Note: The figure shows the distribution of loan sources and collateral requirements across the three waves.

Figure B.5: Sources of loans in rural Ghana

C Additional Empirical Results

C.1 Alternative Measure of Distance

Table C.1 estimates specification 3 using Euclidean distances in place of driving distances (via Google Maps).

	Dependent variable:		
	land-rights$_{v,t}$ Time-varying land rights		
	(1)	(2)	(3)
log(distance-to-LC/CLS$_{v,t}$)	0.018		
	(0.027)		
log(distance-to-LC$_{v,t}$)		−0.016	
		(0.038)	
log(distance-to-CLS$_{v,t}$)			0.027
			(0.033)
Mean of Dep. Variable	0.343	0.343	0.343
Unit of analysis	Vil	Vil	Vil
Unit FE	Yes	Yes	Yes
Time FE	No	No	No
District FE	No	No	No
District × Time FE	Yes	Yes	Yes
F-stat	0.28	0.08	0.39
Observations	565	565	565

Note: Col. 1: Euclidean distance to the nearest CLS if one is located within a 5 km radius of the village; otherwise, distance to the nearest LC. Col. 2: distance to the nearest LC. Col. 3: distance to the nearest CLS. All distances are in kilometers. Standard errors are clustered at the district × wave level.

Table C.1: Access to formal institutions and land rights — Euclidean distance measures

C.2 Omitted-Variable Checks: Population Pressure and Ethnic Fractionalization

Table C.2 examines whether population density and ethnic fractionalization — two additional factors highlighted in the literature on land rights in Sub-Saharan Africa — explain the cross-sectional variation in average land rights alongside the Chief Power Index. We estimate the following specification:

$$\overline{\text{land-rights}}_v = \beta_1 \cdot \text{chief-power-index}_v + \beta_2 \cdot \text{pop-density}_v + \beta_3 \cdot \text{EFI}_v + \mu_d + \varepsilon_v \quad (17)$$

where pop-density$_v$ is the average number of people per km^2 within a 5km radius of the village centroid (see Appendix A.9) and EFI$_v$ is the village-level ethnic fractionalization index (see Appendix A.10). All specifications include district fixed effects μ_d and standard errors are clustered at the district level.

	Dependent variable:		
	$\overline{\text{land-rights}}_v$ Average land rights		
	(1)	(2)	(3)
Chief Power Index$_v$			-0.256^{**}
			(0.105)
log(Population density)$_v$	-0.033		-0.031
	(0.029)		(0.027)
Ethnic fractionalization index$_v$		0.122	0.087
		(0.115)	(0.113)
Mean of Dep. Variable	0.340	0.340	0.340
Unit of analysis	Vil	Vil	Vil
Unit FE	No	No	No
Time FE	No	No	No
District FE	Yes	Yes	Yes
Observations	200	200	200

Note: Col. 1 includes log population density only. Col. 2 includes the ethnic fractionalization index only. Col. 3 includes all three determinants jointly. The Chief Power Index is the only statistically significant determinant of average land rights across all specifications. Standard errors are clustered at the district level throughout. Population density is measured as the average number of people per km^2 within a 5km radius of the village centroid (see Appendix A.9). The ethnic fractionalization index is constructed from individual-level ethnicity data following equation (11) (see Appendix A.10).

Table C.2: Omitted-variable checks: population density, ethnic fractionalization, and land rights

C.3 IV Procedure: Chief Power Index as an Instrument for Average Land Rights

Column (3) of Table 2 addresses potential endogeneity concerns by instrumenting the average level of land rights with the Chief Power Index. The intuition is that the degree of chiefly centralization reflects pre-colonial governance structures and historical institutional legacies that are plausibly exogenous to current economic outcomes, as discussed in Section 4.2.

First stage. Since the Chief Power Index is a time-invariant, village-specific measure, it is fully absorbed by household fixed effects in the second stage regression and therefore cannot be used directly as an instrument in a standard two-stage least squares framework. We therefore implement the IV procedure in two separate stages. In the first stage, we regress average village land rights on the Chief Power Index with district fixed effects:

$$\overline{\text{land-rights}}_v = \gamma \cdot \text{chief-power-index}_v + \mu_d + \eta_v \tag{18}$$

and obtain the predicted values $\widehat{\overline{\text{land-rights}}}_v$. The first stage F-statistic is 5.23, which is below the conventional threshold of 10 [Stock and Yogo, 2005], indicating that the Chief Power Index is a relatively weak predictor of average land rights.

Second stage. In the second stage, we substitute the predicted values $\widehat{\overline{\text{land-rights}}}_v$ for the observed average land rights in the Townsend regression:

$$\begin{aligned} \log(c_{h,t}) = \beta_1 \cdot \log(y_{h,t}) + \beta_2 \cdot \log(y_{h,t}) \cdot \widehat{\overline{\text{land-rights}}}_v \\ + \beta_4 \cdot \log(c_{v,t}) + \mu_h + \mu_t + \varepsilon_{h,t} \end{aligned} \tag{19}$$

Limitations. This two-step procedure is the only feasible implementation given the aggregation mismatch between the instrument, which operates at the village level, and the second stage regression, which operates at the household-wave level. A consequence of this approach is that the second stage standard errors do not account for the estimation uncertainty from the first stage and are therefore potentially understated. Combined with the weak first stage, the IV estimate in column (3) should be interpreted as suggestive evidence of a causal relationship between land rights and informal risk-sharing rather than a definitive result. The sign and magnitude of the coefficient are nonetheless consistent with the OLS estimates in columns (1) and (2).

C.4 Savings and Land Rights

To verify that the improvement in risk-sharing associated with stronger land rights does not operate through a self-insurance channel, we examine whether savings are related to land rights or to the Chief Power Index. We estimate the following specifications at three levels of aggregation:

$$\text{land-rights}_{i,t} = \beta \cdot \log(\text{savings}_{i,t} + 1) + \mu_i + \mu_t + \varepsilon_{h,t} \tag{20}$$

$$\text{land-rights}_{v,t} = \beta \cdot \log(\bar{s}_{v,t} + 1) + \mu_v + \mu_t + \varepsilon_{v,t} \tag{21}$$

$$\overline{\text{land-rights}}_v = \beta \cdot \log(\bar{s}_v + 1) + \mu_d + \varepsilon_v \tag{22}$$

where $\text{savings}_{h,t}$ is household total savings, $\bar{s}_{v,t}$ is the village-wave mean savings and $\bar{s}_v$ is the village average savings across waves. We add 1 before taking logs to accommodate the large share of households with zero savings. Column (4) additionally regresses the Chief Power Index on average village savings to verify that the instrument is not correlated with savings behaviour. All specifications include the relevant fixed effects and standard errors are clustered at the village×time level for column (1) and at the district level for columns (2)–(4).

	Dependent variable:			
	land-rights$_{i,t}$ LR (hh-wave)	land-rights$_{v,t}$ LR (vil-wave)	$\overline{\text{land-rights}_v}$ Avg LR (vil)	CPI$_v$ CPI (vil)
	(1)	(2)	(3)	(4)
log(savings$_{i,t}$ + 1)	−0.001			
	(0.004)			
$\log(\bar{s}_{v,t} + 1)$		0.000		
		(0.000)		
$\log(\bar{s}_v + 1)$			0.004	−0.003
			(0.010)	(0.010)
Unit of analysis	HH	Vil	Vil	Vil
Unit FE	Yes	Yes	No	No
Time FE	Yes	Yes	No	No
District FE	No	No	Yes	Yes
Observations	3,870	565	200	200
Clustered SE	Vil×Time	District	District	District

Note: Savings are set to zero for households reporting missing savings, consistent with the survey design in which non-savers do not receive a savings question. We add 1 before taking logs to handle zero savings observations. Standard errors are clustered at the village×time level for col. 1 and at the district level for cols. 2–4.

Table C.3: Land rights, savings and Chief Power Index

The results show that savings have no statistically significant relationship with land rights at any level of aggregation, nor with the Chief Power Index. This supports our argument that the mechanism of improved consumption insurance associated with land rights operates through informal mutual insurance arrangements within village networks rather than through individual self-insurance.

C.5 Cobb-Douglas Production Function

We estimate a Cobb-Douglas production function at the household level to recover three objects used in the structural estimation: household productivity, village TFP, and idiosyncratic productivity. The specification is:

$$\log(y_{i,t}) = \alpha_z \cdot \log(\text{land}_{i,t}) + \alpha_h \cdot \log(\text{labour}_{i,t}) + \mu_i + \mu_t + \varepsilon_{h,t} \tag{23}$$

where μ_i are household fixed effects capturing time-invariant household-level productivity and μ_t are time fixed effects. The dependent variable is the gross value of agricultural output, defined as the market value of the entire major season's harvest, including both sold and home-consumed production, before netting out production costs. This is consistent with the theoretical specification of the Cobb-Douglas production function, which models gross output as a function of inputs, and avoids the double-counting that would arise from subtracting input costs from the dependent variable while retaining the corresponding inputs on the right-hand side.

Table C.4 reports the estimation results.

	Dependent variable:
	$\log(y)_{i,t}$
	(1)
$\log(\text{land})_{i,t}$	0.396^{***}
	(0.049)
$\log(\text{labour})_{i,t}$	0.350^{***}
	(0.043)
Mean of Dep. Variable	6.972
Unit of analysis	HH
Unit FE	Yes
Time FE	Yes
District FE	No
Observations	3,870
R^2	0.696
Adjusted R^2	0.397

Note: The dependent variable is the log of gross agricultural output, defined as the market value of the entire harvest before netting out production costs. Both land and labour are in logs. Standard errors are clustered at the village × time level.

Table C.4: Estimation of Cobb-Douglas production function

Three objects are recovered from this estimation.

Household productivity. The estimated household fixed effect $\hat{\mu}_h$ is normalised as the deviation from the sample mean:

$$\hat{\mu}_i^{\text{norm}} = \hat{\mu}_i - \frac{1}{I}\sum_i \hat{\mu}_i \tag{24}$$

Village TFP. Village TFP is constructed as the simple average of the normalised household fixed effects across all households in village v:

$$\log(A_v) = \frac{\sum_{i\in v} \hat{\mu}_i^{\text{norm}}}{n_v} \tag{25}$$

where n_v is the number of unique households in village v across the three waves. By construction, $\log(A_v)$ has mean zero across the full sample.

Idiosyncratic productivity. Idiosyncratic productivity is defined as $\xi_{i,t} = \hat{\mu}_i + \varepsilon_{i,t}$, assumed to follow an AR(1) process:

$$\xi_{i,t} = \rho_\xi \cdot \xi_{i,t-1} + \varepsilon_{i,t} \tag{26}$$

estimated on the subsample of household-wave pairs for which a lagged observation is available.

Idiosyncratic Productivity AR(1) Estimates

	Dependent variable:
	$\xi_{i,t}$
	(1)
$\xi_{i,t-1}$	0.228***
	(0.020)
Observations	1,954
R^2	0.061
Adjusted R^2	0.061
Residual Std. Error	1.576

Note: Idiosyncratic productivity is defined as $\xi_{i,t} = \hat{\mu}_i + \hat{\varepsilon}_{i,t}$, where $\hat{\mu}_i$ is the normalised household fixed effect and $\hat{\varepsilon}_{i,t}$ is the residual from the Cobb-Douglas production function (Appendix C.5). The regression is estimated on the subsample of household-wave pairs for which a lagged observation is available, yielding 1,954 observations out of the full sample of 3,870. The estimated persistence $\hat{\rho}_\xi = 0.228$ and innovation standard deviation $\hat{\sigma}_{\varepsilon\xi} = 1.576$ are used to discretize the idiosyncratic productivity process via Rouwenhorst's method.

Table C.5: AR(1) estimation of idiosyncratic productivity

C.6 GMM Weighting Matrix

The GMM weighting matrix Ω is the variance-covariance matrix of the empirical moments vector m^{data}, which consists of six moments estimated at different levels of aggregation:

$$m^{\text{data}} = \left(\bar{h},\ \hat{\beta}_1^{\text{c,y}},\ \hat{\beta}^{\text{LFI}},\ \hat{\beta}^{\text{TFP}},\ \hat{\beta}^{\text{CI}},\ \overline{\text{land-rights}}\right)' \tag{27}$$

where $\bar{h}$ is average household labour supply share, $\hat{\beta}_1^{\text{c,y}}$ is the income coefficient from a simple Townsend consumption smoothing regression of log per capita consumption on log per capita income and log village consumption, with household and time fixed effects, capturing the baseline sensitivity of consumption to idiosyncratic income shocks net of aggregate village shocks. $\hat{\beta}^{\text{LFI}}$ and $\hat{\beta}^{\text{TFP}}$ are the slope coefficients from cross-sectional regressions of the land fluidity index and village TFP on average land rights with district fixed effects, $\hat{\beta}^{\text{CI}}$ is the coefficient from the regression of average land rights on the Chief Power Index (equation 4), and $\overline{\text{land-rights}}$ is the sample mean of average village land rights.

Construction of Ω. Since the six moments are estimated from specifications at different levels of aggregation — the Townsend regression operates at the household-wave level while the remaining regressions operate at the village level — the moments are potentially correlated across specifications. We therefore allow for full cross-moment dependence, $\text{cov}(m_i, m_j) \neq 0$ for all $m_i, m_j \in m^{\text{data}}$, and estimate the full 6×6 variance-covariance matrix Ω via village-level bootstrap.

Bootstrap procedure. We resample at the village level to account for within-village dependence across households and waves. The full sample consists of 200 villages and 3,870 household-wave observations. In each of $B = 999$ bootstrap replications, we draw 200 villages with replacement from the set of all villages $\{v_1, v_2, \ldots, v_{200}\}$. Since villages may appear multiple times in a given replication, the number of household-wave observations fluctuates around 3,870 across replications. For each bootstrap sample we re-estimate all six moments using the same specifications as in the main analysis, applying the Townsend regression at the household-wave level and the remaining regressions at the village level after collapsing the bootstrap sample to one observation per village per wave. The 6×6 weighting matrix is then computed as the sample covariance matrix of the 999×6 matrix of bootstrapped moment estimates:

$$\hat{\Omega} = \frac{1}{B-1} \sum_{b=1}^{B} \left(\hat{m}^{(b)} - \bar{m}\right) \left(\hat{m}^{(b)} - \bar{m}\right)' \tag{28}$$

where $\hat{m}^{(b)}$ is the vector of moments estimated in replication b and $\bar{m} = \frac{1}{B} \sum_{b=1}^{B} \hat{m}^{(b)}$ is the bootstrap mean. Standard errors for the internally calibrated parameters are then computed using the standard GMM sandwich formula.

Simple Townsend Consumption Smoothing Test

As a GMM moment targeting the discount factor β, we estimate a baseline version of the Townsend [1994] consumption smoothing test without the land rights interaction term:

$$\log(c_{h,t}) = \alpha + \beta^{c,y} \cdot \log(y_{h,t}) + \beta^{c_v,y} \cdot \log(c_{v,t}) + \gamma_h + \gamma_t + \varepsilon_{h,t} \tag{29}$$

where $c_{i,t}$ and $y_{i,t}$ are per capita consumption and income of household i at time t, γ_i and γ_t are household and time fixed effects, and $\log(c_{v,t})$ is log village consumption excluding household i, which controls for aggregate shocks. This differs from the extended Townsend specification in Table 2, which additionally includes the interaction between income and land rights. The income coefficient $\hat{\beta}^{c,y} = 0.051$ is used as a GMM moment targeting the discount factor β in the structural estimation.

	Dependent variable:
	$\log(c_{i,t})$
	(1)
$\log(y_{i,t})$	0.051***
	(0.010)
$\log(c_{v,t})$	0.659***
	(0.058)
Unit of analysis	HH
Unit FE	Yes
Time FE	Yes
Observations	3,870
R^2	0.726
Adjusted R^2	0.457

*p<0.1; **p<0.05; ***p<0.01

Note: Standard errors are clustered at the village × time level. This specification excludes the interaction between income and land rights. The income coefficient $\hat{\beta}^{c,y} = 0.051$ serves as a GMM moment targeting the discount factor β.

Table C.6: Simple Townsend consumption smoothing test

D Numerical appendix

We solve the model using policy function iteration, and iterate over the state space checking the participation constraints, and finding updates of the (relative) Pareto weights (also as described in Mazur [2023]). The recursive implementation of the FOC in LRS allocation (and other with limited commitment) relies on the definitions proposed in Kehoe and Perri [2002]. Denote by $x_t = \frac{\lambda_{2,t-1}}{\lambda_{1,t-1}}$ and by $v_{i,t} = \frac{\mu_{i,t}}{\lambda_{i,t}}$. This implies that $v_{i,t} = \frac{\lambda_{i,t}-\lambda_{i,t-1}}{\lambda_{i,t}} = 1 - \frac{\lambda_{i,t-1}}{\lambda_{-i,t}}\frac{\lambda_{-i,t}}{\lambda_{i,t}}$ and also $1 - v_{i,t} = \frac{\lambda_{i,t-1}}{\lambda_{i,t}}$. Thus, we have that:

1. if the limited commitment constraint of household 1 binds and the one of household 2 is slack (i.e. $\mu_{1,t} > 0$ and $\mu_{2,t} = 0$): $v_{1,t} = 1 - \frac{x_{t+1}}{x_t}$ and $v_{2,t} = 0$

2. if the limited commitment constraint of household 1 binds and the one of household 2 is slack (i.e. $\mu_{1,t} = 0$ and $\mu_{2,t} > 0$): $v_{1,t} = 0$ and $v_{2,t} = 1 - \frac{x_t}{x_{t+1}}$

3. $\frac{\mu_{1,t+1}}{\lambda_{1,t}} = \frac{\mu_{1,t+1}}{\lambda_{1,t+1}}\frac{\lambda_{1,t+1}}{\lambda_{1,t}} = \frac{v_{1,t+1}}{1-v_{1,t+1}}$

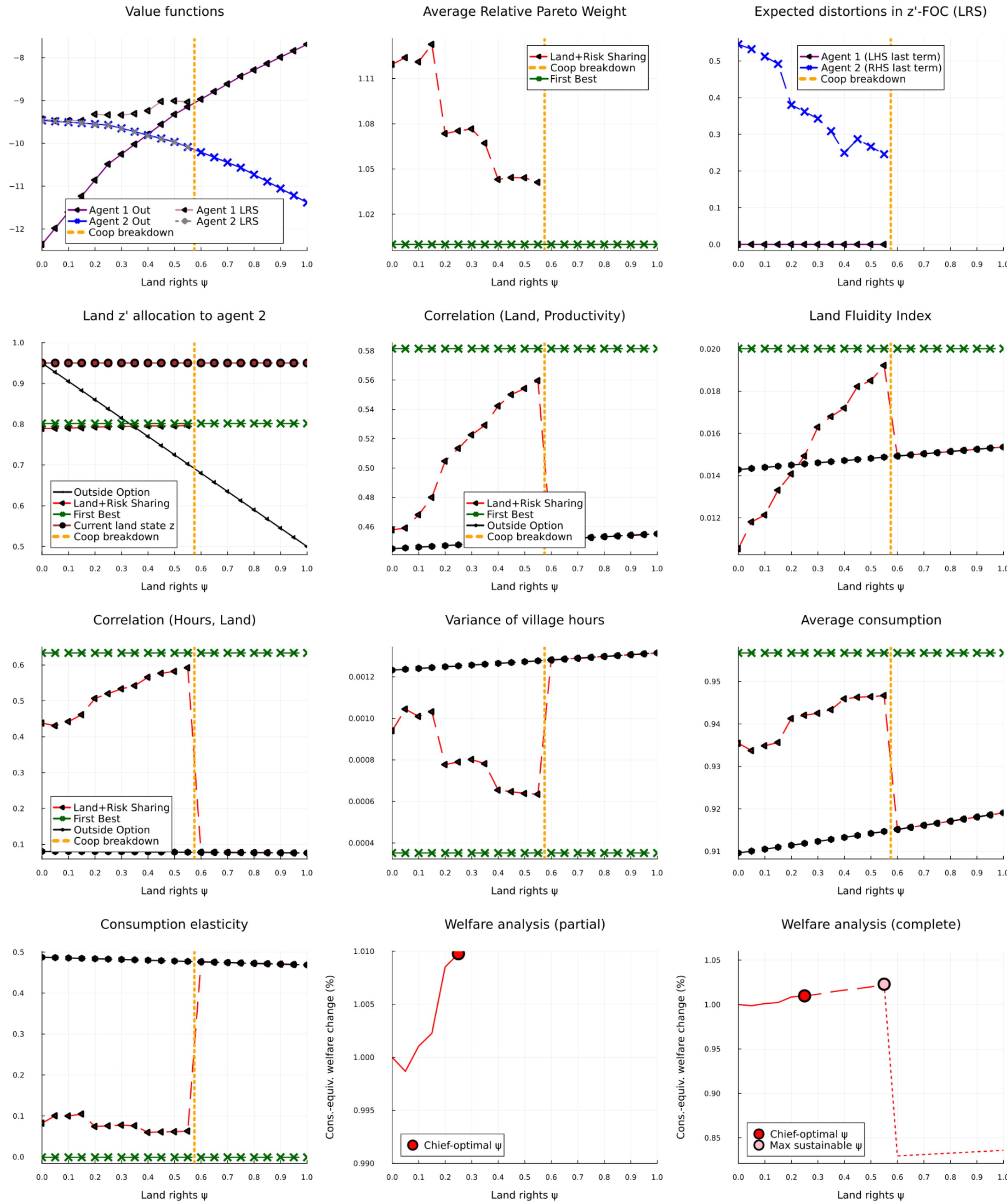
4. $\frac{\mu_{2,t+1}}{\lambda_{1,t}} = \frac{\mu_{2,t+1}}{\lambda_{2,t}}\frac{\lambda_{2,t}}{\lambda_{1,t}} = \frac{v_{2,t+1}}{1-v_{2,t+1}}x_{t+1}$.

With this, and assuming labor away for simpler notation, we can rewrite the FOC recursively as:

$$
\begin{aligned}
&-u_{1,c}\kappa(z_1' - z_1)+\\
&\beta\mathbb{E}_t\Big[\frac{u_{1,c'}}{1-v_1'}\Big(\phi'\theta_1'\alpha\,(z_1')^{\alpha-1} + \kappa(1-\psi)(z_1'' - z_1')\Big) - \frac{v_1'}{1-v_1'}\frac{\partial V_1'^{out}}{\partial z_1'}\Big] =\\
&-u_{2,c}x'\kappa(z_2' - z_2)+\\
&\beta\mathbb{E}_t\Big[u_{2,c'}\frac{x''}{1-v_1'}\Big(\phi'\theta_2'\alpha\,(1-z_1')^{\alpha-1} + \kappa(1-\psi)(z_2'' - z_2')\Big) + \frac{v_2'}{1-v_2'}x'\frac{\partial V_2'^{out}}{\partial z_2'}\frac{\partial z_2'}{\partial z_1'}\Big]
\end{aligned}
\tag{30}
$$

where:

$$
\begin{aligned}
\frac{\partial V_1'^{out}(\tilde{s}')}{\partial z_1'} =& u_{1,c'}^{out}\cdot\Big[(1-\psi)(q_z' + \alpha\phi'\theta_1'(\psi\cdot z_{1,0} + (1-\psi)\cdot z_1')^{\alpha-1})\\
&+\kappa(1-\psi)^2(z_1''^{out} - (\psi\cdot z_{1,0} + (1-\psi)\cdot z_1'))\Big]\\
\frac{\partial V_2'^{out}(\tilde{s}')}{\partial z_2'}\cdot\frac{\partial z_2'}{\partial z_1'} =& -u_{2,c'}^{out}\cdot\Big[(1-\psi)(q_z' + \alpha\phi'\theta_2'(\psi\cdot z_{2,0} + (1-\psi)\cdot(1-z_1'))^{\alpha-1})\\
&+\kappa(1-\psi)^2(z_2''^{out} - (\psi\cdot z_{2,0} + (1-\psi)\cdot z_2'))\Big]
\end{aligned}
\tag{31}
$$



Note: The figure shows the same set of quantitative results as figures in Section 7 for the village with the highest CPI.

Figure C.1: Quantitative results from the model with $\mathcal{P}_v = 1.0$