# Land Tenure Security and Deforestation: Experimental Evidence from Uganda*

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**Abstract**

We conduct a framed field experiment, designed after real tenure structures in Uganda, to elucidate the impact of land tenure security on deforestation. From a sample frame of households with access to forests, we randomly select 1,680 participants, across six districts and 91 villages in Uganda, to make harvest and conservation decisions over an experimental forest. One-third of participants faced insecure tenure through the threat of eviction, one-third had the option to secure tenure through costly certification, and one-third faced secure tenure. The results show that insecure tenure increases tree extraction by 22%, while certification reduces that effect by half. The conservation effects of certification are intensified for participants with a lived experience of land tenure insecurity. Our findings demonstrate that land certification can improve environmental outcomes and that these effects may be amplified in regions with historical legacies of insecurity.

**Keywords:** Land tenure security, overlapping land rights, deforestation, land certification, field experiments, Sub-Saharan Africa.
**JEL Codes:** Q15, Q23, O13, N57

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# 1 Introduction

Tropical deforestation threatens biodiversity, carbon storage, watershed function, and rural livelihoods. Forest loss is particularly acute in sub-Saharan Africa, where deforestation rates are the highest in the world (MacDicken et al., 2016). Between 2001 and 2022, total tree cover in Uganda decreased by 12% and accounted for the release of 463 Mt of CO2 emissions (GFW, 2021). For context, in 2019 Uganda was estimated to have produced 5.8 Mt CO2 from non-land use change sources (Global Carbon Project, 2023).

At the same time, there is a growing emphasis on land tenure security as a priority for the successful implementation of REDD+ (Reducing Emissions from Deforestation and Degradation-plus) programs. Much of the world's carbon-rich forests are located in regions characterized by insecure land tenure systems, which are often rooted in colonial histories of property structures that endure today. Recently, there has been considerable investment in policies to promote land tenure security through formalization and titling. Yet, the evidence remains mixed on the extent to which these interventions positively impact environmental outcomes (see Robinson et al. (2014) and Tseng et al. (2021) for systematic reviews).

This paper provides experimental evidence on the effect of land certification on forest extraction in Uganda. Like many low-income countries, land tenure systems in Uganda are a mix of traditional practices, colonial institutions, and post-colonial efforts to clarify property rights. We focus on a particular form of historical tenure, known as mailo land, in which owners and occupants share overlapping rights to land use. Overlapping land rights are common throughout sub-Saharan Africa and are widely associated with poor land management outcomes (Fenske, 2011). In Uganda, the overlapping nature of mailo tenure has been linked to greater insecurity and conflict (Musinguzi et al., 2020; Ali, Daniel and Marguerite Duponchel, 2018), lower investment, (Deininger and Ali, 2008; Deininger et al., 2008), and higher rates of deforestation (Walker et al., 2023). Recently, there is a push to improve Uganda's land administration, with considerable focus on land titling, supported by the World Bank and European Union, who has provided nearly $8.6 million to expand access to land titles. Recent evidence suggests that the rise in land certification is coincident with a decline in deforestation rates in mailo areas (Walker et al., 2023), but this work is unable to disentangle the separate effects of certification, historical legacy, and land use decisions.

We designed a framed field experiment to elucidate how land certification impacts deforestation behavior. First, we constructed a sample frame of households in regions with dense forest coverage, but relatively high rates of deforestation. We then randomly selected 1,680 households, across 6 districts and 91 villages, to participate in a framed field experiment. Participants were given a forest of 12 trees, which they could conserve or harvest, subject to a constant regrowth rate. Participants were compensated for their harvest decisions, which they made over several rounds until no trees remained or the game finished (at a pre-determined round, undisclosed to the participant *ex ante* to avoid attempts at backward induction).

Prior to the experiment, participants were individually randomized into 3 groups: (i) insecure tenure, (ii) an option to secure tenure through costly certification, and (iii) secure tenure. Participants in group 1 (insecure) were told that a landlord owned the land that they occupied and could evict them at any time. Eviction decisions were made at the start of each round by drawing a marble from a bag that contained 2 red and 8 blue marbles. If a red marble was drawn, the participant was evicted and the game stopped.

Participants in group 2 (certificate) were given the same instructions as those in group 1, but were also given the option to buy a certificate of occupancy, which would allow them to remain on the land in the event a red marble was drawn. Participants in group 3 (secure) played the game as initially described, making harvest and conservation decisions until no trees remained or the experimental rounds ended. Participants completed the experiment individually and in private with a local enumerator, and responded to survey questions about their forest use, current land tenure system, risk and time preferences, and other demographic characteristics.

The experimental results show that participants in the insecure group extract more resources in each round than participants in the secure group. The coefficients suggest a 22-24% increase in deforestation as a result of insecure tenure. Importantly, however, certification reduces forest extraction by almost half compared to the insecure group.

Next, we explore whether lived experience with land tenure insecurity impacts deforestation behavior by comparing participants living in villages with a higher share of mailo tenure to those with less. On average, we observe that participants in villages with a higher share of mailo land harvest more trees in each round. However, when offered a certificate of occupancy, participants currently living in mailo villages are more likely to purchase a certificate. Moreover, the results suggest that in villages entirely comprised of mailo tenure, the overall effect of certification reduces deforestation behavior to levels commensurate with fully secure land tenure.

Our findings contribute broadly to the literature on natural resource extraction in tropical countries, particularly its relationship with land tenure insecurity. Framed field experiments have clearly demonstrated the incentives to over-extract under a common access structure (Cardenas, 2003), and also reveal how communication and endogenous rule development can help improve outcomes (Ostrom, 2006). A number of experiments have also directly tested whether conservation measures, such as payments for ecosystem services, might remedy the exploitation of forest commons (Handberg and Angelsen, 2015, 2019; Yehouenou et al., 2023). Our approach differs from these in that we focus on tenure insecurity, rather than common resources, and the possible solution presented by certification.

Theoretically, the impact of improving land tenure security on natural resource management depends upon the nature of the extractive process. If extraction is capital intensive, securing land tenure should lead to investment in extraction resources and higher rates of deforestation, while if it is labor intensive, tenure security is likely to reduce extraction (Farzin, 1984). In much of sub-Saharan Africa, and in Uganda particularly, forest extraction occurs on a small scale with low capital inputs, mainly for the purpose of fuel wood collection (e.g., charcoal) and low-intensity agricultural production and grazing. Cross-sectional studies, such as Bohn and Deacon (2000), show a correlation between ownership security and forest cover, while observational studies from Brazil (Baragwanath and Bayi, 2020), Ecuador (Holland et al., 2017), and Colombia (Vélez et al., 2020) show small, but short-term reductions in deforestation following formalization of collective property rights. The impacts of land titling, however, are less clear.[1] Our paper provides experimental evidence of the effect of increased tenure security in a context with low-intensity production and high rates of deforestation.

Recent meta-analyses show an association between land tenure security and lower deforestation (Robinson et al., 2014; Tseng et al., 2021), and acknowledge that robust identification of this relationship is scarce. We are aware of only 6 studies evaluating randomized control trials (RCTs) of land titling and/or formalization, with only 2 that focus specifically on environmental outcomes. Evaluations of an RCT in Benin find increased investment in cash crops and tree planting (Goldstein et al., 2018), heterogeneous effects on prosocial preferences (Fabbri, 2021), and evidence that formalization leads to lower rates of deforestation, with limited evidence of spillovers (Wren-Lewis et al., 2020). In Zambia, Huntington and Shenoy (2021) evaluate a randomized land certification program and find that while perceptions of security improved, there was no impact on agro-forestry investment.

In Uganda, the World Bank is steadily invested in land titling. A recent RCT evaluates the impact of subsidizing titles and informing households of the benefits of titling, with a focus on female co-titling (Cherchi et al., 2019). Preliminary evidence suggests that the demand for titles is high and that offering subsidized titles conditional on co-titling increased the take-up of joint titles. Our findings have significant implications for this ongoing policy intervention. First, our results suggest that titling efforts may benefit from scale-up in areas where historical land tenure insecurity is prevalent and the demand for certification is high. In addition, there are potentially large and positive environmental spillovers to scaling up titling in these regions.

Finally, this work speaks to the literature on the conditionalities that historical legacies

[1] Observational studies from Brazil (Probst et al., 2020), Nicaragua (Liscow, 2013), and Ecuador (Buntaine et al., 2015) do not show evidence of improved environmental outcomes from formal land titles.

imprint on current behavior. There are now several experimental studies documenting differential behavior among subjects living across historical boundaries (Robinson, 2016; Lowes et al., 2017; Bai et al., 2022; Karaja and Rubin, 2022). The most closely related to our work is Chaudhary et al. (2020), who find that play in a public goods game is significantly influenced by colonial legacies within India; subjects in former British areas play more cooperatively, which the authors attribute to experience with formal taxation. Our work differs from these studies in that we document not only a difference in experimental deforestation in areas with a history of insecure land tenure, but also a differential response to a policy meant to improve security.

# 2 Land Tenure Insecurity and Deforestation in Uganda

Land tenure in Uganda is characterized by a complicated mix of traditional practices, colonial legacies, and modern reform. Prior to British colonization in 1894, all land was held in customary tenure, an umbrella term that encompasses a diverse array of local practices based on kinship or clan ties. In 1900, an agreement between the British colonial government and Buganda Kingdom established 4 types of land tenure: freehold, leasehold, customary, and mailo, which remain intact today. Freehold and leasehold tenure consist of registered titles, full transferability, and exclusion rights. We refer to these two categories together as "private" land. Customary land is not synonymous with common property, and in many cases is considered at least as secure as traditional private property.

Mailo land is a distinct form of tenure in which owners and occupants share overlapping rights to land use. The mailo system was created out of the 1900 Buganda agreement, which designated square mile blocks of land allocated to specific offices of the colonial government, typically reserved for nobles and royalty of the Buganda Kingdom. This designation effectively forced occupants of the newly defined land, who were the primary cultivators as few nobles farmed, to become tenants overnight. A series of reforms in 1908 and 1928 introduced registered titles for mailo owners and clarified the legal relationship between owners and tenants by creating a system of small rents (*busuulu*) that tenants were expected to pay owners in exchange for legal recognition of usufruct rights.

British rule ended in 1962, with no change to land tenure practices. With the rise of Idi Amin, who seized power in a 1971 coup and nationalized land in 1975, all forms of individual ownership were abolished. 20 years later, the 1995 Constitution returned land to Ugandan citizens and in 1998, the Land Reform Act resurrected the 4 original tenure categories from the 1900 Buganda agreement.

Today, land cannot be converted to mailo tenure – the original titles from 1908 legally define mailo tenure. Formally, mailo owners are a person or institution that bought, inherited or was gifted an original mailo title, and may transfer their land freely (e.g., sell, gift, or subdivide). Mailo tenants can be either *bona fide* (living on the land at least 12 years before the 1995 Constitution), or lawful (provide proof of having paid *busuulu* before 1975 or who entered the land with the permission of the landowner).

In reality, however, most mailo tenants have no proof of legal occupancy, while many owners are absentee landlords (e.g., they fled the country during regime changes or were not informed when they inherited the land). Tenants in these situations may have occupied land for generations without knowing the official owner and thus never paid *busuulu*. Recent evidence suggests that only half of mailo tenants know their landlord, while only 26% have ever paid rent (Ali, Daniel and Marguerite Duponchel, 2018).[2] Such ambiguity has created overlapping claims by owners and tenants, leading to conflict (Musinguzi et al., 2020), lower investment (Deininger and Ali, 2008; Deininger et al., 2008; Place and Otsuka, 2002), and higher rates of deforestation (Walker et al., 2023).

Unsurprisingly, there is a notable perception of insecurity among mailo tenants, where recent evidence suggests that 41% of tenants believe there is a risk of eviction due to sale of the land by the landlord, while 23% believe there is a risk of eviction if they leave the land fallow (Ali, Daniel and Marguerite Duponchel, 2018). In recent decades, various legal reforms have attempted to clarify the rights of mailo tenants. Most recently, a 2013 reform instituted mechanisms and incentives to certify land across all types of land tenure. However, the process of certification has been slow to evolve until very recently (Nakanwagi and Morokong, 2021; Nakanwagi, 2021; GIZ, 2019; Ali, Daniel and Marguerite Duponchel, 2018; Mayanja et al., 2015) – in 2016, about 20% of land had a certificate formally documenting the type of land tenure (Mabikke, 2016), which increased to 33% by 2018 (Uganda Bureau of Statistics, 2021).

Using data on mailo land tenure from the 2002 Uganda Census and deforestation trends from Hansen et al. (2022), Figure 1 plots the percent of land held in mailo tenure in panel (a), while panel (b) plots forest loss from 2010-2019 for the whole of Uganda. Panel (a) shows that mailo land is predominantly held in the south-central part of the country. Panel (b) shows that in recent years, deforestation is highest in mailo areas and in areas of the North that have experienced significant insecurity in recent years due to instability in South Sudan and the DRC. Evidence evidence suggests that the recent rise in certification coincides with a decline in deforestation trends in mailo areas (Walker et al., 2023), but well-identified, micro-level evidence is lacking.

[2] Common reasons for non-payment include not knowing the landlord (36%) and the landlord never asked (23%).

# 3 Data

## 3.1 Sampling

To ensure that the framing of our experiment would be relevant to the study population, we constructed a sample frame of households with access to forests. First, we leveraged forest cover data from Hansen et al. (2022) and selected regions of Uganda with the greatest percentage of land covered by the category of forest called "dense forest" in 2000. Within these regions, we dropped districts with small amounts of detectable forest (less than 10% using the sum of both open and dense forests), and also island districts. We then selected districts with the highest historical deforestation and current area of open and dense forest across 3 regions of Uganda (Eastern, Central, and Western). The final set of districts includes: Bududa, Kazo, Kiruhira, Luwero, Mubende, and Namisindwa. Figure 1 displays the spatial distribution of sampled districts. We combined this information with data from the Ugandan Bureau of Statistics on the latitude and longitude of village locations in 2019. Around each village, we drew a 3 km buffer and dropped villages that had no identifiable forest cover within the buffer. From the remaining sample, we randomly selected 28 villages per region plus a buffer of replacement villages in the case of unforeseen difficulties in locating them.

A locally-hired research firm conducted listing exercises with the village chiefs in each of the randomly selected villages to obtain a sample frame of all households with access to forests. We then randomly selected 20 households from the list, with the aim of 1,680 households in total. Because some villages had less than 20 households, 7 additional villages were added from the randomly selected replacement list to achieve the desired sample size. The experiment and surveys were conducted from January to March 2023 with the household head indicated in the listing exercise.

## 3.2 Experiment and Survey

We designed an incentivized field experiment, modeled after real land tenure systems in Uganda, to better understand deforestation decisions across differing levels of land tenure security.[3] The experimental instructions informed participants that they were responsible for a forest with 12 trees, which they could harvest or conserve over several rounds.[4] In each round, participants chose the number of trees to harvest using laminated pictures of trees and received a real payment for each tree harvested. Following Handberg and Angelsen (2015, 2019) and Yehouenou et al. (2023), we allowed for forest regrowth

[3]The design is inspired by similar experiments by Handberg and Angelsen (2015, 2019) and Yehouenou et al. (2023). Unlike these games, our experiment was not framed as a common pool resource problem. Instead, participants made individual harvest decisions and payouts did not depend on the choices of others.

[4]See Appendix for full instructions and visual aids.

between rounds using a constant regrowth rate of 1 tree for every 5 trees left standing at the end of the round.[5] Participants made their choices until no trees remained or the 10th round was completed, whichever happened first. Players were not informed *ex ante* of the total number of rounds to prevent attempts at backward induction.

Following Yehouenou et al. (2023), we assume a linear revenue function and quadratic cost function, and determine payoffs with the following equation:

$$\pi = ah_{it} - \frac{1}{2}bh_{it}^2 \tag{1}$$

where $h_{it}$ is the number of trees harvested in each round. We validated the functional form of the payoff function and calibrated the marginal revenue ($a$) and cost ($b$) parameters using pilot data. Participants were given a visual aid to assist with their choices, which illustrated the payoff they could receive for each number of trees harvested in a given round (see Appendix Figure B1).[6] After each round, enumerators calculated the profit earned and trees remaining in the forest and communicated this information to the participant.

Prior to the experiment, participants were randomized, at the individual level, into one of 3 groups: (i) insecure tenure, (ii) an option to secure tenure through the purchase of a certificate of occupancy, and (iii) secure tenure. Participants in group 1 (insecure tenure) were informed that their land was owned by a landlord who could evict them from the land at any time. To determine whether the participant was evicted, the enumerator drew a marble out of a bag at the beginning of each round (starting from round 2), where a blue marble meant that the participant could remain on the land and a red marble resulted in eviction, and consequently, the end of the game. Participants were informed that the bag contained 2 red marbles and 8 blue marbles, representing a 20 percent chance of eviction in each round.[7]

The framing for participants in group 2 (certificate) was similar to group 1. However, at the beginning of each round, participants could buy a certificate of occupancy for UGX 1,200 (0.32 USD at the time of the study), which would allow them to maintain access to the land even if a red marble was drawn.[8] To mimic real-world circumstances

[5]The regrowth rate implies that if 5 to 9 trees remain, 1 regrows, and if 10 to 14 trees remain, 2 regrow.

[6]In a single round, maximizing (1) yields an optimal harvest of 5 trees, which corresponds to a payoff of UGX 2,500 (roughly USD 0.65 at the time of the experiment). The dynamic solution assumes that participants make their choices over an infinite time frame, as they were uninformed of the total number of rounds. Our setup abstracts from a marginal user cost or interest rate that determines the value of conserving the resource to extract in the future. Therefore, the future value of the resource is the amount that can be extracted in the next round. Extracting 2 trees in each round would achieve the maximum sustainable yield (i.e., maintain a constant stock of trees over time), which is the optimal harvest with an infinite time horizon and linear regrowth function.

[7]This probability was selected based on the recent observation that 23% of mailo tenants believe they will be evicted if their land is left fallow (Ali, Daniel and Marguerite Duponchel, 2018).

[8]The price of the certificate was calibrated to 1.3 times the profit from harvesting one tree, which is

in which landowners must generate funds to pay for a certificate, the participant had the option to buy the certificate at the beginning of the second round and all future rounds if they had earned enough to afford it.[9] Once purchased, the certificate remained valid for all future rounds (i.e., a marble was still drawn in every round, but in the event of a red marble, the participant could continue if they had a certificate). Note that 81% of participants in the certificate treatment purchased a certificate, 95% of whom purchased it in the second or third round, demonstrating significant demand for land tenure security. Perhaps unsurprisingly, take-up of the certificate was higher for participants living in villages with a greater share of mailo land.[10]

Participants in group 3 (secure tenure) played the game, without risk of eviction, over 10 rounds consisting solely of the decision to harvest or conserve. Participants played until no trees remained or 10 rounds were completed, whichever happened first.

To compensate for the fact that, in expectation, total payouts would be lower across groups facing eviction risk, participants in group 1 received an additional UGX 2,000 in their show-up fee and participants in group 2 received an additional UGX 1,000, but were not told that they were being additionally compensated (i.e., the show-up fees stated in the consent forms for these groups were higher than group 3). These amounts were calibrated from pilot data.

Participants completed the experiment individually and in private with an enumerator. In the same session as the experiment, participants also responded to survey questions, which captured basic demographic and economic information regarding their forest access, land use behavior, and current land tenure system on their forested land. In addition, we elicited risk and time preferences using standard measures.[11]

## 3.3 Summary statistics

We present summary statistics in Table A1. On average, participants are 46.5 years old and only 17% are women. The highest level of education for nearly half of participants is primary school, while 24% have some or completed secondary schooling. Most participants have been living in these communities for nearly their whole lives (35 years on average).

Table A1 further reveals that virtually all participants generate income from their land, and over 60% have trees covering more than half of their land. Roughly a quarter

the same relative cost in real life, based on pilot data.

[9]We abstract from savings and credit markets in our experiment, noting that in real life, some landowners may draw on savings or borrow to purchase certificates.

[10]The coefficient from regressing certificate take-up on the share of mailo land in a participant's village is 0.12 with a p-value of 0.089.

[11]We elicited incentivized risk preferences using the method developed by Eckel and Grossman (2008), which is a simple way of measuring risk preferences in populations with lower math abilities (Charness et al., 2013). We measured unincentivized time preferences using the method developed by Falk et al. (2018), which has been experimentally validated at a global scale.

harvest trees either to produce charcoal themselves or to sell for charcoal production. Just over 70% also use this land for farming and almost two-thirds use the land for grazing animals.

In terms of land tenure, 14% of participants have access to forests on mailo land, 29% on customary land and 49% on private land. At the village level, the average share of mailo land is also 14%. However, this is driven by regional differences (see panel (a) of Figure 1). Within the Central region, where mailo land was historically designated, the average share of mailo land is 42.5% (5.5% minimum, 84.2% maximum, and 21.6% standard deviation).

To verify that the randomization is balanced we conduct a series of t-tests that compare the baseline characteristics of participants across treatment groups. We present the results in Table 1. We achieve balance across several covariates, with some qualitatively small, but statistically significant, differences on a few dimensions. Participants in the secure tenure group are 1.5 years older than those in the insecure group and have 0.37 more people living in their households than the certificate group. Participants in the insecure and secure group are slightly less likely to use their land for people to live on, while participants in the certificate group are slightly more likely to have access to village or community savings. Finally, participants in the secure group are slightly less patient and more likely to have access to forested land with private tenure. Note, however, that each of these normalized differences is notably less than $|0.25|$ standard deviations, which is the threshold at which these differences could impact the causal interpretation of regression results (Imbens and Rubin, 2015). Nonetheless, we present each of our estimates with and without controlling for these covariates.

# 4 Estimation

Our empirical objective is to compare average deforestation behavior under differing types of land tenure security. We construct our main dependent variable as the share of trees harvested in each round:

$$\bar{h}_{it} \;=\; \frac{h_{it}}{S_{it}} \qquad \forall\; S_{it} > 0$$

where $h_{it}$ is the total trees harvested by participant $i$ in round $t$ and $S_{it}$ is the stock in each round.

We then compare harvest rates across treatment groups by estimating the following equation:

$$\bar{h}_{it} \;=\; \alpha + \rho_t + \;\beta_1 Insecure_i + \;\beta_2 Certif_i + \gamma X_i + \;\varepsilon_{it} \qquad (2)$$

The variable $Insecure_i$ is an indicator for whether the participant is in group 1 (insecure tenure) and $Certif_i$ is an indicator for whether the participant is in group 2 (certificate), where the reference category is group 3 (secure tenure). The variable $\rho_t$ is a fixed effect for the round. In some specifications, we also include the following individual controls, $X_i$, which had qualitatively small, but statistically significant differences across treatment groups: age, household size, access to village/community savings, whether the participant could obtain money from selling trees or charcoal, whether their land is used for people to live on, patience, mailo land tenure, and private land tenure. We also control for the following additional covariates in some specifications, as specified in our pre-analysis plan (PAP): asset index,[12] the sex, risk tolerance, and educational attainment of the participant, land area, and whether the household sells trees for or produces charcoal.[13] To account for systematic differences between villages and possible unobservable heterogeneity across enumerators, we also include village and enumerator fixed effects in alternate specifications.

We expect that insecure land tenure increases deforestation relative to secure land tenure, such that $\beta_1 > 0$. To the extent that certification may improve perceived land tenure security, lowering incentives for deforestation, we expect $\beta_1 > \beta_2$. While certification may improve tenure security, it is unclear whether it is equivalent to having secure land tenure from the beginning. We therefore expect $\beta_2 \geq 0$.

Note that participants who harvest all of their trees before the game finishes drop out of the sample in later rounds. This could bias our estimates if there is endogenous sample selection on resource depletion. To address this, we first conduct balance tests on observable characteristics across participants who deplete their trees vs. those who do not. 33% of participants deplete their trees before the game finishes.[14] Appendix Table A4 shows, however, that there are no meaningful observable differences between these groups, with normalized differences below $|0.25|$ standard deviations (Imbens and Rubin, 2015). Next, we re-estimate equation (2) on the sample of participants who never deplete their trees. We expect that these participants are more "conservationist", such that the effect of certification relative to the insecure treatment will be stronger, and behavior in the certificate group will be closer to behavior in the secure group. For the insecure group, we anticipate that tenure insecurity still creates incentives to deforest, such that the effect of the insecure treatment will be similar to or slightly smaller than the effect in the full sample. We test these predictions in Appendix Table A5.

To the extent that mailo land tenure is associated with greater insecurity and higher

[12] We count the total number of the following assets that the participant has in their home: radio, electricity, television, solar panel, electric stove, gas stove, internet access, mobile phone, bicycle, car/truck, and motorcycle.

[13] We replace missing values with the median and control for missing observations in all specifications. Appendix Tables A3 and A7 show the results dropping observations with missing values for controls.

[14] The mean and median round in which trees are depleted is the 7th round.

deforestation in Uganda, we are also interested in how the participant's own experience with land tenure insecurity may interact with the experimental treatment. To see this, we interact each of the treatment categories with the village-level share of mailo tenure and estimate the following equation:

$$\begin{aligned}\bar{h}_{it} \; = \; & \alpha + \rho_t + \theta_1 Insecure_i * Mailo_v + \; \theta_2 Certif_i * Mailo_v \\ & + \theta_3 Insecure_i + \theta_4 Certif_i + \delta Mailo_v + \gamma X_i + \varepsilon_{it}\end{aligned}$$

We use a more aggregated measure of mailo tenure to capture the spatial designation of mailo land during the colonial period and to overcome potentially endogenous individual selection into mailo occupancy today. If the real experience of land tenure insecurity exacerbates deforestation behavior in the game, we would expect $\theta_1 > 0$. If certificates of occupancy are more salient for people with actual land tenure insecurity, we would expect $\theta_2 < 0$.

In each of the main specifications, we implement robust standard errors, as specified in our PAP. In robustness exercises, we introduce a heteroskedasticity-autocorrelation consistent (HAC) correction, following the literature on repeated-game experiments in economics (Vossler, 2013). The HAC correction results in Appendix Tables A2 and A6 are consistent with the main estimates.

# 5 Results

In Figure 2, we plot the mean share of trees harvested in each of the 10 rounds, separately by treatment group, with 90% confidence intervals. Noticeably, the insecure group cuts the highest shares in every round, while the secure group cuts the lowest. The share of trees cut for all groups follows similar patterns, with shares increasing quite quickly over the first 4-5 rounds before stabilizing somewhat for a few rounds and then increasing again.

Table 2 presents the results from estimating equation (2). We present 5 specifications, adding controls and fixed effects parsimoniously. We include round fixed effects in column (1); column (2) adds unbalanced controls from the balance test in Table 1 and column (3) adds additional controls specified in our PAP; columns (4) and (5) include enumerator and village fixed effects, respectively.

The results are robust across specifications and reinforce the trends illustrated in Figure 2. Relative to the secure tenure group, participants with insecure tenure harvest a significantly greater share in each round. Relative to a secure group mean of 0.23, the coefficients suggest a 23-25% increase in deforestation as a result of insecure land tenure.

We do find evidence, however, that increasing land tenure security through certification reduces deforestation. Relative to the secure tenure group, participants in the certificate group harvest a higher share of trees in each round. The coefficients suggest that deforestation is 11-12% higher for participants in the certificate group. Importantly, though, F-tests reject that the coefficients on *Insecure* and *Certificate* are equivalent, showing that deforestation in the certification group is significantly lower than in the insecure group. The difference in coefficients suggests that, relative to a mean of 0.27 in the insecure group, participants in the certificate group reduce their deforestation behavior by roughly 10-12%, which is half of the effect size for the insecure group.

Appendix Table A5 re-runs these specifications on the sample of participants who never fully deplete their stock of trees. Consistent with our predictions, the coefficients on the insecure treatment are nearly identical to the main results in Table 2. The coefficients on the certificate treatment are substantially smaller than the baseline estimates (0.015 vs. 0.028, respectively). This is consistent with our prediction that this sub-sample of participants is more "conservationist" than the full sample, and thus, behaves more similarly to the secure group. We also note that the qualitative difference between the coefficients on the insecure vs. the certificate treatment is larger than the estimates from the full sample, suggesting that certification has a stronger effect on conservation in this sub-sample. Relative to a sub-sample mean of 0.21 in the insecure group, certification reduces deforestation by roughly 16-19%.

Turning to heterogeneity, we examine whether lived experience with tenure insecurity amplifies the effects of insecurity in the experiment by including an interaction term between the share of mailo land in the participant's village and the experimental treatment groups. Table 3 displays the results. The coefficients on the interaction with *Insecure* are small, negative, and statistically insignificant. The coefficients on the interaction with *Certificate*, however, are negative, large, and statistically significant at the 95% level, suggesting that certification is more salient for people who have real-life experience with tenure insecurity. Participants living in villages with a higher share of mailo tenure cut fewer trees in each round when offered certification. The coefficients suggest that in villages entirely comprised of mailo tenure, the overall effect of certification reduces deforestation to levels commensurate with fully secure land tenure. This finding suggests that securing land tenure in places with historical experiences of insecurity may have additional impacts on reducing deforestation.

In addition, we find that in columns (1)-(4), the coefficient on *mailo* is negative. However, this appears to be driven by unobserved spatial heterogeneity that is likely due to the fact that mailo land is designated in specific areas of the country (see Figure 1). In column (5), we include district fixed effects, which limits the variation in mailo tenure to within-district. Here we find that, consistent with observational studies on deforestation in mailo areas, experimental deforestation is higher for participants living in villages with a greater share of mailo tenure.

## 6 Conclusion

We find experimental evidence that land tenure insecurity significantly increases deforestation. Improving security through certification reduces deforestation by half. Moreover, the role of historical legacies matters for interventions aiming to promote land tenure security, where participants living in villages with a higher share of mailo land respond more strongly to certification and reduce their experimental forest extraction significantly.

These findings have implications for our understanding of the relationship between land tenure security and environmental outcomes, where well-identified, micro-level evidence is scarce. Our results suggest that improving land tenure security through certification may be an effective way to curb deforestation, particularly in regions with historical legacies of insecurity. This type of insecurity occurs throughout Africa, including Ghana (Goldstein and Udry, 2008), Nigeria, Ethiopia, Kenya, and Zimbabwe (Fenske, 2011) – countries which are home to biodiverse forest ecosystems. Forests with historical legacies of insecure tenure and high biodiversity are also present in Latin America and Asia, including well-documented cases in Brazil (Moutinho and Azevedo-Ramos, 2023) and India (Banerjee and Iyer, 2005). These areas also have substantial potential for carbon sequestration capacity via sustainable land management choices. Secure land tenure has a strong synergy with these types of climate mitigation solutions.

A few caveats, nonetheless, remain. While our framed field experiment reflects the realistic experience of its participants, it is possible that experimental behavior may not translate to real reductions in deforestation if a certification program were to scale up. Our experimental certification program included a non-trivial cost of purchasing a certificate, but it did not allow for other monetary and non-monetary transaction costs associated with certification, such as information frictions, land demarcation expenses, and other administrative barriers. Moreover, the experimental setting cannot address the potentially off-setting effects that increased tenure security might have on access to credit, which could incentivize deforestation efforts if people use land titles to secure loans that fund larger extraction efforts.

Future work may consider leveraging ongoing randomized evaluations of land titling schemes to examine environmental impacts, as well as their interaction with historical legacies of tenure insecurity.

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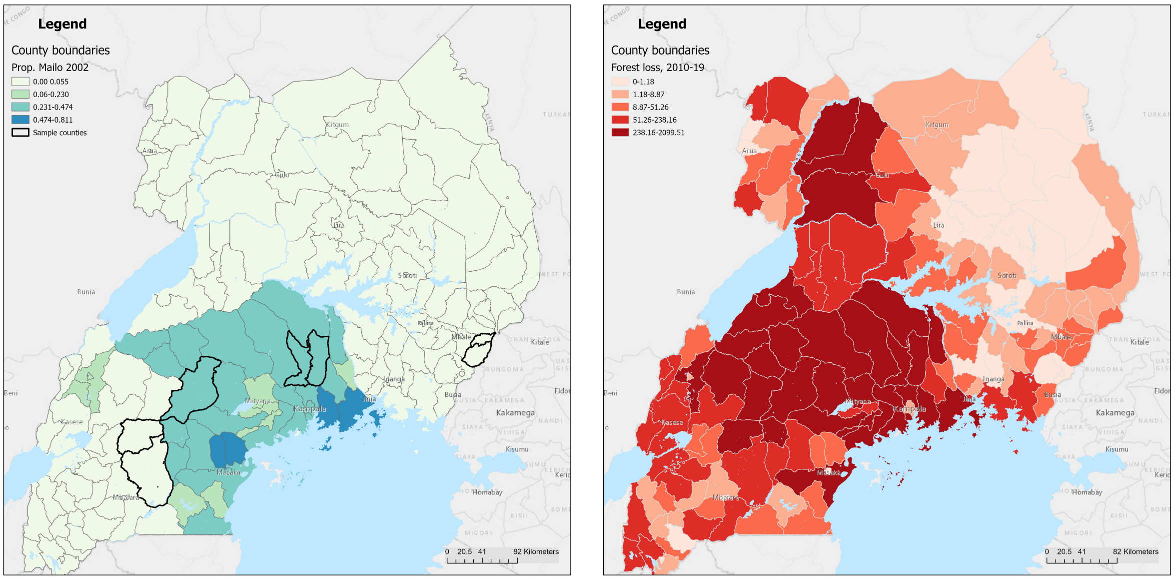
# 7 Figures and Tables

Figure 1: Mailo tenure and deforestation




(a) Tenure

(b) Forest loss, 2010-2019

Panel (a) shows the proportion of land with mailo tenure in according to 2002 census. The four categories are established according to "natural breaks" using the Jenks Natural Breaks algorithm, which maximizes differences between classes. Districts outlined in black indicate the location of the sample. Panel (b) shows hectares of forest lost between 2010 and 2019 shaded by quintiles. Darker shades indicate higher numbers.

Figure 2: Share cut by treatment group

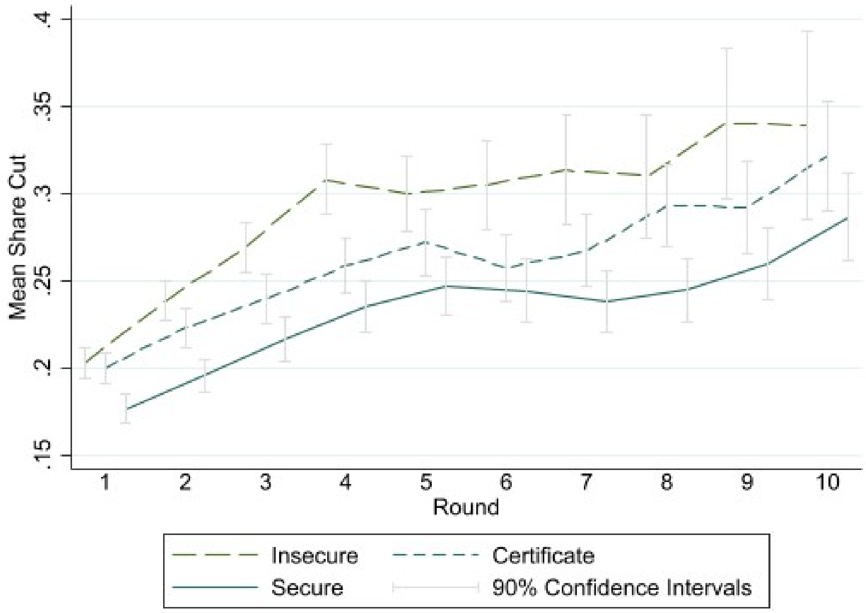


Table 1: Balance Test

| Variable | Insecure | Certificate | Secure | Normalized Differences (1)-(2) | (2)-(3) | (1)-(3) |
|---|---|---|---|---|---|---|
| Age (years) | 45.872 | 46.251 | 47.379 | -0.022 | -0.064 | -0.087** |
| Female | 0.165 | 0.175 | 0.167 | -0.019 | 0.015 | -0.004 |
| Household size | 6.987 | 6.967 | 7.332 | 0.004 | -0.074* | -0.068 |
| # People below age 14 in home | 2.495 | 2.513 | 2.542 | -0.006 | -0.011 | -0.017 |
| Some/completed primary school | 0.562 | 0.562 | 0.567 | 0.001 | -0.007 | -0.006 |
| Some/completed secondary school | 0.230 | 0.248 | 0.245 | -0.030 | 0.005 | -0.025 |
| Years lived in community | 34.264 | 35.625 | 35.203 | -0.061 | 0.019 | -0.043 |
| Earns income from land | 0.986 | 0.992 | 0.991 | -0.044 | 0.007 | -0.038 |
| Total area of all land (acres) | 22.741 | 16.835 | 17.872 | 0.045 | -0.009 | 0.037 |
| Total area of farm/grazing land (acres) | 11.537 | 11.756 | 14.124 | -0.006 | -0.048 | -0.049 |
| Years of access to land | 20.805 | 21.432 | 21.897 | -0.033 | -0.024 | -0.057 |
| Trees cover more than half of land | 0.627 | 0.644 | 0.615 | -0.024 | 0.042 | 0.018 |
| Cuts trees for charcoal | 0.254 | 0.277 | 0.242 | -0.037 | 0.056 | 0.019 |
| Land used for: farming | 0.706 | 0.721 | 0.746 | -0.023 | -0.039 | -0.063 |
| Land used for: grazing | 0.639 | 0.627 | 0.628 | 0.018 | -0.002 | 0.016 |
| Land used for: people to live on | 0.276 | 0.332 | 0.270 | -0.086** | 0.095** | 0.009 |
| Number of cows raised last year | 4.288 | 4.369 | 4.543 | -0.005 | -0.011 | -0.016 |
| Asset index | 3.309 | 3.183 | 3.281 | 0.058 | -0.044 | 0.013 |
| Obtain money: Personal savings | 0.447 | 0.430 | 0.420 | 0.023 | 0.015 | 0.038 |
| Obtain money: Village/community savings | 0.344 | 0.411 | 0.325 | -0.098** | 0.126*** | 0.028 |
| Obtain money: Loan from bank | 0.139 | 0.132 | 0.144 | 0.016 | -0.026 | -0.010 |
| Obtain money: Loans or gift from friends/family | 0.175 | 0.191 | 0.204 | -0.028 | -0.024 | -0.051 |
| Obtain money: Sell cattle | 0.320 | 0.322 | 0.357 | -0.003 | -0.052 | -0.055 |
| Obtain money: Sell trees or charcoal | 0.204 | 0.220 | 0.178 | -0.027 | 0.075* | 0.048 |
| Access to mobile money | 0.069 | 0.049 | 0.072 | 0.059 | -0.068 | -0.009 |
| Risk | 2.232 | 2.295 | 2.295 | -0.029 | 0.000 | -0.029 |
| Patience | 6.528 | 6.723 | 5.377 | -0.013 | 0.095** | 0.082* |
| Mailo land tenure | 0.154 | 0.149 | 0.118 | 0.009 | 0.064 | 0.073* |
| Customary land tenure | 0.242 | 0.291 | 0.256 | -0.078* | 0.055 | -0.023 |
| Private land tenure | 0.483 | 0.464 | 0.539 | 0.027 | -0.107** | -0.079* |

* p< 0.10, ** p<0.05, *** p < 0.01. *Asset index* counts the total number of the following assets that the participant has in their home: radio, electricity, television, solar panel, electric stove, gas stove, internet access, mobile phone, bicycle, car/truck, and motorcycle.

Table 2: Baseline Results

| DV: Share trees cut each round | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Insecure | 0.055*** | 0.055*** | 0.056*** | 0.053*** | 0.059*** |
| | (0.005) | (0.005) | (0.005) | (0.005) | (0.005) |
| Certificate | 0.027*** | 0.027*** | 0.026*** | 0.025*** | 0.025*** |
| | (0.005) | (0.005) | (0.005) | (0.005) | (0.005) |
| Unbalanced controls: | N | Y | Y | Y | Y |
| Additional controls: | N | N | Y | Y | Y |
| Enumerator FE: | N | N | N | Y | N |
| Village FE: | N | N | N | N | Y |
| Observations | 12558 | 12558 | 12558 | 12558 | 12558 |
| Mean Secure Group | 0.230 | 0.230 | 0.230 | 0.230 | 0.230 |
| SD Secure Group | 0.220 | 0.220 | 0.220 | 0.220 | 0.220 |
| P-value Insecure=Certificate | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

* $p < 0.10$, ** $p<0.05$, *** $p < 0.01$. OLS estimates. Unit of observation is a person-round. All estimates control for round fixed effects. Unbalanced controls include: age, household size, whether the respondent could obtain money from village/community savings if in need, whether the respondent could obtain money from selling trees or charcoal if in need, whether land owned is used for people to live on, patience, mailo land tenure, private land tenure. Additional controls include: asset index, sex, education, risk tolerance, land area, and whether or not respondent/household sells trees for or produces charcoal. Robust standard errors in parentheses. Missing observations for control variables replaced with the median value. All estimates control for missing observations.

Table 3: Heterogeneity by Village-Level Mailo Land Tenure

| DV: Share trees cut each round | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Insecure | 0.058*** | 0.056*** | 0.057*** | 0.053*** | 0.057*** |
| | (0.006) | (0.006) | (0.006) | (0.006) | (0.006) |
| Insecure X % Mailo Village | -0.005 | -0.010 | -0.009 | 0.007 | -0.006 |
| | (0.021) | (0.021) | (0.021) | (0.021) | (0.021) |
| Certificate | 0.035*** | 0.034*** | 0.031*** | 0.030*** | 0.031*** |
| | (0.005) | (0.005) | (0.005) | (0.005) | (0.005) |
| Certificate X % Mailo Village | -0.047** | -0.048** | -0.040** | -0.039** | -0.043** |
| | (0.019) | (0.019) | (0.019) | (0.019) | (0.019) |
| % Mailo Village | -0.078*** | -0.077*** | -0.069*** | -0.061*** | 0.047** |
| | (0.014) | (0.014) | (0.014) | (0.014) | (0.019) |
| Unbalanced controls: | N | Y | Y | Y | Y |
| Additional controls: | N | N | Y | Y | Y |
| Enumerator FE: | N | N | N | Y | N |
| District FE: | N | N | N | N | Y |
| Observations | 12558 | 12558 | 12558 | 12558 | 12558 |
| Mean Secure Group | 0.230 | 0.230 | 0.230 | 0.230 | 0.230 |
| SD Secure Group | 0.220 | 0.220 | 0.220 | 0.220 | 0.220 |

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. OLS estimates. Unit of observation is a person-round. All estimates control for round fixed effects. Unbalanced controls include: age, household size, whether the respondent could obtain money from village/community savings if in need, whether the respondent could obtain money from selling trees or charcoal if in need, whether land owned is used for people to live on, and patience. Additional controls include: asset index, sex, education, risk tolerance, land area, and whether or not respondent/household sells trees for or produces charcoal. Robust standard errors in parentheses. Missing observations for control variables replaced with the median value. All estimates control for missing observations.

# Online Appendix

# A Additional Figures and Tables

Table A1: Summary Statistics

| | N | Mean | SD | Min | Max |
|---|---|---|---|---|---|
| Age (years) | 1632 | 46.52 | 12.39 | 18 | 83 |
| Female | 1632 | 0.17 | 0.37 | 0 | 1 |
| Household size | 1632 | 7.10 | 3.50 | 1 | 30 |
| # People below age 14 in home | 1632 | 2.52 | 1.88 | 0 | 15 |
| Some/completed primary school | 1630 | 0.56 | 0.50 | 0 | 1 |
| Some/completed secondary school | 1630 | 0.24 | 0.43 | 0 | 1 |
| Years lived in community | 1632 | 35.02 | 15.63 | 1 | 83 |
| Earns income from land | 1632 | 0.99 | 0.10 | 0 | 1 |
| Total area of all land (acres) | 1567 | 19.18 | 90.01 | 0.00500 | 1000 |
| Total area of farm/grazing land (acres) | 1627 | 12.51 | 33.95 | 0.100 | 650 |
| Years of access to land | 1632 | 21.38 | 13.65 | 0.100 | 76 |
| Trees cover more than half of land | 1627 | 0.63 | 0.48 | 0 | 1 |
| Cuts trees for charcoal | 1631 | 0.26 | 0.44 | 0 | 1 |
| Land used for: farming | 1630 | 0.72 | 0.45 | 0 | 1 |
| Land used for: grazing | 1630 | 0.63 | 0.48 | 0 | 1 |
| Land used for: people to live on | 1630 | 0.29 | 0.45 | 0 | 1 |
| Number of cows raised last year | 1631 | 4.40 | 11.65 | 0 | 160 |
| Asset index | 1632 | 3.26 | 1.56 | 0 | 11 |
| Obtain money: Personal savings | 1631 | 0.43 | 0.50 | 0 | 1 |
| Obtain money: Village/community savings | 1631 | 0.36 | 0.48 | 0 | 1 |
| Obtain money: Loan from bank | 1631 | 0.14 | 0.35 | 0 | 1 |
| Obtain money: Loans or gift from friends/family | 1631 | 0.19 | 0.39 | 0 | 1 |
| Obtain money: Sell cattle | 1631 | 0.33 | 0.47 | 0 | 1 |
| Obtain money: Sell trees or charcoal | 1631 | 0.20 | 0.40 | 0 | 1 |
| Access to mobile money | 1632 | 0.06 | 0.24 | 0 | 1 |
| Risk | 1630 | 2.27 | 1.54 | 0 | 4 |
| Patience | 1630 | 6.19 | 10.14 | 1 | 32 |
| Mailo land tenure | 1628 | 0.14 | 0.35 | 0 | 1 |
| Customary land tenure | 1628 | 0.26 | 0.44 | 0 | 1 |
| Private land tenure | 1628 | 0.50 | 0.50 | 0 | 1 |
| Insecure treatment group | 1632 | 0.34 | 0.47 | 0 | 1 |
| Certificate treatment group | 1632 | 0.31 | 0.46 | 0 | 1 |
| Secure treatment group | 1632 | 0.35 | 0.48 | 0 | 1 |

*Asset index* counts the total number of the following assets that the participant has in their home: radio, electricity, television, solar panel, electric stove, gas stove, internet access, mobile phone, bicycle, car/truck, and motorcycle.

Table A2: Baseline Results with HAC Standard Errors

| DV: Share trees cut each round | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Insecure | 0.055*** | 0.055*** | 0.056*** | 0.053*** | 0.059*** |
| | (0.008) | (0.008) | (0.008) | (0.007) | (0.008) |
| Certificate | 0.027*** | 0.027*** | 0.026*** | 0.025*** | 0.025*** |
| | (0.007) | (0.007) | (0.007) | (0.007) | (0.007) |
| Unbalanced controls: | N | Y | Y | Y | Y |
| Additional controls: | N | N | Y | Y | Y |
| Enumerator FE: | N | N | N | Y | N |
| Village FE: | N | N | N | N | Y |
| Observations | 12558 | 12558 | 12558 | 12558 | 12558 |
| Mean Secure Group | 0.230 | 0.230 | 0.230 | 0.230 | 0.230 |
| SD Secure Group | 0.220 | 0.220 | 0.220 | 0.220 | 0.220 |
| P-value Insecure=Certificate | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

* $p< 0.10$, ** $p<0.05$, *** $p < 0.01$. OLS estimates. Unit of observation is a person-round. All estimates control for round fixed effects. Unbalanced controls include: age, household size, whether the respondent could obtain money from village/community savings if in need, whether the respondent could obtain money from selling trees or charcoal if in need, whether land owned is used for people to live on, patience, mailo land tenure, private land tenure. Additional controls include: asset index, sex, education, risk tolerance, land area, and whether or not respondent/household sells trees for or produces charcoal. Heteroskedasticity-autocorrelation consistent (HAC) standard errors in parentheses, estimated using the *newey* command in Stata with 7 lags. Missing observations for control variables replaced with the median value. All estimates control for missing observations.

Table A3: Baseline Results - with missing observations dropped

| DV: Share trees cut each round | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Insecure | 0.055*** | 0.055*** | 0.052*** | 0.050*** | 0.055*** |
| | (0.005) | (0.005) | (0.005) | (0.005) | (0.005) |
| Certificate | 0.028*** | 0.027*** | 0.024*** | 0.023*** | 0.023*** |
| | (0.005) | (0.005) | (0.005) | (0.005) | (0.005) |
| Unbalanced controls: | N | Y | Y | Y | Y |
| Additional controls: | N | N | Y | Y | Y |
| Enumerator FE: | N | N | N | Y | N |
| Village FE: | N | N | N | N | Y |
| Observations | 12558 | 12482 | 11964 | 11964 | 11964 |
| Mean Secure Group | 0.230 | 0.230 | 0.230 | 0.230 | 0.230 |
| SD Secure Group | 0.220 | 0.220 | 0.220 | 0.220 | 0.220 |
| P-value Insecure=Certificate | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

* $p < 0.10$, ** $p<0.05$, *** $p < 0.01$. OLS estimates. Unit of observation is a person-round. All estimates control for round fixed effects. Unbalanced controls include: age, household size, whether the respondent could obtain money from village/community savings if in need, whether the respondent could obtain money from selling trees or charcoal if in need, whether land owned is used for people to live on, patience, mailo land tenure, private land tenure. Additional controls include: asset index, sex, education, risk tolerance, land area, and whether or not respondent/household sells trees for or produces charcoal. Robust standard errors in parentheses.

Table A4: Normalized Differences: Cut all trees v. Did not cut all trees

| | (1)<br>Cut all trees | (2)<br>Did not cut all trees | (3)<br>Normalized difference |
|---|---|---|---|
| Age (years) | 45.391 | 47.076 | -0.096 |
| Female | 0.177 | 0.164 | 0.024 |
| Household size | 7.070 | 7.117 | -0.010 |
| # People below age 14 in home | 2.491 | 2.530 | -0.015 |
| Some/completed primary school | 0.614 | 0.539 | 0.107 |
| Some/completed secondary school | 0.229 | 0.246 | -0.028 |
| Years lived in community | 34.611 | 35.218 | -0.027 |
| Earns income from land | 0.985 | 0.992 | -0.043 |
| Total area of all land (acres) | 20.776 | 18.375 | 0.018 |
| Total area of farm/grazing land (acres) | 13.372 | 12.079 | 0.026 |
| Years of access to land | 21.304 | 21.421 | -0.006 |
| Trees cover more than half of land | 0.594 | 0.645 | -0.074 |
| Cuts trees for charcoal | 0.277 | 0.247 | 0.048 |
| Land used for: farming | 0.760 | 0.707 | 0.085 |
| Land used for: grazing | 0.642 | 0.626 | 0.024 |
| Land used for: people to live on | 0.317 | 0.278 | 0.060 |
| Number of cows raised last year | 4.701 | 4.253 | 0.026 |
| Asset index | 2.974 | 3.402 | -0.195 |
| Obtain money: Personal savings | 0.410 | 0.444 | -0.049 |
| Obtain money: Village/community savings | 0.378 | 0.348 | 0.044 |
| Obtain money: Loan from bank | 0.116 | 0.150 | -0.070 |
| Obtain money: Loans or gift from friends/family | 0.216 | 0.177 | 0.069 |
| Obtain money: Sell cattle | 0.363 | 0.319 | 0.067 |
| Obtain money: Sell trees or charcoal | 0.234 | 0.183 | 0.090 |
| Access to mobile money | 0.074 | 0.059 | 0.043 |
| Risk | 2.369 | 2.226 | 0.066 |
| Patience | 5.792 | 6.383 | -0.042 |
| Mailo land tenure | 0.090 | 0.165 | -0.159 |
| Customary land tenure | 0.325 | 0.231 | 0.148 |
| Private land tenure | 0.482 | 0.504 | -0.031 |
| Insecure treatment group | 0.253 | 0.382 | -0.198 |
| Secure treatment group | 0.375 | 0.337 | 0.056 |
| Certificate treatment group | 0.373 | 0.282 | 0.138 |
| Observations | 542 | 1090 | 1632 |

Table A5: Baseline Results Dropping Participants Who Cut Everything

| DV: Share trees cut each round | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Insecure | 0.057*** | 0.056*** | 0.057*** | 0.053*** | 0.059*** |
| | (0.004) | (0.004) | (0.004) | (0.004) | (0.004) |
| Certificate | 0.016*** | 0.016*** | 0.016*** | 0.018*** | 0.017*** |
| | (0.003) | (0.003) | (0.003) | (0.004) | (0.004) |
| Unbalanced controls: | N | Y | Y | Y | Y |
| Additional controls: | N | N | Y | Y | Y |
| Enumerator FE: | N | N | N | Y | N |
| Village FE: | N | N | N | N | Y |
| Observations | 8795 | 8795 | 8795 | 8795 | 8795 |
| Mean Secure Group | 0.230 | 0.230 | 0.230 | 0.230 | 0.230 |
| SD Secure Group | 0.220 | 0.220 | 0.220 | 0.220 | 0.220 |
| P-value Insecure=Certificate | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |

* $p < 0.10$, ** $p<0.05$, *** $p < 0.01$. OLS estimates. Unit of observation is a person-round. All estimates control for round fixed effects. Unbalanced controls include: age, household size, whether the respondent could obtain money from village/community savings if in need, whether the respondent could obtain money from selling trees or charcoal if in need, whether land owned is used for people to live on, patience, mailo land tenure, private land tenure. Additional controls include: asset index, sex, education, risk tolerance, land area, and whether or not respondent/household sells trees for or produces charcoal. Robust standard errors in parentheses. Missing observations for control variables replaced with the median value. All estimates control for missing observations.

Table A6: Heterogeneity by Village-Level Mailo Land Tenure with HAC Standard Errors

| DV: Share trees cut each round | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Insecure | 0.058*** | 0.056*** | 0.057*** | 0.053*** | 0.057*** |
| | (0.009) | (0.009) | (0.009) | (0.009) | (0.009) |
| Insecure X % Mailo Village | -0.005 | -0.010 | -0.009 | 0.007 | -0.006 |
| | (0.031) | (0.031) | (0.031) | (0.029) | (0.030) |
| Certificate | 0.035*** | 0.034*** | 0.031*** | 0.030*** | 0.031*** |
| | (0.009) | (0.009) | (0.009) | (0.008) | (0.009) |
| Certificate X % Mailo Village | -0.047* | -0.047* | -0.040 | -0.039 | -0.043 |
| | (0.028) | (0.028) | (0.028) | (0.026) | (0.028) |
| % Mailo Village | -0.078*** | -0.076*** | -0.069*** | -0.061*** | 0.047* |
| | (0.020) | (0.020) | (0.020) | (0.020) | (0.027) |
| Unbalanced controls: | N | Y | Y | Y | Y |
| Additional controls: | N | N | Y | Y | Y |
| Enumerator FE: | N | N | N | Y | N |
| District FE: | N | N | N | N | Y |
| Observations | 12558 | 12558 | 12558 | 12558 | 12558 |
| Mean Secure Group | 0.230 | 0.230 | 0.230 | 0.230 | 0.230 |
| SD Secure Group | 0.220 | 0.220 | 0.220 | 0.220 | 0.220 |

* p< 0.10, ** p<0.05, *** p < 0.01. OLS estimates. Unit of observation is a person-round. All estimates control for round fixed effects. Unbalanced controls include: age, household size, whether the respondent could obtain money from village/community savings if in need, whether the respondent could obtain money from selling trees or charcoal if in need, whether land owned is used for people to live on, and patience. Additional controls include: asset index, sex, education, risk tolerance, land area, and whether or not respondent/household sells trees for or produces charcoal. Heteroskedasticity-autocorrelation consistent (HAC) standard errors in parentheses, estimated using the *newey* command in Stata with 7 lags. Missing observations for control variables replaced with the median value. All estimates control for missing observations.

Table A7: Heterogeneity by Village-Level Mailo Land Tenure - with missing observations dropped

| DV: Share trees cut each round | (1) | (2) | (3) | (4) | (5) |
|---|---|---|---|---|---|
| Insecure | 0.057*** | 0.056*** | 0.053*** | 0.049*** | 0.053*** |
| | (0.006) | (0.006) | (0.006) | (0.006) | (0.006) |
| Insecure X % Mailo Village | -0.006 | -0.009 | -0.008 | 0.007 | -0.006 |
| | (0.021) | (0.021) | (0.022) | (0.021) | (0.022) |
| Certificate | 0.035*** | 0.034*** | 0.031*** | 0.030*** | 0.031*** |
| | (0.005) | (0.005) | (0.006) | (0.005) | (0.006) |
| Certificate X % Mailo Village | -0.046** | -0.046** | -0.045** | -0.045** | -0.048** |
| | (0.019) | (0.019) | (0.020) | (0.019) | (0.020) |
| % Mailo Village | -0.077*** | -0.077*** | -0.070*** | -0.061*** | 0.052*** |
| | (0.013) | (0.014) | (0.014) | (0.015) | (0.020) |
| Unbalanced controls: | N | Y | Y | Y | Y |
| Additional controls: | N | N | Y | Y | Y |
| Enumerator FE: | N | N | N | Y | N |
| District FE: | N | N | N | N | Y |
| Observations | 12558 | 12522 | 12004 | 12004 | 12004 |
| Mean Secure Group | 0.230 | 0.230 | 0.230 | 0.230 | 0.230 |
| SD Secure Group | 0.220 | 0.220 | 0.220 | 0.220 | 0.220 |

* $p< 0.10$, ** $p<0.05$, *** $p < 0.01$. OLS estimates. Unit of observation is a person-round. All estimates control for round fixed effects. Unbalanced controls include: age, household size, whether the respondent could obtain money from village/community savings if in need, whether the respondent could obtain money from selling trees or charcoal if in need, whether land owned is used for people to live on, and patience. Additional controls include: asset index, sex, education, risk tolerance, land area, and whether or not respondent/household sells trees for or produces charcoal. Robust standard errors in parentheses.

# B Experimental Instructions

Now we are going to play a game that asks you to make decisions about harvesting trees. I would like for you to imagine that you are responsible for managing a plot of trees, just as you do in real life. These 12 trees represent your forest.

[ENUMERATOR: *Give the participant their 12 trees; lay them out on the ground or table*]

You are responsible for managing this forest. You can decide to cut down some of the trees, and for each of the trees that you cut, you will earn real money, just as you do in real life.

We will play this game over several rounds. You can think of each round as a year or harvesting season. At the beginning of each round, you must decide how many trees to harvest. For each tree that you harvest, you will earn real money, which I will pay you in total at the end of this interview. This table represents how much you will earn for each tree you harvest.

[ENUMERATOR: *Give the participant the payout table and walk them through the payoffs*]

The profit that you earn from cutting down these trees is similar to the value of charcoal or timber that you would earn from cutting down real trees. For example, if you decide to cut down 2 trees, you will earn 1600/=. If you decide to cut down 5 trees, you will earn 2500/=. The profit you earn from cutting down these trees depends on what you can sell them for and what it costs you to cut them down (for example, paying others to help you, transporting them, or drying, burning, and packaging them). You can see from the table that the more trees you cut down, the more you will earn, but only up to a certain point. After the 5th tree, your profit starts to decline again because the costs of cutting down the trees is increasing faster than the amount you can sell them for.

In each round, you will decide how many trees to cut down. I will then remove these trees from the forest and calculate your earnings in that round. We will then see how many trees remain in the forest. At the end of each round, the forest can regrow. For every 5 trees remaining, 1 tree will grow. So, for example, if you leave all 12 trees in the forest, there will be 14 trees in the forest in the next round. Or if you leave 7 trees in the forest, there will be 8 trees in the next round. If you leave 4 trees in the forest, there will be 4 trees in the next round. We will play the game until the rounds are finished or until there are no more trees left in the forest to harvest, whichever comes first.

Let's do some practice rounds to make sure you understand your choices.

[ENUMERATOR: *Go through 3 practice rounds and answer any questions*]

Okay, now we are going to play the game for real.

[ENUMERATOR: *Read the corresponding instructions for the treatment group to which the participant has been randomly assigned*]

**TREATMENT GROUP 1**

Before we proceed, let me clarify your rights to this land. Your access to this forest is not secure. There is a landlord who owns this land. The landlord has granted you the right to use this land, but in each round, there is a chance that you could be kicked off the land. If this happens, you no longer have the right to access this forest and the game is over. In each round, your chance of being kicked off the land is 2 in 10, or 20 percent. To help you understand these chances, consider this bag of marbles.

[ENUMERATOR: *demonstrate with the bag of marbles*]

As you can see, here I have 10 marbles. 8 are blue and 2 are red. The red marbles represent the chance that you are kicked off the land in each round. We will begin the game with Round 1, as we have been doing so far. At the beginning of Round 2, and for each round that follows, I will ask you to draw a marble from this bag. If it is blue, you can stay on the land and continue making your harvest decisions for that round. If it is red, you have been kicked off the land and the game is over. You will keep any money that you have earned up until you are kicked off the land.

Do you have any questions?

**TREATMENT GROUP 2**

Before we proceed, let me clarify your rights to this land. Your access to this forest is not secure. There is a landlord who owns this land. The landlord has granted you the right to use this land, but in each round, there is a chance that you could be kicked off the land. If this happens, you no longer have the right to access this forest and the game is over. In each round, your chance of being kicked off the land is 2 in 10, or 20 percent. To help you understand these chances, consider this bag of marbles.

[ENUMERATOR: *demonstrate with the bag of marbles*]

As you can see, here I have 10 marbles. 8 are blue and 2 are red. The red marbles represent the chance that you are kicked off the land in each round. We will begin the game with Round 1, as we have been doing so far. At the beginning of Round 2, and for each round that follows, I will ask you to draw a marble from this bag. If it is blue, you can stay on the land and continue making your harvest decisions for that round. If it is red, you have been kicked off the land and the game is over. You will keep the money that you earned up until you were kicked off the land.

However, there is a way to ensure that you are never kicked off the land. You have the option to purchase a certificate of occupancy. You can buy the certificate of occupancy now, or you can wait. You will have the option to buy the certificate of occupancy at the beginning of each round, before you make any decisions about cutting trees and before we draw a marble to decide whether you've been kicked off the land. Once you have the certificate, your access is secure. If you draw a red marble in future rounds, and you have purchased the certificate of occupancy, you will NOT be kicked off the land; you can continue playing the game until we reach the end or there are no more trees left.

The certificate costs 1200/=. If you decide to buy the certificate, I will deduct this amount from your earnings. You have the option to buy the certificate starting at the beginning of round 2. If you choose to purchase the certificate in round 2, I will deduct the 1200/= from your earnings in round 1. If you buy the certificate in later rounds, I will deduct the 1200/= from your total accumulated earnings up to that point.

[ENUMERATOR: *Do a couple of practice rounds to demonstrate how to purchase the certificate and how this affects total earnings*]

Do you have any questions?

[ENUMERATOR: *Proceed with the game. Before starting round 2, ask if they would like to purchase a certificate. If not, then, at the beginning of each round, ask them again if they'd like to purchase a certificate before drawing a marble from the bag. If they do not have enough money to purchase the certificate, they cannot purchase the certificate until they've harvested enough earnings to pay for it.*]

**TREATMENT GROUP 3**

Proceed with the game.

| # | Trees | USh | You receive: |
|---|---|---|---|
| 1 | | 900/= | |
| 2 | | 1600/= | |
| 3 | | 2100/= | |
| 4 | | 2400/= | |
| 5 | | 2500/= | |
| 6 | | 2400/= | |
| 7 | | 2100/= | |
| 8 | | 1600/= | |
| 9 | | 900/= | |
| 10 | | 0/= | |

Figure B1: Payoffs Table