Customary Tenure and Agricultural Investment in Uganda

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1 Introduction

Secure property rights are fundamental to investment and prosperity, as Demsetz (1967) explored in his seminal work. Land tenure in particular has been hypothesized to impact investment through several mechanisms, including two of interest in this paper. The first of these has been termed the assurance mechanism, which captures the farmer's belief that he or she will have continued tenure and thus the ability to realize the gains from investment. The second deals with the fact that a farmer may lack complete rights over their land, which may prevent certain uses (such as mining the land). In customary tenure systems in Sub-Saharan Africa, this incompleteness stems from multiple actors holding different rights over a given piece of land. For instance, although one household or individual may hold primary use rights, another, such as a lineage elder, may hold rights of transfer. In many cases, these rightsholders interact strategically, and therefore the distribution of rights influences the (perceived) security of tenure: anticipating another's actions can be another source of insecurity. We can incorporate this strategic interaction in a model of agricultural investment, and therefore make more detailed predictions about how farmers under different tenure regimes respond to a randomly allocated intervention that increases beliefs about input productivity in different land value environments.

A review of the literature on land rights and customary tenure highlights that these systems are fundamentally socially embedded. Economic models of tenure and agricultural investment have focused on tenure (in)security, typically by examining the probability of expropriation which reduces investment levels from their optimums. The models that are designed to fit customary tenure systems

in Sub-Saharan Africa capture that tenure security may be endogenous to certain types of socially-recognized investment behavior, which *a priori* could even lead to an overallocation to the specified investments; empirically the net effect seems to be negative. Empirical support for these models has been mixed, but this is often due to poor measures of tenure or small sample sizes (see Fenske et al. (2011) for a review of several conceptual models and empirical inquiries). Qualitative work has also documented how local elites have at times exploited their transfer rights. When outsiders struggle to identify land 'owners' in illegible local tenure systems, elites have been able to sell land used by other members of the community for their private benefit. Their incentives to do so are greater in contexts with rapidly increasing land values.

I propose a model which incorporates a liquidity constraint into a standard endogenous model of customary tenure and investment, where long-term investments are lower on (relatively insecure) customary land than freehold land. This model, in the context of traditional smallholder agriculture, implies that optimal investment is an (increasing) function of land values on freehold land. However, I explicitly consider how rising land values, driven by sales options to outsiders, may lead local elites to assert their historic right to sell land to outsiders. The farmer, anticipating this, may actually make fewer long-term investments on customary land as land values rise, in contrast to the freehold case. I also consider how a correction of biased beliefs about input productivity, induced by a randomly-allocated subsidy would change investment in this model, differentially depending on tenure status and the land value environment. This third exogenous dimension of investment will aid in econometric identification. This paper then not only brings qualitative insights to an economic framework, but also uses economic modeling to explore how farmers would strategically respond to changing incentives. This not only returns the focus to the welfare of smallholders, but also, by affecting a broader population, allows us to quantitatively document the effects of this elite capture (which historically has been difficult due to the rarity of observed cases).

I then lay out a triple-difference strategy for empirically testing this model, in the context of a randomized control trial providing time-limited subsidies for agricultural inputs in rural Uganda. As part of this impact evaluation, we conduct an extensive survey on land tenure, use, and agricultural investment at baseline and following one and two years of the subsidy. I exploit the fact that many Ugandan farmers operate several parcels under different tenure regimes by using a household fixed effects specification. This controls for unobserved heterogeneity in farming skill, household shadow prices of inputs, or other traits, which could be associated with both tenure status and investment

decisions. Furthermore, the detailed focus on agricultural investment in the survey will allow me to use continuous measures of investment, as the binary measures used in much of the literature restrict the identifying variation (Fenske et al., 2011). Finally, unlike many previous papers which have conceptually modeled the impacts of tenure *security* but then used tenure *type* as a (poor) proxy, I consider tenure type and the incentives it creates throughout my model, therefore linking more closely to my empirical tests.

The remainder of this prospectus consists of a review of both the quantitative and qualitative literature on customary tenure and agricultural investment in Sub-Saharan Africa, with a particular focus on Uganda, followed by a model which captures many of the insights explored. I then discuss the context and data I propose to use, as well as an empirical strategy with several hypotheses laid out. I conclude by highlighting remaining avenues for this work as well as briefly summarizing additional papers that may be included in my dissertation.

2 A Review of the Literature

2.1 "Rights over land are rights over people": Customary Tenure Arrangements in Sub-Saharan Africa

To begin, it is worth emphasizing the scale of customary tenure regimes in Sub-Saharan Africa: across the continent, only between 2 and 10 percent of the land is formally titled, with the remainder subject to customary tenure, state land (including forest reserves and national parks), or other informal arrangements (Cotula et al., 2007). Indeed, "[customary] tenure represents the *major* tenure regime on the continent" (Alden Wily, 2011).

2.1.1 Features of Customary Tenure

There is an enormous diversity in customary systems around the region, as a hallmark of the customary is its very localized, negotiated nature. However, we can make a few generalizations that tend to hold broadly, and have been pointed to by qualitative researchers as key to local understandings of the customary.

The first point to stress is that tenure is not an isolated sphere of life: "customary land tenure is as much a social system as a legal code" (Alden Wily, 2011), embodying local power relations,

authority, and access to knowledge and labor (Van Leeuwen, 2014). This embedding of land tenure in social relationships means that it is open to negotiation, which both enables adaptability to changing circumstances but can also marginalize those in weaker bargaining positions (Cotula et al., 2007).

One particular way in which this social nature of customary tenure works is by having "overlapping rights over the same resources held by different users" (Cotula et al., 2007). Ensminger, an anthropologist, specifies that "A common characteristic in almost all African customary systems is for use rights to be assigned at the household level, whereas transfer rights are assigned at a higher level such as the lineage, clan, or chiefdom" (Ensminger, 1997). This means that although individuals may be quite secure in their ability to use a particular plot of land in their lifetime, a reallocation within the community could occur to adapt to changing circumstances. Customary leaders also are able to allocate (often unused) land to migrants into an area, as well as adjudicate any conflicts that may occur between members of the community. Although the particular ways in which these rights are divided may vary considerably across the region, this 'disbundling' of property rights is common and adds a strategic dimension to any decisions about land.

In this paper, I do not explicitly consider pastoralist systems, which are found throughout the region but which entail a whole host of other property rights concerns (as modeled by Goodhue and McCarthy (2008)). It is interesting to note, though, that in a more complete evolutionary treatment of property rights, the ability to adapt to relative shocks that they consider could be a reason for allocating different rights to different people in a social structure.

It has been argued that "sufficient investment incentives tend to be provided by basic rights of use that, under normal circumstances, are guaranteed to many villagers (including migrants) by the local informal order": that is, this dispersion of rights is not a cause of instability or underinvestment in itself (Brasselle et al., 2002). However, the continual adaptation of customary institutions means that it is dynamic, and has seen considerable changes over time. Indeed, there is a strain in the literature which posits that land rights will evolve towards a concentration of the bundle of rights in one person, in response to increasing population pressures or the introduction of new crops and cropping systems (Boserup, 1965; Platteau, 1996). However, others have taken issue with this argument, pointing out that even market-based land transactions remain "embedded in complex systems of social relations" (Cotula et al., 2007).

2.1.2 Elites and Customary Tenure

It is worth focusing on the role of elites in customary tenure, both in a (somewhat idealized) 'traditional' world as well as in contemporary contexts. As discussed above, a common feature of customary systems is that elites, representing the family or lineage writ large, have served as trustees or administrators of land owned by the family group. Often, they hold transfer rights, in order to (re)allocate land within the community in response to shocks (such as inheritance), as well as prevent the alienation of a communal resource without the consent of the community.

However, beginning with colonial administrators, outsiders have attempted to fit Western notions of ownership based on freehold tenure onto customary tenure systems, and this institutional mismatch has created ambiguity about who the 'owners' of land are. This ambiguity has been at times exploited by local elites: "There is a fine line between chiefs as (often self-declared) owners of all land in customary laws, and chiefs as trustee administrators" (Alden Wily, 2011). This process is exacerbated by pressures on other features of the traditional social environment. "While customary authorities are still effective in regulating land access, the collegiate bodies that used to oversee their work are not; the result is a breakdown in accountability and a privatization of common lands" (Cotula et al., 2007). Elites are therefore able to respond as individuals rather than as guardians of the corporate group, and represent their rights as ownership to outsiders unfamiliar with the complexities of local tenure arrangements.

Mattingly (2016) documents a similar process in China: when lineage elites join village political institutions, although public goods provision increases, so does the likelihood of land expropriation. He argues that "social institutions serve as channels of bottom-up informal accountability *and* top-down political control', depending on the incentive structure: public goods provision has features of a repeated low-stakes game (inducing cooperation between elites and their communities), but land development is more like a one-shot game with higher stakes. This has important parallels with elites in Sub-Saharan Africa, as we shall see.

2.1.3 Customary Tenure and Rising Land Values

The qualitative literature on customary tenure has documented the tensions and conflicts that emerge as customary systems adapt to external pressures, such as rising land values. Most cases have considered land values to be rising due to *non-agricultural* uses, such as urban and peri-urban

expansion, or the potential for natural resource extraction. Some large scale land acquisitions have been for agricultural purposes, although generally at such a scale or using technologies such that local smallholders are unable to participate. Therefore, this should be thought of as an increase in the marketable value of the land rather than its value to smallholder agriculture.

In a report by IIED and FAO, the stress this puts on customary systems is discussed repeatedly: "As land values rise, farmers may be forced or tempted to sell their land. Where land is still under customary chiefs, these may be tempted to sell off lands for housing and other developments, regardless of the views of those actually farming this land" (Cotula et al., 2004, cited in Cotula et al. (2007)). In Ghana, this is manifest in the same parcel of land being sold multiple times by and to different people; "many of these multiple sales are by different people in a family lineage, each contending that they have the status to sell under the customary system" (Barry and Danso, 2014). More often, however, "land scarcity may lead to a redefinition of the land claims of different groups within the extended family... with weaker groups becoming more vulnerable to losing their land access" (Cotula et al., 2007). Despite abundant stories of how "local elites have been able to use their position and the ambiguities of customary law to appropriate land to further their own economic and political interests" (**?**), especially in peri-urban areas but also in many rural ones (Ubink and Quan, 2008), this particular facet of how customary tenure adapts to external pressures has been little studied by economists. Economics, with its ability to explore the strategic interactions between individuals, can, I believe, contribute to our understanding of this important issue. In particular, economics can model how land users anticipate the changing incentives of local elites, changing their own investment incentives.

2.2 Models of Land Tenure and Investment

It is worth briefly considering other theoretical treatments of land tenure and investment, in order to situate the current model. Broadly, land tenure has been thought to encourage investment through three possible mechanisms, going back as far as Feder's discussion (1988, cited in Place (2009)). These have been termed the assurance, collateralizability, and realizability mechanisms: stronger land rights should provide assurance that the farmer will be able to reap any gains from investment, increase access to capital by serving as collateral, and allow the farmer to sell the land and realize gains from investment sooner (as well as transferring land to those most able or likely to invest) (Besley 1995, cited in Fenske et al. (2011)).

Each of these mechanisms is the subject of an extensive theoretical and empirical literature, and their relevance to customary tenure in Africa has been debated. Credit markets have been shown to be thin, farmers may be credit rationed for other reasons, and land markets are often missing or face other restrictions. This discussion, however, will focus on the first of these, which does not rely on complementary markets to work. Despite the intuitive appeal of stronger tenure inducing higher investment, however, the complexities of land rights in Sub-Saharan Africa mean that defining 'stronger land rights' poses difficulty, and the precise way they are defined and measured empirically can have important implications.

The simplest models attempt to capture tenure as an exogenous probability of losing the land, along with any fixed investments, before the profits of those investments can be fully realized. These models often focus their attention on other features of the investment context, and so make this simplification (Jacoby and Minten, 2006). For instance, Dillon and Voena (2018) focus on intra-household bargaining resulting from tenure insecurity for widows, and so model whether a widow can inherit the marital property as a village-level (exogenous) determination.

However, much qualitative evidence on customary tenure regimes in Sub-Saharan Africa have stressed the endogeneity of tenure security (discussed in more detail below), which has then been incorporated into the quantitative models. That is, actions taken by the farmer, particularly certain investments in the land, demonstrate responsible use of the land and defend against expropriation by others in the community, who recognize these investments as land stewardship. The following is far from comprehensive, but serves to illustrate the variety of ways in which investments have been considered to influence tenure security. Robinson focuses on the state's role in guaranteeing tenure security (Robinson, 2005), while Deininger and Jin emphasize the visibility of an investment to others in the community as key to its efficacy in securing tenure rights, for tenure security is fundamentally about social recognition of rights (Deininger and Jin, 2006). Place and Otsuka (2002) explore this concretely by contrasting three possible investments: planting trees, which is visible and thus reduces the probability of losing the land, management effort, which is invisible and thus has no effect on tenure security, and fallowing, which in a tenure system predicated on land *use*, may actually increase the risk of expropriation.

Goldstein and Udry (2008) focus on this latter effect in their work on tenure security in Ghana, where fallowing is the primary investment in land productivity. However, they add an important dimension: an individual's social status may interact with these incentives: "farmers who lack

political power are not confident of maintaining their land rights over a long fallow. As a consequence, they fallow their land for much shorter durations than would be technically optimal, at the cost of a large proportion of their potential farm output." Crucially, this effect is primarily driven by land obtained through customary tenure (within a household), and social elites do not face the same disincentives (for they would be the ones to transfer lands if unused), so empirically they fallow land similarly regardless of how it was accessed.

There are several models that attempt to capture the relationship between tenure security and investment, given this endogeneity. Fenske et al. (2011) presents one, which has many common features. This two-period model has investment in the first period, and variable inputs used in the second if the land is retained. He argues that variable inputs and fixed investments are almost always complements, which implies that improving tenure should work in the same direction for both. Solving his model, then, he shows that

$$sign\{\frac{\partial I}{\partial T}\} = sign\{-\frac{2S_I\pi_I + S\pi_{II} - k_I}{S_T\pi_I}\}$$

which, if investment has no effect on security, is positive; if investment weakens security (as fallow could), is negative; and if investment increases security, is positive so long as $S_I < \frac{k_I - S\pi_{II}}{2\pi_I}$. This final condition is intriguing: if it is not true, the same factors that weaken tenure security strengthen the incentive to invest. For instance, a challenge to a farmer's rights could induce them to signal their ownership by planting trees.

2.3 Empirical Results

Despite the seeming clarity of the theoretical relationship between tenure security and investment, the discussion of Fenske's model foreshadows the empirically mixed evidence looking at customary tenure and investment (Place and Hazell, 1993; Fenske et al., 2011). Although there is some convincing evidence that tenure regimes do influence investment decisions, particularly from West Africa, many other papers have found no statistically significant results or at times results contrary to theory. Fenske reviews much of the literature in his 'quantitative review', but we will consider a few of them here.

Goldstein and Udry (2008), in a convincing paper in Ghana, find that even even controlling for household and spatial fixed effects (as well as plot characteristics), the tenure status of a given plot

is a significant predictor of how long it is fallowed. The particular dimension of tenure they consider is whether land was allocated by the matrilineage (to a man from his maternal uncles, typically, or his larger maternal group) or purchased. This relationship does not hold as strongly for social elites who have less insecurity over their matrilineal land, particularly for those who inherited their office through the matrilineage (thus ruling out reverse causality, where more secure rightsholders would be able to secure social status). The authors argue that this tenure pathway explains much of the gender productivity gap in agriculture in the context in question, as women are more likely to control plots accessed through the matrilineage. Fenske et al. (2011), however, notes that a household fixed effects specification may select those households with the greatest differences in tenure security (and thus those households most likely to invest differently across plots): only those households who feel insecure about their land allocated through customary mechanisms will purchase other plots.

Despite the strong evidence from Ghana, other papers have found little or no relationship between tenure insecurity and investment. In Madagascar, for instance, Bellemare (2013) finds that after controlling for household fixed effects and soil quality, titling has almost no effect on agricultural productivity. However, an individual's subjective beliefs about their rights do seem to have important (although at times counter-intuitive) implications for productivity. Fenske et al. (2011), in reviewing the dispiriting body of evidence, suggests that perhaps investment is high across all plots because despite insecurity, returns in agriculture may be so much higher than other options. He also conducts a 'quantitative review' of other papers, using nine data sets from West Africa and analyzing them similarly. He argues that small sample sizes have driven some of the lack of empirical results, as larger samples are more likely to find results. He also takes issue with the use of binary investment measures, which have often been used to deal with the common zeroes in investment.

Yet another potential issue in the empirical literature lies in precisely defining tenure security, which could comprise elements of duration of tenure, assurance, and completeness of rights (Bruce and Migot-Adholla, 1994). Although it is theoretically clear, "there is no agreed upon way to measure tenure security and results may be related to choice of proxy" (Place, 2009). Bellemare (2013)'s results in Madagascar highlight this: one measure of tenure security, the presence of a title, seems unimportant for investment, while beliefs about rights do matter. The questions about rights asked, however, are designed to elicit the bundles of rights an individual has over a given piece of land: whether they can sell it or lease it, for example. However, even without complete rights, tenure may be quite secure and persist for generations, and thus the empirical measures diverge from the

theoretical pathway laid out. Other papers have dealt with this more explicitly, such as Brasselle et al. (2002) who use questions on nine different rights in Burkina Faso to categorize households into five hierarchical groups based on the (overlapping) sets of rights they have. Other (generally older) papers have avoided the question entirely, by simply comparing regions with different prevalent tenure systems, although it is unclear if other factors could be at work (Place and Otsuka, 2002).

Instead of modeling tenure security as the fundamental parameter of interest, and then using land institutions as a (very imperfect) proxy for tenure security, I will follow Abdulai et al. (2011) in explicitly modeling particular institutional arrangements and the incentives they create for investment. This seems a more robust treatment: rather than *ex post* justifying results as a product of the 'context', accounting for the tenure context from the start.

2.4 Land Rights in Uganda

Given the enormous diversity of customary tenure arrangements throughout Sub-Saharan Africa, it is worth delving into the particular case of Uganda. Somewhere between 12-14% of land is subject to formal title, so customary tenure remains significant throughout the country (Alden Wily, 2011). And customary authorities still play a major role in Uganda: in lab-in-the-field experiments, references to traditional authorities such as the *kabaka* (the king of Buganda, one of the major regions in Uganda) induce higher contributions to public goods games, and this seems to operate through vertical signaling to the traditional authority rather than horizontal, to others in the community (Goist and Kern, 2018).

Even within Uganda, there is some diversity about the strength and allocation of bundles of rights. In the west, where population pressures on the land are higher, there is more individualized tenure, while the relatively land-abundant north retains stronger rights for customary authorities (Van Leeuwen, 2014). Throughout, however, qualitative work has documented that rights to the land in perpetuity are differentiated from responsibility for managing the land (Adoko and Akin, 2011). Qualitative work on land rights can become extremely detailed: Howard and Nabanoga (2007) document that rights are determined for individual people over individual plants on different types of land under different circumstances (for instance, that a woman who is pregnant or sick is allowed to pick certain medicinal plants from someone else's river plot, but not from a home garden).

Deininger and Castagnini (2004) examine land-related disputes in Uganda, which can illuminate how customary tenure functions and the margins at which it breaks down. They estimate that up to

5% of the population in rural areas is involved in a pending land-related conflict at any given time, and that most of these conflicts are between neighbors because boundaries have been exceeded. The prevalence of boundary disputes has led to many farmers planting trees to demarcate their land; "boundary trees are useful evidence when the land can be visited during a case by customary authorities, but they are less useful when the case is heard in a court of law far away from the land" (Adoko and Akin, 2011). However, there has been a push to incorporate customary leaders into statutory court systems, with mixed success (Van Leeuwen, 2014).

Much of the literature on land rights in Uganda has considered the *mailo* system, a remnant of British indirect colonial rule. In 1900, the British signed a treaty with the Kingdom of Buganda which allocated mile square tracts in the center of the country to Buganda elites for their 'ownership' as absentee landlords, which were then sub-leased to the actual inhabitants and land users (Deininger and Castagnini, 2004). Ever since, there has been a significant tension in government policy towards mailo owners and tenants, and how to balance their interests. The 1998 Land Act attempted to balance these by giving mailo owners the powers of a freehold owner, while still recognizing the rights of 'lawful occupants' of the land who had used it for more than 12 years (Coldham, 2000). This guaranteed occupants' tenure security (including inheritance rights and the ability to sub-let with consent of the owner), while requiring continuous possession of the land and a nominal rent payment.

This Land Act of 1998 did more than merely regulate mailo land, however. Proclamations of state ownership of all land under the dictatorship of Idi Amin in 1975 were largely unenforced and ignored by the population (Hunt, 2004). The Land Act of 1998 then regarded land as the property of the citizens of Uganda, and recognized four tenure types: freehold, leasehold, customary, and mailo (Joireman, 2007). The law provides for an extensive and decentralized land administration (Tripp, 2004), which could issue titles as well as 'certificates of customary ownership' which registered rights held by multiple people and could, in time, be converted into freehold titles (Coldham, 2000). This registration was voluntary, rather than compulsory (as in other countries in the region), which leads Coldham (2000) to point out "where the grant of certificates of title is based on individual applications, there is always a risk of land-grabbing, that is, that an applicant may lay claim to a larger area of land than that to which he is customarily entitled". Furthermore, the widely-lauded land reform has been largely unfunded and thus has been little-implemented (Deininger and Castagnini, 2004; Joireman, 2007).

Two previous economic analyses have looked at the impacts of tenure on agricultural investment in Uganda. Deininger and Castagnini (2004) focus on land conflicts, but argue that the intensive multi-cropping system prevalent in much of Uganda implies individual crop production functions are inappropriate (for productivity measures or investment). Deininger and Ali (2008) use household fixed effects to control for unobservables such as farming skill, and find that households invest in both long-term and short-term inputs significantly more on plots they own outright rather than have only customary rights to. Furthermore, they find that registering customary rights (by getting a certificate of customary ownership) has little impact on investment, but legal efforts to strengthen occupancy rights do increase investment (investment increases with length of occupancy, with a discontinuity at 12 years where rights are recognized by law). However, their analysis is based on the assumption that the tenure status of a given parcel is relatively exogenous for a household, which we have seen can be a strong assumption.

2.5 Models of Subsidies for Learning and Agricultural Investment

It is worth briefly considering how economists have modeled the intervention we will be dealing with, a temporary subsidy to encourage adoption of modern agricultural inputs. A similar program to the Agriculture Cluster Development Project (ACDP) (discussed in more detail later) in Mozambique induced persistent increases in fertilizer use from a one-time voucher, and the evaluation was able to identify treatment spillovers consistent with learning effects driving the adoption behavior (Carter et al., 2016). This learning is important in Uganda, where many modern inputs available on the open market are counterfeit or low-quality (Bold et al., 2016). Bold et al. (2016) model Bayesian learning about input quality, and show that noisy returns can lead to a low adoption equilibrium. They argue this model is able to describe the Ugandan situation, where only 7% of cultivating households use fertilizer and 22% use improved seeds.

Furthermore, a few papers have foreshadowed one relationship of interest in this paper: the interaction between land tenure and incentivized investment. For instance, Fenske et al. (2011), in his model of tenure security and investment, considers that adoption of an investment on the extensive margin is driven by the availability of information, the time horizon of the individual and their capacity to invest, while on the intensive margin it is decided based on marginal productivity. Brasselle et al. (2002), approaching the question from a different angle, state that "if a technological breakthrough were to occur necessitating more substantial investments and higher monetary expen-

ditures, freehold tenure would matter much more than under the current circumstances; or that, even today, dynamic farmers are discouraged from adopting more modern technologies because of the precarity of their land rights": that is, land tenure matters more in contexts that demand new investments. None of these papers to date have looked concretely at the particular nexus which I seek to model, however.

3 A model of tenure and investment

Consider a two-period model. In the first period, the farmer chooses to apply fertilizer, F_1 and trees, T, to his or her exogenously-given land L under tenure system h in order to produce according to $f(F,T)$. The farmer also has some wealth endowment, but can choose to borrow B_1 against the value of the land (depending on the tenure system), to be repaid at the end of the period. The farmer faces an exogenous interest rate, r, and has a discount rate of β for second period returns (the optimized expected second-period profit is given by π_2^*). There is some probability that the farmer's land will be expropriated before the second period, and fixed investments (trees) would be lost then as well. This probability is given by $(1-\phi(T,h,vL))$ and could be a function of tree investment, tenure systems, as well as the value of the land. For convenience, I will use the word 'expropriate' to capture both 'horizontal' expropriation where others in the community take over a farmer's use rights, as well as the exertion of sales rights by local elites without the permission of the land user. After working through the main features of the model, I will consider what different forms of this ϕ function could imply for the farmer's decisions.

The first period problem faced by the farmer is then to:

$$\max_{F_1,T,B_1} \; p_a f(F_1,T) - p_F F_1 - p_T T - rB_1 + \beta\phi(T,h,vL)\pi_2^*(F_1,T,B_1)$$

$$\text{subject to:} \quad \begin{aligned} p_F F_1 + p_T T &\leq w_1 + B_1 \\ B_1 &\leq s(vL,h) \end{aligned}$$

While in the second period, the farmer only chooses fertilizer (F_2):

$$\max_{F_2} \; p_a f(F_2, T) - p_F F_2$$

$$\text{subject to:} \quad \begin{aligned} p_F F_2 &\leq w_2 \\ w_2 &= w_1 + (1-r)B_1 + p_a f(F_1, T) - p_F F_1 - p_T T \end{aligned}$$

3.1 Land Values and Investment

To begin with, consider the case where the farmer is certain their land will not be expropriated before the second period (that is, the land is freeheld ($h = 1$), and $\phi(T, vL|h = 1) = 1 \; \forall \; T, vL$).

Figure 1 follows Carter and Olinto (2003) in depicting the constrained solution to the model. The width of the horizontal axis represents the available liquidity, $w + s(vL, h)$. γ and τ represent the total expected marginal productivity of each input, F and T (respectively). Fertilizer is modeled to only last for one period, while trees continue to produce in both periods, therefore:

$$\begin{aligned} \gamma &= p_a \frac{\partial f}{\partial F_1} - p_F \\ \tau &= p_a \frac{\partial f}{\partial T} - p_T + \beta \frac{\partial \phi}{\partial T} \pi_2^* + \beta \phi \frac{\partial \pi_2^*}{\partial T} \end{aligned}$$

However, as mentioned above, for the moment ϕ is constant with respect to trees, so $\frac{\partial \phi}{\partial T} = 0$.

As in Carter and Olinto (2003), the liquidity-constrained farmer will choose inputs F and T such that the expected rates of return are equal between the two, labeled A on the figure. These input levels will be necessarily lower than the unconstrained optimums (determined by where γ and τ each cross the dashed line, and summing to more than the available liquidity).

If, however, there is an exogenous increase in the value of the land, $v' > v$, then the available liquidity provided by that land will increase as well, illustrated by an expansion of the horizontal axis to $w + s(v'L, h)$. τ is measured from the right-hand axis, and so as the available liquidity space expands, this curve graphically shifts to the right, to τ'. The marginal productivity curves now cross at A', indicating higher investments in both fertilizer and trees. We can therefore see that increasing land values will allow for increased investment in both short and long-term inputs for liquidity-constrained farmers.

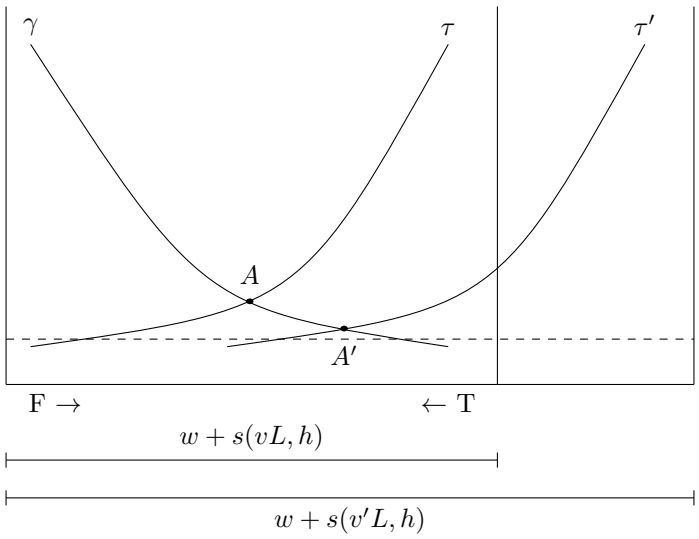

Figure 1: Land Values Increasing Investment

3.2 Customary Tenure and Investment

However, the threat of future expropriation of the land is real for many farmers, particularly on customary land. The model captures this risk in two ways, as illustrated in figure 2.

The simplest models of customary tenure and investment merely consider customary land to have a higher risk of alienation than freehold land: $\phi(T, vL|h = 0) < \phi(T, vL|h = 1)\ \forall\ T, v, L$, with $\frac{\partial \phi}{\partial T} = 0$. That is, for any level of investment in trees or land values, the risk of expropriation is higher on customary land, and this risk does not change in response to investment in the land. This lowers the expected total marginal productivity of investment in trees, as shown by a shift right (towards the origin for T) from τ to τ'', decreasing the investment in trees to the equilibrium shown at A''.

Drawing upon qualitative understandings of customary tenure, though, more subtle models have sought to capture the endogenous nature of tenure security on customary land. Place and Otsuka (2002), for instance, model the probability of losing land as a decreasing function of planting trees, a visible investment in the land. In my model, this implies that $\frac{\partial \phi}{\partial T} > 0$, which would attenuate the rightward shift of the τ curve (and could perhaps even lead to an 'overinvestment' in trees relative to the unconstrained optimum, if the tenure-enhancing effect is large, although empirically this is rarely documented). This combined effect leads to the marginal productivity of trees indicated by τ'''.

The equilibrium determined by the marginal productivity of trees under (less-secure) customary

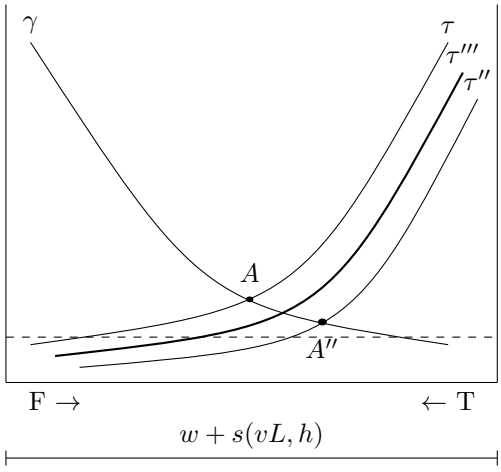

Figure 2: Customary Tenure Influences Long-Term Investment

tenure, then, sees underinvestment in trees relative to the allocation under freehold tenure.

3.3 ACDP and Learning about Returns to Fertilizer

We could also extend the model to consider the effects of the ACDP program on input use. One aim of the ACDP program is to subsidize learning about the true returns to inputs, particularly short-term inputs such as fertilizer. Therefore, we could imagine that the perceived beliefs about the marginal productivity of F are downward-biased, which graphically could be represented as a leftward shift in the γ curve. A correction towards the 'true' γ curve induced by the ACDP subsidy could be included and the model should predict increases in fertilizer use, although to varying extents depending on tenure status and land values. The increase in fertilizer use should be relatively similar between customary and freehold land in a low land values context, as the marginal returns to trees are similar in shape between the two tenure regimes. In a context of higher land values, however, the changing perception of elite expropriation of customary land should lead to more drastic differences between freehold and customary fertilizer use.

3.4 Expropriation Risk under Customary Tenure

Customary tenure is not simply insecure tenure. Earlier, we showed that an attention to the complexities of how customary tenure functions can have important implications: visible investment decisions such as planting trees can demonstrate responsible land use (a condition of tenure), thus endogenously strengthening tenure rights. It is worth devoting some attention to how this works:

by planting trees on a plot, a farmer demonstrates to the community that it is under use. If another member of the community tries to encroach on the plot, these visible investment decisions can be used as evidence of responsible land use, and thus make it more likely that disputes will be resolved in the farmer's favor.

The model so far, however, has ignored the particular bundles of rights and their distribution among individuals that is a hallmark of customary tenure systems. That is, many customary tenure systems in Sub-Saharan Africa, and those in Uganda in particular, do not vest all types of rights over a given piece of land in the same individual or household. Primary use rights may be held by one household, but other members of the lineage or extended family may have access rights or even claims to certain plants (Howard and Nabanoga, 2007). Importantly for this analysis, local elites (such as lineage heads or traditional chiefs) often hold transfer rights over large areas of customary land.

The long-term stability of customary tenure systems is evidence that these decentralized rights did not in themselves cause major tenure insecurity (Bruce and Migot-Adholla, 1994). This is perhaps due to mechanisms such as planting trees to demonstrate tenure against other claimants, with local elites serving as arbiters and rightsholders for all in a community.

However, there has been some concern in policy spheres recently about the potential for local elites to make deals with outsiders (often national or international investors) that alienate local rightsholders, in what have been termed 'Large-Scale Land Acquisitions' (Smalley and Corbera, 2012; Purdon, 2014). While the details of these deals are beyond the scope of this model, they represent but one example of local elites using their traditional rights to the land to their own advantage. Outside investors often find it difficult to navigate the complex realities of customary rights, and thus may not realize that they are expropriating land from existing users without their consent.

In the context of this model, it suffices to note that increasing land values may not only increase the value of the asset for the primary land user, but also for other rightsholders. This could increase the value of expropriation for these other individuals (namely, local elites with transfer rights). Local elites may not have found it profitable to exercise their traditional rights in a inactive land market, preferring instead to maintain the traditional status quo. However, as land values rise (whether due to offers from outside investors, population pressures from growing urban areas, or other exogenous forces that introduce outsiders less familiar with the customary contact as potential buyers) they

may be more likely to expropriate from the land user in order to alienate the land to others.

Within the model, then, this is why we write ϕ as a function of vL as well as h, the tenure system, and T, tree investment. In particular, $\phi(T, h, vL)$ could have the following properties:

$$\phi(T, h, vL) = \begin{cases} 1 & \text{if } h = 1, \\ g(T, vL) & \text{if } h = 0. \end{cases}$$

Where $\frac{\partial g}{\partial T} > 0$, as in Place and Otsuka (2002), and $\frac{\partial g}{\partial v} < 0$ given the intuition above.

The land user (farmer-decisionmaker) can anticipate these changing incentives for their co-rightsholders, as captured in $\frac{\partial \phi}{\partial v} < 0$. Rising land values may mean that no matter the level of their own investment in production, the risk of expropriation has increased. This could outweigh the liquidity constraint-relaxing effects of increasing land values, and perhaps even on net decrease longer-term investments in the land. This is illustrated by Figure 3. The shift from A to A' indicates the effect of increasing land values on investment on freehold land: although still bound by the liquidity constraint, investment in both fertilizer and trees has increased. However, for customary land, increasing the value of the land and relaxing the liquidity constraint does not simply shift the marginal productivity of trees rightward, but changes the shape due to the effect of $\frac{\partial \phi}{\partial v}$ discussed above. Graphically, the farmer has actually left the liquidity-constrained case, but investment in trees has decreased to $T_C^{*'}$.

4 Context and Data

To test this model empirically, I plan to use data collected in Uganda as part of the Agriculture Cluster Development Project impact evaluation. This is a six year project, supported by the Government of Uganda and the World Bank, which aims to provide farmers in five crop-specific 'clusters' (maize, rice, beans, cassava, and coffee) with the resources needed to transform from subsistence farmers to commercialized producers. To that end, the project will provide subsidized farm inputs to selected farmers, improve agricultural infrastructure and support post-harvest handling technologies.

The impact evaluation is being conducted as part of the pilot phase of the project, and focuses on the provision of electronic vouchers for subsidized inputs, redeemable at certified local agro-input

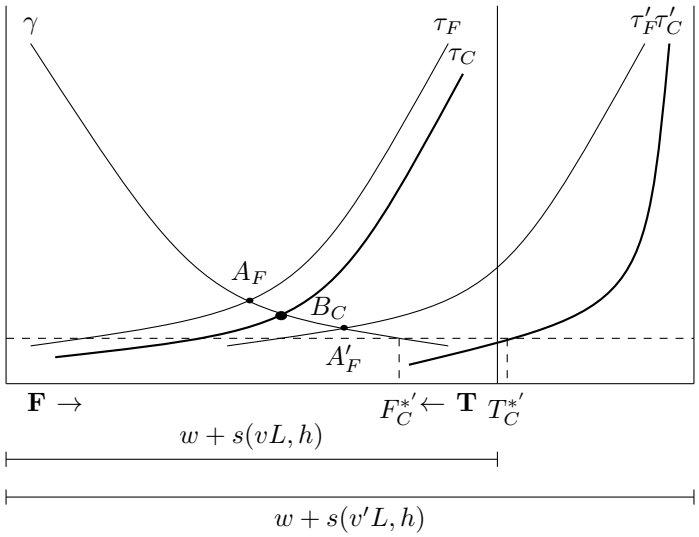

Figure 3: Land Values and Strategic Interactions

dealers. These subsidies are designed to diminish over the course of three seasons (each roughly 6 months), under the theory that farmers will be able to experiment with these modern investments and correct their (biased) beliefs about their returns. The impact evaluation is occurring in 4 districts throughout Uganda, each with one of 4 target crops (maize, rice, beans, and coffee; cassava was omitted as it has a longer growing season). The impact evaluation randomly assigned farmer organizations eligible for the ACDP subsidy to one of two treatment groups (the groups differ in the timing of benefits) or to a 'downstream' control group (36 farmer organizations per treatment arm), and then selected to survey on average 20 members from each of 108 farmer groups distributed throughout the 4 districts, for a total of 2,160 farmers interviewed (by endline, 1,440 will have received ACDP e-vouchers, and 770 will not yet have received direct benefits).

The districts selected for the impact evaluation are located throughout the country, and thus encompass some of the diversity of customary tenure arrangements in Uganda. Districts are located in the east, southwest, center (where *mailo* land predominates), and north (where instability has led to many internally displaced people).

As part of the impact evaluation, we are conducting an extensive baseline survey (to be followed at midline and endline in one and two years respectively), which has data well-suited to the structure of this model. Given that the program is designed to induce investment in agriculture, the survey has an exhaustive plot-level elicitation of all inputs and outputs with detailed continuous measures

of investment. As will be discussed below, investment measures have been an empirical weakness of many papers on land tenure. Furthermore, the survey asks detailed questions about the tenure status of each agricultural parcel farmed by the respondent household. These tenure questions ask about the tenure system the parcel is under; which individual members of the household are owners; what kind(s) of documentation exist for the parcel, if any, and whose names are on the documentation; who within or outside the household hold particular rights (such as transfer rights); and questions on perceived tenure security. Finally, the survey asks about land purchase and rental prices in the region, and I will also communicate with subcounty extension officers (who are intimately familiar with agricultural conditions in their region) about prevailing prices. External pressures on land prices should act primarily on purchase prices, as outsiders (who could purchase from opportunistic elites) generally want to take the land out of agriculture for other uses (such as residential in peri-urban environments, or extractive in the case of mining). Agricultural suitability and/or rising crop prices, which may relax the liquidity constraint without changing elite incentives, should influence both rental and purchase prices. Therefore, I am considering using purchase prices, controlling for rental prices, as my measure of external land values. There could be some concern that some regions have seen an increase in land prices, but then have stabilized at a higher level and thus the changing incentives for expropriation are no longer a concern. However, the sources of land price rises I am focusing on, such as urbanization, have only accelerated in Uganda in recent history. Therefore, although these processes may have been continuing for some time, rising land prices will only continue to incentivize elite assertion of sales rights.

5 Empirical Strategy

I will exploit the random ACDP treatment status (which in the model is an exogenous positive shock to the (expected) marginal returns to short-term inputs such as fertilizer) of households who hold multiple parcels under different tenure regimes, along with these households' locations in areas of high and low land prices (due to exogenous factors), in order to test the predictions outlined in the model. These go beyond existing models of land tenure and investment by considering how multiple rightsholders respond to rising land prices, and thus incentives may change differently on customary land. Furthermore, I will be able to make two improvements over the empirical strategies that have commonly been used in the literature.

First, rather than modeling tenure *security*, or the expected probability of expropriation before realizing the fruits of investment, as the sole parameter of interest but then only empirically measuring rough proxies such as tenure type, I explicitly model the relationship between tenure *type* and investment (operating through tenure security). Secondly, there has been some discussion as to whether binary measures of investment are appropriate for this question. The ACDP survey's detailed agricultural production module will allow me to construct continuous measures of investment, accounting for the wide prevalence of intercropping systems in Uganda.

Besides these two advancements, I will use methods generally accepted in the literature. In particular, I hope that our sample, like the LSMS in Uganda, will have a sufficient proportion of respondents who operate multiple parcels under different tenure regimes, so that I can use household fixed effects even in cross-sectional data from the baseline (Deininger and Ali, 2008). This controls for unobserved heterogeneity in household farming decisions, caused by factors such as household shadow prices or farming skill. There remain two concerns with this strategy. First, the tenure regime of particular parcels may not be exogenous (for example, households may be more likely to pursue titling higher-quality plots). Deininger and Ali (2008), however, argue that Uganda has what amounts to an "exogenous historical assignment of land rights... and the absence of readily available opportunities to change the tenure status of occupied land to full ownership imply that the case at hand can be considered akin to a natural experiment." The second concern is that households with the most insecure rights on their customary land would have the strongest incentives to purchase (secure) freehold land, and thus our identification comes from precisely those households who have the largest difference in tenure security between their two types of parcels. If, however, the majority of households in our sample have multiple parcels under different tenure systems, then it seems reasonable that the effects estimated would approach the population average.

5.1 Hypotheses

Before turning to the empirical specification I will actually run, consider a cross-sectional variant which closely follows the model discussed above. This will help illustrate the hypothesized comparative statics from the model illustrated in Figure 3, and which terms would capture them in regressions. However, concerns with the comparability of low and high land value areas mean that this model alone would be insufficient; I intend to additionally use the truly random assignment of the ACDP intervention as an identifying source of variation. The simplified regression would look

like:

$$I_{hi}^{Q} = \gamma_0 + \gamma_1^{Q} D_{hi} + \gamma_2^{Q} \bar{v} + \gamma_3^{Q} D_{hi} * \bar{v} + \gamma_4^{Q} W_h * D_{hi} + \beta' X_{hi} + \eta_h + \epsilon_{hi}$$

Where I_{hi}^{Q} is a continuous measure of investment of type Q (either short- or long-term) by household h on parcel i, where D_{hi} is a dummy for if the parcel is freehold, $\bar{v}$ is the average land price in the locality, W_h is a measure of household wealth, X_{hi} is a vector of household characteristics, and η_h controls for household fixed effects. This equation would be separately estimated for long and short-term inputs.

The particular hypotheses I would like to test, as predicted by the model, are derived in the mathematical appendix. However, to briefly summarize, I would like to investigate the signs of the following in cross-sectional data:

1. $\frac{\partial F}{\partial h}$: That is, how does fertilizer (or short-term input) use vary between tenure systems? The model would predict that *ceteris paribus*, a liquidity-constrained farmer would put more fertilizer on customary land than on freehold. This is tested by examining the sign of γ_1^S.

2. $\frac{\partial T}{\partial h}$: That is, how does tree planting (or long-term input use) vary between tenure systems? The model would predict that *ceteris paribus*, a liquidity-constrained farmer would plant fewer trees on customary land than on freehold. This is tested by examining the sign of γ_1^L.

3. $\frac{\partial F}{\partial v}\Big|_{h=1}$: That is, how does fertilizer use respond to changes in land values on freehold land? The model would predict that *ceteris paribus*, a liquidity-constrained farmer would use more fertilizer as land values increase. This is tested by examining the sign of $\gamma_2^S + \gamma_3^S$.

4. $\frac{\partial T}{\partial v}\Big|_{h=1}$: That is, how does tree planting respond to changes in land values on freehold land? The model would predict that *ceteris paribus*, a liquidity-constrained farmer would plant more trees as land values increase. This is tested by examining the sign of $\gamma_2^L + \gamma_3^L$.

5. $\frac{\partial F}{\partial v}\Big|_{h=0}$: That is, how does fertilizer use respond to changes in land values on customary land? The model would predict that *ceteris paribus*, a liquidity-constrained farmer would use more fertilizer as land values increase. This is tested by examining the sign of γ_2^S.

6. $\left.\frac{\partial T}{\partial v}\right|_{h=0}$: That is, how does tree planting respond to changes in land values on customary land? The model would predict that *ceteris paribus*, a liquidity-constrained farmer would plant fewer trees as land values increase. This is tested by examining the sign of γ_2^L.

With the last of these being the primary innovation of this model; without considering the changing incentives of local elites, the impact of rising land values on customary land would parallel that on freehold. This stems from the qualitative fact that tree planting behavior is effective at securing tenure within the community, but less so to outside investors who find this demonstration of rights illegible.

5.2 Estimation Strategy

However, land values in a region do not provide sufficient identifying variation. Therefore, I propose to use random assignment of households within a region to the ACDP program, which should exogenously shift their subjective beliefs about the returns to subsidized (short-term) inputs. This way, we have two plausibly exogenous dimensions of variation, and so can think of land values being a dimension of heterogeneity along which we examine the difference-in-differences. That is, I will examine investment decisions across customary and freehold land within a household, between households assigned to ACDP and not. Then I will see how the relationship uncovered differs between areas with different land values.

The randomization for the ACDP impact evaluation was stratified at the sub-county level, meaning that within each sub-county (a mid-level administrative unit, generally consisting of between six to several dozen villages) there are an equal number of farmer organizations assigned to each treatment arm as well as the control group. This means that within a single land price environment, there are some farmers who have received an exogenous correction to biased beliefs about the returns to specified (short-term) inputs ($T_h = 1$), and others who have not. These farmers have parcels under both customary and freehold tenure systems, so we are able to use household fixed effects to compare within-household allocations of inputs to customary and freehold land. This comparison isolates variation due to the tenure type, as opposed to systematic differences in farming ability or household liquidity between *farmers* on different types of land. These households are then randomly allocated to a treatment status, so I will compare the difference in investment across tenure types, across treatment status. Finally, these households are located in areas with different land values,

which will create different incentives for long-term inputs on customary land as predicted by the model. Therefore, I will examine the interaction of the land value environment with the treatment status and tenure type, to capture heterogenenous effects:

$$\Delta I_{hi}^{Q} = \alpha_0^Q + \alpha_1^Q T_h + \alpha_2^Q D_{hi} + \alpha_3^Q \bar{v} + \alpha_4^Q T_h * D_{hi} + \alpha_5^Q T_h \bar{v} + \alpha_6^Q D_{hi} * \bar{v} + \alpha_7^Q T_h * D_{hi} * \bar{v} + \eta_h + \epsilon_{hi}$$

The primary purpose of the experiment is to see if α_1 is positive for those inputs promoted by the program: that is, does input use increase for those who receive the vouchers. However, we can also examine the signs on other coefficients. In particular, the model would predict that despite α_3 being positive, for treated households in low land-value contexts, α_5 should be close to zero (input use does not respond significantly differently to treatment across freehold and customary parcels). On the other hand, in high land-value environments, treatment response should differ by tenure status, which amounts to examining the sign of $\alpha_6 + \alpha_7$.

5.3 Measuring Tenure Security

Several papers, in 'taking stock' of the body of empirical evidence on tenure security and investment, have noted the variety of definitions of tenure security as well as the proxies used empirically (Arnot et al., 2011; Deininger and Ali, 2008). Common empirical measures include the existence of legal title, duration of tenure, method of acquisition, tenure type, existence of a conflict over the land, subjective perceptions of tenure security, as well as existence of particular rights (often transfer rights) (Arnot et al., 2011). However, it is often left implicit how these proxies are related to tenure security, which is the parameter modeled. Fenske et al. (2011) notes that the choice of proxy does seem to be related to the effect found, and therefore this is a crucial choice.

This model, however, addresses these concerns by explicitly considering the relationship of the empirically observable trait, tenure type, to the fundamental parameter of interest, tenure security. The importance of this consideration is illustrated by the final hypothesis, that customary tenure exists in an institutional context that responds differently to changes in land value, and therefore the relationship between tenure type and security is different in high and low land value areas. Arnot et al. (2011) distinguish between the 'content' and 'assurance' aspects of tenure, and rather than eliding between those, I consider how the two are related.

5.4 Measuring Investment

Another point at which many papers allow their model and empirics to diverge is in the measurement of agricultural investment, the outcome of interest. Because many smallholders operate low-input, even subsistence farms, it is difficult to measure investment well. Therefore, many papers have used binary investment outcomes (Fenske et al., 2011). Although econometric methods to account for endogeneity in a binary outcome model have become standard (such as the two stage conditional maximum likelihood model, discussed in Abdulai et al. (2011), or using a linear probability model to allow household fixed effects, as Deininger and Ali (2008) do), Fenske et al. (2011) has argued that measuring investment in a continuous way can make a substantial difference to the results. He argues for the trimmed LAD estimator to deal with the prevalence of zeroes in types of investment. This is the panel equivalent of the Tobit estimator (Honore, 1992).

Although I still need to determine the most appropriate methods, I will be able to use continuous measures of investment thanks to the rich detail of the ACDP data.

5.5 Land Values

Importantly, the model presented above takes land values to be an exogenous force shaping the incentives faced by farmers. This modeling choice was driven by the qualitative literature, which has focused on the breakdown of customary institutions caused by outside pressures, such as the rapid urban expansion in much of Africa or international large-scale land acquisitions. However, the value of an individual parcel of land is in reality a product of its particular features, including any investments made. Therefore, simply including land values would induce endogeneity, to say nothing of the difficulty of measuring land values in thin land sales markets. Instead, I would like to include an instrument for land values. This instrument, to satisfy the exclusion restriction, should only impact investment through the pathways in the model: that is, it could impact the credit constraint faced by the household, as well as the incentives for local elites to expropriate, but not stem from an increase in total factor productivity (for example).

I still have not settled on an instrument to use in the Ugandan context, but it is worth considering some instruments used in the literature. Miceli et al. (2001) use rainfall potential as a district-level instrument for the value of agricultural land in Kenya, while also controlling for population density (to account for land scarcity) and the male literacy rate and distance from the government center

as instruments for the cost of using the title system in their investigation of land values and titling. Outside of the region, Alston et al. (1996) use distance to market, and title status as instruments for land values on the frontier in Brazil. However, titling status could also influence tenure security, so this seems less than ideal for this question.

If I cannot determine an appropriate instrument, or as a robustness check, I am considering using a methodology similar to that used by Jacoby and Minten (2006) in order to bound the bias caused by endogeneity instead of instrumenting for the endogenous land values. This method relies on assumptions about the relative magnitude of selection on observables vs. unobservables, the contextual validity of which I will investigate further.

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A General Analytical Solution

Consider a two-period model. In the first period, the farmer chooses to apply fertilizer, F_1 and trees, T, to his or her exogenously-given land L under tenure system h. The farmer also has some

wealth endowment, but can choose to borrow B_1 against the value of the land (and the tenure system). The farmer faces an exogenous interest rate, r, and has a discount rate of β for second period returns. There is some probability that the farmer's land will be expropriated before the second period, and fixed investments (trees) would be lost then as well. This probability is given by $(1 - \phi(T, h, vL))$ and could be a function of tree investment, tenure systems, as well as the value of the land. After working through the main features of the model, I will consider what different forms of this ϕ function could imply for the farmer's decisions.

The first period problem faced by the farmer is then to:

$$\max_{F_1,T,B_1} p_a f(F_1, T) - p_F F_1 - p_T T - rB_1 + \beta\phi(T, h, vL)\pi_2^*(F_1, T, B_1)$$

$$\text{subject to: } \begin{aligned} p_F F_1 + p_T T &\leq w_1 + B_1 \\ B_1 &\leq s(vL, h) \end{aligned}$$

While in the second period, the farmer only chooses fertilizer (F_2):

$$\max_{F_2} p_a f(F_2, T) - p_F F_2$$

$$\text{subject to: } \begin{aligned} p_F F_2 &\leq w_2 \\ w_2 &= w_1 - rB_1 + p_a f(F_1, T) - p_F F_1 - p_T T \end{aligned}$$

The First Order Conditions of this second stage are:

$$\frac{p_a}{p_F}\frac{\partial f}{\partial F_2} - p_F - \lambda_1 p_F = 0$$

$$\lambda_1[p_F F_2 - w_1 + rB_1 - p_a f(F_1, T) + p_F F_1 + p_T T] = 0$$

There are two cases: Either the budget constraint binds in the second stage, or it does not.

A.1 Case A: Unconstrained Second Stage

First consider the case where the budget constraint does not bind in the second stage, $\lambda_1 = 0$

Then F_2^* such that:

$$\frac{\partial f}{\partial F_2} = \frac{p_F}{p_a}$$

Therefore

$$\pi_2^* = p_a f(F_2^*, T) - p_F F_2^*$$

and the derivatives are:

$$\begin{aligned} \frac{\partial \pi_2^*}{\partial F_1} &= 0 \\ \frac{\partial \pi_2^*}{\partial T} &= p_a \frac{\partial f}{\partial T}\Big|_{F_2^*} \\ \frac{\partial \pi_2^*}{\partial B_1} &= 0 \end{aligned}$$

Turning to the first stage, then:

$$\begin{aligned} \max_{F_1,T,B_1} \; & p_a f(F_1, T) - p_F F_1 - p_T T - r B_1 + \beta \phi(T, h, vL) \pi_2^*(F_1, T, B_1) \\ \text{subject to } & p_F F_1 + p_T T \leq w_1 + B_1 \\ & B_1 \leq s(vL, h) \end{aligned}$$

FOCs are:

$$\begin{aligned} p_a \frac{\partial f}{\partial F_1} - p_F + \beta \phi(T, h, vL) \frac{\partial \pi_2^*}{\partial F_1} - \lambda_2 p_F &= 0 \\ p_a \frac{\partial f}{\partial T} - p_T + \beta \frac{\partial \phi}{\partial T} \pi_2^* + \beta \phi(T, h, vL) \frac{\partial \pi_2^*}{\partial T} - \lambda_2 p_T &= 0 \\ -r + \beta \phi(T, h, vL) \frac{\partial \pi_2^*}{\partial B_1} + \lambda_2 - \lambda_3 &= 0 \\ \lambda_2 (p_F F_1 + p_T T - w_1 - B_1) &= 0 \\ \lambda_3 (B_1 - s(vL, h)) &= 0 \end{aligned}$$

Which simplify to:

$$
\begin{aligned}
p_a \frac{\partial f}{\partial F_1} - p_F - \lambda_2 p_F &= 0 \\
p_a \frac{\partial f}{\partial T} - p_T + \beta \frac{\partial \phi}{\partial T} \pi_2^* + \beta \phi(T, h, vL) \frac{\partial \pi_2^*}{\partial T} - \lambda_2 p_T &= 0 \\
-r + \lambda_2 - \lambda_3 &= 0 \\
\lambda_2 (p_F F_1 + p_T T - w_1 - B_1) &= 0 \\
\lambda_3 (B_1 - s(vL, h)) &= 0
\end{aligned}
$$

A.1.1 Case 1A: Totally Unconstrained

As a benchmark, consider a farmer who has a sufficient initial endowment of wealth w_1 that neither the borrowing nor the budget constraint bind ($\lambda_1 = \lambda_2 = \lambda_3 = 0$

The FOCs are then:

$$
\begin{aligned}
p_a \frac{\partial f}{\partial F_1} - p_F &= 0 \\
p_a \frac{\partial f}{\partial T} - p_T + \beta \frac{\partial \phi}{\partial T} \pi_2^* + \beta \phi(T, h, vL) p_a \frac{\partial f}{\partial T}\Big|_{F_2^*} &= 0
\end{aligned}
$$

This then gives us:

$$
\frac{\partial f}{\partial F_1} = \frac{p_F}{p_a}
$$

Therefore, in the totally unconstrained case, $F_1^* = F_2^*$. Furthermore, if we assume that under freehold tenure, $\phi = 1$ and $\frac{\partial \phi}{\partial T} = 0$ (tenure is perfectly secure and planting trees has no effect on tenure security), then

$$
\frac{\partial f}{\partial T}\Big|_{h=1} = \frac{p_T}{p_a} \frac{1}{(1+\beta)}
$$

However, we can see that if $\phi < 1$, such as is possible under customary tenure, then the marginal productivity of trees in equilibrium would be higher, and therefore investment in trees would be lower. This effect would be attenuated by $\frac{\partial \phi}{\partial T} > 0$, as would be the case if planting trees helped secure tenure.

This is only a benchmark case, as our real interest is in the liquidity-constrained farmer (where the borrowing constraint, and therefore the budget constraint, bind). However, it demonstrates that our model accords with most theoretical models of tenure and long-term investments.

A.1.2 Case 2A: Binding Budget Constraint

Now consider a world in which the farmer is not constrained in their ability to borrow, but they do exhaust their budget constraint ($\lambda_1 = \lambda_3 = 0$; $\lambda_2 \neq 0$)

The FOCs in this case are:

$$\begin{aligned} p_a \frac{\partial f}{\partial F_1} - p_F - \lambda_2 p_F &= 0 \\ p_a \frac{\partial f}{\partial T} - p_T + \beta \frac{\partial \phi}{\partial T} \pi_2^* + \beta \phi(T, h, vL) \frac{\partial \pi_2^*}{\partial T} - \lambda_2 p_T &= 0 \\ -r + \lambda_2 &= 0 \\ p_F F_1 + p_T T - w_1 - B_1 &= 0 \end{aligned}$$

We now have fertilizer use in the first stage determined by setting the marginal product not equal to the relative price, as in the totally unconstrained case, but instead to a (higher) shadow price determined by the interest rate, and thus lower than optimal fertilizer usage.

$$\frac{\partial f}{\partial F_1} = \frac{p_F}{p_a}(1 + r)$$

Similarly, in the freehold case, where tree planting has no effect on (full) tenure security,

$$\frac{\partial f}{\partial T}\Big|_{h=1} = \frac{p_T}{p_a}\frac{(1+r)}{(1+\beta)}$$

Which mirrors the unconstrained case, but has the marginal product of trees (discounted across both periods) equal to a shadow price which is higher than the true price and thus tree planting will be lower than in 1A. Furthermore, as in 1A, if tenure security was incomplete ($\phi < 1$), but unresponsive to tree planting, the condition would be:

$$\frac{\partial f}{\partial T}\Big|_{h=0} = \frac{p_T}{p_a}\frac{(1+r)}{(1+\beta\phi)} > \frac{p_T}{p_a}\frac{(1+r)}{(1+\beta)} = \frac{\partial f}{\partial T}\Big|_{h=1}$$

Therefore, the marginal productivity of trees is higher under customary tenure and thus under normal assumptions of diminishing marginal returns, the level of investment in trees is lower on customary land than freehold. If $\frac{\partial \phi}{\partial T} > 0$, that would attenuate this result somewhat (as the marginal product of trees in equilibrium would be reduced by the (positive) term $\beta\frac{\partial \phi}{\partial T}\pi_2^*$), for reasonable parameter values the net effect would be similar to that found empirically: that investment in trees on customary land is no higher than on freehold.

A.1.3 Case 3A: Binding Borrowing Constraint

This case will never occur, as the farmer would not exhaust the (costly) borrowing option if wealth was high enough for the budget constraint not to bind.

A.1.4 Case 4A: Both Constraints Binding

Finally, consider a liquidity-constrained farmer who faces both a binding borrowing and budget constraint: $\lambda_1 = 0, \lambda_2 \neq 0, \lambda_3 \neq 0$

This is the case depicted in Figures 1-3, so we will devote particular attention to it.

Working with the constraints, the FOCs are:

$$
\begin{aligned}
p_a \frac{\partial f}{\partial F_1} - p_F - \lambda_2 p_F &= 0 \\
p_a \frac{\partial f}{\partial T} - p_T + \beta \frac{\partial \phi}{\partial T} \pi_2^* + \beta \phi(T, h, vL) \frac{\partial \pi_2^*}{\partial T} - \lambda_2 p_T &= 0 \\
-r + \lambda_2 - \lambda_3 &= 0 \\
p_F F_1 + p_T T - w_1 - s(vL, h) &= 0 \\
B_1 &= s(vL, h)
\end{aligned}
$$

First, consider the freehold case ($\phi = 1$). Then the equilibrium condition is:

$$
\frac{\partial f}{\partial T}\Big|_{F_1^*} + \beta \frac{\partial f}{\partial T}\Big|_{F_2^*} = \frac{p_T}{p_F} \frac{\partial f}{\partial F_1}
$$

Despite not being able to solve this explicitly for F_1 and T, we can use the implicit function theorem to see how input choices respond to the parameters of interest. The Jacobian for choice variables is the following:

$$
D_x = \begin{bmatrix}
\frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_1^*} + \beta \frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_2^*} - \frac{p_T}{p_F} \frac{\partial^2 f}{\partial F_1^2} & \frac{\partial^2 f}{\partial T^2}\Big|_{F_1^*} + \beta \frac{\partial^2 f}{\partial T^2}\Big|_{F_2^*} - \frac{p_T}{p_F} \frac{\partial^2 f}{\partial F_1 \partial T}\Big|_{F_1^*} \\
p_F & p_T
\end{bmatrix}
$$

and its inverse is:

$$
D_x^{-1} = \frac{1}{|D_x|} \begin{bmatrix}
p_T & -\frac{\partial^2 f}{\partial T^2}\Big|_{F_1^*} - \beta \frac{\partial^2 f}{\partial T^2}\Big|_{F_2^*} + \frac{p_T}{p_F} \frac{\partial^2 f}{\partial F_1 \partial T}\Big|_{F_1^*} \\
-p_F & \frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_1^*} + \beta \frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_2^*} - \frac{p_T}{p_F} \frac{\partial^2 f}{\partial F_1^2}
\end{bmatrix}
$$

Where the determinant, $|D_X|$, is given by:

$$
\begin{aligned}
|D_x| &= \Big(\frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_1^*} + \beta \frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_2^*} - \frac{p_T}{p_F} \frac{\partial^2 f}{\partial F_1^2}\Big) p_T - \Big(\frac{\partial^2 f}{\partial T^2}\Big|_{F_1^*} + \beta \frac{\partial^2 f}{\partial T^2}\Big|_{F_2^*} - \frac{p_T}{p_F} \frac{\partial^2 f}{\partial F_1 \partial T}\Big|_{F_1^*}\Big) p_F \\
&= \left(2 p_T \frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_1^*} + \beta p_T \frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_2^*} - \frac{p_T^2}{p_F} \frac{\partial^2 f}{\partial F_1^2} - p_F \frac{\partial^2 f}{\partial T^2}\Big|_{F_1^*} - \beta p_F \frac{\partial^2 f}{\partial T^2}\Big|_{F_2^*}\right)
\end{aligned}
$$

or equivalently,

$$D_x^{-1} = \frac{1}{|D_x|}\begin{bmatrix} p_T & -\frac{\partial^2 f}{\partial T^2}\Big|_{F_1^*} - \beta\frac{\partial^2 f}{\partial T^2}\Big|_{F_2^*} + \frac{p_T}{p_F}\frac{\partial^2 f}{\partial F_1 \partial T}\Big|_{F_1^*} \\ -p_F & \frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_1^*} + \beta\frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_2^*} - \frac{p_T}{p_F}\frac{\partial^2 f}{\partial F_1^2} \end{bmatrix}$$

And for the parameters (v is the primary parameter of interest for the empirical hypotheses):

$$D_q = \begin{bmatrix} 0 \\ -\frac{\partial s}{\partial vL}L \end{bmatrix}$$

The product is therefore:

$$\frac{-1}{\left(2p_T\frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_1^*} + \beta p_T\frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_2^*} - \frac{p_T^2}{p_F}\frac{\partial^2 f}{\partial F_1^2} - p_F\frac{\partial^2 f}{\partial T^2}\Big|_{F_1^*} - \beta p_F\frac{\partial^2 f}{\partial T^2}\Big|_{F_2^*}\right)}\begin{bmatrix} (-\frac{\partial s}{\partial vL}L)[-\frac{\partial^2 f}{\partial T^2}\Big|_{F_1^*} - \beta\frac{\partial^2 f}{\partial T^2}\Big|_{F_2^*} + \frac{p_T}{p_F}\frac{\partial^2 f}{\partial F_1 \partial T}\Big|_{F_1^*}] \\ (-\frac{\partial s}{\partial vL}L)[\frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_1^*} + \beta\frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_2^*} - \frac{p_T}{p_F}\frac{\partial^2 f}{\partial F_1^2}] \end{bmatrix}$$

In order to sign these, we need to specify reasonable assumptions about signs. First, many intercropping systems such as are commonly used in Uganda mean that the cross-partials are positive: $\frac{\partial^2 f}{\partial F \partial T} > 0$. Prices are all positive, as is β. The borrowing constraint is increasing in the value of land used as collateral, so $\frac{\partial s}{\partial vL} > 0$. Finally, diminishing marginal returns implies that $\frac{\partial^2 f}{\partial i^2} < 0$, for $i \in F, T$.

These assumptions allow us to sign the matrix: the determinant is negative (therefore the fraction is positive), and both terms inside the matrix are positive. Therefore we can say that $\frac{\partial F_1}{\partial v} > 0$ and $\frac{\partial T}{\partial v} > 0$: both optimal fertilizer and tree investment are increasing in the value of land if the freeholder farmer is liquidity constrained. This allows us to make hypotheses (3) and (4).

$$\frac{1}{\left(2p_T\frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_1^*} + \beta p_T\frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_2^*} - \frac{p_T^2}{p_F}\frac{\partial^2 f}{\partial F_1^2} - p_F\frac{\partial^2 f}{\partial T^2}\Big|_{F_1^*} - \beta p_F\frac{\partial^2 f}{\partial T^2}\Big|_{F_2^*}\right)}\begin{bmatrix} (\frac{\partial s}{\partial vL}L)\left[-\frac{\partial^2 f}{\partial T^2}\Big|_{F_1^*} - \beta\frac{\partial^2 f}{\partial T^2}\Big|_{F_2^*} + \frac{p_T}{p_F}\frac{\partial^2 f}{\partial F_1 \partial T}\Big|_{F_1^*}\right] \\ (\frac{\partial s}{\partial vL}L)\left[\frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_1^*} + \beta\frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_2^*} - \frac{p_T}{p_F}\frac{\partial^2 f}{\partial F_1^2}\right] \end{bmatrix}$$

If we instead consider customary tenure, the equilibrium condition is:

$$p_a \frac{\partial f}{\partial T}\Big|_{F_1^*} + \beta \frac{\partial \phi}{\partial T}(p_a f(F_2^*, T) - p_F F_2^*) + \beta\phi p_a \frac{\partial f}{\partial T}\Big|_{F_2^*} = \frac{p_T p_a}{p_F}\frac{\partial f}{\partial F_1}$$

Which can also be written as:

$$\frac{\partial f}{\partial T}\Big|_{F_1^*} + \beta \frac{\partial \phi}{\partial T}(f(F_2^*, T) - \frac{p_F}{p_a} F_2^*) + \beta\phi \frac{\partial f}{\partial T}\Big|_{F_2^*} = \frac{p_T}{p_F}\frac{\partial f}{\partial F_1}$$

We can again use the implicit function theorem on this condition, along with the budget constraint. The Jacobian for choice variables is:

$$\begin{bmatrix} \frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_1^*} + \beta\phi \frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_2^*} - \frac{p_T}{p_F}\frac{\partial^2 f}{\partial F_1^2} & \frac{\partial^2 f}{\partial T^2}\Big|_{F_1} + \beta \frac{\partial^2 \phi}{\partial T^2}\left[f(F_2^*, T) - \frac{p_F}{p_a} F_2^*\right] + 2\beta \frac{\partial \phi}{\partial T}\frac{\partial f}{\partial T}\Big|_{F_2} + \beta\phi \frac{\partial^2 f}{\partial T^2}\Big|_{F_2} - \frac{p_T}{p_F}\frac{\partial^2 f}{\partial F_1 \partial T}\Big|_{F_1} \\ p_F & p_T \end{bmatrix}$$

Which we can invert:

$$D_x^- 1 = \frac{1}{|D_x|}\begin{bmatrix} p_T & -\left[\frac{\partial^2 f}{\partial T^2}\Big|_{F_1} + \beta \frac{\partial^2 \phi}{\partial T^2}\left[f(F_2^*, T) - \frac{p_F}{p_a} F_2^*\right] + 2\beta \frac{\partial \phi}{\partial T}\frac{\partial f}{\partial T}\Big|_{F_2} + \beta\phi \frac{\partial^2 f}{\partial T^2}\Big|_{F_2} - \frac{p_T}{p_F}\frac{\partial^2 f}{\partial F_1 \partial T}\Big|_{F_1}\right] \\ -p_F & \frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_1^*} + \beta\phi \frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_2^*} - \frac{p_T}{p_F}\frac{\partial^2 f}{\partial F_1^2} \end{bmatrix}$$

Where $|D_x|$ is the determinant,

$$\begin{aligned} |D_x| = &\left[\frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_1^*} + \beta\phi \frac{\partial^2 f}{\partial T \partial F_1}\Big|_{F_2^*} - \frac{p_T}{p_F}\frac{\partial^2 f}{\partial F_1^2}\right] p_T \\ -&\left[\frac{\partial^2 f}{\partial T^2}\Big|_{F_1} + \beta \frac{\partial^2 \phi}{\partial T^2}\left[f(F_2^*, T) - \frac{p_F}{p_a} F_2^*\right] + 2\beta \frac{\partial \phi}{\partial T}\frac{\partial f}{\partial T}\Big|_{F_2} + \beta\phi \frac{\partial^2 f}{\partial T^2}\Big|_{F_2} - \frac{p_T}{p_F}\frac{\partial^2 f}{\partial F_1 \partial T}\Big|_{F_1}\right] p_F \end{aligned}$$

The Jacobian with respect to land values is:

$$D_q = \begin{bmatrix} \beta \frac{\partial^2 \phi}{\partial T \partial v}\left[f(F_2^*, T) - \frac{p_F}{p_a} F_2^*\right] + \beta \frac{\partial \phi}{\partial v}\frac{\partial f}{\partial T}\Big|_{F_2} \\ -\frac{\partial s}{\partial v L} L \end{bmatrix}$$

The product is therefore:

$$\frac{-1}{|D_x|}\begin{bmatrix} p_T\left[\beta\frac{\partial^2\phi}{\partial T\partial v}\left[f(F_2^*,T)-\frac{p_F}{p_a}F_2^*\right]+\beta\frac{\partial\phi}{\partial v}\frac{\partial f}{\partial T}\Big|_{F_2}\right]+\left[\frac{\partial^2 f}{\partial T^2}\Big|_{F_1}+\beta\frac{\partial^2\phi}{\partial T^2}\left[f(F_2^*,T)-\frac{p_F}{p_a}F_2^*\right]+2\beta\frac{\partial\phi}{\partial T}\frac{\partial f}{\partial T}\Big|_{F_2}+\beta\phi\frac{\partial^2 f}{\partial T^2}\Big|_{F_2}-\frac{p}{p}\right. \\ \left.-p_F\left[\beta\frac{\partial^2\phi}{\partial T\partial v}\left[f(F_2^*,T)-\frac{p_F}{p_a}F_2^*\right]+\beta\frac{\partial\phi}{\partial v}\frac{\partial f}{\partial T}\Big|_{F_2}\right]-\left[\frac{\partial^2 f}{\partial T\partial F_1}\Big|_{F_1^*}+\beta\phi\frac{\partial^2 f}{\partial T\partial F_1}\Big|_{F_2^*}-\frac{p_T}{p_F}\frac{\partial^2 f}{\partial F_1^2}\right]\frac{\partial s}{\partial vL}L\right.\end{bmatrix}$$

It is convenient to make a few further minor assumptions:

- $\frac{\partial^2\phi}{\partial T\partial v}=0$ Without substantial loss of generality, assume the risk of elite expropriation (which responds to land values) is unrelated to the risk of neighbor expropriation (which responds to trees), so the cross-partial of ϕ is zero.
- $\frac{\partial\phi}{\partial v}<0$: tenure security is decreasing in land values as risk of elite expropriation increases, the fundamental new insight of this model
- $\frac{\partial^2\phi}{\partial T^2}=0$ For the current purposes, assume the risk of expropriation by neighbors is a linear function of tree investment, or a close enough approximation.

This matrix product then simplifies to:

$$\frac{-1}{|D_x|}\begin{bmatrix}\beta\frac{\partial\phi}{\partial v}\frac{\partial f}{\partial T}\Big|_{F_2}+\left[\frac{\partial^2 f}{\partial T^2}\Big|_{F_1}+2\beta\frac{\partial\phi}{\partial T}\frac{\partial f}{\partial T}\Big|_{F_2}+\beta\phi\frac{\partial^2 f}{\partial T^2}\Big|_{F_2}-\frac{p_T}{p_F}\frac{\partial^2 f}{\partial F_1\partial T}\Big|_{F_1}\right]\frac{\partial s}{\partial vL}L \\ -p_F\left[\beta\frac{\partial\phi}{\partial v}\frac{\partial f}{\partial T}\Big|_{F_2}\right]-\left[\frac{\partial^2 f}{\partial T\partial F_1}\Big|_{F_1^*}+\beta\phi\frac{\partial^2 f}{\partial T\partial F_1}\Big|_{F_2^*}-\frac{p_T}{p_F}\frac{\partial^2 f}{\partial F_1^2}\right]\frac{\partial s}{\partial vL}L\end{bmatrix}$$

The top component of the matrix is then positive under reasonable parameter values (the determinant is also generally positive). This implies that, as in Hypothesis (5), a liquidity-constrained farmer on customary land will increase fertilizer application as land values increase and the liquidity constraint relaxes.

The sign of the second term, however, depends on the relative magnitudes of the different mechanisms. If tenure insecurity responds drastically enough to rising land values (captured by the term $\frac{\partial\phi}{\partial v}$) to counteract the increasing ability to invest given by the second term, then net investment in trees will actually decrease. This is noted in Hypothesis (6).

Finally, comparing the equilibria conditions for customary and freehold tenure allows us to see that the marginal productivity of tree investment will be higher in the customary case, meaning that

liquidity-constrained farmers plant fewer trees on customary land than on freehold. This also means, because the budget constraint binds, that they invest more in fertilizer. This speaks to hypotheses (1) and (2).

A.2 Case B: Constrained Second Stage

A detailed solution to Case B, where the budget constraint binds in the second period, does not add substantively to the understanding and so is omitted here.