The Countervailing Investment and Rental-supply Effects of Securing Land Ownership: Theory and Evidence from Nicaragua.[†]

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Abstract: Securing land ownership has been hypothesized to significantly boost agricultural output and reduce poverty in rural economies with unequal land ownership distributions. This paper demonstrates that non-security barriers to long-term land rental contracts can induce countervailing effects of land ownership security on land-attached investments and land rentals, which may disproportionately diminish the poverty reduction gain at equilibrium. I also provide empirical evidence from Nicaragua, one of the poorest countries in Latin America. Using spatial variation in credit supply shocks from the 2008 financial and microfinance crises, I find that participation in land security improvement programs led large landowners in less-affected districts to significantly increase agricultural credit use, expand land-attached investments, and reduce land rentals.

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1 Introduction

Securing land ownership contributes to agricultural growth by boosting land-attached investments and productive land transfers.[1] Higher security will enhance landowners' incentives to invest as it lowers the risk of losing the land and thus land-attached investments (e.g., Feder et al., 1988). Higher security will also enhance landowners' ability to invest when the safer land collateral induces lenders to offer more credit (e.g., Carter and Olinto, 2003). Both mechanisms will lead to more land-attached investments—the investment effect. In parallel, higher security will enhance landowners' incentives to rent out land to more productive farmers—the rental-supply effect—as it reduces the threat of losing the rented-out land (e.g., Macours et al., 2010). This paper studies the interaction between these two effects which have long been treated in isolation. Importantly, I demonstrate that in theory, the investment effect can attenuate the rental-supply effect in the presence of common market failures. I provide supporting empirical evidence from Nicaragua, one of the poorest countries in Latin America.

Securing land ownership in Latin America has been hypothesized to bring about significant gains in both agricultural output and poverty reduction (e.g., Deininger, 2003). The size of these win-win economic gains, especially the poverty reduction gain, depends on the extent to which security improvement facilitates an egalitarian distribution of operational land by activating land rental markets (e.g., Boucher et al., 2005). However, my theoretical analysis demonstrates that the investment effect can attenuate the concurrent rental-supply effect, thus limiting equitable access to operational land. The welfare gain for the rural poor with no or limited land endowments—proxied by the percentage growth in the farm labor wage rate at equilibrium—can then decrease significantly, as evidenced by the numerical results in this paper. However, thanks to the large investment effect, the agricultural output gain may only experience a slight reduction.

[1] For concreteness, this paper focuses on the land tenure system of private ownership. In the communal or collective land tenure system, securing use and transfer rights can also induce agricultural growth by boosting land-attached investments (e.g., Jacoby et al., 2002; Deininger and Jin, 2006) and productive land transfers (e.g., Holden et al., 2011; Chari et al., 2021). Securing land tenure may also affect agricultural growth through sectoral occupation choices (e.g., Chen, 2017; Gottlieb and Grobovšek, 2019; Liu et al., 2023). To maintain tractability, I do not incorporate this channel into my already complex theoretical analysis. However, I present brief evidence on it using household survey data.

I start the theoretical analysis with an agricultural household model that builds on the following market failures, which are interlinked through land ownership. The first market failure is the agency cost of hired labor, i.e., hired labor tends to shirk and thus is less efficient than family labor without costly supervision (Eswaran and Kotwal, 1986; Frisvold, 1994). Holding land-attached investments constant, large landowners who suffer from the agency cost of hired labor will rent out (more) land in response to the improvement in land ownership security that lowers the risk of losing the rented-out land. The agency cost of hired labor is an essential efficiency argument for the egalitarian distribution of operational land that can help reduce rural poverty in Latin America (Deininger, 2003).

The second market failure is the credit rationing of small landowners, i.e., they are rationed out of the credit market due to insufficient land endowments for collateral, regardless of land ownership security (Carter, 1988; Carter and Olinto, 2003). Thus, only large landowners will be able to increase monetary land-attached investments after an improvement in land ownership security that reduces the risk of losing these investments. In this paper, I do not consider labor-based land-attached investments, such as terracing (e.g., Deininger and Jin 2006), which are not biased towards large landowners.[2]

The third market failure is the moral hazard of tenants not taking care of landlords' long-term land-attached capital, such as irrigation facilities like wells, long-lived tree crops like citrus and mangoes, under short-term rental contracts. In Latin America, there have been frequent incidences of tenants abusing landlords' attached capital under short-term land leasing (de Janvry et al., 2002). Beyond insecure land ownership, non-security barriers, such as landlords' inclination for flexible short-term contracts and legal caps on contract durations, will make landlords not commit to long-term land leasing (Bandiera, 2007; Díaz et al., 2002).[3] In particular, Bandiera (2007) provides supportive evidence from rural Nicaragua on this commitment issue. In my data, more than 95% of rented land in rural Nicaragua had durations below one year and this pattern persisted even as more households participated in programs that enhanced land ownership security. In my

[2]In the theory outlined below, I also abstract away from the lump-sum labor input for installing the monetary land-attached investments, such as livestock structures and perennial tree crops, for simplicity.

[3]Díaz et al. (2002) find that civil codes in Argentina, Nicaragua, Peru, and Uruguay prohibit land leasing of longer than 10 or 15 years, although actual rental durations are usually much shorter.

theory, I model the problem of tenants not taking sufficient care of land-attached capital as a capital depreciation risk facing landlords, i.e., the attached capital invested in the rented-out land may depreciate faster than that invested in the self-cultivated land.

The capital depreciation risk under short-term land rental contracts will induce landlords' preferences for attached capital investments on the self-cultivated land. Importantly, large landowners will increase attached capital investments more on the endowed land to be self-cultivated than on the endowed land to be rented out after an improvement in land ownership security. This biased investment effect favors self-cultivation and thus dampens the concurrent rental-supply effect. The attenuated rental-supply effect will in turn limit the scope of large landowners to reduce inefficient hired labor input on the self-cultivated land. This can downsize the investment effect when labor complements land-attached capital in farm production (Carter and Yao, 1999).

All else equal, the degree to which the investment effect of securing land ownership will attenuate the concurrent rental-supply effect is positively associated with landowners' capacity to make land-attached investments. I provide empirical evidence for this theoretical hypothesis from Nicaragua, one of the poorest countries in Latin America. Rural Nicaragua is a relevant context, as it witnessed a notable increase in land-attached investments but a mild expansion of land rental markets after land titling and registrations in the 1990s (Deininger and Chamorro, 2004; Boucher et al., 2005). In this paper, I find that this "puzzling" phenomenon is still present in contemporary Nicaragua. More importantly, I provide supportive evidence that it is possibly due to the countervailing interaction between the investment and rental-supply effects of securing land ownership.

In the empirical analysis, I use the panel data from household surveys conducted by the Millennium Challenge Corporation's rural business development project in Nicaragua (Carter et al., 2019). I study the impacts of land security improvement programs while controlling for the effects of the rural business development project. In the data, the salient security improvement program was the World Bank's land administration program which aimed to systematically demarcate land boundaries, resolve ownership conflicts, and title as well as register land. Recent evidence indicates that it significantly improved landowners' perception of land ownership security in rural Nicaragua (De la O Campos et al., 2023). Consistent with this, I find significant resource allocation effects.

I identify the investment and rental-supply effects by controlling for the self-selection of households and communities into the security improvement programs. I find that after program participation, households increased land-attached investments and hired more labor but reduced land rentals. These effects are more pronounced among households with relatively large initial land endowments. Importantly, leveraging spatial variation in credit supply shocks from the 2008 financial and microfinance crises between survey rounds, I find that participation in security improvement programs led large landowners in districts with limited credit contraction to increase agricultural credit use, expand land-attached investments, hire more labor, and reduce land rentals. These findings are consistent with the theoretical prediction that the extent to which the investment effect attenuates the rental-supply effect is positively associated with landowners' investment capacity.

This paper contributes to the extensive literature on the economic effects of land tenure security in two main aspects. Theoretically, I establish an agricultural household model that allows for the *contemporaneous* interaction between the investment and rental-supply effects for the first time. Besley (1995) and Carter and Yao (1999) study their *intertemporal* interaction and show that securing land tenure can facilitate renting out land to reap investment fruits in the risky future, and thus enlarge the current investment effect. However, I demonstrate that the investment effect can attenuate the concurrent rental-supply effect when non-security barriers to long-term land rental contracts induce the capital depreciation risk facing potential landlords.

Empirically, I provide evidence that securing private land ownership decreases land rentals in rural Nicaragua, where land ownership distributions are highly unequal and non-security barriers to long-term land rental contracts are present. This finding is in contrast with that securing land use rights boosts land rentals in the collective or communal land tenure system (e.g., Chari et al., 2021; Chen et al., 2022). An important mechanism is that potential landlords—large landowners who have access to credit but suffer from the agency cost of hired labor—use more credit to make land-attached investments and rent out less land as they are concerned about potential tenants not taking care of their long-term investments under short-term rental contracts. The attenuated rental-supply effect can significantly reduce the income benefits of securing land ownership for the rural poor due to the limited improvement in land access, as evidenced by numerical simulations.

This paper also contributes to the broader literature on the interplay between land misallocation and market frictions by providing additional insights from Nicaragua. Foster and Rosenzweig (2022) finds that the fixed transaction costs of hiring labor on a daily basis help explain land misallocation across farms of different sizes in India. Adamopoulos et al. (2022) suggests that farmers' inability to use land as collateral for borrowing can result in capital misallocation, which in turn exacerbates land misallocation among farmers with differing levels of agricultural productivity in China. Acampora et al. (2025) shows that land rental market frictions—arising from search, risk, and learning—contribute to land misallocation among heterogeneous farmers in Kenya. For Nicaragua, I demonstrate that non-security barriers to long-term land rental contracts and credit rationing can contribute to land misallocation among farmers with varying land endowments.

The rest of the paper proceeds as follows. First, we outline the agricultural household model in Section 2. Then, I study landowners' land rental choices given land ownership security in Section 3, which facilitates my investigation into the countervailing investment and rental-supply effects and their welfare implications in Sections 4 and 5. In Section 6, I provide empirical evidence from rural Nicaragua. Section 7 concludes the paper.

2 The Agricultural Household Model

In this section, I introduce the agricultural household model that will be used to study the interaction between the investment effect of higher land ownership security and the concurrent rental-supply effect as well as its welfare implications in Sections 4 and 5. First, I outline model assumptions. Then, I set up the utility maximization problem. In Section 3, I study land rental choices of households endowed with different sizes of land given the same land ownership security, which facilitates my analyses in Section 4.

2.1 Model assumptions

The agrarian economy described below consists of households with heterogeneous land endowments. They engage in the same C.R.S. (constant returns to scale) agricultural production that involves complementary inputs of land, attached capital, and labor. They allocate land, credit, and labor to maximize discounted incomes in the presence of multiple market failures. The detailed assumptions are outlined below.

Preferences: Each agent has the same risk-neutral preferences for the income flow over infinite production periods and shares the same discount factor β.[4]

Endowments: Labor and land.

(i) *Labor*: Each landed or landless agent is endowed with one unit of labor that is divisible between two usages—family labor on their own farms and hired labor on others' farms.

(ii) *Land*: Each landed agent is endowed with the land of size $A_e > 0$ and security level $S_e \in [0, 1]$. Larger S_e means a lower risk of losing the endowed land and its attached capital, and $S_e = 1$ means no risk. All endowed land is embedded with the same intensity of minimal natural capital k_n.[5]

Technologies: Farm production and the extraction of effective labor.

(i) *Farm production*: Each agent has access to the same C.R.S. production technology $F(A, K, L)$ with three complementary inputs—raw land A, attached capital K, and effective labor L.[6] Attached capital consists of the embedded minimal natural capital and the invested artificial capital, and they are perfect substitutes. The classic Inada conditions, such as diminishing marginal returns, hold for this production function.

(ii) *The extraction of effective labor under the agency cost of hired labor (the first market*

[4]The risk-neutral preferences imply a linear unity function in income, which simplifies the discounted utility formula outlined in Section 2.2.

[5]I introduce minimal natural capital to allow the possibility of landlords making zero attached capital investments on the rented-out land, which is common in reality (e.g., Bandiera, 2007).

[6]For simplicity, movable capital, such as machines and other farming equipment, is not considered in the production technology. See related discussions in Section 7.

failure): Hired labor is an imperfect substitute for family labor as hired labor tends to shirk without costly supervision (e.g., Eswaran and Kotwal, 1986). When hired labor is employed, family labor will supervise them by working together with them. The resulted amount of effective labor is a function of family labor input L_f and hired labor input L_h, denoted by $L(L_f, L_h)$, with the following regular properties (e.g., Frisvold, 1994): When hired labor is not used, one unit of family labor produces one unit of effective labor; when hired labor is used together with family labor, its effectiveness decreases as more hired labor is employed or equivalently the supervision intensity, namely $\frac{L_f}{L_h}$, decreases.

Markets: Land rental, labor, attached capital, credit, and agricultural output.

(i) *Land rental market*: Land rental contracts are of fixed rent.[7] Agents face the same land rental rate schedule $r(\cdot)$—rental rates for land with different intensities of attached capital—determined in the competitive equilibrium. Landlords provide tenants with full security to cultivate the rented land and collect its fruits during contract periods by protecting land ownership (see details below). However, landlords may or may not invest attached capital in the rented-out land, depending on its return and cost. Tenants do not invest in the rented-in land though.[8]

(ii) *Labor market*: Agents face the same wage rate w determined in the competitive equilibrium.

(iii) *Attached capital market*: Agents face the same exogenous price of artificial attached capital, which is normalized to one, i.e., attached capital is the numeraire in this economy.

(iv) *Credit market with rationing of small landowners (the second market failure)*: Credit, the only source of money to make attached capital investments, requires land collateral. Agents endowed with the land of a size smaller than $A_e^m > 0$ will have no access to credit due to quantity rationing, regardless of land ownership security (e.g., Carter, 1988; Carter

[7]To focus on the inefficiency of labor input caused by the agency cost of hired labor, I do not consider alternative land rental contracts which may introduce additional inefficiency of labor input, such as the Marshallian inefficiency associated with sharecropping contracts (e.g., Shaban, 1987).

[8]That tenants do not invest in the rented-in land seems reasonable for an unequal agrarian society of interest in this paper, such as rural Nicaragua where it is often the rich landlord who makes attached capital investments on the rented-out land (Bandiera, 2007). Without this assumption, landed agents who have access to credit would otherwise invest in the rented-in land rather than their endowed land given the full security provided by landlords, which contradicts common sense.

and Olinto, 2003).[9] Non-rationed landed agents, however, have access to credit up to $A_e\theta(S_e)$ with the leverage ratio $\theta(S_e) > 0$ and its responsiveness to land ownership security $\theta'(S_e) > 0$. The accessible credit caps her or his attached capital investments on the self-cultivated and rented-out land $A_o k_o$ and $A_t^{out} k_t^{out}$, i.e., $A_o k_o + A_t^{out} k_t^{out} \leq A_e\theta(S_e)$. Here, $\{A_o, k_o\}$ denote the size of self-cultivated land and its investment intensity, and $\{A_t^{out}, k_t^{out}\}$ denote the size of rented-out land and its investment intensity. Nevertheless, each agent faces the same exogenous interest rate i. Following Eswaran and Kotwal (1986), I set the discount factor β equal to $\frac{1}{1+i}$, i.e., $\beta = \frac{1}{1+i}$.

(v) *Agricultural output market*: Agents face the same exogenous output price p given by the outside output market, such as the global agricultural output market.

Depreciation costs: The artificial attached capital depreciates over time while the minimal natural attached capital does not. The depreciation rate of the artificial attached capital invested in the rented-out land d_t may be larger than the depreciation rate of the artificial attached capital invested in the self-cultivated land d_o, i.e., $d_t \geq d_o > 0$. Given risk-neutral preferences, a positive gap $d_t - d_o$ captures the capital depreciation risk facing landlords under the short-term land rental contract that induces the moral hazard of tenants not taking care of landlords' long-term attached capital (*the third market failure*). Establishing long-term land rental contracts is either impossible due to legal caps on contract durations (e.g., Díaz et al., 2002) or too costly for landlords as they have to give up the option of adjusting contract terms or self-cultivating the land to changes in the economic environment (e.g., Bandiera, 2007). In rural Nicaragua, my data shows that more than 95% of land rentals had durations below one year. To make the model tractable, I assume that landed agents including landlords conduct regular maintenance to keep the attached capital invested in the endowed land unchanged.[10] Hence, the per-period depreciation costs facing a landed agent will be $d_o A_o k_o$ and $d_t A_t^{out} k_t^{out}$ for the attached capital invested in the self-cultivated and rented-out land, respectively.

[9] In this model, I do not consider risk rationing (Boucher et al. 2008) given the risk-neutral preferences.

[10] Together with the assumption that landowners incur costs to protect the endowed land and its attached capital, this assumption simplifies the theoretical analyses below by making the problem of maximizing the discounted incomes static. See details in Section 2.2.

Protection costs: Insecure land ownership induces the risk of losing the endowed land and its attached capital. Renting out land raises such risk.[11] To maintain land ownership, landed agents periodically incur costs to protect the endowed land and its attached capital.[12] These outlays translate into the following periodical protection costs.

(i) *For the self-cultivated land and its attached capital investments*: $c_o(S_e)A_o\left[\frac{r(k_n)}{i}+k_o\right]$.

(ii) *For the rented-out land and its attached capital investments*: $c_t(S_e)A_t^{out}\left[\frac{r(k_n)}{i}+k_t^{out}\right]$.

Here, $c_o(S_e)$ and $c_t(S_e)$ denote the cost rates of protecting the self-cultivated and rented-out land (and their attached capital investments), respectively. The market value of the endowed land is measured by its discounted rents in the land rental market $\frac{r(k_n)}{i}$. Given risk-neutral preferences, we may interpret $c_o(S_e)$ and $c_t(S_e)$ as the periodical probabilities of losing the self-cultivated and rented-out land (and their attached capital investments) under no protection, respectively. The protection costs above may then be interpreted as the expected losses of the endowed land and its attached capital investments that a landowner would face if she or he did not protect land ownership. Moreover, we have $c_t(S_e) > c_o(S_e) > 0$ and $c_t'(S_e) < c_o'(S_e) < 0$, for any $S_e \in [0, 1)$, as renting out land raises the risk of losing the endowed land and its attached capital and higher land ownership security reduces such risk. When land ownership is fully secure, namely $S_e = 1$, there will be no risk and thus zero protection cost rates, namely $c_t(1) = c_o(1) = 0$.

No working capital requirement: Agents pay for hiring in labor, renting in land, protecting the endowed land and its attached capital investments, and maintaining the attached capital invested in the endowed land after each harvest, i.e., no working capital is required. This assumption simplifies my theoretical analysis, which focuses on the interaction between the investment and rental-supply effects of land ownership security.[13]

[11] The increased ownership risk comes from either tenants who may squat the rented land or overlapping claimants for whom it may be easier to occupy the tenant-cultivated land than the owner-cultivated land.

[12] In a conventional model of insecure land ownership, landowners passively lose the endowed land and its attached capital cum output with some positive probability (e.g., Feder et al., 1988; Besley, 1995). The alternative assumption used here ensures that all land cultivators can collect their outputs at each harvest. Importantly, this means that insecure land ownership only indirectly affects the variable labor input through the fixed attached capital input that complements labor input in farm production. Nevertheless, insecure land ownership will still dampen landowners' incentives to invest in land-attached capital and rent out land as that in the traditional approach, given the structure of protection cost rates above.

[13] Eswaran and Kotwal (1986) uses the working capital requirement to study the relationship between

2.2 The utility maximization problem

Let me revisit existing notations and introduce several new ones for the resource allocation possibly made by an individual agent, namely *choice variables* listed below:

A_o—*the size of the endowed land to be self-cultivated;*

k_o—*the intensity of the attached capital to be invested in the self-cultivated land;*

L_o—*the amount of the effective labor to cultivate the self-cultivated land;*

A_t^{out}—*the size of the endowed land to be rented out;*

k_t^{out}—*the intensity of the attached capital to be invested in the rented-out land;*

A_t^{in}—*the size of the land to be rented in;*

k_t^{in}—*the intensity of attached capital investments on the rented-in land made by the landlord (the capital characteristic of the rented-in land);*

L_t^{in}—*the amount of the effective labor to cultivate the rented-in land;*

L_f—*the amount of the endowed labor to produce the effective labor input* $L(L_f, L_h^{in})$ *on her or his own farm (including the self-cultivated and rented-in land) as family labor;*

L_h^{in}—*the amount of labor to hire in and produce the effective labor input* $L(L_f, L_h^{in})$ *on her or his own farm (including the self-cultivated and rented-in land); and*

L_h^{out}—*the amount of the endowed labor to hire out and work on others' farms.*

Under the model assumptions above, we have the general structure of revenues and costs in Figure 1. The blue integer "0" denotes the initial production point when *up-front attached capital investments* on the self-cultivated and rented-out land, namely $A_o k_o + A_t^{out} k_t^{out}$, occur. The blue integer "1" denotes the harvest point when periodical revenues and costs occur for the first time, which deliver *four sources of income* as follows.

(i) *The pseudo-profit of cultivating the self-cultivated land* $\pi_o(A_o, k_o, L_o)$:[14]

$pF(A_o, A_o k_o + A_o k_n, L_o) - [d_o + c_o(S_e)]A_o k_o - c_o(S_e)A_o \frac{r(k_n)}{i}$.

access to capital and farm size, which is not of research interest in this paper.

[14]Profits and returns in (i)-(iii) are pseudo as they do not include the credit and/or labor costs. The credit cost is embedded in the upfront cost of attached capital investments $A_o k_o + A_t^{out} k_t^{out}$, which equals the present value of credit interests and its principal given the discount factor $\beta = \frac{1}{1+i}$. The labor cost shared across the farm production on the self-cultivated and rented-in land is embedded in (iv).

(ii) *The pseudo-return of renting out land* $\pi_t^{out}(A_t^{out}, k_t^{out})$:

$A_t^{out} r(k_t^{out} + k_n) - [d_t + c_t(S_e)]A_t^{out} k_t^{out} - c_t(S_e)A_t^{out}\frac{r(k_n)}{i}$.

(iii) *The pseudo-profit of cultivating the rented-in land* $\pi_t^{in}(A_t^{in}, k_t^{in}, L_t^{in})$:

$pF(A_t^{in}, A_t^{in}k_t^{in} + A_t^{in}k_n, L_t^{in}) - A_t^{in} r(k_t^{in} + k_n)$.

(iv) *The net wage income of hiring out and in labor*: $wL_h^{out} - wL_h^{in}$.

Holding prices and land ownership security constant, these incomes will repeatedly occur in later harvests as agents will not change land and labor allocations.[15] The reason is that land-attached capital will remain unchanged after initial investments thanks to the periodical maintenance made by landowners (*assumption*). Also, there will be no change in land ownership due to landowners' protection efforts. Hence, we have the following utility maximization problem (UMP) facing an arbitrary agent, given the risk-neutral preferences over the periodical incomes and the discount factor $\frac{1}{1+i}$:

$$max_{\{choice\ variables\}} \frac{1}{i}\Big\{\pi_o(A_o, k_o, L_o) + \pi_t^{out}(A_t^{out}, k_t^{out}) + \pi_t^{in}(A_t^{in}, k_t^{in}, L_t^{in}) + (wL_h^{out} - wL_h^{in})\Big\}$$

$$- (A_o k_o + A_t^{out} k_t^{out})$$

$$s.t.\quad A_o + A_t^{out} \leq A_e; \tag{1}$$

$$A_o k_o + A_t^{out} k_t^{out} \leq I_{\{A_e \geq A_e^m\}} A_e \theta(S_e); \tag{2}$$

$$L_o + L_t^{in} \leq L(L_f, L_h^{in}); \tag{3}$$

$$L_f + L_h^{out} \leq 1; and \tag{4}$$

$$\{A_o, A_t^{out}, A_t^{in}, k_o, k_t^{out}, k_t^{in}, L_o, L_t^{in}, L_f, L_h^{out}, L_h^{in}\} \geq 0, \tag{5}$$

where *choice variables* are A_o, A_t^{out}, A_t^{in}, k_o, k_t^{out}, k_t^{in}, L_o, L_t^{in}, L_f, L_h^{out}, and L_h^{in}.

The land constraint (1) says that the gross size of the endowed land to be self-cultivated and rented out should not exceed the size of land endowment. The credit constraint (2) says that the gross attached capital investments on the self-cultivated and rented-out land

[15] For instance, a landlord or a tenant will keep renting out or renting in land by consecutively renewing the same contract, although her or his tenant or landlord may change. However, the depreciation rate of the attached capital invested in the rented-out or rented-in land by its landowner should remain unchanged since it is the contract duration but not the duration of the rental relationship that matters for attached capital investments on the land in rental (Bandiera, 2007; Jacoby and Mansuri, 2008).

should not exceed the accessible credit for an agent who has access to credit. An agent endowed with land of a size below the minimum size of land collateral required for credit access A_e^m will be rationed out of the credit market, namely $I_{\{A_e \geq A_e^m\}} = 0$, and thus have no accessible credit to make attached capital investments. The effective labor constraint (3) says that the total amount of the effective labor to cultivate the self-cultivated and rented-in land should not exceed the amount of the effective labor extracted from family and hired labor. Constraint (4), on the other hand, says that the total amount of the endowed labor to work on her or his own farm as family labor and work on others' farms as hired labor should not exceed the amount of labor endowment. Finally, constraint (5) says that all the allocations of land, credit, and labor should be nonnegative.

For readability, I put the first-order optimality conditions for the UMP in Supplementary Appendix A, which is not essential for later sections. Concerning the complex nature of this problem, I study the interaction between the investment effect of higher land ownership security and the concurrent rental-supply effect in the following two steps. In Section 3, I explain how the three market failures introduced in the model assumptions will affect the land rental choices of agents with different sizes of land endowments given the same land ownership security. Building on that, I examine the contemporaneous interaction between the investment and rental-supply effects of higher land ownership security through the lens of land rental supply in Section 4. I explore the associated welfare implications using numerical simulations in Section 5.

3 Land Rental Choices given Land Ownership Security

In this section, I study when a landed agent will rent in or out land in terms of the size of land endowment at a given security level of land endowment, holding prices constant. Studying this helps us understand how the three market failures—the agency cost of hired labor, the credit rationing of small landowners, and the moral hazard of tenants not taking care of landlords' land-attached capital—will affect agents' renting choices. More importantly, this analysis prepares us for the investigation into the interaction between the investment effect of higher land ownership security and the concurrent rental-supply effect in Section 4. In the following, I focus on the general case when land ownership is insecure. To proceed, let me introduce Lemma 1 below.

***Lemma 1**: Under the C.R.S. production technology and the competitive land rental and labor markets, the unit return of the effective labor input on any rented land equals wage rate.*

Lemma 1 comes from the following two reasons (Supplementary Appendix B): (i) Under the C.R.S. production technology, tenants earn the same unit return of the effective labor input on any rented land in the competitive land rental market, as they only provide labor input; and (ii) tenants and laborers are indifferent between the two usages of their endowed labor—cultivating the rented land as family labor and working on others' farms as hired labor—in the competitive land rental and labor markets. Lemma 1 implies that tenants will not use any hired labor but family labor to cultivate the rented land as one unit of hired labor produces less than one unit of effective labor due to the agency cost.

As a corollary, a landed agent will not rent in land if she or he opts to use all the endowed labor to self-cultivate all or part of her or his endowed land. Note that a landed agent will not rent out land if self-cultivating all the endowed land does not consume all the endowed labor at its opportunity cost—the wage rate. Under this condition, renting out land will only raise the protection and capital depreciation cost rates resulting from the higher risk of losing the rented-out land cum its attached capital investments and the moral hazard of tenants not taking care of landlords' land-attached capital. Therefore, landed agents will use the endowed labor to self-cultivate the endowed land up to the point where the marginal return of the family labor input on the self-cultivated land equals wage rate, and use the remaining endowed labor (if any) to cultivate the land to be rented in or on others' farms. With that, I obtain the following proposition about the threshold of renting in land, denoted by A_e^{in}:

***Proposition I**: There exists a unique size of land endowment A_e^{in}, above which landed* *agents will stop renting in land at a given security level of land endowment.*

The threshold of renting in land A_e^{in} is shown in Figure 2. In this figure, the solid lines represent the marginal return of the endowed land under self-cultivation at different sizes of land endowment. By definition, it equals the marginal output revenue of the endowed land (including its minimal natural attached capital) minus the unit cost of protecting the endowed land under self-cultivation. At a given security level of land endowment S_e, the protection cost part is constant, whereas the output revenue part depends on the size of land endowment A_e.

When A_e is smaller than the minimum size of land collateral required for credit access A_e^m, self-cultivating all the endowed land will not involve attached capital investments as landed agents of this category have no accessible credit to do investments. Nevertheless, self-cultivating all the endowed land will always involve the usage of family labor. It will not consume all the endowed labor though, since the size of land endowment is small, given that A_e^m is usually small (Carter and Olinto, 2003). Under the C.R.S. production technology, landed agents of this category will have the same intensity of the effective labor input on the endowed land under self-cultivation as they face the same marginal cost of the effective labor input extracted from family labor, namely wage rate. Hence, the marginal output revenue of the endowed land under self-cultivation will be the same for them as well. So will the marginal return of the endowed land under self-cultivation.

For $A_e \geq A_e^m$, landed agents have accessible credit to make attached capital investments. *Assume that they will invest attached capital in the endowed land under self-cultivation.* Then, the marginal return of the endowed land under self-cultivation will increase right at $A_e = A_e^m$, as attached capital investments raise the marginal output revenue of the endowed land under self-cultivation through the complementarity between attached capital and land inputs in farm production. When A_e^m is sufficiently small, self-cultivating all the endowed land of size A_e, which equals A_e^m, will still not consume all the endowed labor at its opportunity cost, namely wage rate.

As the size of land endowment increases, however, self-cultivating all the endowed land will consume more endowed labor. Hence, there exists a unique size of land endowment, namely the threshold of renting in land A_e^{in}, at which self-cultivating all the endowed land will just consume all the endowed labor at its opportunity cost. Agents endowed with land of a size above A_e^{in} will not use any endowed labor to cultivate any land to be rented in as self-cultivating all or part of the endowed land will generate higher labor returns than the wage rate (the labor return of cultivating any rented land, Lemma 1).

For $A_e \in [A_e^m, A_e^{in}]$, the marginal return of the endowed land under self-cultivation will be invariant with respect to the size of land endowment. Landed agents of this category face the same marginal cost of the effective labor input extracted from family labor, namely wage rate. Under the C.R.S. production technology, they will then demand the same intensity of attached capital investments on the endowed land under self-cultivation. Hence, they will invest the same intensity of attached capital in the endowed land under self-cultivation, regardless of the credit constraint status. Because they face the same leverage ratio of the accessible credit over the size of land endowment as collateral at a given security level of land ownership (*assumption*).[16] At the same time, they will have the same intensity of the effective labor input on the endowed land under self-cultivation, as they face the same marginal cost of the effective labor input. These constant input intensities will deliver a constant marginal output revenue of the endowed land under self-cultivation given the C.R.S. production technology. Then, the marginal return of the endowed land under self-cultivation will remain unchanged for $A_e \in [A_e^m, A_e^{in}]$.

For $A_e > A_e^{in}$, however, the marginal return of the endowed land under self-cultivation will decrease as the size of land endowment increases. The reason is that self-cultivating all the endowed land now will involve the usage of the inefficient hired labor, which raises the marginal cost of the effective labor input above the wage rate due to the agency cost of hired labor. Moreover, a larger size of land endowment requires more hired labor input while family labor input is fixed. Then, the marginal cost of the effective labor input on

[16]They will be either credit constrained or unconstrained. If the constant intensity of attached capital investments demanded on the endowed land under self-cultivation is larger than the constant leverage ratio, then they will be credit constrained and invest the same intensity of attached capital that equals the constant leverage ratio. Otherwise, they will be credit unconstrained and invest the same demanded intensity of attached capital in the endowed land under self-cultivation.

the endowed land under self-cultivation will keep increasing as one unit of hired labor will produce less and less effective labor due to the decreasing supervision intensity.[17] Therefore, the marginal output revenue of the endowed land under self-cultivation will keep decreasing as the size of land endowment increases. So will the marginal return of the endowed land under self-cultivation.

The increasing marginal cost of the effective labor input will also dampen the intensity of attached capital investments demanded on the endowed land under self-cultivation, due to the complementarity between labor and attached capital inputs in farm production. Then, the intensity of the attached capital invested in the endowed land under self-cultivation will start to decrease after the credit constraint becomes not binding at a sufficiently large size of land endowment. This will contribute to the decrease in the marginal return of the endowed land under self-cultivation as well.

The credit constraint, however, usually binds for agents endowed with medium sizes of land (Carter and Olinto, 2003). For them, the decreasing intensity of attached capital investments demanded on the endowed land under self-cultivation implies a decreasing shadow price of the accessible credit, although the intensity of the attached capital invested in the endowed land under self-cultivation will remain changed. *Assume that they will invest attached capital in the endowed land to be rented out.* Then, the lower shadow price of the accessible credit will lead to a higher intensity of attached capital investments on the first unit of the endowed land to be rented out. This is true as the marginal cost of the effective labor input on any rented land equals the wage rate (Lemma 1). Due to input complementarity, the marginal output revenue of the endowed land to be rented out for the first unit will increase as the size of land endowment increases. So will the marginal return of the endowed land to be rented out for the first unit, as shown by dashed lines in Figure 2.[18] Of course, it will eventually plateau out as the credit constraint becomes not binding at a sufficiently large size of land endowment.

[17] In the model, I assume that family labor supervises hired labor by working together with them.

[18] Like the marginal return of the endowed land under self-cultivation, the marginal return of the endowed land to be rented out for the first unit is defined as the marginal output revenue of the endowed land to be rented out for the first unit minus its unit protection cost. The unit protection cost is fixed but higher than that for the endowed land under self-cultivation, at a given security level of land endowment.

For $A_e \in [A_e^m, A_e^{in}]$, as explained above, the intensity of attached capital investments demanded on the endowed land under self-cultivation will be invariant to the size of land endowment. Given the constant leverage ratio of the accessible credit for attached capital investments, the shadow price of the accessible credit will be invariant to the size of land endowment as well. So will the intensity of attached capital investments on the first unit of the endowed land to be rented out. Under the C.R.S. production technology, the marginal output revenue of the endowed land to be rented out for the first unit will then be a positive constant for $A_e \in [A_e^m, A_e^{in}]$, regardless of the size of land endowment. So will the marginal return of the endowed land to be rented out for the first unit. This constant pattern also applies to the case of $A_e < A_e^m$ when landed agents have no accessible credit to make attached capital investments, although the return level will be lower.

Put everything together, both the marginal return of the endowed land under self-cultivation and the marginal return of the endowed land to be rented out for the first unit will follow the same constant patterns for $A_e \leq A_e^{in}$. But the former will be always higher than the latter as renting out land will only increase the protection and capital depreciation cost rates but not the efficiency of the labor input on the endowed land when self-cultivating all the endowed land does not consume all the endowed labor. For $A_e > A_e^{in}$, however, self-cultivating all the endowed land will consume all the endowed labor and involve the usage of the inefficient hired labor. The marginal cost of the effective labor input will keep increasing due to the decreasing supervision intensity. As a result, the marginal return of the endowed land under self-cultivation will keep decreasing. In contrast, thanks to the constant marginal cost of the effective labor input on any rented land, the marginal return of the endowed land to be rented out for the first unit will keep increasing until the shadow price of the accessible credit for attached capital investments stops decreasing at a sufficiently large size of land endowment.[19] Based on these opposite patterns, I obtain the following proposition about the threshold of renting out land, denoted by A_e^{out}.

[19]When landed agents do not invest attached capital in the endowed land to be rented out due to a high capital depreciation rate, the marginal return of the endowed land to be rented out for the first unit will stay constant for $A_e > A_e^{in}$. Proposition II will still hold true as the marginal return of the endowed land under self-cultivation will always keep decreasing for $A_e > A_e^{in}$ as the size of land endowment increases, even if landed agents do not invest attached capital in the endowed land under self-cultivation, either.

Proposition II: *There exists a unique size of land endowment A_e^{out}, above which agents will start renting out land at a given security level of land endowment.*

Fundamentally, renting out land brings both gain and loss in the marginal return of the endowed land to large landed agents who have the accessible credit for attached capital investments but suffer from the agency cost of hired labor. The gain comes from the relatively lower marginal cost of the effective labor input on the rented-out land, as tenants only use family labor but not the less efficient hired labor to cultivate any rented land. The loss comes from the relatively higher unit cost of protecting the rented-out land and its attached capital investments, as renting out land raises the risk of losing the endowed land and its attached capital investments. The moral hazard of tenants not taking care of landlords' land-attached capital under short-term rental contracts also contributes to the loss in the marginal return of the endowed land, given that it raises the capital depreciation rate.

As the size of land endowment increases, the gain keeps increasing while the loss keeps decreasing. As a result, a landed agent will rent out land if and only if her or his size of land endowment exceeds the threshold of renting out land A_e^{out}, at which the gain just equals the loss. In the next section, I will build on this equality condition to study the interaction between the investment effect of higher land ownership security and the concurrent rental-supply effect through the lens of individual land rental supply.

4 Land Rental Supply at Higher Land Ownership Security

In this section, I study land rental supply at higher land ownership security, holding prices constant. First of all, I present the main results using the threshold of renting out land defined in the previous section. Then, I use the first-order condition for the optimal land allocation made by a landlord to explain the economics behind them. These analyses help us understand why securing land ownership may not necessarily increase land rental supply in the presence of multiple market failures, especially the moral hazard of tenants not taking care of landlords' land-attached capital under short-term rental contracts. In the next section, I will explore its welfare implications.

4.1 Main results

As shown in Figure 3, holding prices constant both the marginal return of the endowed land under self-cultivation and the marginal return of the endowed land to be rented out for the first unit will increase for a higher security level of land endowment, at any given size of land endowment. Higher land ownership security raises these marginal returns as it reduces the unit cost of protecting endowed land and its attached capital investments. Agents endowed with land of sizes smaller than the minimum size of land collateral required for credit access A_e^m will only capture the benefit of a lower unit cost of protecting endowed land, as they do not have accessible credit to make attached capital investments. However, agents endowed with land of sizes greater than or equal to A_e^m will capture the additional benefit of a lower unit cost of protecting attached capital investments by using (increased) accessible credit to make more investments. Hence, they will witness relatively larger gains in marginal returns of the endowed land.

The higher intensity of attached capital investments will demand a higher intensity of labor input due to their complementarity in farm production. Holding prices constant, self-cultivating all the endowed land at higher land ownership security will consume all the endowed labor at a smaller size of land endowment for landed agents having access to credit, i.e., the threshold of renting in land A_e^{in} will become smaller at a higher security level of land endowment. However, whether the threshold of renting out land A_e^{out} will also become smaller or not and to what extent depend on the increase in the marginal return of the endowed land to be rented out for the first unit relative to the increase in the marginal return of the endowed land under self-cultivation. The moral hazard of tenants not taking care of landlords' land-attached capital modulates the relative increases in these marginal returns through attached capital investments, as summarized below.

Fundamentally, there are two types of barriers to the even distribution of attached capital investments between the self-cultivated and rented-out land. On the one hand, renting out land raises the risk of losing the insecure endowed land and its attached capital investments and thus the unit cost of protecting them. Higher land ownership security will reduce this protection cost rate gap between the rented-out and self-cultivated land. On the other hand, the moral hazard of tenants not taking care of landlords' land-attached capital generates the capital depreciation risk facing landlords, captured by the capital depreciation rate gap between the rented-out and self-cultivated land. Higher land ownership security, however, does not help close this gap as it comes from non-security barriers to long-term land rental contract, such as legal caps on contract durations and landlords' inclination for flexible short-term contracts (Díaz et al., 2002; Bandiera, 2007).

The capital depreciation rate gap induces landed agents having access to credit to increase attached capital investments more on the self-cultivated land than on the rented-out land at higher land ownership security. This biased investment effect can offset and even surpass the opposite relative investment effect induced by the decreased protection cost rate gap between the rented-out and self-cultivated land. The overall investment effect of higher land ownership security may favor the self-cultivated land, especially when the capital depreciation rate gap is sufficiently large. Nevertheless, the smaller protection cost rate gap reduces the unit cost of protecting the rented-out land more relative to the self-cultivated land, which favors the rented-out land (the rental-supply effect of higher land ownership security). Because of these two potential countervailing effects, the marginal return of the endowed land under self-cultivation may not necessarily witness a smaller increase than the marginal return of the endowed land to be rented out for the first unit. Then, the threshold of renting out land A_e^{out} may not decrease at a higher security level of land endowment.

4.2 Economic analyses

In this section, I demonstrate how the moral hazard of tenants not taking care of landlords' land-attached capital can attenuate the rental-supply effect of higher land ownership security by inducing the bias of the concurrent investment effect toward self-cultivation. For readability, I only present economic reasoning here and put the math in Supplementary Appendices C and D. There are two variables of interest: (i) The threshold of renting out land (the size of land endowment above which landed agents start renting out land); and (ii) the optimal size of the self-cultivated land (the size of the endowed land minus the optimal size of the rented-out land). Their responsivenesses to land ownership security can tell us how higher land ownership security will affect the renting-out behaviors of landed agents at the extensive and intensive margins, respectively.

To proceed, let me introduce Lemma 2 below. It says that the moral hazard of tenants not taking care of landlords' land-attached capital may induce the bias of the investment effect of higher land ownership security towards the endowed land to be self-cultivated. As explained later, this biased investment effect tends to attenuate the rental-supply effect.

Lemma 2*: When the moral hazard of tenants not taking care of landlords' land-attached capital is present, landed agents at the extensive and intensive margins of renting out land may increase the intensity of attached capital investments more on the self-cultivated land than on the rented-out land at higher land ownership security, holding prices constant.*

Renting out land invokes the moral hazard of tenants not taking care of landlords' land-attached capital due to non-security barriers to long-term land rental contracts. As modeled above, this capital depreciation risk facing landlords means a relatively higher depreciation rate for the attached capital invested in the rented-out land on average, namely $d_t > d_o$. Renting out land also raises the risk of losing the endowed land and its attached capital investments, which induces a higher protection cost rate, namely $c_t(S_e) > c_o(S_e)$. Nevertheless, attached capital investments on the rented-out and self-cultivated land share the same shadow price of the accessible credit $i(1 + \mu)$, where μ denotes the shadow value of relaxing the credit constraint (if applicable).

In Section 3, I have shown that landlords are likely among landed agents who have access to credit. *As before, I assume that they invest attached capital in the self-cultivated* *and rented-out land.*[20] However, a landlord tends to invest a relatively lower intensity of attached capital in the rented-out land at a given security level of land ownership $S_e < 1$ (insecure), since the (per-period) marginal cost of attached capital investments on the rented-out land $d_t + c_t(S_e) + i(1+\mu)$ is higher than that on the self-cultivated land $d_o + c_o(S_e) + i(1+\mu)$. This is usually the case, e.g., in rural Nicaragua (Bandiera, 2007).

Holding prices constant, higher land ownership security will decrease the marginal costs of attached capital investments on the self-cultivated and rented-out land, as it lowers their protection cost rates, namely $c_t'(S_e) < 0$ and $c_o'(S_e) < 0$. Importantly, the protection cost rate gap between the rented-out and self-cultivated land $c_t(S_e) - c_o(S_e)$ will decrease given $c_t'(S_e) - c_o'(S_e) < 0$. The increase in the accessible credit resulting from a higher leverage ratio, namely $\theta'(S_e) > 0$, will also lower the marginal costs of attached capital investments by reducing the shadow value of relaxing the credit constraint μ (if applicable). This investment cost reduction will apply equally to the self-cultivated and rented-out land. In sum, the rented-out land will witnesses a higher investment cost reduction. However, a landlord may increase attached capital investments more on the self-cultivated land than on the rented-out land due to the positive, fixed capital depreciation rate gap $d_t - d_o$. This can be particularly true when the decrease in the protection cost rate gap $c_t'(S_e) - c_o'(S_e)$ is not large enough to compensate for the capital depreciation rate gap $d_t - d_o$. Based on this potential biased investment effect of higher land ownership security, I obtain the following two propositions.

Proposition III: *Higher land ownership security may not necessarily decrease the threshold of renting out land when the moral hazard of tenants not taking care of landlords' land-attached capital is present, holding prices constant.*

Proposition IV: *Higher land ownership security may not necessarily decrease the optimal size of the self-cultivated land for a preexisting landlord when the moral hazard of tenants not taking care of landlords' land-attached capital is present, holding prices constant.*

[20] Lemma 2 will automatically hold true if landlords only invest capital in the self-cultivated land.

Propositions III and IV are about the effects of higher land ownership security on land rental supply at the extensive and intensive margins, respectively. At these margins, the marginal return of the endowed land to be self-cultivated should equal the marginal return of the endowed land to be rented out. The associated first-order condition for the optimal land allocation is as follows:

$$MR_o - c_o(S_e)\frac{r(k_n)}{i} = MR_t - c_t(S_e)\frac{r(k_n)}{i},$$

On each side, the first term represents the marginal output revenue of the endowed land (raw land plus its minimal natural attached capital), while the second term represents the unit cost of protecting the endowed land.

Higher land ownership security reduces the risk of losing the endowed land, either self-cultivated or rented out, and thus the associated protection cost rates, namely $c_o'(S_e) < 0$ and $c_t'(S_e) < 0$. Importantly, renting out land will raise the unit cost of protecting the endowed land by a smaller amount than before, namely $c_t'(S_e)\frac{r(k_n)}{i} - c_o'(S_e)\frac{r(k_n)}{i} < 0$. This will incentivize a landed agent to rent out (more) land, holding prices constant, given that renting out (more) land will help her or him reduce the inefficient hired labor input on the endowed land.

Higher land ownership security also reduces the risk of losing attached capital investments and raises the accessible credit. As explained before, holding prices constant, these improvements will incentivize a landed agent to increase attached capital investments on the endowed land, either self-cultivated or rented out, by lowering the associated marginal costs. However, Lemma 2 tells us that this investment effect is likely biased towards the self-cultivated land when the moral hazard of tenants not taking care of landlords' land-attached capital is present. Then, the marginal output revenue of the self-cultivated land may witness a larger increase than the marginal output revenue of the rented-out land, namely $\frac{\partial MR^o}{\partial S_e} > \frac{\partial MR^t}{\partial S_e}$, as attached capital complements land in farm production.

In sum, higher land ownership security may bring about two offsetting effects on land rental supply.[21] The potentially biased investment effect favors self-cultivation and

[21]See the associated comparative statics of renting out land in Supplementary Appendix D.

thus attenuates the concurrent rental-supply effect. In the next section, I use numerical simulations to explore its equilibrium impacts on the economic gains generated from securing land ownership, for a rural economy with an unequal land ownership distribution.

Holding prices constant, individual landowners may have differential exposures to the countervailing investment and rental-supply effects, depending on their investment capacity. In particular, landowners with better access to credit are likely to witness larger positive investment effects. All else equal, they may thus witness smaller and even negative rental-supply effects. In Section 6, I provide empirical evidence supporting this theoretical prediction based on recent household survey data from rural Nicaragua.

5 Welfare Implications

Securing land ownership in Latin America has the great potential to bring about significant gains in agricultural output and poverty reduction (Deininger, 2003). The size of these win-win economic gains, especially the poverty reduction gain, depends on the extent to which the security improvement facilitates an egalitarian distribution of operational land by activating land rental markets (Boucher et al., 2005). However, my theoretical analysis above demonstrates that the investment effect may attenuate the concurrent rental-supply effect, thus limiting equitable access to operational land. This can happen when non-security barriers to long-term land rental contracts are present and severe, a situation that is likely true for some Latin American countries, such as Nicaragua. (Díaz et al., 2002; Bandiera, 2007). In this section, I use numerical simulations to explore the possible impacts of these barriers on the welfare gains generated from securing land ownership for a rural economy similar to rural Nicaragua.

Non-security barriers to long-term land rental contracts induce the moral hazard of tenants not taking care of landlords' land-attached capital. In the theory outlined above, this moral hazard problem is modeled as a positive capital depreciation rate gap between the rented-out and self-cultivated land, namely $d_t > d_o$. In the simulation, I leverage the ratio of these two capital depreciation rates, namely d_t/d_o, to explore the potential impacts of securing land ownership on agricultural output and the wage rate of farm labor at equilibrium. The percentage increase in agricultural output measures the aggregate welfare gain. The percentage increase in the wage rate measures the welfare gain for the rural poor who have no or limited land endowments.[22]

The simulated rural economy has the following relevant characteristics: (i) The land ownership distribution is highly unequal, and a significant portion of households are landless (Corral and Reardon, 2001); (ii) the agency cost of hired labor is pronounced (Frisvold, 1994);[23] (iii) small landed households have no access to credit, regardless of land ownership security (Carter and Olinto, 2003); and (iv) large landed households enjoy higher land ownership security and access to credit before securing land ownership (Boucher et al., 2005). For simplicity and tractability, land rental and labor markets are assumed to be perfectly competitive, while the credit interest rate and land-attached capital price are assumed to be exogenously given. Model parameters are set at reasonable values following the literature. Supplementary Appendix E details the calibration.

Table 1 summarizes the simulation results. The size of the gain in the wage rate of farm labor notably decreases as the capital depreciation rate ratio increases. In parallel, the size of the land rental market expansion also significantly decreases. In fact, the land rental market can even shrink after securing land ownership, when the capital depreciation rate ratio is sufficiently high. These numerical results corroborate the theoretical argument that the size of the poverty reduction gain depends on the extent to which securing land ownership facilitates an egalitarian distribution of operational land through the land rental market (Boucher et al., 2005).

Interestingly, the size of the gain in agricultural output does not always decrease as the capital depreciation rate ratio increases. This is due to the large investment effect, measured by the increase in land-attached capital, which is almost invariant to the capital depreciation rate ratio. Intuitively, a higher capital depreciation rate ratio means a higher

[22]In reality, all landowners can benefit from labor-based land-attached investments, such as terracing, which is not of research interest in this paper as it is not biased towards large landowners.

[23]Estimates for the agency cost of hired labor in Nicaragua or other Latin American countries are not available in the empirical literature. Therefore, I use a reasonable estimate based on Frisvold (1994)'s work on rural India. See details in Supplementary Appendix E.

depreciation risk for landlords' attached capital invested in the rented-out land. This higher capital depreciation risk will discourage more landed households from renting out land, which shrinks the donor pool of landlords before land ownership is secured. That is, fewer landed households will suffer from the investment effect attenuating the concurrent rental-supply effect. Hence, the overall investment effect of securing land ownership can still be large when the capital depreciation risk increases. In sum, the capital depreciation risk tends to disproportionately diminish the welfare gain for the rural poor, who have no or limited land endowments, that is generated from securing land ownership.

6 Empirical Evidence

In this section, I provide supportive evidence from Nicaragua on the countervailing investment and rental-supply effects of securing land ownership. In short, I find that recent security improvement programs increased land-attached investments but reduced land rentals for rural Nicaraguan households. Heterogeneity analyses reveal that these unbalanced effects are pronounced among households who had relatively large initial land endowments and lived in districts with relatively better credit supply conditions. These findings are consistent with the theoretical prediction that large landowners with better access to credit are more likely to face severe countervailing investment and rental-supply effects as they have higher capacity to materialize the investment effect. As follows, I describe the context and data first. Then, I outline the empirical strategy and econometric design. Finally, I present and discuss results.

6.1 Context and data

Nicaragua is one of the poorest countries in Latin America. According to the World Bank's recent poverty assessment report, about 70% of rural Nicaraguan lived under poverty in 2005 (Demombynes, 2008). Part of the reason is that rural Nicaragua has suffered from insecure land ownership due to the incomplete agrarian reforms of the 1980s (Stanfield, 1995). In light of this and others, the Nicaraguan government and various donors like the World Bank have exerted constant efforts to improve land ownership security in rural Nicaragua since the 1990s. In this paper, I focus on recent security improvement programs, mainly the World Bank's land administration program (contributing to about 80% of enrolled households).[24] This program further improved land ownership security in rural Nicaragua by systematically demarcating land boundaries, resolving ownership conflicts, and titling as well as registering land (De la O Campos et al., 2023).[25] The other security improvement programs employed similar approaches. Hereafter, I use the term "program" to refer to these security improvement programs.

The data that I use in this paper is from the household surveys conducted by the Millennium Challenge Corporation's rural business development project in Nicaragua (University of California, Davis, 2012). The rural business development project is an RCT that aims to raise households' incomes by helping farmers develop and implement agricultural business plans through technical and financial training as well as input supplies (Carter et al., 2019). The rural business development project was implemented in the western region of Nicaragua, including the departments of Chinandega and León, from 2007 to 2011. Like other Nicaraguan regions, agriculture played a central role in this region, although the western region was more suitable for agricultural business development. In 2005, this region had a rural poverty rate of 73%, a figure comparable to other regions. In each rural community, the project identified a group of eligible farmers who had prior experiences in the same agricultural crop (sesame, beans, vegetables, or cassava) or livestock.[26] These eligible crop and livestock farming households were then randomly selected for three rounds of household surveys. The rural business development project was randomly assigned at the community level though.

In my empirical analysis, I focus on the first two survey rounds (2007/2009) during which a large proportion of surveyed households started participating in security improve-

[24] Early security improvement programs, such as the land management component of the World Bank's agricultural technology and land management project, mainly focused on titling for agrarian reform land. They improved land ownership security but did not fully eliminate the risk of losing the land and its attached investments. These early security programs had notably boosted land-attached investments but not land rental activities (Deininger and Chamorro, 2004; Boucher et al., 2005). I find similar effects of recent security improvement programs at the household level.

[25] See program details at https://documents1.worldbank.org/curated/en/790831468756987463/pdf/multi0page.pdf.

[26] See details about surveyed communities and project eligibilities in Carter et al. (2012).

ment programs.[27] A panel of 1579 households living in 142 communities were covered in these surveys. For identification purpose, I focus on the 1103 households who had not yet participated in any security improvement programs by the first survey round. In other words, I identify the treatment effects of security improvement programs by comparing the outcomes of interest between switchers and never-takers.

Table 2 provides summary statistics of the main data used in this paper. Households had similar family sizes with an average number of household members between 5 and 6. An average household head was of an age above 52 and had less than 4 years of schooling. Among these 1103 households, 257 or about 23% of them participated in security improvement programs between the two survey rounds.

At survey round 1, households had an average land endowment of 36.6 manzanas (63.7 acres) with a sizable dispersion across households. This number slightly increased to 37.1 manzanas (64.6 acres) by survey round 2 mostly due to land purchases, especially made by program participants. Meanwhile, work-oriented migration rate increased by 8 percentage points; on average, 0.1 more household members migrated from 2007 to 2009. My regression analysis suggests that program participants who initially had relatively small land endowments migrated more for work whereas those who initially had relatively large land endowments did the opposite.

Among the 1103 households, 318 of them changed their land endowments more or less due to purchases, sales, and inheritances. To fix ideas, I focus on panel plots within each household as my goal in this paper is to provide evidence on the countervailing investment and rental-supply effects of securing land ownership predicted by my theory. Nevertheless, my theory can also shed lights on the impacts of securing land ownership on land endowments and migration. I will articulate this point in Section 7 where I outline future research. In my empirical analysis, I will also show that my main results are robust to changes in land endowments and migration.

Table 2 shows that most households had attached facilities (e.g., livestock corrals and water tanks, pigsties, chicken coops, storehouses, irrigation wells, etc.) on their panel plots

[27]New program participants were limited between the second and third survey rounds.

at survey round 1 and the share of these households increased by 2 percentage points by survey round 2. The average monetary-metric amount of attached facilities also increased by 3 thousand córdobas (about 147 U.S. dollars in 2009) at the household level. These increases in attached facilities are mostly common trends for both program participants and nonparticipants. These two types of households also experienced similar increases in rented-out land. My empirical results indicate that households actually reduced the area of rented-out land after participating in security improvement programs, especially among those who initially had relatively large land endowments.

The sizable reductions in perennial trees (e.g., citrus, mangoes, cashews, avocados, bananas, coconuts, etc.) planted on the panel plots, however, only apply to program nonparticipants. In fact, program participants with relatively large initial land endowments witnessed significant increases in planted trees. By leveraging differential exposures to credit supply shocks across survey districts from 2007 to 2009, I provide evidence that the opposite program impacts on planted trees and rented-out land were possibly due to the countervailing investment and rental-supply effects of securing land ownership, as predicted by my theory.

In terms of agricultural credit used by each household, no time patterns stand out. But my empirical results show that households significantly increased agricultural credit use after participating in security improvement programs, which helps explain the associated increases in planted trees.[28] When it comes to (long-term) hired labor, there is a downward trend. However, my empirical results show that households hired more labor after program participation, especially among those who initially had relatively large land endowments.

6.2 Identification strategy and econometric design

My first goal is to identify the average impacts of security improvement programs on land-attached investments (attached facilities and planted trees) and rented-out land at the household level. There are three empirical changes. First, program participation was

[28]Households often used agricultural credit to finance expenditures on agricultural production cycles. Apart from the initial establishment costs, perennial trees require recurring inputs, such as irrigation, fertilization, pest and weed control, before reaching fruit maturity. Households, however, usually relied on their own funds for investments in land-attached facilities.

not random in my setting; households and communities were thus self-selected into the treatment. Second, security improvement programs could have equilibrium effects on factor prices, such as credit interests and labor wages, which could in turn affect households' decisions on land-attached investments and land rentals on top of land ownership security. Third, community-level confounding time trends, such as the evolution of non-farming outside options and the implementation of the rural business development project, could also affect households' choices of land-attached investments and land rentals.

To address the second and third identification concerns, I include community-level time trends in all regressions. Regarding the first identification concern, I control for confounding household characteristics and baseline outcomes in each outcome regression. I use LASSO and stepwise regressions to pin down specific household characteristics and baseline outcomes that significantly predict households' program participation within a community. Table 3 shows that conditional on community fixed effects, households who felt unsafe about their land properties or had low shares of endowed land with public deed documents at survey round 1 were more likely to participate in security improvement programs by survey round 2. This makes sense as the World Bank's land administration program, the major program recorded in the data, aimed to systematically increase land ownership security by demarcating land boundaries, resolving ownership conflicts, and formalizing land documents. De la O Campos et al. (2023) shows that this program significantly increased participants' perceived land ownership security.[29] The other predictive household characteristics are the age and education of household head. The relevant outcome variables include the amount of attached facilities and whether planting trees or renting in land. All the variables are measured at survey round 1.

The household-level program participation can be plausibly regarded as exogenous when the confounding factors—community-level time trends and household-level relevant characteristics and baseline outcome variables—are controlled for. Given that, I use the following linear regression model to estimate the impacts of security improvement

[29] In my data, households also increased their perceived land ownership security after participating security improvement programs, although this increase is not statistically significant possibly due to the fact that more than 90% of households already felt safe about their land properties in survey round 1.

programs on household-level land-attached investments and rented-out land:

$$Y_{i,2} = \alpha \times Y_{i,1} + \beta \times program\_enrollment_i \\ + household\_confounding\_factors'_{i,1}\gamma + community\_fixedeffects_{j(i)} + v_i,$$

where (i) $Y_{i,2}$ and $Y_{i,1}$ are the outcome variables of interest for household i in survey round 2 and 1, respectively; (ii) $program\_enrollment_i$ is a dummy variable indicating if household i was enrolled in a security improvement program by survey round 2; (iii) $household\_confounding\_factors_{i,1}$ are the selected household characteristics and outcome variables measured in survey round 1, which control for the selection of households into security improvement programs, together with the flexible time trend of community j where household i resided, namely $community\_fixedeffects_{j(i)}$; and (iv) v_i is the regression error or anything not modeled in the regression.

My main outcomes of interest are household-level land-attached investments and rented-out land as well as agricultural credit. Land-attached investments are physical facilities installed and perennial trees planted on the panel plots owned by each household. Outcomes for rented-out land are also based on the panel plots owned by each household. Agricultural credit, however, is a pooled resource across all plots within a household. I use agricultural credit to investigate the mechanism behind the program impacts on land-attached investments and rented-out land. As shown in Table 2, these outcomes are censored below zero. Hence, I use both the dummy and continuous variables to measure each outcome in the linear regression model above. For the continuous variable, following Chari et al. (2021), I transform the original data using the inverse hyperbolic sine to deal with the censoring. Other outcomes of interest include long-term hired labor, migration and the area of endowed land (logged).[30] I use these outcomes to facilitate my discussions on the main outcomes of interest.

My theory predicts the countervailing investment and rental-supply effects of securing land ownership. In line with this, I find that program participants significantly increased

[30]The first two outcomes are censored below zero. Thus, I use their dummy and continuous variables (transformed by inverse hyperbolic sine) for regression analyses.

land-attached investments after program enrollment while they reduced land rentals. As expected, these findings are pronounced among households who initially had relatively large land endowments. My second-but-primary empirical goal is to provide evidence on the credit channel through which the counteraction may take effect. To do this, I conduct heterogeneity analyses by leveraging differential exposures to credit supply shocks across survey districts from 2007 to 2009.

The credit supply shocks come from the combination of the global financial crisis and the Nicaraguan microfinance crisis in 2008, which significantly reduced credit supply in the formal financial sector for rural Nicaraguans.[31] The rural household survey classifies credit unions, private and microfinance banks as formal credit providers[32] Panel A of Figure 4 shows that the total amount of formal credit decreased by more than 40% while the total amount of informal credit increased by more than 60%. Importantly, Panel B shows that survey districts that initially had formal credit shares above the median experienced a reduction in the aggregate credit by roughly 40% while the other group of survey districts only witnessed a reduction of less than 5%.

For agricultural credit, the former district group experienced a reduction of more than 10% whereas the latter district group witnessed the opposite, as shown in Panel C of Figure 4. Meanwhile, Panel D shows that agricultural credit interest rates increased by more than 1 percentage point in the former district group whereas they decreased by more than 3 percentage points in the latter district group.[33] These contrast changes in credit amounts and interest rates suggest that survey districts with initial formal credit shares below the median experienced a smaller decrease in credit supply. Regression results show that in these districts, households used more agricultural credit, made more land-attached investments and rent out less land after participating in security improvement programs. This is in line with my theoretical prediction that landowners with higher investment capacity are more likely to face the countervailing investment and rental-supply effects.

[31] Bastiaensen et al. (2013) shows that in 2008, the local Non-Payment Movement substantially reduced both the credit supply capacity and lending willingness of Nicaraguan microfinance banks. Meanwhile, international donors significantly reduced funding to these banks during the global financial crisis.

[32] Informal providers include various cooperatives, NGOs, friends, merchants and money lenders, etc.

[33] The Central Bank of Nicaragua reduced long-term lending interest rates by 3.5% from 2008 to 2009.

6.3 Main results

Table 4 shows that on average, participation in security improvement programs significantly increased planting trees by 9%. Households who initially had land endowments above the median (large landowners) witnessed slightly smaller increases at this extensive margin. Security improvement programs also sizably increased participants' numbers of planted trees, roughly by 37%.[34] At this intensive margin, large landowners experienced much larger increases though. They also experienced moderate increases in attached facilities while small landowners did not (slight reduction if any), although these results are not statistically significant.

When it comes to land rentals, program participants reduced activities of renting out land at both the extensive and intensive margins. In particular, large landowners significantly reduced the area of rented-out land by roughly 13% after program participation.[35] My theory predicts that large landowners may reduce their land rental supply when they make land-attached investments in response to an improvement in land ownership security, as short-term rental contracts provide tenants limited incentives to take care of such long-term investments. The data show that more than 95% of rented land was under short-term rentals (below one year). Rental durations did not increase even as more households participated in security improvement programs.

Large landowners who have better access to credit are more likely to face severe countervailing investment and rental-supply effects of securing land ownership, holding other things constant. To test this theoretical prediction, I exploit variation in credit supply across survey districts between 2007 and 2009, which was plausibly driven by the 2008 global financial crisis and Nicaraguan microfinance crisis. As explained in Section 6.2, survey districts with initial formal credit shares below the median witnessed limited reductions in credit supply, as they were much less affected by these financial crises. Table 5 shows that large landowners in these survey districts with low formal credit shares significantly used more agricultural credit, made more land-attached investments

[34] Changes in variables transformed by inverse hyperbolic sine are approximately percentages.

[35] Small landowners also reduced land rentals, as some of them chose to expand agricultural production. For example, they significantly increased land endowments and family labor, as shown in Table A.4.

(particularly trees), and rented out less land, after participating in security improvement programs.[36] As expected, they also hired more long-term labor.

Large landowners have incentives to rent out land to reduce the agency cost of hired labor. To partly test this argument, I add the labor to land ratio and area of land endowment into the regression model outlined in Section 6.2 and rerun regressions for land rentals. The number of household member divided by the area of land endowment in survey round 1 is defined as the labor to land ratio. Table 6 shows that a higher labor-to-land ratio is significantly associated with a smaller area of rented-out land. The magnitude of this negative relationship is more pronounced among large landowners. These findings hold true for landowners who experienced no changes in land endowments or migration between survey rounds. Furthermore, Figure A.4 in Supplementary Appendix F shows that my data fits my theoretical model broadly well in the patterns of the labor to land ratio, land-attached investments, land rentals, and (long-term) hired labor.

6.4 Robustness checks and discussions

For reasons explained in Section 6.2, I focus on land-attached investments and land rentals for panel plots owned by each household. However, households experienced changes in resource allocation beyond land-attached investments and land rentals between survey rounds. In particular, Table A.4 in Supplemental Appendix F shows that small and large landowners significantly increased land endowments, mostly through land purchases, after participating in security improvement programs.

An increase in the land endowment will lower the ratio of endowed labor to land, which may incentivize large landowners to rent out (more) land. This is not a concern for my main results as I find that large landowners, especially those from survey districts with limited decreases in credit supply, reduced the area of rented-out land after program participation. Nevertheless, Table A.5 in Supplemental Appendix F shows that this result holds true when I restrict my sample to households with constant land endowments, although statistical significance drops due to smaller sample sizes.

[36] To increase sample sizes, I reclassify households with initial land endowments above 15 manzanas (35 percentile) as large landowners.

Table A.4 in Supplemental Appendix F also shows that small landowners significantly migrated more for off-home work after participating in security improvement programs. This is consistent with the empirical literature (e.g., de Janvry et al. 2015; Liu et al., 2023). In contrast, large landowners slightly reduced their migration, if any, after program participation. A reduction in migration will increase the available family labor for farming, which may discourage large landowners from renting out land. Table A.6 in Supplemental Appendix F shows that large landowners who experienced no changes in migration between survey rounds still reduced the area of rented-out land after program participation. This is especially true for households from survey districts with limited decreases in credit supply, as they significantly used more agricultural credit and made more land-attached investments after program participation.

In my theory, I do not consider agricultural machines, which may have notable economies of scale. Foster and Rosenzweig (2022) shows that in rural India, larger farms are more suitable to exploit scale economies in machinery capacity. As a result, farm productivity may rise with farm size once it exceeds a small threshold. This will hold true before a farm reaches the maximum size for machines' economies of scale. The implication is that households with land endowments below the maximum farm scale will not have incentives to rent out land, regardless of land ownership security. In my data, the common scalable agricultural machines include sprayers, tractors and related equipment as well as forage choppers[37]. Sprayers are a typical agricultural machine with economes of scale. Foster and Rosenzweig (2022) estimated that the maximum farm scale for sprayers in rural India is about 24 acres. In my empirical analyses, large landowners are defined as households who had land endowments of at least 15 manzanas or 26 acres, exceeding this maximum farm scale. Hence, their farm productivity may not rise with farm size, although sprayers in Nicaragua could differ from those in India. The fixed transaction cost of hiring short-term labor is less of a concern as large landowners mainly hired long-term labor with an average duration about a year. See detailed hiring patterns in Figure 5.

[37]The other common agricultural equipment includes working animals (horses or oxen), grain silos, horse or ox carts, water pumps, liquid containers, trucks, chainsaws, etc.

7 Conclusion

This paper studies the interaction between the investment and rental-supply effects of securing land ownership, which have been treated mostly in isolation. Based on a novel agricultural household model, I demonstrate that the investment effect can attenuate the concurrent rental-supply effect due to non-security barriers to long-term land rental contracts. Intuitively, these non-security barriers, such as legal caps on contract durations and landlords' inclination for flexible short-term contracts, trigger the moral hazard of tenants not taking care of landlords' long-term land-attached investments under short-term rental contracts. Because of this capital depreciation risk, potential landlords prefer to invest attached capital in the endowed land to be self-cultivated. This biased investment effect favors self-cultivation and thereby discourages potential landlords from renting out (more) land at higher land ownership security.

I provide supportive evidence on the countervailing investment and rental-supply effects of securing land ownership from Nicaragua, one of the poorest countries in Latin America. Using recent panel data of rural household surveys, I find that security improvement programs, mainly the World Bank's land administration program, significantly increased land-attached investments (trees) but reduced the area of rented-out land at the household level. By leveraging differential exposures to credit supply shocks from the 2008 financial and microfinance crises across survey districts, I find that large landowners in less-affected districts significantly increased agricultural credit use, expanded land-attached investments, and reduced land rentals after program participation. This is consistent with the theoretical prediction that landowners with higher investment capacity face more severe countervailing investment and rental-supply effects of securing land ownership.

The theory developed in this paper deepens our understanding of how market failures could limit the equitable distribution of economic benefits generated from land tenure security. Without the moral hazard of tenants not taking care of landlords' land-attached capital, securing land ownership would facilitate the egalitarian distribution of the operational land among agents with heterogeneous land endowments and the even distribution of attached capital between the self-cultivated and rented-out land. By doing so, securing land ownership would help circumvent the agency cost of hired labor and the credit rationing of small landowners, thereby generating a more equitable distribution of welfare gains for a rural economy endowed with an unequal land ownership distribution, as evidenced by numerical simulations.

In the current model, I do not consider some relevant features of modern agriculture, such as machinery input. This simplification makes the model tractable without losing the generality of its prediction on the countervailing investment and rental-supply effects of securing land ownership. Agricultural machines or equipment substitute labor and favor large farms due to economies of scale (e.g., Sheng et al., 2019; Foster and Rosenzweig, 2022). Importantly, it may induce a U-shape relationship between the unit return of land and farm size and thus change the donor pool of landlords, e.g., potential landlords may be only among landholders with medium sizes of land endowment. This can be particularly true in the communal or collective land tenure system where landholdings are usually not large. Nevertheless, the data used in this paper indicate that most landlords in rural Nicaragua are landowners with landholdings large enough to exceed the maximum farm size at which scale economies in machinery capacity can be achieved.

An important channel missing from the model is sectoral labor allocation, through which securing land ownership can also influence agricultural output and labor income (e.g., de Janvry et al., 2015; Chen, 2017; Gottlieb and Grobovšek, 2019). My empirical analysis shows that in rural Nicaragua, security improvement programs increased work-oriented migration among small landowners, but not among large landowners. My theory suggests that large landowners, due to better access to credit, are able to reap sizable investment benefits and therefore do not migrate. How did this interplay affect sectoral labor allocation or structural transformation for Nicaragua remains unknown, which I leave for future research.[38]

[38]The existing literature has primarily examined the interaction between land and sectoral labor allocations and its implications for output and income gains from improvements in land tenure security. See a comprehensive review conducted by Deininger et al. (2022). More recently, Adamopoulos et al. (2022) find that idiosyncratic capital market frictions exacerbate sectoral labor misallocation in rural China. Whether the systematic capital market frictions contribute to sectoral labor misallocation in Nicaragua depends on the distribution of human capital among households with varying land endowments.

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Main Tables

Table 1: The Simulated Resource Allocation and Welfare Impacts of Securing Land Ownership.

capital depreciation rate ratio $(d_t/d_o)^a$	impacts at equilibrium land-attached capital[b]	rented-out land[b]	agricultural output	wage rate
1.5	21.2%	4.6%	5.3%	3.1%
2.0	19.7%	0.9%	4.9%	2.4%
2.5	20.6%	-1.4%	4.9%	2.0%

Note: [a]The capital depreciation rate ratio between the rented-out and self-cultivated land measures the degree to which tenants do not take care of landlords' land-attached capital. When the capital depreciation rate ratio equals one, tenants take sufficient care of landlords' land-attached capital. In this ideal case, almost all large landed households will rent out part of their land, even before securing land ownership, such that no one will hire labor on their farms. This will cause a mechanical kink in the relationship between the listed equilibrium impacts and the capital depreciation rate ratio; therefore, I do not report it here to avoid unnecessary confusion. [b]Changes in land-attached capital and rented-out land are measured in percentage points. For rented-out land, it is compared to the gross endowed land; for land-attached capital, it is compared to the maximum accessible credit, the product of the gross endowed land and the maximum applicable credit per land collateral.

Table 2: Summary Statistics of the Household Survey Data.

variable	round 1 (mean/s.e.)	round 2 (mean/s.e.)	difference (mean/s.e.)
No. of household members	5.27	-[a]	-[a]
	[2.23][b]		
age of household head (years)	52.93	-	-
	[13.33]		
education of household head (school years)	3.75	-	-
	[4.02]		
enrolled in a security improvement program (0/1)	0	0.23	0.233***
	[NA]	[0.42]	(0.020)[c]
area of endowed land (manzana)	36.60	37.13	0.525
	[42.27]	[43.96]	(0.477)
migration (work off home for 6+ months, 0/1)	0.07	0.16	0.081***
	[0.26]	[0.36]	(0.011)
number of migrated household members	0.09	0.20	0.106***
	[0.34]	[0.51]	(0.016)
having attached facilities (0/1)	0.85	0.87	0.020***
on panel plots within a household	[0.36]	[0.34]	(0.005)
amount of attached facilities (1,000 córdoba)	20.73	23.78	3.048***
on panel plots within a household	(36.46)	(40.09)	(0.537)
planting trees in two years (0/1)	0.51	0.47	-0.043**
on panel plots within a household	[0.50]	[0.50]	(0.020)
number of planted trees in two years	224.75	150.04	-74.711***
on panel plots within a household	[850.64]	[511.34]	(22.986)
renting out land (0/1)	0.05	0.06	0.015**
of panel plots within a household	[0.21]	[0.24]	(0.006)
area of rented-out land (manzana)	0.51	0.65	0.140**
of panel plots within a household	[4.06]	[4.30]	(0.063)
credit usage for agriculture (0/1)	0.42	0.40	-0.016
pooled at the household level	[0.49]	[0.49]	(0.015)
credit amount for agriculture (1,000 córdoba)	15.48	19.04	3.565
pooled at the household level	[52.37]	[87.31]	(2.898)
hiring long-term labor (0/1)	0.27	0.25	-0.015
pooled at the household level	[0.44]	[0.44]	(0.014)
amount of long-term hired labor (month)	4.84	3.57	-1.267***
pooled at the household level	[10.75]	[7.17]	(0.323)
No. of households	1103	1103	1103
No. of communities	137	137	137
No. of survey districts	56	56	56

Note: [a]I only report household members and demographics of household heads in the first survey round due to their limited changes between survey rounds. [b]The standard errors in brackets are the standard deviations across households. [c]The standard errors in the parentheses are clustered at the survey district level for comparisons between survey rounds. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 3: Household-level Predictors for Enrollment in Security Improvement Programs.

household variables (survey round 1)	enrolled in a security program (0/1)		
	LASSO choice[a]	stepwise choice[b]	my choice[c]
feel safe about land property	-0.149***	-0.139***	-0.145***
(0/1)	(0.044)	(0.046)	(0.046)
share of endowed land with	-0.097***	-0.105***	-0.106***
public deed documents	(0.026)	(0.027)	(0.027)
education of household head	-0.011***	-0.012***	-0.012***
(school years)	(0.003)	(0.003)	(0.003)
age of household head	-0.003***	-0.003***	-0.003***
(years)	(0.001)	(0.001)	(0.001)
amount of attached facilities	-0.007**	-0.009**	-0.009**
(inverse hyperbolic sine)	(0.003)	(0.003)	(0.003)
planting trees in two years	-0.035	-0.038*	-0.037*
(0/1)	(0.021)	(0.020)	(0.020)
renting in land	-0.052*	-0.054**	-0.053**
(0/1)	(0.026)	(0.026)	(0.026)
area of endowed land	-1.86e-06		
squared	(1.62e-6)		
share of endowed land with	-0.020		
own names on the land documents	(0.034)		
amount of long-term ag credit	-0.002		
(inverse hyperbolic sine)	(0.003)		
hiring short-term labor	-0.035		
(0/1)	(0.041)		
hiring any labor	-0.008		
(0/1)	(0.029)		
hiring long-term labor		-0.196	
(0/1)		(0.120)	
amount of long-term hired labor		0.055	
(inverse hyperbolic sine)		(0.036)	
community fixed effects	YES	YES	YES
F statistics	5.12***	5.80***	6.69***
p-value for F statistics	0.00	0.00	0.00
adjusted R^2	0.41	0.41	0.41
within R^2	0.07	0.06	0.06
No. of observations[d]	1096	1096	1096
No. of survey districts (cluster)[d]	55	55	55

Note: This table reports post-selection regression results estimated using *reghdfe*, which adjusts degrees of freedom to account for fixed effects. [a]I use LASSO with cross validation to select predictive household variables for program enrollment. [b]I also use forward and backward stepwise regressions for the variable selection with 10% as the significance threshold. Community fixed effects are always included due to the reasons discussed in Section 6.2. Apart from the 14 listed variables, the other 18 household variables included in the LASSO and stepwise regressions are area of endowed land, share of endowed land with registered documents, number of household members, gender of household head, perceived formal credit access, amount of formal credit (inverse hyperbolic sine), amount of any credit (inverse hyperbolic sine), migration (dummy), number of migrated household members (inverse hyperbolic sine), having attached facilities, number of planted tress in two years (inverse hyperbolic sine), amount of agricultural equipment (inverse hyperbolic sine), renting out land, area of rented-out land (inverse hyperbolic sine), area of rented-in land (inverse hyperbolic sine), amount of family labor (inverse hyperbolic sine), amount of short-term hired labor (inverse hyperbolic sine), and amount of any hired labor (inverse hyperbolic sine). [c]I choose household variables based on their post-selection statistical significance. [d]7 singleton observations and 1 survey district are dropped by *reghdfe* in all post-selection regressions. Standard errors in the parentheses are clustered at the survey district level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 4: The Impacts of Security Improvement Programs on Land-attached Investments and Land Rentals.[a]

outcome variable	all landowners	small landowners[b]	large landowners[b]
No. of attached facilities	0.05	-0.07	0.12
(inverse hyperbolic sine)	(0.15)	(0.22)	(0.18)
having attached facilities (0/1)	-0.00	-0.01	0.00
	(0.01)	(0.02)	(0.02)
No. of trees planted in two years	0.37	0.15	0.63
(inverse hyperbolic sine)	(0.24)	(0.31)	(0.40)
planting trees in two years (0/1)	0.09**	0.09	0.06
	(0.04)	(0.06)	(0.06)
area of rented-out land	-0.06	-0.11	-0.13*
(inverse hyperbolic sine)	(0.08)	(0.09)	(0.07)
renting out land (0/1)	-0.02	-0.03	-0.05
	(0.03)	(0.04)	(0.03)
lag of the outcome variable	YES	YES	YES
household-level confounding factors[c]	YES	YES	YES
community-level fixed effects	YES	YES	YES
No. of household observations[d]	1096	538	521

Note: [a]I use the regression model outlined in Section 6.2. In this table, I report the coefficients and standard errors for the program impacts on each outcome variable. For reasons explained there, I focus on panel plots owned by each household between the two survey rounds. [b]Small landowners had land endowments below the median by survey round 1; the rest of landowners are classified as large landowners. [c]Table 3 lists household-level confounding factors. [d]Singleton observations are dropped in each fixed-effect regression; hence numbers of household observations are not exactly matched. Standard errors in the parentheses are clustered at the survey district level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 5: Formal Credit Shocks and the Impacts of Security Improvement Programs on Land-attached Investments and Land Rentals among Large Landowners.[a]

outcome variable	districts with high formal credit share[b]	districts with low formal credit share	all districts pooled
amount of agricultural credit	0.31	1.58**	1.02*
(inverse hyperbolic sine)	(0.85)	(0.59)	(0.53)
agricultural credit usage (0/1)	0.02	0.15**	0.09*
	(0.08)	(0.06)	(0.05)
No. of attached facilities	-0.01	0.43	0.19
(inverse hyperbolic sine)	(0.14)	(0.42)	(0.22)
having attached facilities (0/1)	-0.01	0.03	0.01
	(0.01)	(0.03)	(0.02)
No. of trees planted in two years	0.31	1.06*	0.66**
(inverse hyperbolic sine)	(0.41)	(0.53)	(0.32)
planting trees in two years (0/1)	0.07	0.18**	0.12**
	(0.07)	(0.09)	(0.05)
area of rented-out land	-0.04	-0.17**	-0.09
(inverse hyperbolic sine)	(0.10)	(0.07)	(0.06)
renting out land (0/1)	0.01	-0.07**	-0.02
	(0.04)	(0.03)	(0.03)
amount of long-term hired labor	0.08	0.28	0.19
(inverse hyperbolic sine)	(0.15)	(0.23)	(0.14)
hiring long-term labor (0/1)	0.07	0.06	0.07
	0.05	0.07	0.04
lag of the outcome variable	YES	YES	YES
household-level confounding factors[c]	YES	YES	YES
community-level fixed effects	YES	YES	YES
No. of household observations	347	351	698

Note: [a]I use the same regression model as in Table 4. To increase sample sizes, I reclassify households with land endowments above 15 manzanas (35 percentile) as large landowners. [b]These districts had initial formal credit shares above the median by survey round 1. [c]Table 3 lists household-level confounding factors. Standard errors in the parentheses are clustered at the survey district level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 6: Labor to Land Ratios and Land Rentals.[a]

outcome variable	all landowners	small landowners[b]	large landowners[b]
Panel A: Panel plots owned by each household			
area of rented-out land	-0.10**	-0.06	-0.28
(inverse hyperbolic sine)	(0.04)	(0.09)	(0.32)
renting out land (0/1)	-0.04*	-0.02	-0.08
	(0.02)	(0.04)	(0.10)
Panel B: Households with constant land endowments			
area of rented-out land	-0.09*	-0.02	-0.34
(inverse hyperbolic sine)	(0.05)	(0.07)	(0.29)
renting out land (0/1)	-0.04	-0.01	-0.11
	(0.02)	(0.04)	(0.08)
Panel C: Households without changes in migration			
area of rented-out land	-0.10*	-0.08	-0.12
(inverse hyperbolic sine)	(0.05)	(0.09)	(0.24)
renting out land (0/1)	-0.04	-0.02	-0.04
	(0.03)	(0.05)	(0.09)
lag of the outcome variable	YES	YES	YES
household-level confounding factors[c]	YES	YES	YES
community-level fixed effects	YES	YES	YES

Note: [a]The labor to land ratio is measured by the number of household members divided by the area of endowed land in survey round 1. I exclude 1% of households who had land endowments below 2 manzanas in survey round 1 as their labor to land ratios are too large to be relevant for changes in land rentals. Then, I add the labor to land ratio and area of land endowment as two additional regressors into the regression model outlined in Section 6.2. Here, I report the coefficients and standard errors for the labor to land ratio in each regression. [b]Small landowners had land endowments below the median by survey round 1; the rest of landowners are classified as large landowners. [c]Table 3 lists household-level confounding factors. Standard errors in the parentheses are clustered at the survey district level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Main Figures

Revenues (+)

	Production Periods 0	1
Output revenue: self-cultivated land		$pF(A_o, A_o k_o + A_o k_n, L_o)$
rented-in land		$pF(A_t^{in}, A_t^{in} k_t^{in} + A_t^{in} k_n, L_t^{in})$
Land rent: rented-out land		$A_t^{out} r(k_t^{out} + k_n)$
Labor wage: hired-out labor		wL_h^{out}

Costs (-)

	0	1
Upfront investments: attached capital investments on the self-cultivated land	$A_o k_o$	
attached capital investments on the rented-out land	$A_t^{out} k_t^{out}$	
Maintenance costs: the attached capital invested in the self-cultivated land		$d_o A_o k_o$
the attached capital invested in the rented-out land		$d_t A_t^{out} k_t^{out}$
Protection costs: self-cultivated land & its attached capital investments		$c_o(S_e) A_o \left[\frac{r(k_n)}{i} + k_o\right]$
rented-out land & its attached capital investments		$c_t(S_e) A_t^{out} \left[\frac{r(k_n)}{i} + k_t^{out}\right]$
Land rent: rented-in land		$A_t^{in} r(k_t^{in} + k_n)$
Labor wage: hired-in labor		wL_h^{in}

Figure 1: The General Structure of Revenues and Costs.

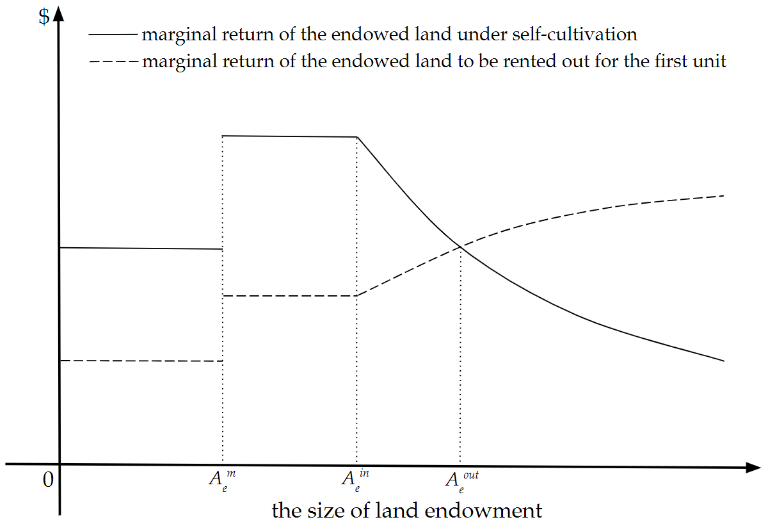

Figure 2: Thresholds of Renting in and out Land at a Given Security Level of Land Endowment.

Note: (i) The marginal return of the endowed land equals the marginal output revenue of the endowed land minus its unit protection cost (fixed at given security). (ii) A_e^m is the minimum size of land collateral required for credit access. (iii) The threshold of renting in land A_e^{in} is the size of land endowment above which landed agents stop renting in land. (iv) The threshold of renting out land A_e^{out} is the size of land endowment above which landed agents start renting out land.

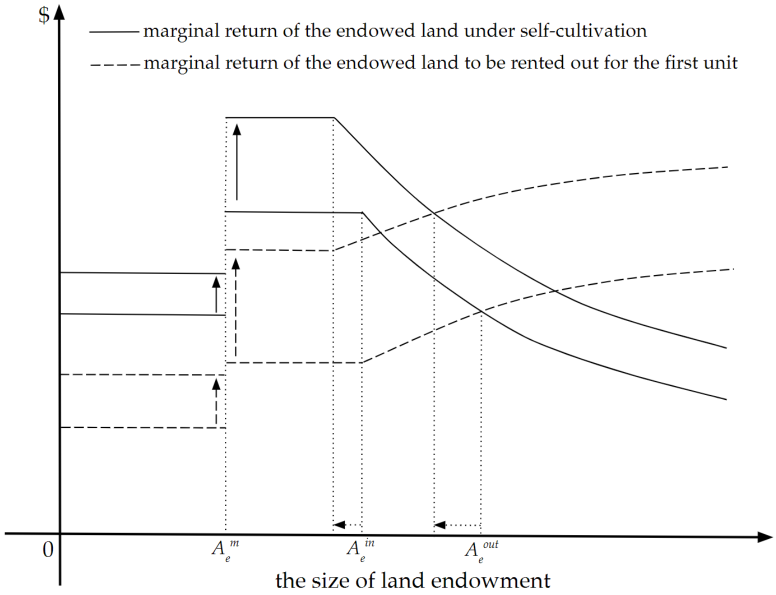

Figure 3: Thresholds of Renting in and out Land at a Higher Security Level of Land Endowment.

Note: (i) The marginal return of the endowed land is defined as the marginal output revenue of the endowed land minus its unit protection cost. Higher land ownership security will reduce the unit cost of protecting the endowed land and its attached capital investments. (ii) A_e^m is the minimum size of land collateral required for credit access. (iii) The threshold of renting in land A_e^{in} is the size of land endowment above which landed agents stop renting in land. (iv) The threshold of renting out land A_e^{out} is the size of land endowment above which landed agents start renting out land.

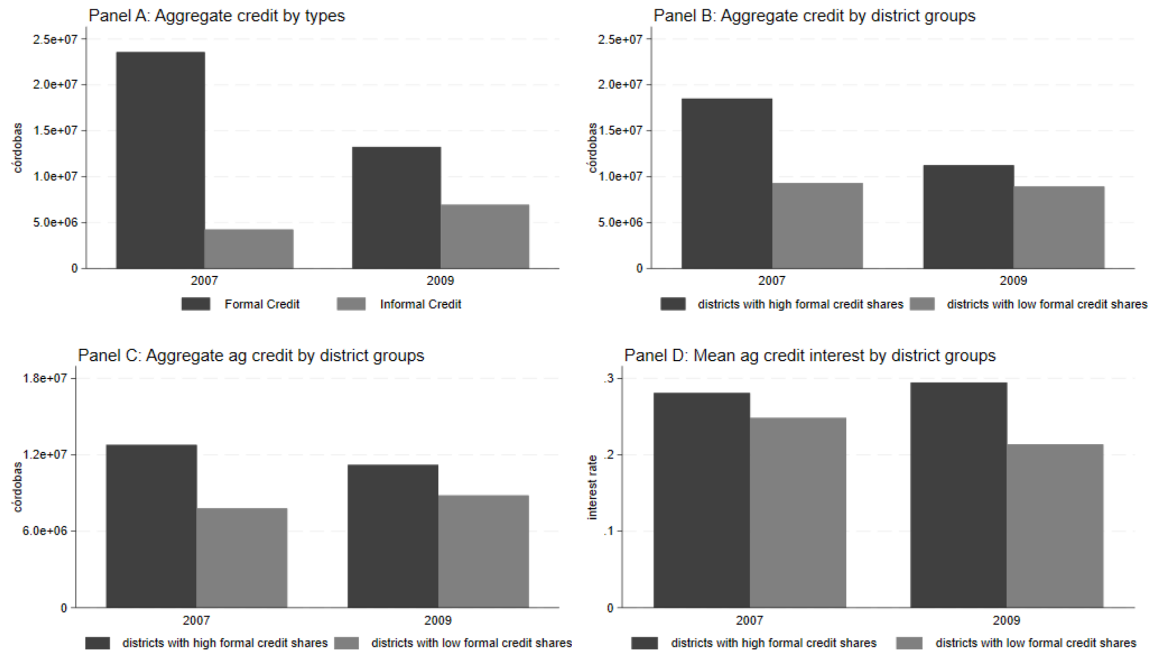

Figure 4: Credit Market Dynamics across Survey Districts.

Note: Survey districts with high formal credit shares had initial formal credit shares above the median, about 87%. For each agricultural credit, I calculate the compound annual interest based on principals, total payments, and terms. Then, I obtain agricultural credit interest rates at the household level using agricultural credit amounts within each household as weights. The mean agricultural credit interest rate is the simple average across households within each district group. Households from both district groups experienced increases in credit terms between survey rounds. However, the average term increase was larger for households from districts with high formal credit shares. Nevertheless, these districts witnessed reductions in both short- and long-term agricultural credit whereas districts with low formal credit shares experienced the opposite. For all subfigures, I exclude 76 households living in 3 survey districts where formal credit substantially increased (outliers). Hence, I make these subfigures based on the household survey data for 1503 households living in 53 survey districts. Table A.7 in Supplemental Appendix F shows that my main regression results are robust to the exclusion of these three districts.

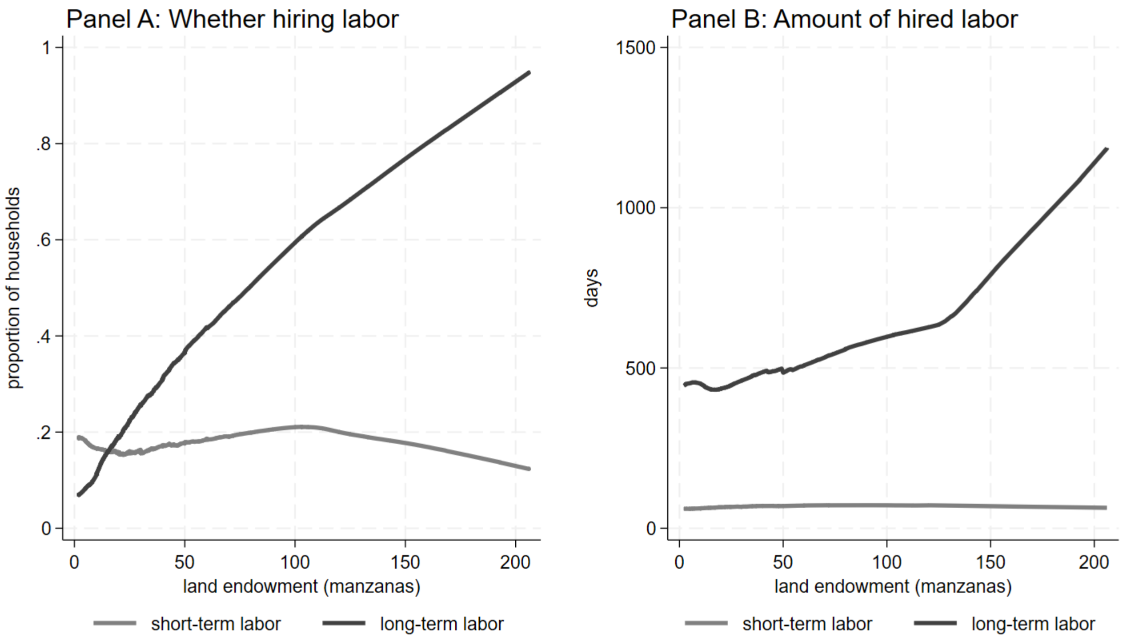

Figure 5: Labor Hiring Patterns by Land Endowments.

Note: These two figures illustrate year-round labor hiring patterns against land endowments across households in survey round 1. Panel A shows the proportions of households who hired labor while Panel B shows the average amounts of hired labor in days among households who hired labor. All the lines of average measures are smoothed by LOWESS. Labor hired on a daily basis is short-term labor while labor hired on a monthly or yearly basis is long-term labor. Long-term hired labor worked on a farm for at least 6 months. The average hiring duration within an agricultural year is close to 12 months or one year.

Supplementary Appendices

Appendix A. The first-order conditions for the optimal resource allocation made by an arbitrary agent

The first-order optimality conditions below will be used in later appendices, which supplement the analyses above in the main text. To proceed, I obtain the following Lagrangian for the UMP above in Section 2.2.

$$\begin{aligned}
\mathcal{L} = & \frac{1}{i}\Big\{\pi_o(A_o, k_o, L_o) + \pi_t^{out}(A_t^{out}, k_t^{out}) + \pi_t^{in}(A_t^{in}, k_t^{in}, L_t^{in}) + (wL_h^{out} - wL_h^{in})\Big\} \\
& - (A_o k_o + A_t^{out} k_t^{out}) \\
& - \lambda(A_o + A_t^{out} - A_e) \\
& - \mu[A_o k_o + A_t^{out} k_t^{out} - I_{\{A_e \geq A_e^m\}} A_e \theta(S_e)] \\
& - \nu[L_o + L_t^{in} - L(L_f, L_h^{in})] \\
& - \xi(L_f + L_h^{out} - 1) \\
& + \zeta_o A_o + \zeta_t^{out} A_t^{out} + \zeta_t^{in} A_t^{in} \\
& + \delta_o k_o + \delta_t^{out} k_t^{out} + \delta_t^{in} k_t^{in} \\
& + \chi_o L_o + \chi_t^{in} L_t^{in} + \psi L_f + \phi L_h^{out} + \eta L_h^{in},
\end{aligned}$$

where λ, μ, ν, and ξ are the Lagrangian multipliers for constraints (1)-(4), respectively, while ζ's, δ's, χ's, ψ, ϕ, and η are the Lagrangian multipliers for the nonnegativity requirement on the eleven choice variables summarized in constraint (5). Then, the first-order conditions for the optimal resource allocation are:

(6) $\frac{\partial \mathcal{L}}{\partial A_o} : \frac{1}{i}\frac{\partial \pi_o}{\partial A_o} - \lambda - (1+\mu)k_o + \zeta_o = 0;$

(7) $\frac{\partial \mathcal{L}}{\partial k_o} : \frac{1}{i}\frac{\partial \pi_o}{\partial k_o} - (1+\mu)A_o + \delta_o = 0;$

(8) $\frac{\partial \mathcal{L}}{\partial L_o} : \frac{1}{i}\frac{\partial \pi_o}{\partial L_o} - \nu + \chi_o = 0;$

(9) $\frac{\partial \mathcal{L}}{\partial A_t^{out}} : \frac{1}{i}\frac{\partial \pi_t^{out}}{\partial A_t^{out}} - \lambda - (1+\mu)k_t^{out} + \zeta_t^{out} = 0;$

(10) $\frac{\partial \mathcal{L}}{\partial k_t^{out}} : \frac{1}{i}\frac{\partial \pi_t^{out}}{\partial k_t^{out}} - (1+\mu)A_t^{out} + \delta_t^{out} = 0;$

(11) $\frac{\partial \mathcal{L}}{\partial A_t^{in}} : \frac{1}{i} \frac{\partial \pi_t^{in}}{\partial A_t^{in}} + \zeta_t^{in} = 0;$

(12) $\frac{\partial \mathcal{L}}{\partial k_t^{in}} : \frac{1}{i} \frac{\partial \pi_t^{in}}{\partial k_t^{in}} + \delta_t^{in} = 0;$

(13) $\frac{\partial \mathcal{L}}{\partial L_t^{in}} : \frac{1}{i} \frac{\partial \pi_t^{in}}{\partial L_t^{in}} - \nu + \chi_t^{in} = 0;$

(14) $\frac{\partial \mathcal{L}}{\partial L_f} : \nu \frac{\partial L}{\partial L_f} - \xi + \psi = 0;$

(15) $\frac{\partial \mathcal{L}}{\partial L_h^{out}} : \frac{1}{i} w - \xi + \phi = 0;$

(16) $\frac{\partial \mathcal{L}}{\partial L_h^{in}} : -\frac{1}{i} w + \nu \frac{\partial L}{\partial L_h^{in}} + \eta = 0;$

(17) $\lambda \geq 0,\ A_o + A_t^{out} \leq A_e,\ \lambda(A_o + A_t^{out} - A_e) = 0;$

(18) $\mu \geq 0,\ A_o k_o + A_t^{out} k_t^{out} \leq I_{\{A_e > A_e^m\}} A_e \theta(S_e),\ \mu[A_o k_o + A_t^{out} k_t^{out} - I_{\{A_e > A_e^m\}} A_e \theta(S_e)] = 0;$

(19) $\nu \geq 0,\ L_o + L_t^{in} \leq L(L_f, L_h^{in}),\ \nu[L_o + L_t^{in} - L(L_f, L_h^{in})] = 0;$

(20) $\xi \geq 0,\ L_f + L_h^{out} \leq 1,\ \xi(L_f + L_h^{out} - 1) = 0;$ and

(21) $\{\zeta_o A_o, \zeta_t^{out} A_t^{out}, \zeta_t^{in} A_t^{in}, \delta_o k_o, \delta_t^{out} k_t^{out}, \delta_t^{in} k_t^{in}, \chi_o L_o, \chi_t^{in} L_t^{in}, \psi L_f, \phi L_h^{out}, \eta L_h^{in}\} = 0,$
$\{\zeta_o, A_o, \zeta_t^{out}, A_t^{out}, \zeta_t^{in}, A_t^{in}, \delta_o, k_o, \delta_t^{out}, k_t^{out}, \delta_t^{in}, k_t^{in}, \chi_o, L_o, \chi_t^{in}, L_t^{in}, \psi, L_f, \phi, L_h^{out}, \eta, L_h^{in}\} \geq 0.$

Appendix B. Properties of the land rental rate schedule

In this appendix, I derive properties of the land rental rate schedule based on the first-order conditions above, which have been used to prove Lemma 1 in Section 3. Note that the properties outlined below do not pin down the land rental rate schedule which exact value also depends on the wage rate in the labor market, although I use some necessary equilibrium conditions to derive these properties. In other words, the properties derived here tell us the relationship between the land rental rate schedule and wage rate but not their exact values in equilibrium.

First of all, we always have the size of the land to be rented in $A_t^{in} > 0$ at the optimum for a tenant. Thus, we have the associated Lagrangian multiplier $\zeta_t^{in} = 0$ in the first-order condition (11) above. Also, we always have $L_t^{in} > 0$ for a tenant and thus its associated Lagrangian multiplier $\chi_t^{in} = 0$ in the first-order condition (13) above. The reason is that it is always profitable to have the first unit of the effective labor input on the rented-in land at a finite wage rate w given the infinite marginal return of the effective labor input on the rented-in land for the first unit. Now, let us rewrite the first-order conditions (11)-(13) above as follows, given $\pi_t^{in}(A_t^{in}, k_t^{in}, L_t^{in}) = pF(A_t^{in}, A_t^{in} k_t^{in} + A_t^{in} k_n, L_t^{in}) - A_t^{in} r(k_t^{in} + k_n)$.

(22) $\frac{1}{i}\frac{\partial \pi_t^{in}}{\partial A_t^{in}} = 0$: $p\frac{\partial F}{\partial A}|_{A=A_t^{in}} + p\frac{\partial F}{\partial K}|_{K=A_t^{in}k_t^{in}+A_t^{in}k_n}(k_t^{in}+k_n) = r(k_t^{in}+k_n)$;

(23) $\frac{1}{i}\frac{\partial \pi_t^{in}}{\partial k_t^{in}} + \delta_t^{in} = 0$: $p\frac{\partial F}{\partial K}|_{K=A_t^{in}k_t^{in}+A_t^{in}k_n} \leq \frac{dr}{dk_t^{in}} = r'(k_t^{in}+k_n)$ with the equality for $k_t^{in} > 0$;

(24) $\frac{1}{i}\frac{\partial \pi_t^{in}}{\partial L_t^{in}} - \nu = 0$: $p\frac{\partial F}{\partial L}|_{L=L_t^{in}} = i\nu$.

Condition (22) says that the marginal return of the land to be rented in (including its attached capital investments made by its owner) equals the rental rate for that land (during each production period). Under the C.R.S. production technology, it means that a tenant will just earn the return of the effective labor input on the rented-in land as they only provide the effective labor input, i.e.,

$$\pi_t^{in}(A_t^{in}, k_t^{in}, L_t^{in}) = p\frac{\partial F}{\partial A}A_t^{in} + p\frac{\partial F}{\partial K}[A_t^{in}(k_t^{in}+k_n)] + p\frac{\partial F}{\partial L}L_t^{in} - r(k_t^{in}+k_n)A_t^{in} = p\frac{\partial F}{\partial L}L_t^{in}.$$

In the following, I will show that the marginal return of the effective labor input on the rented-in land, namely $p\frac{\partial F}{\partial L}|_{L=L_t^{in}}$, should always equal wage rate w in the competitive equilibrium of land rental and labor markets. Note that condition (22) is equivalent to the following equality condition under the C.R.S. production technology:

$$pF(1, k_t^{in}+k_n, l_t^{in}) - pF_l(1, k_t^{in}+k_n, l_t^{in})l_t^{in} = r(k_t^{in}+k_n),$$

where l_t^{in} denotes the intensity of the effective labor input and $F_l(1, k_t^{in}+k_n, l_t^{in})$ denotes the marginal return of the effective labor input $p\frac{\partial F}{\partial L}|_{L=L_t^{in}}$.[39]

For a given type of the land to be rented in, measured by the intensity of attached capital investments made by its owner k_t^{in}, the marginal return of the land to be rented in on the left-hand side increases at a higher intensity of the effective labor input l_t^{in} due to the diminishing marginal return of the effective labor input. The rental rate for that type of land on the right-hand side, however, is a positive constant. Hence, there exists a

[39] Under the C.R.S. production technology, we have: $F(A_t^{in}, A_t^{in}k_t^{in}+A_t^{in}k_n, L_t^{in}) = A_t^{in}F(1, k_t^{in}+k_n, l_t^{in})$ $= A_t^{in}\left[\frac{\partial F}{\partial A}|_{A=A_t^{in}} + F_k(1, k_t^{in}+k_n, l_t^{in})(k_t^{in}+k_n) + F_l(1, k_t^{in}+k_n, l_t^{in})l_t^{in}\right]$, where $F_k(1, k_t^{in}+k_n, l_t^{in})$ denotes the marginal return of attached capital investments.

unique intensity of the effective labor input l_t^{in} such that the left-hand side equals the right-hand side. That is, the intensity of the effective labor input l_t^{in} will be the same at the optimum for all the tenants who rent in the same type of land. So will the marginal return of the effective labor input on that type of land $pF_l(1, k_t^{in} + k_n, l_t^{in})$ or equivalently $p\frac{\partial F}{\partial L}|_{L=L_t^{in}}$.

Next, I will show that the marginal return of the effective labor input on any type of the land to be rented in should equal wage rate at the optimum in the competitive equilibrium, i.e., $p\frac{\partial F}{\partial L}|_{L=L_t^{in}} = w, \forall k_t^{in} \geq 0$. Without loss of generality, suppose that both land rental and labor markets are active in the competitive equilibrium. That is, both markets have positive supply and demand and they equal each other at some wage rate w and land rental rate schedule $r(\cdot)$.

On the one hand, if the marginal return of the effective labor input on some type of the land to be rented in is smaller than wage rate w, then tenants who rent in that type of land will either change to rent in another type of land instead or hire out labor in the labor market. The reason is that the marginal cost of the effective labor input, namely $i\nu$ in condition (24), is no less than wage rate w as one unit of labor, either family labor or hired labor, can only produce one unit of effective labor at most. This contradicts the premise that the land rental market is in equilibrium.

On the other hand, if the marginal return of the effective labor input on some type of the land to be rented in is larger than wage rate w, then all laborers in the labor market will change to rent in that type of land in the land rental market instead of hiring out labor. For instance, by using family labor to cultivate that type of the land to be rented in, they can earn a higher labor return than wage rate as one unit of family labor produces one unit of effective labor. This contradicts the premise that the labor market is in equilibrium.

In sum, the marginal return of the effective labor input on any type of the land to be rented in should equal wage rate w in the competitive equilibrium where both land rental and labor markets are active. This property, namely $p\frac{\partial F}{\partial L}|_{L=L_t^{in}} = w, \forall k_t^{in} \geq 0$, also holds true for any other competitive equilibria where either the land rental market or the labor market is inactive.[40] For instance, we can define wage rate w as the marginal return of family labor input on the rented-in land when the labor market is inactive while the land rental market is active.[41] Similarly, we can define the land rental rate schedule $r(\cdot)$ such that it satisfies the properties (22)-(24) above when the land rental market is inactive while the labor market is active.[42]

Importantly, the property that the marginal return of the effective labor input on any type of the land to be rented in equals wage rate means that tenants will use family labor but not hired labor to cultivate the land to be rented in due to the agency cost of hired labor. This is why renting out land will improve the efficiency of labor input on the endowed land when self-cultivating all the endowed land involves the usage of the relatively inefficient hired labor.

Back to condition (23), we have:

$$p\frac{\partial F}{\partial K}|_{K=A_t^{in}k_n+A_t^{in}k_t^{in}} = r'(k_t^{in}+k_n)$$

[40]Land rental and labor markets cannot be simultaneously inactive in a competitive equilibrium as landless agents in an agrarian economy will either hire out the endowed labor or use it to cultivate the land to be rented in.

[41]The inactive labor market means that agents will neither hire in nor hire out labor at wage rate w, i.e., they use all the endowed labor as family labor to cultivate land, either the self-cultivated land or the rented-in land or both. Note that the marginal return of family labor input on the rented-in land should be the same across tenants. Otherwise, a tenant who obtains a lower marginal return of family labor input will switch to renting in another type of land that delivers a higher marginal return of family labor input, which contradicts the premise that the land rental market is in equilibrium. At the same time, the marginal return of hired labor input on the self-cultivated land for the first unit should be no higher than the marginal return of family labor input on the rented-in land. Otherwise, self-cultivators will hire in labor and tenants will hire out labor, which contradicts the premise that the labor market is inactive. Of course, the marginal return of hired labor input on the rented-in land for the first unit is also no higher than the marginal return of family labor input on the rented-in land due to the agency cost of hired labor. Last but not least, the marginal return of family labor input on the self-cultivated land is no lower than that on the rented-in land. Otherwise, some landed agents will rent out more land, which contradicts the premise that the land rental market is in equilibrium. In sum, no agent will have any incentives to either hire in or hire out labor when wage rate is set equal to the marginal return of family labor input on the rented-in land. Hence, introducing this specific wage rate will not alter the original competitive equilibrium.

[42]The inactive land rental market means that no landed agent will rent out land and no agent will rent in land at the land rental rate schedule $r(\cdot)$, i.e., all the endowed land will be self-cultivated by owners. Note that the properties of the land rental rate schedule $r(\cdot)$ derived above simply say that landlords will recoup all the returns of the endowed land to be rented out and its attached capital investments through land rental rates and tenants will just earn wage rate for family labor input on the land to be rented in. Under this land rental rate schedule, using the endowed labor to cultivate the land to be rented in will deliver the same labor return as hiring out the endowed labor in the labor market. Thus, no laborer will have any incentives to rent in land and thus no landed agent will rent out land. Hence, introducing this specific land rental rate schedule will not alter the original competitive equilibrium.

for $k_t^{in} > 0$. It says that the marginal return of the attached capital investments on the land to be rented in made by its owner equals the associated marginal increment of the rental rate for that land. That is, landlords will recoup all the returns of their attached capital investments on the rented-out land through land rental rates. This reconfirms that tenants will only earn market returns on their labor inputs on the rented-in land.

Appendix C. The first-order conditions for the optimal resource allocation at the extensive or intensive margin of renting out land

In this appendix, I establish the first-order optimality conditions for when a landed agent will rent out land (the extensive margin) and by how much (the intensive margin). These conditions have been used to investigate the interaction between the investment effect of higher land ownership security and the concurrent rental-supply effect in Section 4. As shown above in the main text, landlords are among landed agents who have the accessible credit to make attached capital investments. Also, I assume that they will invest attached capital in the endowed land to be self-cultivated at least, although they may not invest attached capital in the endowed land to be rented out if the moral hazard of tenants not taking care of landlords' land-attached capital is severe (see details below).

Before moving to the first-order optimality conditions derived below, let us look at the general picture about the labor input on the endowed land made by landed agents at the extensive and intensive margins of renting out land first. The previous appendix shows that cultivating the rented-in land delivers the same unit return of the endowed labor as working on others' farms, namely wage rate. Thus, the opportunity cost of using the endowed labor to cultivate the endowed land equals wage rate. At this opportunity cost, a landed agent will not rent out land if self-cultivating all the endowed land does not consume all the endowed labor. Otherwise, renting out land would not improve the efficiency of the labor input on the endowed land but raise the protection cost rate and the capital depreciation cost rate resulting from the higher risk of losing the rented-out land cum its attached capital investments and the moral hazard of tenants not taking care of landlords' land-attached capital. As a corollary, a landed agent at the extensive or intensive margin of renting out land will always use all the endowed labor to cultivate all or part of the endowed land.

With all that being said above, I obtain the following first-order conditions for the optimal resource allocation made by a landed agent at the extensive and intensive margins of renting out land. These refined conditions are derived from properties of the land rental rate schedule and other first-order conditions in the previous appendices and the definitions of π_o and π_t^{out} in Section 2.2. For readability, I omit the detailed derivations.

(25) $p\frac{\partial F^o}{\partial A} + p\frac{\partial F^o}{\partial K}k_n - c_o(S_e)\frac{r(k_n)}{i} = p\frac{\partial F^t}{\partial A} + p\frac{\partial F^t}{\partial K}k_n - c_t(S_e)\frac{r(k_n)}{i}$;

(26) $p\frac{\partial F^o}{\partial K} = d_o + c_o(S_e) + i(1+\mu)$ with $k_o > 0$;

(27) $p\frac{\partial F^o}{\partial L} = w\Big/\frac{\partial L}{\partial L_h^{in}}|_{L=L(L_f,L_h^{in}),L_f=1,L_h^{in}>0}$;

(28) $p\frac{\partial F^t}{\partial K} \leq d_t + c_t(S_e) + i(1+\mu)$ with the equality for $k_t^{out} > 0$;

(29) $p\frac{\partial F^t}{\partial L} = w$;

(30) $A_o > 0$, $A_t^{out} \geq 0$, $A_o + A_t^{out} = A_e$;

(31) $\mu \geq 0$, $A_o k_o + A_t^{out} k_t^{out} \leq A_e\theta(S_e)$, $\mu[A_o k_o + A_t^{out} k_t^{out} - A_e\theta(S_e)] = 0$.

Here, F^o denotes the output produced on the self-cultivated land $F(A_o, A_o k_o + A_o k_n, L_o)$; and F^t denotes the output produced on the rented-out land $F(A_t^{out}, A_t^{out} k_t^{out} + A_t^{out} k_n, L_f^t)$ with L_f^t denoting the family labor input provided by the tenant who rents in the land of size equal to A_t^{out} and intensity of attached capital investments equal to k_t^{out}.

Condition (25) says that the marginal return of the endowed land to be self-cultivated—the marginal output revenue of the endowed land to be self-cultivated (including the minimal natural attached capital) minus its unit protection cost—should equal the marginal return of the endowed land to be rented out—the marginal output revenue of the endowed land to be rented out (including the minimal natural attached capital) minus its unit protection cost at the extensive or intensive margin of renting out land. This equality condition tells us whether a landed agent will rent out land or not and by how much depend on the difference between the marginal output revenue of the endowed land to be rented out and the marginal output revenue of the endowed land to be self-cultivated, namely $\left(p\frac{\partial F^t}{\partial A}+p\frac{\partial F^t}{\partial K}k_n\right)-\left(p\frac{\partial F^o}{\partial A}+p\frac{\partial F^o}{\partial K}k_n\right)$, relative to the difference between the unit cost of protecting the endowed land to be rented out and the unit cost of protecting the endowed land to be self-cultivated, namely $c_t(S_e)\frac{r(k_n)}{i}-c_o(S_e)\frac{r(k_n)}{i}$. Sections 3 and 4 examine this from the perspectives of the size and security level of land endowment, respectively.

Conditions (26) and (27) state that the marginal return or output revenue of an input on the self-cultivated land, either attached capital or effective labor, equals its marginal cost. We have the intensity of attached capital investments $k_o > 0$ as I assume that it is always profitable to invest attached capital in the self-cultivated land. We have the amount of family labor input $L_f = 1$ as a landed agent at the extensive or intensive margin of renting out land will use all the endowed labor to cultivate all or part of the endowed land. Moreover, cultivating the self-cultivated land will involve the usage of the inefficient hired labor, namely $L_h^{in} > 0$. Otherwise, a landed agent will not rent out land as explained above. Hence, the marginal effective labor extracted from family labor cum hired labor, namely $\frac{\partial L}{\partial L_h^{in}}$, is smaller than 1 and will decrease as more hired labor is employed due to the agency cost. This means that the marginal cost of the effective labor input on the self-cultivated land is higher than wage rate w.

In contrast, the marginal cost of the effective labor input, provided by a tenant, on the rented-out land always equals wage rate w since tenants only use family labor to cultivate the rented-in land, as shown in Appendix B. Thus, we have condition (29) for the optimal effective labor input on the rented-out land. The lower marginal cost of the effective labor input favors renting out land. However, attached capital investments on the rented-out land satisfy condition (28), which says that investing attached capital in the rented-out land may be unprofitable. The reason is that renting out land induces a higher protection cost rate and a higher depreciation cost rate, namely $c_t(S_e) > c_o(S_e)$ and $d_t > d_o$, leading to a higher marginal cost of attached capital investments, namely $d_t + c_t(S_e) + i(1+\mu) > d_o + c_o(S_e) + i(1+\mu)$, although the self-cultivated and rented-out land share the shadow price of the accessible credit $i(1+\mu)$ with μ denoting the shadow value of relaxing the credit constraint (if any).[43]

Finally, conditions (30) and (31) capture constraints on the land allocation and attached capital investments, respectively. Condition (30) says that a landed agent may or may not rent out part of the endowed land. In terms of renting out land, we have $A_t^{out} = 0$ at the extensive margin and $A_t^{out} > 0$ at the intensive margin. Condition (31) says that the gross attached capital investments on the self-cultivated and rented-out land, namely $A_o k_o + A_t^{out} k_t^{out}$, should not exceed the amount of the accessible credit $A_e \theta(S_e)$.

Appendix D. Comparative statics of renting out land

In Section 4, I have explained why the moral hazard of tenants not taking care of landlords' land-attached capital tends to attenuate the rental-supply effect of higher land ownership security by inducing the bias of the concurrent investment effect towards the endowed land to be self-cultivated. Here, I present the associated comparative statics based on the first-order conditions above in Appendix C. Specifically, Table A.1 below shows the comparative statics of the threshold of renting out land A_e^{out} with respect to land ownership security S_e, namely $\frac{\partial A_e^{out}}{\partial S_e}$, which demonstrates the attenuation that may happen at the extensive margin. Table A.2 below shows the comparative statics of the optimal size of the self-cultivated land A_o^* with respect to land ownership security S_e, namely $\frac{\partial A_o^*}{\partial S_e}$, which demonstrates the attenuation that may happen at the intensive margin.

In both tables, we clearly see that the size of the investment effect of higher land ownership security on the endowed land to be rented out is increasing in its initial intensity of attached capital investments, namely k_t^{out}. Note that the moral hazard of tenants not taking care of landlords' attached capital dampens attached capital investments on the endowed land to be rented out. Hence, it induces the bias of the investment effect towards the endowed land to be self-cultivated, which tends to attenuate the concurrent rental supply effect of higher land ownership security as shown by these comparative statics.

[43]Because of the positive intensity of the minimal natural attached capital k_n, the marginal return of attached capital investments on the rented-out land $p\frac{\partial F^t}{\partial K}$ evaluated at $k_t^{out} = 0$ is finite and thus can be lower than the associated marginal cost $d_t + c_t(S_e) + i(1+\mu)$, i.e., no attached capital should be invested in the rented-out land at the optimum.

Table A.1: Marginal Effects of Land Ownership Security on the Threshold of Renting out Land.

credit constrained	credit unconstrained
$I^c_{e,1}\theta'(S_e) - R^c_e\{-[c'_t(S_e) - c'_o(S_e)]\frac{r(k_n)}{i}\}$ $-I^c_{e,2}k^{out}_t\theta'(S_e)$ $-I^c_{e,3}k^{out}_t\{-[c'_t(S_e) - c'_o(S_e)]\}$,	$I^{uc}_{e,1}[-c'_o(S_e)] - R^{uc}_e\{-[c'_t(S_e) - c'_o(S_e)]\frac{r(k_n)}{i}\}$ $-I^{uc}_{e,2}k^{out}_t[-c'_t(S_e)]$,
$I^c_{e,1} > 0, I^c_{e,2} > 0, I^c_{e,3} = R^c_e > 0.$	$I^{uc}_{e,1} > 0,\ I^{uc}_{e,2} = R^{uc}_e > 0.$

Note: (i) The marginal effects of land ownership security on the threshold of renting out land $\frac{\partial A^{out}_e}{\partial S_e}$ are obtained under the assumption that a landed agent at the extensive margin of renting out land will use the accessible credit to invest attached capital in the endowed land to be self-cultivated at least. I obtain all the I's and R's above from the first-order conditions (25)-(31) using the implicit function theorem. Here, I stands for the investment effect while R stands for the rental-supply effect. (ii) She or he will not invest attached capital in the endowed land to be rented out when the marginal cost of attached capital investments on the endowed land to be rented out is sufficiently higher than that on the endowed land to be self-cultivated, e.g., the capital depreciation rate is much higher for the rented-out land than the self-cultivated land due to the severe moral hazard of tenants not taking care of landlords' land-attached capital. (iii) She or he will be credit constrained when her or his demand for attached capital investments exceeds the accessible credit. (iv) The protection cost rate for the rented-out land and its attached capital investments $c_t(S_e)$ will decrease more than that for the self-cultivated land and its attached capital investments $c_o(S_e)$ given higher land ownership security. This will reduce both their difference in the unit cost of protecting the endowed land and their gap in the marginal cost of attached capital investments.

Table A.2: Marginal Effects of Land Ownership Security on the Size of the Self-cultivated Land.

scenario	credit constrained	credit unconstrained
$k_t^{out} = 0$	$I_o^c \theta'(S_e) - R_o^c\{-[c_t'(S_e) - c_o'(S_e)]\frac{r(k_n)}{i}\}$, $I_o^c > 0, R_o^c > 0.$	$I_o^{uc}[-c_o'(S_e)] - R_o^{uc}\{-[c_t'(S_e) - c_o'(S_e)]\frac{r(k_n)}{i}\}$, $I_o^{uc} > 0, R_o^{uc} > 0.$
$k_t^{out} > 0$	$\tilde{I}_{o,1}^c \theta'(S_e) - \tilde{R}_o^c\{-[c_t'(S_e) - c_o'(S_e)]\frac{r(k_n)}{i}\}$ $-\tilde{I}_{o,2}^c k_t^{out}\theta'(S_e)$ $-\tilde{I}_{o,3}^c\{-[c_t'(S_e) - c_o'(S_e)]\}$, $\tilde{I}_{o,1}^c > 0, \tilde{I}_{o,2}^c > 0, \tilde{I}_{o,3}^c > 0, \tilde{R}_o^c > 0.$	$\tilde{I}_{o,1}^{uc}[-c_o'(S_e)] - \tilde{R}_o^{uc}\{-[c_t'(S_e) - c_o'(S_e)]\frac{r(k_n)}{i}\}$ $-\tilde{I}_{o,2}^{uc} k_t^{out}[-c_t'(S_e)]$, $\tilde{I}_{o,1}^{uc} > 0, \tilde{I}_{o,2}^{uc} = \tilde{R}_o^{uc} > 0.$

Note: (i) The marginal effects of land ownership security on the size of the self-cultivated land $\frac{\partial A_o^*}{\partial S_e}$ are obtained under the assumption that a landed agent at the intensive margin of renting out land will use the accessible credit to invest attached capital in the self-cultivated land at least. I obtain all the I's, R's, $\tilde{I}$'s, and $\tilde{R}$'s above from the first-order conditions (25)-(31) using the implicit function theorem. Here, I and $\tilde{I}$ stand for the investment effects while R and $\tilde{R}$ stand for the rental-supply effects. (ii) She or he will not invest attached capital in the rented-out land when the marginal cost of attached capital investments on the rented-out land is sufficiently higher than that on the self-cultivated land, e.g., the capital depreciation rate is much higher for the rented-out land than the self-cultivated land due to the severe moral hazard of tenants not taking care of landlords' land-attached capital. (iii) She or he will be credit constrained when her or his demand for attached capital investments exceeds the accessible credit. (iv) The protection cost rate for the rented-out land and its attached capital investments $c_t(S_e)$ will decrease more than that for the self-cultivated land and its attached capital investments $c_o(S_e)$ at higher land ownership security. This will reduce both their difference in the unit cost of protecting the endowed land and their gap in the marginal cost of attached capital investments.

Appdenix E. Model calibration for the numerical analysis

In this appendix, I provide relevant details behind the simulation results presented in Section 5. First, I define the general equilibrium for the theoretical model outlined in the main text. Then, I calibrate the model based on the related empirical literature.

Note that the land rental rate schedule $r(k_n + k)$, with k denoting the intensity of land-attached capital investments, solely depends on the wage rate w, given the C.R.S. production technology and the competitive land rental and labor markets. In other words, a given wage rate will pin down the land rental rate schedule. To proceed, let me introduce the following notations for individual optimal labor allocations at any given wage rate w.

The optimal labor allocations of a landed agent:

$L_o(w; A_e, S_e)$—the optimal amount of effective labor input on the land to be self-cultivated;

$L_t^{in}(w; A_e, S_e)$—the optimal amount of effective labor input on the land to be rented in;

$L_f(w; A_e, S_e)$—the optimal amount of family labor input;

$L_h^{out}(w; A_e, S_e)$—the optimal amount of hired-out labor input;

$L_h^{in}(w; A_e, S_e)$—the optimal amount of hired-in labor input.

The optimal labor allocations of a landless agent: $\varnothing$ denotes no land endowment.

$L_t^{in}(w; \varnothing)$—the optimal amount of effective labor input on the land to be rented in;

$L_f(w; \varnothing)$—the optimal amount of family labor input;

$L_h^{out}(w; \varnothing)$—the optimal amount of hired-out labor input.

$L_h^{in}(w; \varnothing)$—the optimal amount of hired-in labor input.

Like the landless, landed agents for whom self-cultivating all the endowed land does not consume all the endowed labor are indifferent between hiring out the rest of the endowed labor and using it to cultivate the land to be rented in as they deliver the same unit return of labor under the C.R.S production technology and the competitive land rental and labor markets, namely the wage rate (see Lemma 1). To pin down their optimal labor allocations at any given wage rate w, I assign the endowed labor excluding the part that is used to self-cultivate all the endowed land (if applicable) to cultivate the land to be rented in and hire out following an endogenous regularity rule. Denote $HLDO(w)$ and $FLDT(w)$ as the aggregate hired labor demanded on the land to be self-cultivated and the aggregate family labor demanded on the land to be rented out, respectively. Then, the endogenous labor allocation rule can be specified as follows.

The rule of the optimal labor allocations for a landless agent:

(i) $L_h^{in}(w; \varnothing) = 0, L_h^{out}(w; \varnothing) = \frac{HLDO(w)}{HLDO(w)+FLDT(w)}$; and

(ii) $L_t^{in}(w; \varnothing) = L_f(w; \varnothing) = \frac{FLDT(w)}{HLDO(w)+FLDT(w)}$.

The rule of the optimal labor allocations for a landed agent who self-cultivates all the endowed land and self-cultivation does not consume all the endowed labor: $A_e < A_e^{in}(S_e)$ where $A_e^{in}(S_e)$ denotes the threshold of renting out land—the size of land endowment above which landowners will just stop renting land at a given security level of land endowment

S_e.

(i) $L_h^{in}(w; A_e, S_e) = 0, L_h^{out}(w; A_e, S_e) = \frac{HLDO(w)}{HLDO(w)+FLDT(w)}[1 - L_o(w; A_e, S_e)]$; and

(ii) $L_t^{in}(w; A_e, S_e) = L_f(w; A_e, S_e) - L_o(w; A_e, S_e) = \frac{FLDT(w)}{HLDO(w)+FLDT(w)}[1 - L_o(w; A_e, S_e)]$.

When it comes to the ideal case where there is no capital depreciation rate gap between the rented-out and self-cultivated land, namely $d_t = d_o$, I assume that landed agents whose land ownership is fully secure will still use the endowed labor to cultivate the endowed land before hiring the rest of the endowed labor out or using it to cultivate the land to be rented in (if applicable), although they are indifferent between self-cultivating and renting out the endowed land as renting out land will not raise protection or capital depreciation cost rate. Nevertheless, they would still invest the same intensities of attached capital in the endowed land even if they rented out all the endowed land, as both the land to be self-cultivated and the land to be rented out will be cultivated by family labor, and thus earn the same returns of the endowed land and its attached capital investments as that under the foregoing assumption. Thus, this technical assumption itself will not affect their incomes in equilibrium as they will earn the wage rate for their endowed labor anyway. Likewise, it will not affect the aggregate resource allocation and thus equilibrium prices, either.

Now, let me define the general equilibrium below. Denote the distribution of the size and security level of the land endowment as $GH(A_e, S_e)$. Also, denote the ratio of the landless population to the landed population as RLL. Given the labor allocation rule above that has accounted for land allocations in the land rental market, the general equilibrium will then be characterized by the following clearance condition for the labor market which determines the equilibrium wage rate w and thus the land rental rate schedule $r(k_n + k)$. The clearance condition for the land rental market is implicitly incorporated in the endogenous labor allocation rule above.

The clearance condition for the labor market:

$$RLL \times [L_h^{out}(w;\varnothing) - L_h^{in}(w;\varnothing)] + \int [L_h^{out}(w;A_e,S_e) - L_h^{in}(w;A_e,S_e)]dGH(A_e,S_e) = 0.$$

Next, let us move to the model calibration detailed below.

Land endowment: Landless rate and the size and security distributions of the endowed land.

First of all, I set the landless rate equal to $\frac{1}{3}$, i.e., one out of every three agents has no land. This level of landless rate is common in Latin America, e.g., rural Nicaragua had a landless rate of 38% in 1998 (Corral and Reardon, 2001).

Secondly, following Eswaran and Kotwal (1986), I index a landowner by the proportion, $z_e \in (0,1]$, of landowners who own smaller sizes of land than she or he does. The proportion, $G(z_e) \in (0,1]$, of land that is held by all the landowners with $z_e' \leq z_e$ follows a Pareto C.D.F, i.e., $G(z_e) = 1-(1-z_e)^a, a \in (0,1)$. Here, a controls the degree of the equality of land ownership distribution, i.e., the larger it is, the more egalitarian the size distribution of land endowment among landowners is. I set a equal to $\frac{1}{9}$, which implies that the Gini coefficient of land endowment in size (including the zero land endowment for the landless) is about 0.87. This is also common in Latin America, e.g., rural Nicaragua had almost the same land Gini coefficient in 1998 (Davis and Stampini, 2002).

Finally, the security level of the land endowment, $S_e \in (0,1)$, has the following C.D.F conditional on the size of the land endowment indexed by z_e: $H(S_e|z_e) = {S_e}^{b_1 z_e + b_2}, b_1 > 0, b_2 \geq \frac{\sqrt{5}-1}{2}$. Here, b_1 controls the strength of the positive correlation between the size and security level of the land endowment. Specifically, the mean security level of land ownership conditional on land size, namely $\frac{b_1 z_e + b_2}{b_1 z_e + b_2 + 1}$, is strictly increasing in the product of b_1 and the land size indexed by z_e. The larger b_1 is, the higher the average land ownership security for large landowners will be relative to that for small landowners. The inequality condition for b_2 guarantees that the conditional variance of land ownership security is strictly decreasing in land size. In other words, large landowners are more likely to enjoy similar high land ownership security than small landowners.

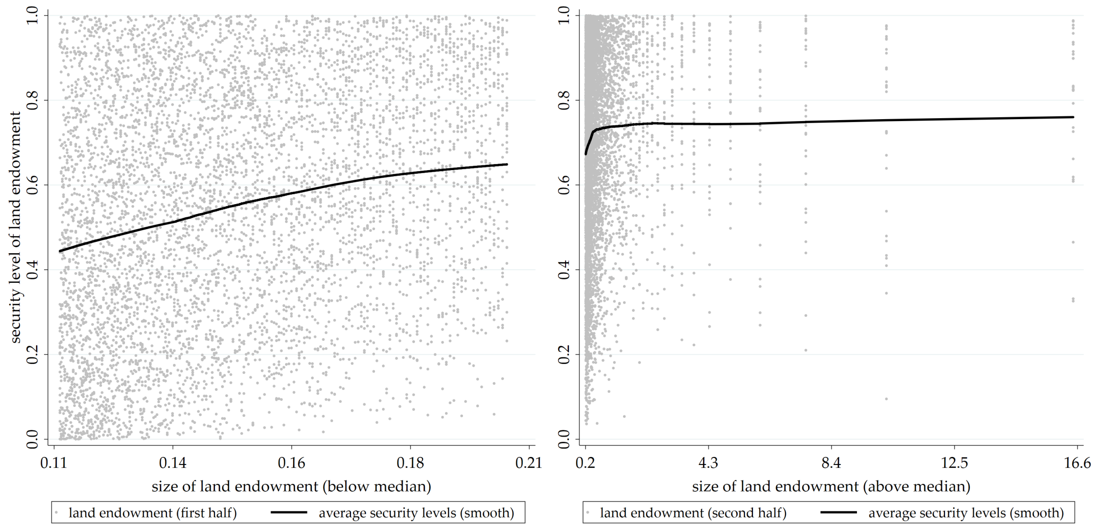

Figure A.1: The Simulated Land Endowments among Landowners.

I set b_1 and b_2 equal to $\frac{\sqrt{5}+3}{2}$ and $\frac{\sqrt{5}-1}{2}$, respectively. This implies that the average security level of land ownership conditional on land size ranges from 0.38 (for the smallest landowner) to 0.76 (for the largest landowner). This range is somewhat in line with the distribution of land ownership security in rural Nicaragua before the major land titling and registration programs that were implemented in the 1990s (Boucher et al., 2005).[44] Figure A.1 above shows the simulated land endowments in dots.

[44]According to Deininger and Chamorro (2004), in the 1990s, the Nicaragua government implemented land titling and registration programs, especially between 1994 and 1997, under the help of various donors like the World Bank. In Nicaragua, a registered title delivers full secure land ownership while an unregistered title does not; landowners strongly hesitate to rent out untitled land due to fear of tenants squatting on the land (Deininger et al., 2003). Most households would like to register land titles if they had enough resources to do so, although many households even do not want to expend efforts like time to title their land (Deininger and Chamorro, 2004). Hence, it might be reasonable to assign the following security levels of land ownership—1, 0.5, and 0.25—to registered land, titled-but-not-registered land, and untitled land, respectively. In 1995 or at the early stages of security improvement programs, households endowed with the smallest sizes of land only had about 50% of the endowed land being titled while households endowed with the largest sizes of land had almost 85% of the endowed land being titled, as shown by the nonparametric estimates of the land title status at the household level (Boucher et al., 2005). Thus, the imputed average security levels of land ownership enjoyed by these two groups of landowners are about 0.38 and 0.75, respectively, given that small landowners hardly have resources to register land titles while large landowners often do not have this issue, say with an odd of one third. Back to the size distribution of land endowment in Nicaragua, it had largely remained unchanged for many years including the 1990s and thereby it should be fine to simply use the size distribution in 1998 that is well-measured by the LSMS data (Bandiera, 2007).

Technologies: Farm production and the extraction of effective labor.

(i) *The farm production technology*: A hybrid C.E.S. function $F(A,K,L) = A^{\alpha}\left[(\alpha_k K^{\rho} + \alpha_l L^{\rho})^{\frac{1}{\rho}}\right]^{1-\alpha}$ with $\{\alpha, \alpha_k, \alpha_l\} \in (0,1)$, $\alpha_k + \alpha_l = 1$, and $\rho < 1-\alpha$, is employed for the C.R.S. agricultural production technology that each agent has access to.[45] Here, α and $1-\alpha$ can be interpreted as output shares contributed by land A and attached capital K cum effective labor L, respectively. Similarly, α_k and α_l can be interpreted as the shares of attached capital and effective labor in their combined output contribution, respectively.

The parameter ρ, on the other hand, controls the degree of substitution between attached capital and effective labor, i.e., the elasticity of substitution between them equals $\varepsilon = \frac{1}{1-\rho}$. The inequality condition, $\rho < 1-\alpha$, captures the assumption that attached capital and effective labor complement each other (Carter and Yao, 1999). For simplicity, I set $\alpha = \rho = \frac{1}{3}$ and $\alpha_k = \alpha_l = \frac{1}{2}$, i.e., $F(A,K,L) = A^{\frac{1}{3}}(\frac{1}{2}K^{\frac{1}{3}} + \frac{1}{2}L^{\frac{1}{3}})^2$.[46]

(ii) *The technology of extracting effective labor*: The effective labor extraction function is a modified version of the labor effort model proposed by Frisvold (1994)—$L = (L_f + L_h)\left(\frac{L_f}{L_f+L_h}\right)^{\gamma}$ with $\gamma \in (0,1)$.[47] Here, γ controls the efficiency of hired labor relative to family labor, i.e., the smaller it is, the more similar hired labor will be to family labor in terms of efficiency.

I set γ equal to 0.1 since Frisvold (1994) found that hired labor productivity approaches that of family labor when the supervision intensity is sufficiently high. This number means that the first unit of hired labor input is equivalent to 0.9 units of effective labor input. But the efficiency unit will decrease as more hired labor is used to produce effective labor or equivalently the supervision intensity—family labor over hired labor—decreases. When hired labor is used, family labor supervises hired labor while working. Without hired labor, one unit of family labor produces one unit of effective labor. Figure A.2 below illustrates the parameterized model for effective labor. Note that there is a kink right at

[45] This function enables us to reasonably set the intensity of minimal natural attached capital k_n, without knowing any prior information about the competitive equilibrium, such that landlords will not invest attached capital in the rented-out land when the associated capital depreciation cost is sufficiently high. However, it is practically hard to achieve this convenience using a simpler Cobb-Douglas function.

[46] Our output shares are within reasonable ranges in the empirical literature (Ma and Sexton, 2021).

[47] Frisvold's original labor effort model is $L = (L_f + L_h)\left(\frac{L_f+1}{L_f+L_h}\right)^{\gamma}$ which incorporates the case when a landlord is absent, namely $L_f = 0$. However, in this paper I do not consider that case and thereby I use L_f as the numerator instead of $L_f + 1$ for the component in the second parenthesis.

1. To avoid its potential contamination on the simulation results, I carefully design the simulation exercises below (see the capital depreciation cost rate part).

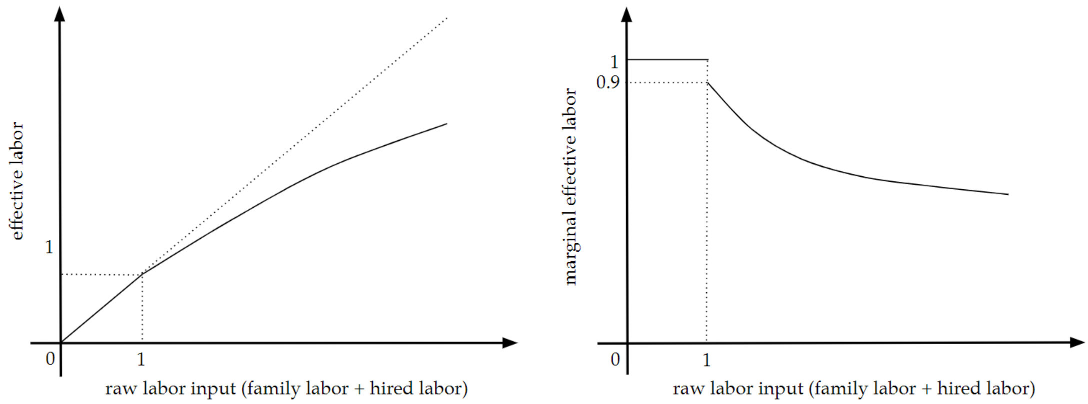

Figure A.2: The Graphical Representation of the Effective Labor Model.

Credit and output markets: Interest rate and leverage ratio for credit access and output price.

(i) *Credit market*: First of all, I set the exogenous interest rate i equal to 10%. This number seems to be conservative for Latin American countries. For example, the average real commercial loan rate for Nicaragua was about 10% in 1996 (Jonakin and EnrÃquez, 1999). The rural credit interest there should be higher than 10% due to various market frictions like high screening and management costs. Secondly, landowners whose sizes of the land endowment are below the median are set to be quantity-rationed in the credit market, i.e., those landowners will have no accessible credit to make land-attached capital investments. Credit access data is limited. But this design is in line with the status of credit access for rural Nicaraguan agricultural producers in 1999 (Boucher et al., 2005).

Finally, I use a linear function $\theta \times [mS_e + (1-m)]$ with $\theta > 0$ and $m \in (0,1)$ to parameterize the leverage ratio (for landowners who have access to credit)—the amount of accessible credit per unit of land collateral. I set the maximum leverage ratio θ equal to 2 times the intensity of minimal natural attached capital k_n, i.e., $\theta = 2k_n$. This low maximum leverage ratio ensures that a large proportion of landowners will be credit constrained, which is often the case in developing countries. Considering the important role of land ownership security in credit access (e.g., Feder et al., 1988; Carter and Olinto, 2003), I set the associated parameter m equal to 0.9. By this design, large landowners will be less likely to be credit constrained at higher land ownership security, which is in line with the empirical literature (Carter and Olinto, 2003).

(ii) *Output price*: I set the exogenous output price p equal to 1 for simplicity, following Eswaran and Kotwal (1986).

Protection and capital depreciation cost rates

(i) *Protection cost rates*: For simplicity, I approximate the protection cost per unit of the self-cultivated land by a linear function $c_o \times (1 - S_e)$ with $c_o > 0$.[48] Likewise, I approximate the protection cost per unit of the rented-out land by a linear function $c_t \times (1 - S_e)$ with $c_t > 0$. Here, c_o and c_t can be interpreted as the probabilities of losing the self-cultivated and rented-out land under no protection, respectively, when the associated land ownership is the most insecure, namely $S_e = 0$. I set c_o and c_t equal to 5% and 6%, respectively.

These probabilities are not uncommon in the literature. For instance, Chen (2017) sets the probability of losing the untitled land in Malawi equal to 6.7%; Goldstein and Udry (2008) find a similar probability of losing the insecure land in Ghana, another developing country in Africa. In Latin America, land insecurity has been widespread and severe. Hence, it is reasonable to set a similar high probability of losing the insecure land. These parameters imply that renting out insecure land will raise the risk of losing the land and its attached capital by 20%, which is a sizable security barrier for large landowners to rent out the insecure land.

(ii) *Capital depreciation rates*: For the attached capital invested in the self-cultivated land, I set the depreciation rate per production period d_o equal to 5%, which is comparable to the interest rate i in magnitude. For the attached capital invested in the rented-out land, I set the depreciation rate per production period $d_t > d_o$. Their difference captures the capital depreciation risk induced by the moral hazard of tenants not taking care of landlords' land-attached capital.

I set the capital depreciation rate ratio $d_t/d_o \in \{1.5, 2, 2.5\}$. I do not start with

[48] There can be a fixed component in the protection cost, but it is not a relevant feature for this paper.

$d_t/d_o = 1$ as simulation results have a mechanical break somewhere between 1 and 1.5 due to the kink of the effective labor extraction technology introduced above.[49] The larger this ratio is, the higher the capital depreciation risk is. In the simulation exercises outlined below, I vary this ratio to investigate the extent to which the investment effect of securing land ownership may attenuate the concurrent rental-supply effect, and the extent to which their countervailing interaction may downsize the welfare gains generated from securing land ownership for an unequal rural economy.

Minimal natural attached capital: In the model, I introduce minimal natural attached capital to allow for the possibility that landlords may not invest attached capital in the rented-out land, which is common in Latin America (e.g., Bandiera, 2007). I set k_n equal to 1.5 times the intensity of attached capital k_o satisfying $\frac{\partial F}{\partial K}|_{A>0,K=Ak_o,L=0} = c_o + i$. Given other parameters, this design ensures that landowners who have access to credit will invest attached capital in the endowed land to be self-cultivated but not necessarily in the endowed land to be rented out, which is of research interest in this paper.

Table A.3 below summarizes the parameterized model. The simulated treatment is to improve land ownership security to the highest level for all landowners for free. This mimics land titling and registration programs funded by NGOs, such as the World Bank. After security improvement, there will be no risk of losing the land and its attached capital, namely $S_e = 1$ and $c_t(S_e) = c_o(S_e) = 0$. However, the capital depreciation rate gap between the rented-out and self-cultivated land remains unchanged as non-security barriers to long-term land rental contracts are still there.

[49] Detailed results are available upon request.

Table A.3: The Parameterized Model.

	function/value/feature
Panel A: Technologies.	
farm production	$F(A,K,L) = A^{\alpha}\left[(\alpha_k K^{\rho} + \alpha_l L^{\rho})^{\frac{1}{\rho}}\right]^{1-\alpha}, \alpha = \rho = \frac{1}{3}, \alpha_k = \alpha_l = \frac{1}{2}$
effective labor extraction	$L(L_f, L_h) = (L_f + L_h)\left(\frac{L_f}{L_f + L_h}\right)^{\gamma}, \gamma = 0.1$
Panel B: Protection and capital depreciation costs.	
protection cost rates	
self-cultivated land	$c_o(S_e) = c_o \times (1 - S_e), c_o = 5\%$
rented-out land	$c_t(S_e) = c_t \times (1 - S_e), c_t = 6\%$
capital depreciation rates	
self-cultivated land	$d_o = 5\%$
rented-out land	$d_t \geq d_o$ with $d_t/d_o \in \{1.5, 2, 2.5\}$*
Panel C: Agents.	
preferences over income	
discount factor	$\beta = \frac{1}{1+i}$, i is the exogenous interest rate 10%
endowments	
labor	1
landless rate	$\frac{1}{3}$
land	
C.D.F. of land size	$G(z_e) = 1 - (1 - z_e)^a, z_e \in (0, 1], a = \frac{1}{9}$
C.D.F. of land security	$H(S_e \mid z_e) = S_e^{b_1 z_e + b_2}, S_e \in (0, 1], b_1 = \frac{\sqrt{5}+3}{2}, b_2 = \frac{\sqrt{5}-1}{2}$
minimal natural attached capital intensity	$k_n = 1.5 \times k_o$ satisfying $\frac{\partial F}{\partial K}\vert_{A>0, K=Ak_o, L=0} = c_o + i$
Panel D: Markets.	
labor	wage rate w determined in the competitive equilibrium
land rental	rent schedule $r(k)$ determined in the competitive equilibrium
attached capital	price fixed at 1 (numeraire)
credit	
exogenous interest rate	$i = 10\%$
quantity-rationing threshold	$A_e^m =$ the median size of land endowment
leverage ratio	$\theta(S_e) = \theta \times [m \times S_e + (1 - m)], \theta = 2k_n, m = 0.9$
output	
exogenous price	$p = 1$

Note: *In the simulation exercises, I vary this ratio along those discrete values to investigate the extent to which the investment effect of securing land ownership may attenuate the concurrent rental-supply effect, and the extent to which their countervailing interaction may downsize the welfare gains generated from securing land ownership for the unequal rural economy specified here.

Appendix F. Supplemental figures and tables for the empirical analysis

This appendix includes figures and tables that facilitate empirical analyses in the main text. Figure A.3 shows that the data matches the theoretical model broadly well. Table A.4-7 present regression results for various robustness checks.

As follows, let me illustrate Figure A.3. First of all, the size of endowed land and the amount of endowed labor (No. of household members) have no systematic relationship at the household level (Panel A). This is largely in line with the model assumption that labor endowment is the same or uncorrelated with land endowment across households.

Secondly, households having larger land endowments or equivalently smaller ratios of labor to land endowment invested more in land-attached investments (Panel B). I use trees here; but the same pattern applies to attached facilities. This is roughly consistent with the model assumption that small landowners are rationed out of access to credit and thus do not have money to make land-attached investments. Households having smaller ratios of labor to land endowment also rented out more land (Panel C). This is consistent with the model assumption that they suffer more from the agency cost of hired labor, which motivates them to rent out more land. Households having larger land endowments or equivalently smaller ratios of labor to land endowment did hire more (long-term) labor as predicted by the model (Panel D).

Although not shown here, households who invested more in land-attached investments rented out less land. This negative association is possibly due to non-security barriers to long-term land rental contracts in rural Nicaragua, such as legal caps on contract durations and landlords' preference for flexible short-term land leasing. The model predicts that these barriers will induce the capital depreciation risk facing potential landlords, making them prefer attached investments on the endowed land to be self-cultivated. This will then discourage them from renting out land. All the data patterns above prepare my investigations into the unbalanced changes in land-attached investments and rented-out land before and after participating in security improvement programs in the main text.

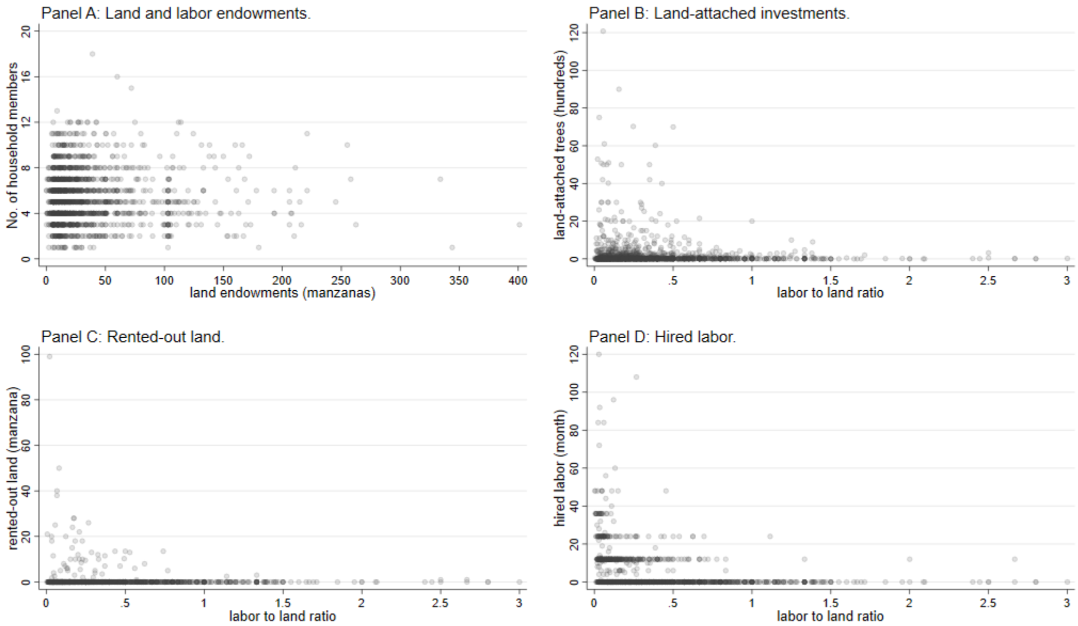

Figure A.3: Patterns of Household-level Attached Capital, Land Rental, and Hired Labor Sizes.

Table A.4: The Impacts of Security Improvement Programs on Agricultural Credit Use, Land Endowments, Migration and Labor.[a]

outcome variable	all landowners	small landowners[b]	large landowners[b]
amount of agricultural credit	0.71*	0.08	1.68**
(inverse hyperbolic sine)	(0.39)	(0.49)	(0.64)
agricultural credit usage (0/1)	0.07*	0.02	0.15**
	(0.04)	(0.05)	(0.06)
area of endowed land	0.12**	0.13**	0.13**
(logged)	(0.05)	(0.06)	(0.06)
No. of migrated household members	0.02	0.11**	-0.04
(inverse hyperbolic sine)	(0.03)	(0.05)	(0.05)
migration (0/1)	0.02	0.08*	-0.03
(work off home for 6+ months)	(0.03)	(0.05)	(0.05)
amount of family labor	0.12**	0.15**	0.12
(inverse hyperbolic since)	(0.06)	(0.06)	(0.09)
amount of long-term hired labor	0.12	0.11	0.29*
(inverse hyperbolic sine)	(0.10)	(0.13)	(0.17)
hiring long-term labor (0/1)	0.04	0.03	0.10*
	(0.03)	(0.04)	(0.05)
lag of the outcome variable	YES	YES	YES
household-level confounding factors[c]	YES	YES	YES
community-level fixed effects	YES	YES	YES
No. of household observations[d]	1096	538	521

Note: [a]I use the same regression model as outlined in Section 6.2. [b]Small landowners had land endowments below the median by survey round 1; the rest of landowners are classified as large landowners. [c]Table 3 lists household-level confounding factors. [d]Singleton observations are dropped in each fixed-effect regression; hence numbers of household observations are not exactly matched. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table A.5: Formal Credit Shocks and the Impacts of Security Improvement Programs for Large Landowners with Constant Land Endowments.[a]

outcome variable	districts with high formal credit share[b]	districts with low formal credit share	all districts pooled
No. of attached facilities	-0.02	0.33	0.15
(inverse hyperbolic sine)	(0.08)	(0.62)	(0.27)
having attached facilities (0/1)	-0.00	0.03	0.01
	(0.00)	(0.05)	(0.02)
No. of trees planted in two years	-0.17	0.87	0.36
(inverse hyperbolic sine)	(0.56)	(0.55)	(0.39)
planting trees in two years (0/1)	0.04	0.21*	0.12
	(0.10)	(0.10)	(0.07)
area of rented-out land	-0.05	-0.15	-0.09
(inverse hyperbolic sine)	(0.13)	(0.10)	(0.08)
renting out land (0/1)	-0.01	-0.07	-0.03
	(0.04)	(0.04)	(0.03)
amount of agricultural credit	0.48	0.95	0.82
(inverse hyperbolic sine)	(1.05)	(0.84)	(0.73)
agricultural credit usage (0/1)	0.03	0.09	0.07
	(0.09)	(0.08)	(0.07)
amount of long-term hired labor	-0.04	0.06	0.08
(inverse hyperbolic sine)	(0.22)	(0.33)	(0.18)
hiring long-term labor (0/1)	0.03	0.01	0.04
	(0.07)	(0.11)	(0.06)
lag of the outcome variable	YES	YES	YES
household-level confounding factors[c]	YES	YES	YES
community-level fixed effects	YES	YES	YES
No. of household observations	246	219	465

Note: [a]I use the same regression model as in Table 4. To increase sample sizes, I reclassify households with land endowments above 15 manzanas (35 percentile) as large landowners. [b]These districts had initial formal credit shares above the median by survey round 1. Relative to districts with low formal credit shares, they experienced significant reductions in credit supply between survey rounds. [c]Table 3 lists household-level confounding factors. Standard errors in the parentheses are clustered at the survey district level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table A.6: Formal Credit Shocks and the Impacts of Security Improvement Programs for Large Landowners without Changes in Migration.[a]

outcome variable	districts with high formal credit share[b]	districts with low formal credit share	all districts pooled
No. of attached facilities	-0.01	0.43	0.19
(inverse hyperbolic sine)	(0.14)	(0.42)	(0.22)
having attached facilities (0/1)	-0.01	0.03	0.01
	(0.01)	(0.03)	(0.02)
No. of trees planted in two years	0.31	1.06*	0.66**
(inverse hyperbolic sine)	(0.41)	(0.53)	(0.32)
planting trees in two years (0/1)	0.07	0.18**	0.12**
	(0.07)	(0.09)	(0.05)
area of rented-out land	-0.04	-0.17**	-0.09
(inverse hyperbolic sine)	(0.10)	(0.07)	(0.06)
renting out land (0/1)	0.01	-0.07**	-0.02
	(0.04)	(0.03)	(0.03)
amount of agricultural credit	0.61	1.73**	1.22**
(inverse hyperbolic sine)	(0.98)	(0.69)	(0.60)
agricultural credit usage (0/1)	0.05	0.17**	0.11*
	(0.09)	(0.07)	(0.06)
amount of long-term hired labor	0.10	0.14	0.13
(inverse hyperbolic sine)	(0.18)	(0.25)	(0.16)
hiring long-term labor (0/1)	0.07	0.03	0.05
	(0.06)	(0.08)	(0.05)
lag of the outcome variable	YES	YES	YES
household-level confounding factors[c]	YES	YES	YES
community-level fixed effects	YES	YES	YES
No. of household observations	284	286	570

Note: [a]I use the same regression model as in Table 4. To increase sample sizes, I reclassify households with land endowments above 15 manzanas (35 percentile) as large landowners. [b]These districts had initial formal credit shares above the median by survey round 1. Relative to districts with low formal credit shares, they experienced significant reductions in credit supply between survey rounds. [c]Table 3 lists household-level confounding factors. Standard errors in the parentheses are clustered at the survey district level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table A.7: Formal Credit Shocks in Refined Survey Districts and the Impacts of Security Improvement Programs for Large Landowners.[a]

outcome variable	districts with high formal credit share[b]	districts with low formal credit share	all districts pooled
No. of attached facilities	-0.05	0.49	0.19
(inverse hyperbolic sine)	(0.15)	(0.43)	(0.23)
having attached facilities (0/1)	-0.01	0.03	0.01
	(0.01)	(0.04)	(0.02)
No. of trees planted in two years	0.24	1.25*	0.70**
(inverse hyperbolic sine)	(0.43)	(0.53)	(0.33)
planting trees in two years (0/1)	0.05	0.21**	0.12**
	(0.08)	(0.09)	(0.06)
area of rented-out land	-0.04	-0.17**	-0.09
(inverse hyperbolic sine)	(0.10)	(0.07)	(0.06)
renting out land (0/1)	0.01	-0.06**	-0.02
	(0.05)	(0.03)	(0.03)
amount of agricultural credit	0.13	1.32**	0.80
(inverse hyperbolic sine)	(0.86)	(0.59)	(0.54)
agricultural credit usage (0/1)	0.01	0.12*	0.07
	(0.08)	(0.06)	(0.05)
amount of long-term hired labor	0.07	0.24	0.16
(inverse hyperbolic sine)	(0.16)	(0.24)	(0.14)
hiring long-term labor (0/1)	0.06	0.05	0.06
	(0.05)	(0.07)	(0.04)
lag of the outcome variable	YES	YES	YES
household-level confounding factors[c]	YES	YES	YES
community-level fixed effects	YES	YES	YES
No. of household observations	337	317	654

Note: [a]I run the same regressions as in Table 5 except that I exclude 3 survey districts where there were huge increases in formal credit (outliers). [b]These districts had initial formal credit shares above the median by survey round 1. Relative to districts with low formal credit shares, they experienced significant reductions in credit supply between survey rounds. [c]Table 3 lists household-level confounding factors. Standard errors in the parentheses are clustered at the survey district level. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.