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 bring about significant gains in both agricultural output and poverty reduction for rural economies endowed with unequal land ownership distributions. However, these win-win economic gains largely hinge on the premise that security improvement will simultaneously boost land-attached investments and increase land rental supply to facilitate land access for the rural poor. This paper argues that in theory, non-security barriers to long-term land rental contracts could break this premise by causing a countervailing interaction between the investment and rental-supply effects of securing land ownership. I provide suggestive evidence from Nicaragua, one of the poorest countries in Latin America. Recent panel data of rural household surveys show that after a plausibly exogenous improvement in land ownership security, previously-credit-unconstrained households significantly increased land-attached investments but not rented-out land, while previously-credit-constrained households did the opposite. These findings hold even for matched households based on their likelihood of being initially credit-constrained.

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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.[2] Importantly, I show that in theory, the investment effect can attenuate the concurrent rental-supply effect in the presence of common market failures. I also provide suggestive evidence from rural Nicaragua where land titling and registration programs have been implemented to secure land ownership.

The countervailing investment and rental-supply effects of securing land ownership can have profound welfare implications for rural economies endowed with unequal land ownership distributions. In particular, 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). However, these win-win economic gains largely hinge on the condition that security improvement facilitates the egalitarian distribution of the operational land by activating land rental markets besides increasing land-attached investments (e.g., Boucher et al., 2005). This premise will break down when the investment effect attenuates the concurrent rental-supply effect. The realized welfare gains of securing land ownership could then be notably smaller than expected.

I start the theoretical analysis with an agricultural household model that builds on the following three common market failures that 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). 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 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

[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). For simplicity, this paper will not consider the sectoral occupation choice through which securing land tenure can notably affect agricultural growth, either (e.g., Chen, 2017; Gottlieb and Grobovšek, 2019). See Deininger et al. (2022) for a comprehensive review of this strand of economic literature.

[2] Besley (1995) and Carter and Yao (1999) studied the *intertemporal* interaction between the investment and rental-supply effects. They found that the rental-supply effect can strengthen the investment effect as the option of renting out land in the future helps reap investment fruits in an uncertain world. This paper, however, studies the *contemporaneous* interaction between the investment and rental-supply effects and thus complements their works.

of land ownership security (Carter, 1988; Carter and Olinto, 2003). Thus, only large landowners will increase land-attached investments, which require upfront monetary outlays, in response to the improvement in land ownership security that lowers the risk of losing land-attached investments.

The third market failure is the moral hazard of tenants not taking care of landlords' long-term land-attached capital (e.g., irrigation facilities like wells, livestock structures like stables and fences, long-lived tree crops like coffee and citrus, etc.) under short-term land rental contracts. Non-security barriers like legal caps on contract durations and landlords' inclination for flexible short-term contracts will make landlords not commit to long-term land leasing even if they have secure land ownership (Díaz et al., 2002; Bandiera, 2007).[3] In the theory outlined below, I model this moral hazard problem 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 on the endowed land to be self-cultivated more than that on the endowed land to be rented out after an improvement in land ownership security. This bias of the investment effect favors self-cultivation and thus dampens the concurrent rental-supply effect. The attenuated rental-supply effect will limit the scope of large landowners to reduce the inefficient hired labor input on the self-cultivated land. This will in turn downsize the investment effect when labor complements land-attached capital in farm production (Carter and Yao, 1999).

The third market failure described above is critical for the countervailing interaction between the investment and rental-supply effects of securing land ownership. Without it, large landowners would not face the capital depreciation risk as they could rent out land under long-term contracts. Then, they would invest the same intensity of attached capital investments on the endowed land to be self-cultivated and rented out. That is, the investment effect would not be biased towards the endowed land to be self-cultivated and thus not attenuate the concurrent rental-supply effect. Importantly, the unattenuated rental-supply effect would then get around the other two land-size-sensitive market failures by facilitating both the egalitarian distribution of the operational land and the even distribution of land-attached capital between the self-cultivated and rented-out land.

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' ability or willingness to invest in land-attached capital. I provide suggestive evidence for this theoretical hypothesis from Nicaragua, one of the poorest countries in Latin America. Rural Nicaragua is a relevant context as

[3] In Latin America, there have been frequent incidences of tenants abusing landlords' land-attached capital under short-term land leasing (de Janvry et al., 2002). The fundamental problem is that landlords lack the commitment to long-term land rental contracts. Unlike de Janvry and Sadoulet (2002) who emphasize insecure land ownership, Bandiera (2007) argues that landlords may not have the commitment simply because they want to have the option of adjusting contract terms or self-cultivating the land to changes in the economic environment. Importantly, legal regulations directly dampen long-term land rental contracts. Díaz et al. (2002) find that civil codes in Argentina, Nicaragua, Peru, and Uruguay prohibit land leasing of longer than 10 or 15 years. Other countries, like Chile and Costa Rica, put similar regulations on the indigenous and agrarian reform land.

it had witnessed a notable increase in land-attached capital 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 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 of household surveys conducted by the Millennium Challenge Corporation's rural business development project in Nicaragua (Carter et al., 2019). I study the impacts of security improvement programs as recorded in the data while controlling for the rural business development project. 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). I find similar results for security improvement programs in my data.

I identify the investment and rental-supply effects of securing land ownership by leveraging the sizable increases in community-level enrollment rates of security improvement programs across time while controlling for community-level potential confounding factors. I find that after program participation, households significantly increased land-attached capital but not rented-out land. However, these effects are pronounced only among households that were previously credit-unconstrained. Households that were previously credit-constrained did the opposite. This contrast holds even for matched households based on their likelihood of being initially credit-constrained. These findings are consistent with the theoretical prediction that the degree to which the investment effect attenuates the rental-supply effect is positively associated with landowners' investment capacities.

This paper contributes to the extensive literature on the economic effects of land tenure security by establishing an agricultural household model that allows the *contemporaneous* interaction between the investment and rental-supply effects for the first time. Importantly, the model predicts that the investment effect will attenuate the concurrent rental-supply effect when non-security barriers to long-term land rental contracts induce the capital depreciation risk facing potential landlords. I also provide suggestive evidence on this model prediction from Nicaragua, one of the poorest countries in Latin America. In principle, the countervailing investment and rental-supply effects could notably downsize the economic gains of securing land ownership in agricultural output and poverty reduction for rural economies endowed with unequal land ownership distributions. These insights and findings may deepen our understanding of how market failures can limit the economic benefits of securing land tenure.

The most closely related works are conducted by Besley (1995) and Carter and Yao (1999) who studied the *intertemporal* interaction between the investment and rental-supply effects of land tenure security. They argue that securing land tenure facilitates renting out land to reap investment fruits in the risky future, enlarging the current investment effect. In contrast, I demonstrate that under short-term land rental contracts, the capital depreciation risk discourages renting out land at higher land tenure security, which may downsize the current investment effect as explained above.

The rest of the paper proceeds as follows. First, I introduce 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 contemporaneous interaction between the investment and rental-supply effects of higher land ownership in section 4. In section 5, I provide suggestive empirical evidence on the countervailing investment and rental-supply effects of securing land ownership from rural Nicaragua. Finally, I conclude the paper in section 6.

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 in section 4. 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 considered below consists of heterogeneous households in land endowment. They engage in the same C.R.S. 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 agent, either landed or landless, 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 investments, and $S_e = 1$ means no risk. Landed agents are heterogeneous in the size and security level of land endowment, although the same intensity of natural capital k_n is embedded in their endowed land.

Technologies: farm production and the extraction of effective labor.
(i) *Farm production*: Each agent has access to the same C.R.S. production technology $F(A, K, L)$

[4]The risk-neutral preferences imply a linear unity function in income, which simplifies the discounted utility formula outlined in section 2.2. See more details out there.

that is strictly increasing, concave, and twice-continuously differentiable in its three inputs—raw land A, attached capital K, and effective labor L.[5] Attached capital consists of the embedded natural capital (endowments like rainfalls) and the invested artificial capital (investments like irrigation installments), and they are perfect substitutes.[6] All the inputs are ordinary and strictly gross complements for each other (e.g., Carter and Yao, 1999).[7] Also, the marginal output of each input, evaluated at zero, goes to positive infinity, given nonzero other inputs.[8]

(ii) *The extraction of effective labor under the agency cost of hired labor (the first market 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 workers are 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): $L(L_f, 0) = L_f, \forall L_f \geq 0$, i.e., family labor is used as the numeraire for effective labor; and $0 < \frac{\partial L}{\partial L_h} \leq 1, \frac{\partial^2 L}{\partial L_h^2} < 0, \forall L_h \geq 0, L_f > 0$, i.e., the first unit of hired labor is as efficient as family labor; but its effectiveness decreases as more hired labor is used or equivalently the supervision intensity, namely $\frac{L_f}{L_h}$, decreases.

Markets: land rental, labor, attached capital, credit, and output.

(i) *Land rental market*: Land rental contracts are of fixed rent.[9] 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, they may or may not invest attached capital in the rented-out land, depending on its return and cost, while tenants do not invest in the rented-in land.[10]

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

(iii) *Attached capital market*: Each agent faces the same exogenous price of the artificial attached capital. Such price is normalized to one, i.e., attached capital is the numeraire in this economy.

[5] This technical assumption is a common regularity assumption that simplifies the analytical analyses below. For simplicity, I do not incorporate any intermediate input in the production technology above. Movable capital, like machines and other farming equipment, is not considered, either. See related discussions in section 5.

[6] I introduce natural attached capital to allow the possibility of landlords making zero attached capital investments on the rented-out land, which is not uncommon in reality (e.g., Bandiera, 2007). See details in the follow-up paper.

[7] At the optimum, an ordinary input will decrease as its price increases. That two inputs are strictly gross complements for each other means that at the optimum, one input will decrease as the price of the other increases.

[8] This common technical assumption simplifies the analytical analyses below by ruling out corner solutions with one or more zero optimal inputs in the farm production.

[9] 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 like the Marshallian inefficiency associated with sharecropping contracts (e.g., Shaban, 1987).

[10] This ad hoc assumption that tenants do not invest in the rented-in land seems reasonable for an unequal agrarian society of interest in this paper, like rural Nicaragua in Latin America and the Caribbean where it is often the rich landlord who makes attached capital investments on the rented-out land (e.g., 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.

(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 below the minimum size of land collateral A_e^m will have no access to credit due to quantity rationing, regardless of land ownership security (e.g., Carter, 1988; Carter and Olinto, 2003).[11] 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 responsivity to land ownership security $\theta'(S_e) > 0$ at each security level S_e. 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., $A_o k_o + A_t^{out} k_t^{out} \leq A_e\theta(S_e)$, where $\{A_o, k_o\}$ denote the size of the self-cultivated land and the intensity of its attached capital investments and $\{A_t^{out}, k_t^{out}\}$ denote the size of the rented-out land and the intensity of its attached capital investments. 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) *Output market*: Agents face the same exogenous output price p given by the outside output market like the global agricultural output market.

Depreciation costs: The artificial attached capital depreciates over time while the natural attached capital does not.[12] 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 capital depreciation rate 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*).[13] Nevertheless, landed agents including landlords conduct regular maintenance to keep the attached capital invested in the endowed land unchanged over time.[14] 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.

Protection costs: Insecure land ownership induces the risk of losing the endowed land and its attached capital investments. Renting out land raises such risk.[15] To maintain land ownership, landed agents periodically expend money to protect the endowed land and its attached capital

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

[12] The assumption that the natural attached capital does not depreciate simplifies analyses below, although it is not essential for the model predictions of interest in sections 3 and 4.

[13] Establishing long-term land rental contracts may be either impossible due to legal regulations on contract durations (e.g., Díaz et al., 2002) or too costly for landlords as they have to give up the option of adjusting terms of the contract or self-cultivating the land to changes in the economic environment (e.g., Bandiera, 2007).

[14] Together with the next assumption that landowners expend costs to protect the endowed land and its attached capital investments, this assumption simplifies the theoretical analyses below by making the problem of maximizing the discounted incomes over the infinite production periods static. See the elaboration in subsection 2.2.

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

investments.[16] 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 in market values that a landowner would face if she or he did not protect her or his land ownership.[17] Moreover, we have $c_t(S_e) > c_o(S_e) > 0$ and $c_t'(S_e) < c_o'(S_e) < 0, \forall S_e \in [0,1)$, as renting out land raises the risk of losing the endowed land and its attached capital investments 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.

2.2 The utility maximization problem

To proceed, 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;*

[16] In the conventional way of modeling insecure land ownership, landowners passively lose the endowed land and its attached capital investments cum output with some positive probability (e.g., Feder et al., 1988; Besley, 1995). Here, I deviate from it and introduce this alternative approach in which landowners actively expend resources like money in this model to protect insecure land ownership. This new approach ensures that all land cultivators can collect all 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.

[17] It seems simpler to use $\frac{r(k_n+k_o)}{i}$ or $\frac{r(k_n+k_t^{out})}{i}$ for the gross market value of the endowed land and its attached capital investments. However, doing so will further complicate the already-sophisticated theoretical analyses below without bringing us additional insights. Thus, I choose to treat the endowed land and attached investments separately.

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

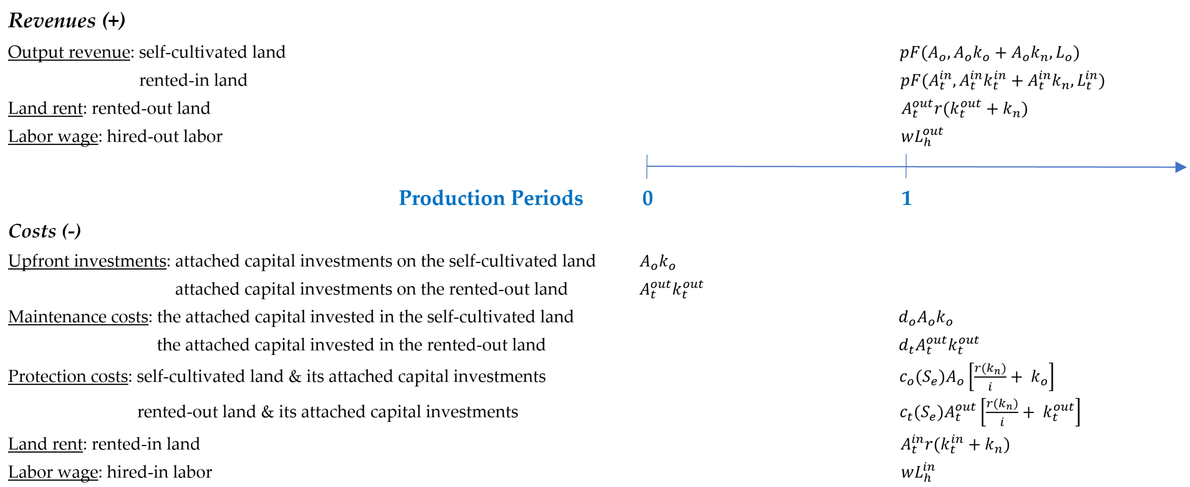

Figure 1: The General Structure of Revenues and Costs.

Under the model assumptions in subsection 2.1, we have the general structure of revenues and costs as outlined in Figure 1. Here, the blue integer "0" denotes the initial production period when the *upfront 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 first harvest when the periodical revenues and costs occur for the first time, which deliver the following *four sources of income.*

(i) *The pseudo-profit of cultivating the self-cultivated land* $\pi_o(A_o, k_o, L_o)$:[18]
$pF(A_o, A_o k_o + A_o k_n, L_o) - [d_o + c_o(S_e)] A_o k_o - c_o(S_e) A_o \frac{r(k_n)}{i}$.
(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*: $wL_h^{out} - wL_h^{in}$.

[18]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) the net wage income of hiring out and in labor.

Holding prices and land ownership security constant, these incomes will repeatedly occur in later harvests since agents will allocate land and labor as before.[19] The reason is that attached capital on any land will remain unchanged after initial investments thanks to the periodical maintenance made by landowners. 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 incomes and the discount factor $\beta = \frac{1}{1+i}$:

$$
\begin{aligned}
max_{\{choice\ variables\}} \frac{1}{i}\Big\{&\pi_o(A_o, k_o, L_o) + \pi_t^{out}(A_t^{out}, k_t^{out}) + \pi_t^{in}(A_t^{in}, k_t^{in}, L_t^{in}) + (wL_h^{out} - wL_h^{in})\Big\} \\
&- (A_o k_o + A_t^{out} k_t^{out}) \\
s.t.\ \ &A_o + A_t^{out} \leq A_e; \qquad (1)\\
&A_o k_o + A_t^{out} k_t^{out} \leq I_{\{A_e \geq A_e^m\}} A_e \theta(S_e); \qquad (2)\\
&L_o + L_t^{in} \leq L(L_f, L_h^{in}); \qquad (3)\\
&L_f + L_h^{out} \leq 1; and \qquad (4)\\
&\{A_o, A_t^{out}, A_t^{in}, k_o, k_t^{out}, k_t^{in}, L_o, L_t^{in}, L_f, L_h^{out}, L_h^{in}\} \geq 0, \qquad (5)
\end{aligned}
$$

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}, as defined above.

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 A_e. The credit constraint (2) says that the gross attached capital investments on the self-cultivated and rented-out land should not exceed the accessible credit $A_e\theta(S_e)$ for an agent who has access to credit. An agent endowed with land of size below the minimum size of land collateral required for access to credit 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-in 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) simply 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 above in Appendix A, which will be used in 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 previous subsection will affect the land rental choices of agents endowed with

[19] 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. Nevertheless, the depreciation rate of the attached capital invested in the rented-out land or the 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 as shown in the empirical literature (Bandiera, 2007; Jacoby and Mansuri, 2008).

different sizes of land endowment 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.

3 Land Rental Choices given Land Ownership Security

In this section, I study when landed agents 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.[20] 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. 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 the next section. In the following, let us focus on the general case when land ownership is insecure, i.e., landed agents need to expend costs to protect the endowed land and its attached capital investments. 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 the rented land equals wage rate, regardless of the intensity of attached capital investments made by the landlord.*

Lemma 1 comes from the following two facts: (i) under the C.R.S. production technology, tenants earn the same unit return of the effective labor input on the rented land in the competitive land rental market, regardless of the intensity of attached capital investments made by landlords; and (ii) tenants and laborers are indifferent between the two usages of the 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 (see details in Appendix B). 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 while one unit of family labor just produces one unit of effective labor. 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 the 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 wage rate. Under this condition, renting out land will not improve the efficiency of the labor input on the endowed land as self-cultivating all the endowed land does not involve the usage of the inefficient hired labor. In fact, 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

[20] Admittedly, landed agents are also heterogeneous in the security level of land endowment. See their land rental choices at different security levels of land endowment in section 4.

hazard of tenants not taking care of landlords' land-attached capital. More generally, 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 others' farms.[21] Based on this fact, 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.*

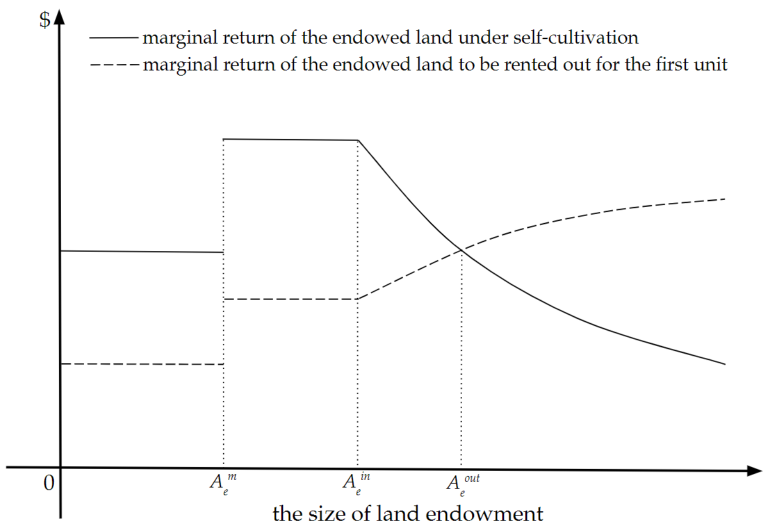

Figure 2: Thresholds of Renting in and out Land at a Given Security Level of Land Endowment.

Note: (i) The marginal return of the endowed land is defined as the marginal output revenue of the endowed land minus its unit protection cost, where the unit protection cost only depends on the security level of land endowment. Thus, the patterns of the two marginal returns of the endowed land listed above capture the effects of the size of land endowment on these marginal returns. (ii) A_e^m is the minimum size of land collateral required for access to credit, i.e., an agent endowed with land of size below A_e^m will have no accessible credit to make attached capital investments. This leads to jump-ups in both marginal returns of the endowed land right at the size of land endowment equal to A_e^m and their changes at larger sizes of land endowment. See the text below for detailed explanations. (iii) A_e^{in} is the threshold of renting in land, the size of land endowment above which landed agents stop renting in land. (iv) A_e^{out} is the threshold of renting out land, the size of land endowment above which landed agents start renting out land.

As shown in Figure 2, the solid lines represent the marginal return of the endowed land under self-cultivation at different sizes of land endowment. It is defined as the marginal output revenue of the endowed land (including its natural attached capital) under self-cultivation minus the unit cost of protecting the endowed land under self-cultivation.[22] At a given security level of land endowment S_e, the protection cost part is constant, whereas the output revenue part depends on

[21] Agents are indifferent between the latter two usages of the endowed labor as they deliver the same unit return.

[22] In the farm production, the endowed land provides two inputs—raw land and attached capital. The latter comes from the natural attached capital embedded in the endowed land. Hence, the marginal output revenue of the endowed land equals the marginal output revenue of the raw land plus the marginal output revenue of attached capital times the intensity of the natural attached capital. See the mathematical formula below in subsection 4.2.

the size of land endowment A_e. That is, the size of land endowment affects the marginal return of the endowed land under self-cultivation only through the output revenue part.

When A_e is smaller than the minimum size of land collateral required for access to credit 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 at its opportunity cost wage rate though, since the size of land endowment is small, namely $A_e < A_e^m$ where 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 become larger right at $A_e = A_e^m$ than that 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 the farm production.[23] Although attached capital also complements labor in the farm production, self-cultivating all the endowed land of size A_e equal to A_e^m will still not consume all the endowed labor at its opportunity cost wage rate given that A_e^m is small.

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 wage rate. This means that agents endowed with land of size above A_e^{in} will not use any endowed labor to cultivate any land to be rented in as they will use all the endowed labor to self-cultivate all or part of the endowed land.[24]

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. Note that 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

[23] Admittedly, attached capital investments at $A_e = A_e^m$ will reduce the output revenue of the natural attached capital per unit of the endowed land—the marginal output revenue of attached capital times the intensity of the natural attached capital—if the marginal output revenue of attached capital becomes smaller than that at $A_e < A_e^m$. Nevertheless, the marginal output revenue of the endowed land under self-cultivation will increase right at $A_e = A_e^m$ where a landed agent just becomes able to make attached capital investments to maximize the profit of cultivating all the endowed land. So will the marginal output revenue of the endowed land to be rented out for the first unit.

[24] As explained before, renting out land without using out all the endowed labor for self-cultivation is unprofitable.

constraint status, since 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 (*one of model assumptions*).[25] 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. Thus, 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 that raises the marginal cost of the effective labor input above wage rate due to the agency cost of hired labor. Moreover, a larger size of land endowment requires more hired labor input, although family labor input is fixed. Then, the marginal cost of the effective labor input on 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 rising agency cost resulting from the decreasing supervision intensity.[26] 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 the 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, contributing to the decrease in the marginal return of the endowed land under self-cultivation as well.[27] Nevertheless, the credit constraint is usually binding 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.*[28] Then, the lower shadow price of the accessible credit

[25] Under this assumption, they will be either all credit constrained or all credit 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 all credit constrained and invest the same intensity of attached capital investments on the endowed land under self-cultivation, which equals the constant leverage ratio that they face. Otherwise, they will be all credit unconstrained and invest the same intensity of attached capital investments on the endowed land under self-cultivation as they demand.

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

[27] For a given security level of land endowment, the decreasing intensity of attached capital investments demanded on the endowed land under self-cultivation will eventually equal the constant leverage ratio, i.e., the credit constraint will turn to be not binding at a sufficiently large size of land endowment. Then, the intensity of the attached capital invested in the endowed land under self-cultivation will equal the intensity of attached capital investments demanded on the endowed land under self-cultivation and thus keep decreasing afterwards.

[28] It will become clear later that this assumption is not essential for the main theoretical predictions of interest.

will lead to a higher intensity of attached capital investments on the first unit of the endowed land to be rented out. 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.[29] So will the marginal return of the endowed land to be rented out for the first unit, as shown above by the long-dashed lines in Figure 2.[30] Of course, it will eventually plateau out as the credit constraint becomes not binding at a sufficiently large size of land endowment.

For $A_e \in [A_e^m, A_e^{in}]$, however, the intensity of attached capital investments demanded on the endowed land under self-cultivation will be invariant to the size of land endowment as landed agents of this category face the same constant marginal cost of the effective labor input, namely wage rate. 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. Then, the marginal cost of the effective labor input will keep increasing due to the rising agency cost of hired labor caused by the decreasing supervision intensity. As a result, the marginal return of the endowed land under self-cultivation will keep decreasing. In contrast, 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 after the credit constraint becomes not binding at a sufficiently large size of land endowment.[31] Based on these opposite patterns, I obtain the following proposition about the threshold of renting out land, denoted by A_e^{out}.

[29]The marginal cost of the effective labor input on the rented-out land always equals wage rate. See Lemma 1.

[30]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. Again, the unit protection cost is fixed at a given security level of land endowment, although it is higher than that for the endowed land under self-cultivation.

[31]When landed agents do not invest attached capital in the endowed land to be rented out due to a super high capital depreciation rate, the marginal return of the endowed land to be rented out for the first unit will instead stay constant for $A_e > A_e^{in}$. Nevertheless, Proposition II above still holds 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 the 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 also contributes to the loss in the marginal return of the endowed land as it raises the capital depreciation rate.

The analyses before Proposition II show that the larger the size of land endowment is, the larger the gain will be relative to the loss at a given security level of land endowment. As a result, a landed agent will rent out land 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 above. 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 to what extent securing land ownership can 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.

4.1 Main Results

As shown in Figure 3, 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 become higher at any given size of land endowment for a higher security level of land endowment, holding prices constant. Higher land ownership security raises these marginal returns as it reduces the unit cost of protecting the endowed land and its attached capital investments. Agents endowed with land of size below the minimum size of land collateral required for access to credit A_e^m will only capture the benefit of a lower unit cost of protecting the endowed land as they do not have accessible credit to make attached capital investments. Agents endowed with land of size above A_e^m, however, will additionally capture the benefit of a lower unit cost of protecting attached capital investments by using the (increased) accessible credit to make more investments. Hence, they witness larger gains in these marginal returns than the other landed agents who have no access to credit.

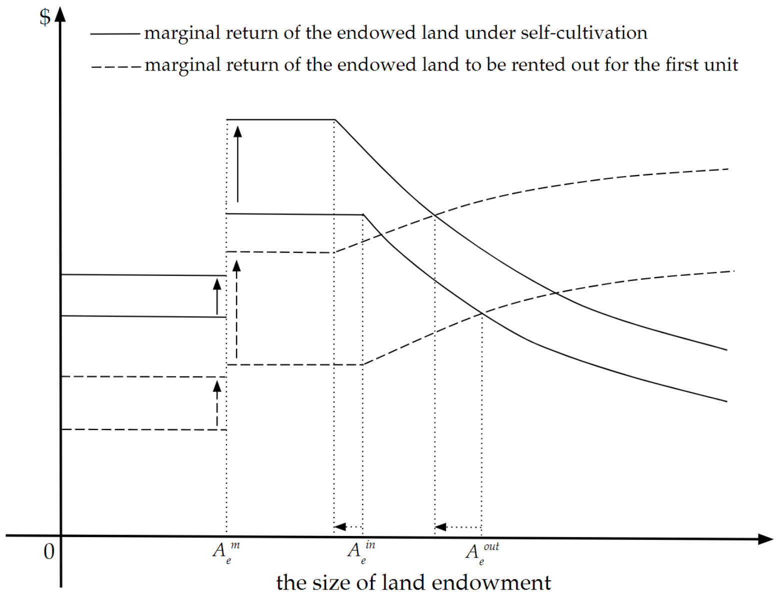

Figure 3: Thresholds of Renting in and out Land at a Higher Security Level of Land Endowment.

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, where the unit protection cost only depends on the security level of land endowment. For all landed agents, higher land ownership security will reduce the unit cost of protecting the endowed land. For landed agents having access to credit, it will also raise the marginal output revenue of the endowed land by increasing their attached capital investments. Thus, they will witness relatively larger increases in the two marginal returns of the endowed land listed above in the figure. See the text for detailed discussions about the relative increases of these two marginal returns. (ii) A_e^m is the minimum size of land collateral required for access to credit, i.e., an agent endowed with land of size below A_e^m will have no accessible credit to make investments. (iii) A_e^{in} is the threshold of renting in land, the size of land endowment above which landed agents stop renting in land. (iv) A_e^{out} is the threshold of renting out land, the size of land endowment above which landed agents start renting out land.

The higher intensity of attached capital investments will demand a higher intensity of labor input due to their complementarity in farm production. Then, 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, holding prices constant, i.e., the threshold of renting in land A_e^{in} will become smaller at a higher security level of land endowment, as shown in Figure 3.[32] 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

[32]As shown in the previous section, the marginal return of the endowed land to be rented out for the first unit is always smaller than the marginal return of the endowed land under self-cultivation at any size of land endowment below the threshold of renting in land A_e^{in} where self-cultivating all the endowed land just consumes all the endowed labor at its opportunity cost wage rate. That is, landed agents will always use the endowed labor to self-cultivate the endowed land before using it to cultivate any rented-in land.

under self-cultivation. As formally studied in the next subsection, the moral hazard of tenants not taking care of landlords' land-attached capital, resulting from non-security barriers to long-term land rental contracts, plays a critical role in modulating the relative increase in these marginal returns through the investment effect of higher land ownership security.

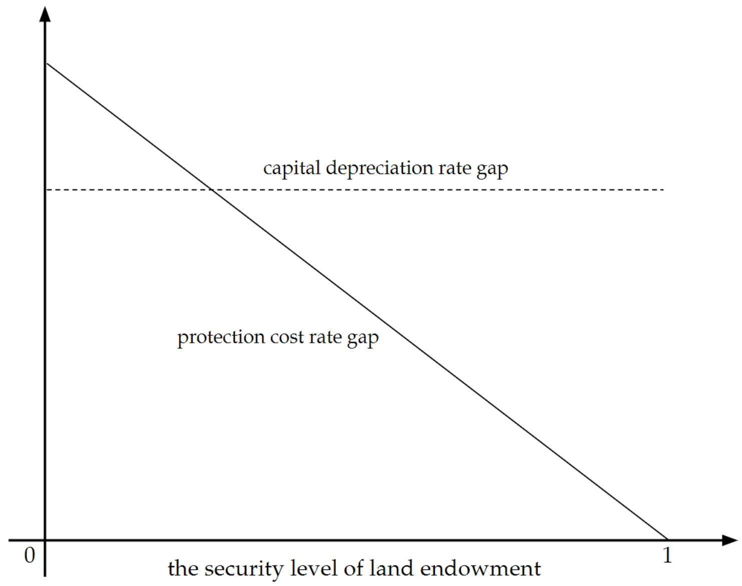

Figure 4: The Two Types of Barriers to the Even Distribution of Attached Capital Investments between the Rented-out and Self-cultivated Land.

Note: (i) The protection rate gap between the rented-out and self-cultivated land captures the security barrier to the even distribution of attached capital investments, namely insecure land ownership. (ii) The capital depreciation rate gap between the rented-out and self-cultivated land captures the non-security barrier to the even distribution of attached capital investments, namely the moral hazard of tenants not taking care of landlords' land-attached capital.

As shown above in Figure 4, there are two types of barriers to the even distribution of attached capital investments between the self-cultivated and rented-out land, represented by the protection cost rate gap and the capital depreciation rate gap. 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 contracts.

The economic analyses in the next subsection show that the capital depreciation rate gap induces landed agents having access to credit to increase attached capital investments on the self-cultivated land more than that on the rented-out land at higher land ownership security, which tends to surpass the opposite relative investment effect induced by the smaller protection cost rate gap.

This bias of the investment effect favors self-cultivation. In contrast, the smaller protection cost rate gap reduces the unit cost of protecting the rented-out land relatively more and thus favors renting out land (the rental-supply effect of higher land ownership security). Putting together, 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.

Nevertheless, the threshold of renting out land A_e^{out} will decrease at a higher security level of land endowment if the capital depreciation rate gap is small enough so that the marginal return of the endowed land to be rented out for the first unit witnesses a larger increase than the marginal return of the endowed land under self-cultivation. In the ideal case when there is no capital depreciation rate gap, the threshold of renting out land A_e^{out} will witness a larger reduction than the threshold of renting in land A_e^{in}, as shown in Figure 3. Eventually, A_e^{out} will coincide with A_e^{in} at the highest security level of land endowment (fully secure) where renting out land will neither raise the unit cost of protecting the endowed land and its attached capital investments nor increase the depreciation rate of the attached capital invested in the endowed land. This means that each agent endowed with land of size above A_e^{in} will rent out land of enough size to get around the agency cost of hired labor and invest the same intensity of attached capital in the rented-out land as that in the self-cultivated land if land ownership is fully secure.

The presence of the capital depreciation rate gap, however, will dampen the foregoing pro-egalitarian improvement in the distribution of complementary production factors (land, attached capital, and labor). First of all, it will discourage agents endowed with land of large sizes from renting out land, regardless of land ownership security, as it lowers the marginal return of the endowed land to be rented out by raising the capital depreciation rate. As shown in Figure 5, holding prices constant thresholds of renting out land at different security levels of land endowment (the two short-dashed lines on the right) will become larger than those (the long-dashed line in the middle) under no capital depreciation rate gap, i.e., fewer landed agents will rent out land.

More importantly, the threshold of renting out land may decrease less at a higher security level of land endowment (on the inclined short-dashed line) as the capital depreciation rate gap induces the bias of the investment effect towards the endowed land to be self-cultivated. It may even not decrease at all (on the vertical short-dashed line) if the capital depreciation rate gap is sufficiently large. This means that higher land ownership security may not necessarily induce more landed agents to rent out land, holding prices constant. The next subsection shows that it may not necessarily encourage preexisting landlords to rent out more land, either. In sum, the capital depreciation rate gap 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.

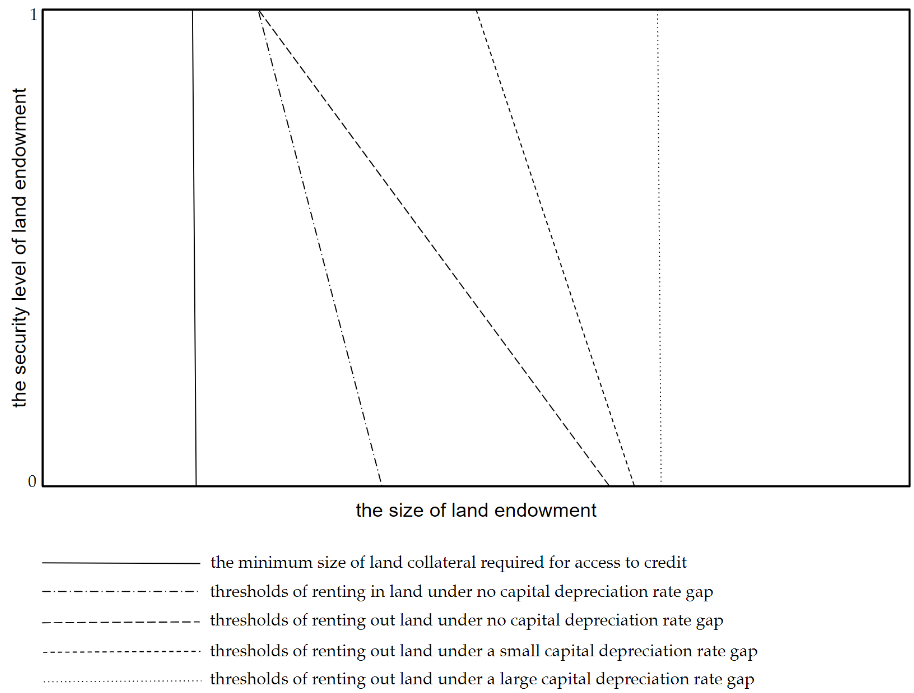

Figure 5: The Impact of the Capital Depreciation Rate Gap between the Rented-out and Self-cultivated Land on the Threshold of Renting out Land.

Note: (i) On the left of the figure, "0" means the lowest land ownership security, whereas "1" means the highest, namely no risk of losing the endowed land and its attached capital investments. (ii) The size of the capital depreciation rate gap between the rented-out and self-cultivated land captures the severity of the moral hazard of tenants not taking care of landlords' land-attached capital. (iii) The long-dashed line collates the thresholds of renting out land at different security levels of land endowment in the case when the moral hazard of tenants not taking care of landlords' land-attached capital is not present. (iv) The inclined short-dashed line represents the case when the moral hazard of tenants not taking care of landlords' land-attached capital is moderate so that the threshold of renting out land still decreases but less at a higher security level of land endowment. (v) The vertical short-dashed line represents the case when the moral hazard of tenants not taking care of landlords' land-attached capital is severe such that the threshold of renting out land remains unchanged at a higher security level of land endowment.

4.2 Economic Analyses

In this subsection, 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 towards the endowed land to be self-cultivated. For readability, I only present economic reasoning here and put all the math in Appendix 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 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 induces the bias of the investment effect of higher land ownership security towards the endowed land to be self-cultivated. As shown later, this bias of the investment effect tends to attenuate the concurrent 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 tend to increase the intensity of attached capital investments on the self-cultivated land more than that on the rented-out land at higher land ownership security, holding other things constant.*

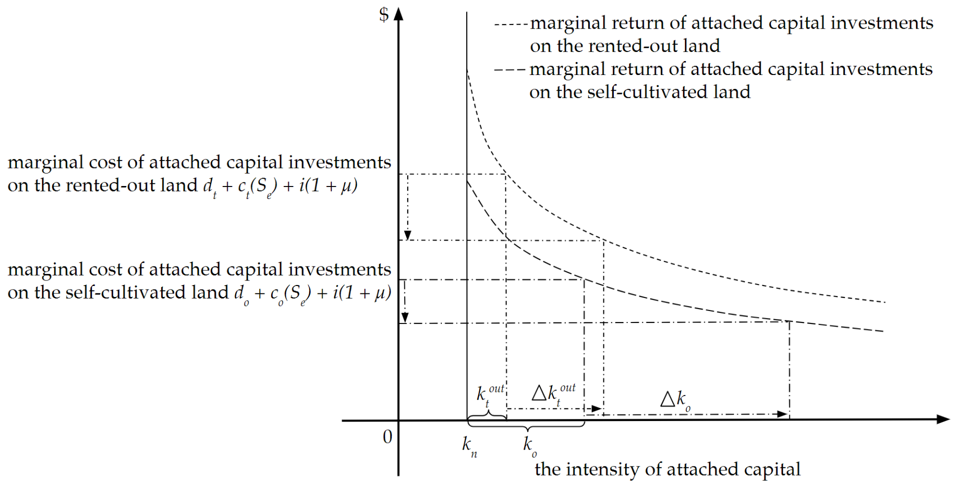

Figure 6: The Bias of the Investment Effect of Higher Land Ownership Security.

Note: Here, k_n denotes the intensity of the natural attached capital embedded in the endowed land, which is small. For illustration purposes, I assume that landed agents at the extensive and intensive margins of renting out land invest attached capital in both the self-cultivated and rented-out land, i.e., the marginal returns of attached capital investments on both the self-cultivated and rented-out land, evaluated at k_n, are higher than their marginal costs. Hence, we have positive intensities of attached capital investments on both the self-cultivated and rented-out land before the security improvement, namely $k_o > 0$ and $k_t^{out} > 0$. At a given intensity of attached capital, the marginal return or output revenue of attached capital investments on the rented-out land is higher than that on the self-cultivated land. This results from the relatively higher efficiency of the labor input on the rented-out land and the complementarity between attached capital and labor inputs in the farm production. The arrows above show the effects of higher land ownership security on attached capital investments and their marginal costs. See detailed explanations about these effects in the main text below.

In section 3, I have shown that landlords are 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.*[33] However, as shown in Figure 6, a landlord will 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), namely $k_t^{out} < k_o$, 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 $d_o + c_o(S_e) + i(1 + \mu)$.[34]

[33] Lemma 2 will mechanically hold true if landlords do not invest attached capital in the rented-out land.

[34] I assume that the relatively higher marginal return or output revenue of attached capital investments on the rented-out land, resulting from the relatively higher efficiency of the labor input on the rented-out land, does not alter the incentives of a landlord to invest a relatively lower intensity of attached capital in the rented-out land.

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.

Holding other things 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 $c_o'(S_e) < 0$. The increase in the accessible credit resulting from a higher leverage ratio, namely $\theta'(S_e) > 0$, will also lower these marginal costs of attached capital investments by reducing the shadow value of relaxing the credit constraint μ. However, as shown in Figure 6, a landlord tends to increase attached capital investments on the self-cultivated land more than that on the rented-out land, namely $\Delta k_o > \Delta k_t^{out}$, given $k_o > k_t^{out}$ and the diminishing marginal return of attached capital investments. This is particularly true when the decrease in the protection cost rate gap between the rented-out and self-cultivated land $c_t'(S_e) - c_o'(S_e)$ is not too large in magnitude relative to the capital depreciation rate gap between the rented-out and self-cultivated land $d_t - d_o$. Based on this bias of the investment effect of higher land ownership security towards the endowed land to be self-cultivated, I obtain the following two propositions.

Proposition III*: Higher land ownership security may not necessarily decrease the threshold of renting out land A_e^{out} 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 A_o^* for a preexisting landlord when the moral hazard of tenants not taking care of landlords' land-attached capital is present, holding prices constant.*

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:[35]

$$p\frac{\partial F^o}{\partial A} + p\frac{\partial F^o}{\partial K}k_n - c_o(S_e)\frac{r(k_n)}{i} = p\frac{\partial F^t}{\partial A} + p\frac{\partial F^t}{\partial K}k_n - c_t(S_e)\frac{r(k_n)}{i}, \tag{6}$$

where F^o denotes the output produced on the self-cultivated land, F^t denotes the output produced

[35] See the corresponding first-order conditions for the optimal allocations of credit and labor in Appendix C.

on the rented-out land, A and K denote raw land and attached capital, respectively.[36] On each side, the first two terms represent the marginal output revenue of the endowed land (raw land plus its natural attached capital) while the third term represents the unit cost of protecting the endowed land. To simplify notations, I denote MR^o and MR^t as the marginal output revenues of the self-cultivated and rented-out land, respectively, i.e., $MR^o = p\frac{\partial F^o}{\partial A} + p\frac{\partial F^o}{\partial K}k_n$ and $MR^t = p\frac{\partial F^t}{\partial A} + p\frac{\partial F^t}{\partial K}k_n$.

On the one hand, 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 other things constant, given that renting out (more) land will help her or him reduce the inefficient hired labor input on the endowed land.

On the other hand, higher land ownership security also reduces the risk of losing attached capital investments and raises the accessible credit. As explained before, holding other things 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 of higher land ownership security will be 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 the farm production.[37]

In sum, higher land ownership security may bring about two offsetting effects on land rental supply.[38] Intuitively, the investment effect will be biased towards the endowed land to be self-cultivated when the moral hazard of tenants not taking care of landlords' land-attached capital induces the capital depreciation risk facing potential landlords. This bias of the investment effect will favor self-cultivation and thus attenuate the concurrent rental-supply effect.

For a given context, the capital depreciation risk is fixed. However, individual landowners may have differential exposures to the countervailing interaction between the investment and rental-supply effects due to differences in land and labor endowments as well as other factors not modeled here. In particular, credit-constrained landowners are likely to witness limited investment effects. All else equal, they may witness sizable rental-supply effects instead.

[36]Specifically, we have $F^o = F(A_o, A_o k_o + A_o k_n, L_o)$ and $F^t = F(A_t^{out}, A_t^{out} k_t^{out} + A_t^{out} k_n, L_f^t)$ with L_f^t denoting the family labor input provided by the tenant.

[37]Admittedly, whether a relatively larger increase in attached capital investments on the self-cultivated land will lead to a relatively larger increase in the marginal output revenue of the self-cultivated land largely depends on the easiness of credit access. For instance, the self-cultivated land might not necessarily witness a relatively larger increase in its marginal output revenue if its relatively larger increase in attached capital investments is small in the absolute amount due to limited credit access or equivalently a small leverage ratio in the model. Due to the input complementarity in farm production, the relatively lower efficiency of the labor input on the self-cultivated land, resulting from the agency cost of hired labor, downsizes the contribution of attached capital investments to the marginal output revenue of the self-cultivated land relative to the marginal output revenue of the rented-out land.

[38]See the associated comparative statics of renting out land at the extensive and intensive margins in Appendix D.

5 Empirical Evidence

In this section, I provide suggestive evidence from Nicaragua on the countervailing investment and rental-supply effects of securing land ownership. In short, I find that recent security improvement programs significantly increased land-attached capital but not rented-out land for rural Nicaraguan households. Further analysis reveals that these unbalanced effects are pronounced only among households that were initially credit-unconstrained, while households that were initially credit-constrained witnessed the opposite effects. These findings are consistent with the theoretical prediction that credit-unconstrained households are more likely to face a severe countervailing interaction between the investment and rental-supply effects as they have higher capacities to materialize investment effects. As follows, I describe the context and data first. Then, I outline the empirical strategy and econometric design. Finally, I present and discuss empirical results.

5.1 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 behind the super high rural poverty rate is possibly that rural Nicaragua has suffered from insecure land ownership due to the incomplete agrarian reforms of the 1980s (e.g., 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).[39] 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, among others (De la O Campos et al., 2023).[40] The other security improvement programs employed similar approaches. The data that I use in this paper is from the household survey conducted in the Millennium Challenge Corporation's rural business development project in Nicaragua.[41] In my empirical analysis below, I study the impacts of security improvement programs on land-attached capital and rented-out land while controlling for the random assignment of the rural business

[39]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 capital. 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. More importantly, I provide suggestive evidence of a potential mechanism behind these persistent patterns.

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

[41]The data is publically available at https://microdata.worldbank.org/index.php/catalog/2296. The rural business development project is an RCT that aims to raise households' incomes by helping farmers develop and implement agricultural business plans. See detailed descriptions in Carter et al. (2019).

development project.

Regarding the sample, I focus on the first two rounds of the original household survey (2007/2009) during which households did not change their land endowments much. The 1004 households who did not change their land endowments between these two rounds are of research interest in this paper.[42] These households lived in 56 communities that are located in 2 departments of western Nicaragua—Chinandega and León.[43] In these communities, households that were eligible for the rural business development project were surveyed.[44]

Table 1: Summary Statistics of the Household Survey Data.

variable	round 1 (mean/s.e.)	round 2 (mean/s.e.)	difference (round 2 - round 1)
area of endowed land (manzana)	30.9	-[a]	-[a]
	[35.5][b]		
No. of household members	5.5	-	-
	[2.3]		
gender of household head (0/1, 1 for male)	0.88	-	-
	[0.33]		
age of household head (years)	52.3	-	-
	[12.7]		
education of household head (school years)	3.7	-	-
	[4.0]		
enrolled in any security improvement program (0/1)	0.30	0.45	0.15***
	(0.02)[c]	(0.03)[c]	(0.01)[c]
credit constrained (0/1)	0.43	0.40	-0.02
	(0.01)	(0.02)	(0.02)
having land-attached capital (0/1)	0.69	0.71	0.01***
	(0.02)	(0.02)	(0.00)
amount of land-attached capital (1,000 córdoba)	15.18	17.24	2.06***
	(1.24)	(1.35)	(0.51)
having rented out land (0/1)	0.04	0.05	0.01
	(0.01)	(0.01)	(0.01)
area of rented-out land (manzana)	0.55	0.63	0.07
	(0.14)	(0.15)	(0.07)
having hired labor (0/1)	0.80	0.74	-0.06***
	(0.02)	(0.02)	(0.02)
amount of hired labor (day)	164.80	161.62	-3.18
	(13.32)	(9.58)	(8.95)

Note: [a]In this study, I focused on households that did not change land endowments between survey rounds. Hence, I did not report endowed land in round 2 and the difference between rounds. Neither did I report the data of round 2 for the number of household members and demographics of household heads due to their limited changes between rounds. [b]The standard error in the bracket is the standard deviation across households. [c]These standard errors, however, are clustered at the community level for precise comparisons between rounds. According to the data, there are 56 communities located in 2 departments of western Nicaragua—Chinandega and León. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

[42]Studying changes in land endowments is beyond the scope of this paper, which I leave for future research. In the cleaning process, I also dropped households who misreported plot sizes of 5% between survey rounds.

[43]These departments had similar rural poverty rates as other departments in Nicaragua. See details about these survey communities and departments as well as the original household sample in Carter et al. (2012).

[44]See the specific eligibility criteria for the rural business development project in Carter et al. (2019).

Table 1 above provides the summary statistics of the main data used in this paper. Households had an average land endowment of 30.9 manzanas (21.8 hectares); but there are sizable dispersions among households. However, households had similar family sizes with an average number of household members between 5 and 6. About 88% of household heads were male. An average household head was of an age just above 52 and had less than 4 years of schooling.

From survey round 1 (2007) to survey round 2 (2009), households who had enrolled in any security improvement programs increased by 15 percentage points while credit-constrained households slightly decreased by 2 percentage points. Along with these changes, households who had land-attached capital increased by 1 percentage point. More importantly, an average household increased land-attached capital by 14% mostly through investments at the intensive margin.[45] These increases in land-attached capital are highly statistically significant. However, the increases in rented-out land are not statistically significant, neither at the extensive margin nor at the intensive margin. Meanwhile, however, households notably decreased the usage of hired labor.

In my empirical analysis below, I show that the unbalanced changes in land-attached capital and rented-out land were largely driven by security improvement programs. Importantly, I provide suggestive evidence that these unbalanced increases were possibly due to the countervailing investment and rental-supply effects of securing land ownership, as predicted by the theory above. The countervailing investment and rental-supply effects of securing land ownership also helps reveal heterogeneous changes in the usage of hired labor among households.

5.2 Identification Strategy and Econometric Design

My first goal is to identify the causal impacts of security improvement programs on land-attached capital and rented-out land at the household level. The data indicates that there were notable changes in program enrollment rates at the community level between survey rounds. Figure 7 below shows that the community-level enrollment rate of security improvement programs—the proportion of households in a community who had ever enrolled in any security improvement programs—witnessed sizable increases from survey round 1 to survey round 2 across 56 communities in the original household sample.

More importantly, Table 2 below shows that the expansion of security improvement programs significantly increased participated households' perceived land ownership security. This finding is consistent with De la O Campos et al. (2023) who find similar security-enhancing effects of the World Bank's land administration program, the major security improvement program recorded in my data. This gives me confidence in that the identified investment and rental-supply effects of security improvement programs presented in the next subsection should be, at least partly, through the security enhancement channel as outlined in the theory above.

[45] Based on the detailed data, I find that more than 80% of the increased land-attached capital came from households who already had land-attached capital in the first survey round.

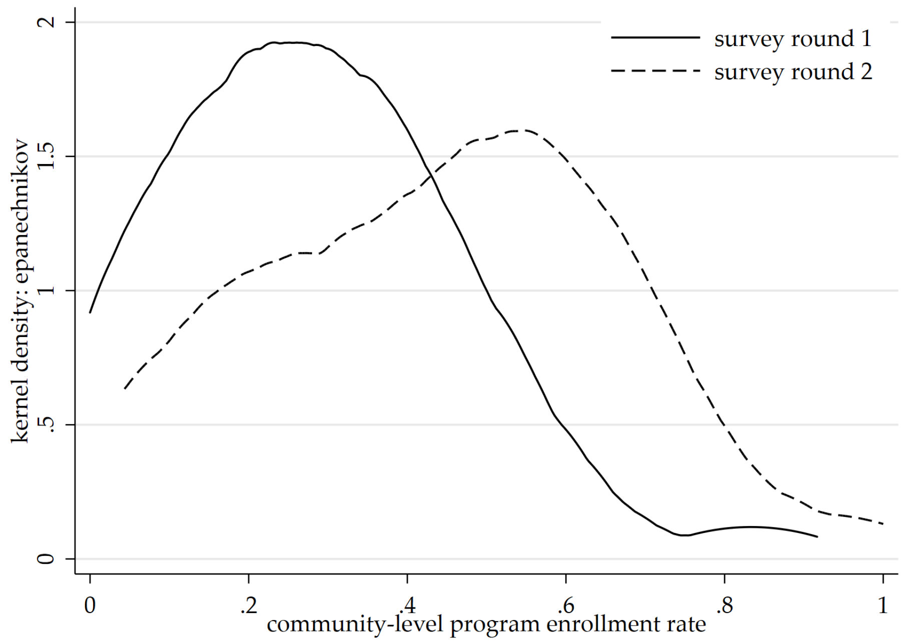

Figure 7: The Community-level Enrollment Rates of Security Improvement Programs.

Table 2: The Security-Enhancing Effect of Security Improvement Programs.

	Panel-IV regression[a]	
	First Stage program enrolled (0/1)	Second Stage feel safe about land (0/1)
program enrolled		0.145*
(household level)		(0.087)
IV: program enrollment rate	0.839***	
(community level)	(0.061)	
Controls for all the regressions above		
household fixed effects	YES	YES
department-survey round fixed effects	YES	YES
rural business development project[b]	YES	YES
No. of households[c]	1579	1579

Note: [a]I used community-level program enrollment rate to instrument for household-level program enrollment status while controlling for household and department-survey round fixed effects. [b]The rural business development project is an RCT that aims to raise households' incomes by boosting agricultural investments and business operations (Carter et al., 2019); I controlled for the random assignment of this project over time. [c]I included all households in the original household surveys for this regression. Standard errors are clustered at the community level and listed in parentheses. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

Table 3 below shows that changes in program enrollment rate across communities were driven by a couple of community socioeconomic demographics in the first survey round. Specifically, communities having higher shares of female-headed households witnessed significantly larger increases in program enrollment rate between survey rounds. This makes sense as these communities were prioritized in the World Bank's land administration program (De la O Campos et al., 2023), the major program in my data. Communities having higher shares of initially-credit-unconstrained households also witnessed significantly larger increases in program enrollment rate. This may be due to that part of security improvement processes, such as registration, were usually not free for program beneficiaries as found earlier in rural Nicaragua (e.g., Deininger and Chamorro, 2004).

Table 3: The Community-Level Socioeconomic Predictors for Changes in Program Enrollment Rate.

socioeconomic vars in survey round 1	changes in program enrollment rate between rounds					
(avg. across households per community)	(1)	(2)	(3)	(4)	(5)	(6)
area of endowed land		0.00				
(manzana)		(0.00)				
area share of endowed land with		-0.07				
registered public deeds		(0.11)				
Number of household			-0.02			
members			(0.03)			
male-headed household			-0.68***			-0.71***
(proportion)			(0.23)			(0.20)
age of household head			-0.00			
(years)			(0.00)			
education of household head			0.00			
(school years)			(0.01)			
credit-constrained household				-0.27*		-0.26**
(proportion)				(0.15)		(0.13)
household having land-attached capital					-0.12	
(proportion)					(0.14)	
amount of land-attached capital					0.00	
(1,000 córdoba)					(0.00)	
household having rented out land					-0.42	
(proportion)					(0.42)	
area of rented out land					0.03	
(manzana)					(0.02)	
household having hired land					-0.09	
(proportion)					(0.22)	
amount of hired labor					0.00	
(day)					(0.00)	
first-round program enrollment rate	0.03					
	(0.08)					
constant	0.15***	0.16**	0.98***	0.27***	0.28*	0.90***
	(0.03)	(0.05)	(0.33)	(0.07)	(0.16)	(0.19)
F statistics	0.12	0.30	2.95**	3.21*	0.72	9.04***
p-value for F statistics	0.73	0.74	0.03	0.08	0.64	0.00
adjusted R^2	-0.02	-0.02	0.11	0.06	-0.03	0.20
No. of observations (communities)	56	56	56	56	56	56

Note: I calculated program enrollment rates using the full original survey data. All the regressions above are OLS at the community level. Standard errors are heterskedasticity-robust and listed in parentheses. Although not reported here, LASSO selected the same predictors as in column (6). $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

The increases in program enrollment rates across communities can be plausibly exogenous to individual households when the confounding factors—community-level initial shares of female-headed and credit-unconstrained households—are controlled. Moreover, due to the common salience effect, an individual household in a community will be more likely to participate in a security improvement program when the community has a higher program enrollment rate. With all that being said, I estimate the impacts of security improvement programs on household-level land-attached capital and rented-out land using the following panel-IV Tobit model:

Stage 1: A panel linear regression.

$$\begin{aligned} program_{i,t} =& \alpha \times programrate_{j(i),t} + \lambda \times rbp_{i,t} \\ &+ household_i \\ &+ linear\_confounding\_timetrends\_of\_community_{j(i)} \\ &+ department_{k(i)} \times round_t + u_{i,t}, \end{aligned}$$

Stage 2: A panel Tobit regression.

$$\begin{aligned} Y_{i,t} =& \beta \times program_{i,t} + \gamma \times \hat{u}_{i,t} + \mu \times rbp_{i,t} \\ &+ household_i \\ &+ linear\_confounding\_timetrends\_of\_community_{j(i)} \\ &+ department_{k(i)} \times round_t + v_{i,t}, \end{aligned}$$

where (i) $program_{i,t}$ is a dummy variable indicating if household i had ever enrolled in any security improvement program by survey round t, while the instrumental variable $programrate_{j(i),t}$ is the enrollment rate of security improvement programs in survey round t, community j where household i resided;
(ii) $Y_{i,t}$ is the outcome variable of interest for household i in survey round t, which is either the amount of land-attached capital or the area of rented-out land; the amount of hired labor is also considered to facilitate discussions;
(iii) $\hat{u}_{i,t}$ is the residual of the regression in stage 1, which is used as a control in the regression of stage 2 (see more illustrations below);
(iv) $rbp_{i,t}$ is a dummy variable indicating if household i had received the random assignment of the rural business development project by survey round t; $household_i$'s and $department_{k(i)} \times round_t$'s are household fixed effects and department-survey round fixed effects, respectively; $linear\_confounding\_timetrends\_of\_community_{j(i)}$ are linear time trends interacted with community-level shares of female-headed and initially-credit-unconstrained households; $u_{i,t}$ and $v_{i,t}$ are disturbance errors of the two regressions in stage 1 and 2, respectively.

Following Wooldridge (2015), I employ the control function approach to estimate the panel Tobit model in the second stage by including the OLS residuals of the first-stage panel linear regression, namely $\hat{u}_{i,t}$, as a "control" in addition to household and department-survey round fixed effects. Intuitively, I identify the impacts of security improvement programs on land-attached capital and rented-out land by controlling for the endogenous part of household-level program participation. I also control for the potential confounding time trends associated with the community-level shares of female-headed and initially-credit-unconstrained households that may have drived changes in program enrollment rate across communities. Moreover, I rely on household and department-survey round fixed effects to control for household-specific but time-invariant factors, such as farming and management skills, and department-wide but time-variant market conditions, such as agricultural input and output prices. Last but not least, to improve estimation precisions, I also control for the random assignment of the rural business development project.

My second-but-primary goal is to provide suggestive evidence that the statistically insignificant impact of security improvement programs on the area of rented-out land (presented below) is possibly due to the investment effect attenuating the rental-supply effect. The theory outlined above predicts that the degree to which the investment effect attenuates the rental-supply effect is positively associated with landowners' capacity to materialize the investment effect, holding other things constant.[46] In particular, credit-constrained landowners are likely to witness sizable rental-supply effects due to limited investment effects, while the opposite may be true for credit-unconstrained landowners. To demonstrate this theoretical point, I rerun the regressions above for initially-credit-constrained households and initially-credit-unconstrained households, separately.

Admittedly, households that were initially credit-unconstrained and those that were initially credit-constrained could be so different that their differential responses to security improvement programs may not reflect the critical role of credit constraint status in leveraging the countervailing investment and rental-supply effects of security improvement programs. Concerning this, I match households within each community using their demographics-predicted likelihood of being initially credit-constrained in the first survey round. These paired households not only had similar initial credit-constrained likelihood but also had the same exposures to community-level shocks. Results in the next section suggest that these households still had the differential investment and rental-supply responses to security improvement programs as predicted by the theory.

5.3 Empirical Results

Table 4 below shows that in the first stage, the community-level program enrollment rate significantly predicts household-level program participation at the 1% significance level. This holds not only for the full sample but also for the two subsamples grouped by households' initial credit

[46] Figure A.1 in Appendix E shows that the data matches the theory broadly well, e.g., households that had invested in land-attached capital or rented out land are among those who had large land endowments. Households that had hired labor are also among those who had large land endowments.

constraint statuses. Initially-credit-constrained households were relatively less responsive to higher community-level program enrollment rates possibly because part of security improvement processes, such as registration, were not free and thereby slightly discouraged their participation. Nevertheless, the strong instrument provides statistical power for identifying the impacts of security improvement programs on land-attached capital and rented-out land as well as hired labor in the second stage.

Table 4: The Resource Allocation Impacts of Security Improvement Programs.

	First Stage[a]	Second Stage[a]		
	program enrolled (0/1)	land-attached capital (1,000 córdoba)	rented-out land (manzana)	hired labor (day)
Full sample: all households (1004)				
program enrolled		38.6**	29.3	-22.1
(household level)		[17.1][b]	[33.1][b]	[112.3][b]
program enrollment rate	0.94***			
(community-level)	[0.13][b]			
Subsample: initially-credit-constrained households (428)				
program enrolled		8.6	66.9***	-185.7
(household-level)		[17.7]	[27.1]	[243.6]
program enrollment rate	0.71***			
(community-level)	[0.18]			
Subsample: initially-credit-unconstrained households (576)				
program enrolled		54.7**	11.9	59.8
(household-level)		[26.4]	[47.8]	[127.2]
program enrollment rate	1.14***			
(community-level)	[0.19]			
Controls for all the regressions above				
community confounding linear trends[c]	YES	YES	YES	YES
household fixed effects	YES	YES	YES	YES
department-survey round fixed effects	YES	YES	YES	YES
rural business development project[d]	YES	YES	YES	YES

Note: [a]I estimated the impacts of security improvement programs in two stages. In the first stage, I used community-level "program enrollment rate" to instrument for "program enrolled" at the household level. The former variable measures the proportion of households in a community who had ever enrolled in any security programs by a given survey round and the latter variable indicates if a household in the same community had ever enrolled in any security programs by the same survey round. In the second stage, I employed a control function approach to estimate the impacts of security improvement programs on the amount of land-attached capital and the area of rented-out land as well as the amount of hired labor at the household level, based on a panel Tobit model. See the specific econometric design in the main text above. Standard errors are listed in brackets. [b]I estimated the second-stage regression coefficients and their standard errors using Honoré's Stata command for panel Tobit models, namely "pantob". Honoré (1992) has shown that his estimation approach will deliver a consistent point estimate under general assumptions while others may not. To the best of my knowledge, however, there is no rigorous way to obtain robust or clustered standard errors for panel Tobit models. Hence, I used the asymptotic estimates provided by Honoré (1992) under i.i.d. To be consistent, standard errors of the first-stage linear regression coefficients were also obtained under i.i.d; but they had similar magnitudes as the standard errors clustered at the community level. [c]I controlled for the linear time trends interacted with the initial community-level shares of female-headed and credit-unconstrained households that may have driven changes in program enrollment rate between survey rounds. [d]The rural business development project is an RCT that aims to raise households' incomes by boosting agricultural investments and business operations (Carter et al., 2019); I controlled for the random assignment of this project over time. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

For the full sample, security improvement programs significantly increased the amount of land-attached capital but not the area of rented-out land at the household level.[47] These results are in line with Deininger and Chamorro (2004) and Boucher et al. (2005) who found that early land titling and registration programs in rural Nicaragua had notably increased household-level investments of land-attached capital but not the market size of land leasing during the 1990s. This means that these uneven investment and rental-supply effects of securing land ownership have persisted over time. Interestingly, security improvement programs mildly decreased the amount of hired labor at the household level, which is consistent with the general reduction in the usage of hired labor (see Table 1 above).

The theory outlined above suggests that the uneven investment and rental-supply effects of securing land ownership may result from the investment effect attenuating the concurrent rental-supply effect. In particular, such attenuation tends to be more pronounced among credit-unconstrained landowners who can make sizable land-attached investments. This motivates me to conduct the subsample analyses below, which also helps me reveal heterogeneous hired labor effects of securing land ownership.

As expected, households that were initially credit-unconstrained significantly and sizably increased the amount of land-attached capital but not the area of rented-out land after participating in security improvement programs. In contrast, households that were initially credit-constrained did the opposite. Intuitively, these households either did not have access to (sufficient) credit for desirable land-attached investments or did not want to take the risk of losing land collateral due to the possibility of low investment returns. Both could contribute to the insignificant and small investment effect, which would then have a limited negative impact on the rental-supply effect even if the investment effect attenuated the rental-supply effect. Therefore, these households significantly and sizably rented out more land after participating in security improvement programs.

According to the theory, households that were initially credit-unconstrained would have rented out more land as well after participating in security improvement programs, without the investment effect attenuating the rental-supply effect. Figure A.2 in Appendix E shows that they had similar land and labor endowments as households that were initially credit-constrained. The data also shows that households having large land endowments in both groups had initially rented out land and hired labor. Hence, large landed households in the initially-credit-unconstrained group would have rented out more land to mitigate the agency cost of hired labor in response to an improvement in land ownership security. After participating in security improvement programs, however, they hired more labor along with investing in land-attached capital as shown above in Table 4. Theoretically, this could result from the complementarity between land-attached capital and labor in farm production. Nevertheless, large landed households in the initially-credit-constrained group hired less labor as they rented out more land after participating in security improvement programs.

[47] Tobit models estimate latent effects, not actual effects. This is fine for this paper as my goal is to show the latent countervailing investment and rental-supply effects of security improvement programs.

Admittedly, the small differences in demographics between households that were initially credit-unconstrained and those that were initially credit-constrained may lead to their differential responses to security improvement programs. A practical way to alleviate this concern is to pair initially-credit-unconstrained and -constrained households within each community based on their closeness in the likelihood of being initially credit-constrained. These paired households not only had similar initial credit-constrained likelihood but also had the same exposures to community-level shocks. As shown below in Table 5, regression results indicate that relative to initially-credit-constrained households, initially-credit-unconstrained households sizably increased the amount of land-attached capital and significantly decreased the area of rented-out land after participating in security improvement programs.[48] This is consistent with the main findings above, suggesting that initial credit constraint status did leverage the tension between the investment and rental-supply effects of securing land ownership, as predicted by the theory. As expected, relative to initially-credit-constrained households, initially-credit-unconstrained households also sizably increased the amount of hired labor, possibly due to the complementarity between land-attached capital and labor in farm production.

Table 5: The Resource Allocation Impacts of Security Improvement Programs for Households Having Similar Likelihoods of being Initially Credit-constrained within Each Community (Second Stages)[a].

	land-attached capital (1,000 córdoba)	rented-out land (manzana)	hired labor (day)
program enrolled	0.5	80.0	-618.0
(instrumented)	[40.3][b]	[73.5]	[551.3]
program enrolled × initially	35.0	-140.6**	549.7
credit-unconstrained (instrumented)	[54.5]	[61.5]	[569.2]
Controls for all the regressions above			
community confounding linear trends[c]	YES	YES	YES
household fixed effects	YES	YES	YES
department-survey round fixed effects	YES	YES	YES
rural business development project[d]	YES	YES	YES
No. of paired households	530	530	530
No. of communities	54	54	54

Note: [a]I used households' demographics to predict their probabilities of being initially credit-constrained, based on a standard Logit regression model. Then, I matched pairs of initially-credit-constrained and -unconstrained households within each community when their differences in predicted probabilities are no larger than 0.03. After pairing, I reran the panel-IV Tobit model, as outlined in the main text above, but with interactions with an dummy variable indicating if a household was initially credit-unconstrained. For the ease of presentation, I only reported regression results of the associated second stages here. [b]Like the main regressions presented in Table 4, I obtained conservative standard errors under i.i.d. [c]I controlled for the linear time trends interacted with the initial community-level shares of female-headed and credit-unconstrained households that may have driven changes in program enrollment rate between survey rounds. [d]The rural business development project is an RCT that aims to raise households' incomes by boosting agricultural investments and business operations (Carter et al., 2019); I controlled for the random assignment of this project over time. $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

[48]Figure A.3 in Appendix E shows that after matching, the demographics-predicted likelihood of being initially credit-constrained is much more similar between the initially-credit-unconstrained and -constrained households. These matched households also have common support over demographics, although not reported here.

6 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 non-security barriers to long-term land rental contracts can attenuate the rental-supply effect by inducing the bias of the concurrent investment effect towards the endowed land to be self-cultivated. 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' land-attached capital 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 rather than rent out land at higher land ownership security.

I provide suggestive 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 the amount of land-attached capital but not the area of rented-out land at the household level. By leveraging households' initial credit constraint statuses that affect their capacities to make land-attached investments, I show that the limited increase in the area of rented-out land is possibly due to the countervailing interaction between the investment and rental-supply effects as predicted by the theory.

The agricultural household model established in this paper is sophisticatedly simple. On the one hand, the model does not incorporate all relevant features of modern agriculture, such as machinery input and value chain. This simplification makes the model tractable without losing the generality of its prediction on the countervailing interaction between the investment and rental-supply effects of securing land ownership.[49] On the other hand, the model includes common market failures in rural areas of developing countries, including the agency cost of hired labor (Frisvold, 1994), the credit rationing of small landowners (Carter and Olinto, 2003), and the moral hazard of tenants not taking care of landlords' land-attached capital under short-term land rental contracts (Bandiera, 2007). These market failures, particularly the last one mentioned, result in the counteracting 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 economic benefits of securing land ownership. Without the moral hazard of tenants not

[49] Machine is a salient agricultural input even in some developing countries. It often substitutes labor and favors 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., landlords may be only among landowners with medium sizes of land endowment. However, the data used in this paper indicates that landlords are among large landowners in rural Nicaragua, which is consistent with the model prediction. Nevertheless, adding machinery input into the model will not alter the attenuation of the rental-supply effect from the concurrent investment effect of securing land ownership. This is because the latter effect will still be biased towards the endowed land to be self-cultivated as long as the moral hazard of tenants not taking care of landlords' land-attached capital is present. The same argument also applies to the modern value chain through which larger farms receive higher output prices (e.g., Henderson and Isaac, 2017).

taking care of landlords' land-attached capital, securing land ownership would help get around the agency cost of hired labor and the credit rationing of small landowners by facilitating the egalitarian distribution of the operational land among heterogeneous agents in land endowment and the even distribution of attached capital investments between the self-cultivated and rented-out land. The presence of such moral hazard, however, will dampen these double-efficiency improvements in resource allocation and thereby downsize the economic gains of securing land ownership in rural economies. Future research may assess the extent to which the economic benefits of securing land ownership will be downsized and how the associated welfare gains will be distributed among heterogeneous agents in land endowment.

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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 subsection 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:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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 (12) 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 (14) 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 (12)-(14) above as follows, given $\pi_t^{in}(A_t^{in}, k_t^{in}, L_t^{in}) = pF(A_t^{in}, A_t^{in} k_t^{in} + A_t^{in} k_n, L_t^{in}) - A_t^{in} r(k_t^{in} + k_n)$.

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

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

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

Condition (23) 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 (23) 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 $p\frac{\partial F}{\partial L}|_{L=L_t^{in}}$.[50]

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 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 (25), 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

[50] Under the C.R.S. production technology, we have:

$$F(A_t^{in}, A_t^{in}k_t^{in} + A_t^{in}k_n, L_t^{in}) = A_t^{in}F(1, k_t^{in} + k_n, l_t^{in}) = A_t^{in}\Big[\frac{\partial F}{\partial A}|_{A=A_t^{in}} + F_k(1, k_t^{in} + k_n, l_t^{in})(k_t^{in} + k_n) + F_l(1, k_t^{in} + k_n, l_t^{in})l_t^{in}\Big],$$

where $F_k(1, k_t^{in} + k_n, l_t^{in})$ denotes the marginal return of attached capital investments.

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.[51] 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.[52] Similarly, we can define the land rental rate schedule $r(\cdot)$ such that it satisfies the properties (23)-(25) above when the land rental market is inactive while the labor market is active.[53]

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 (24), we have:

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

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.

[51] 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.

[52] 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.

[53] 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.

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.

(26) $p\frac{\partial F^o}{\partial A} + p\frac{\partial F^o}{\partial K}k_n - c_o(S_e)\frac{r(k_n)}{i} = p\frac{\partial F^t}{\partial A} + p\frac{\partial F^t}{\partial K}k_n - c_t(S_e)\frac{r(k_n)}{i}$;
(27) $p\frac{\partial F^o}{\partial K} = d_o + c_o(S_e) + i(1+\mu)$ with $k_o > 0$;
(28) $p\frac{\partial F^o}{\partial L} = w\Big/\frac{\partial L}{\partial L_h^{in}}|_{L=L(L_f,L_h^{in}),L_f=1,L_h^{in}>0}$;
(29) $p\frac{\partial F^t}{\partial K} \leq d_t + c_t(S_e) + i(1+\mu)$ with the equality for $k_t^{out} > 0$;
(30) $p\frac{\partial F^t}{\partial L} = w$;
(31) $A_o > 0,\ A_t^{out} \geq 0,\ A_o + A_t^{out} = A_e$;
(32) $\mu \geq 0,\ A_o k_o + A_t^{out} k_t^{out} \leq A_e\theta(S_e),\ \mu[A_o k_o + A_t^{out} k_t^{out} - A_e\theta(S_e)] = 0$.

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 (26) 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 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 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 (27) and (28) 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 (30) 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 (29), 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).[54]

[54]Because of the positive intensity of the natural attached capital k_n, the marginal return of attached capital

Finally, conditions (31) and (32) capture constraints on the land allocation and attached capital investments, respectively. Condition (31) 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 (32) 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.

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

credit constrained	credit unconstrained
$I_{e,1}^c \theta'(S_e) - R_e^c\{-[c_t'(S_e) - c_o'(S_e)]\frac{r(k_n)}{i}\}$ $-I_{e,2}^c k_t^{out} \theta'(S_e)$ $-I_{e,3}^c k_t^{out}\{-[c_t'(S_e) - c_o'(S_e)]\}$,	$I_{e,1}^{uc}[-c_o'(S_e)] - R_e^{uc}\{-[c_t'(S_e) - c_o'(S_e)]\frac{r(k_n)}{i}\}$ $-I_{e,2}^{uc} k_t^{out}[-c_t'(S_e)]$,
$I_{e,1}^c > 0, I_{e,2}^c > 0, I_{e,3}^c = R_e^c > 0.$	$I_{e,1}^{uc} > 0,\ I_{e,2}^{uc} = R_e^{uc} > 0.$

Note: (i) The marginal effects of land ownership security on the threshold of renting out land $\frac{\partial A_e^{out}}{\partial S_e}$ 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 (26)-(32) 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.

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.

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.

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 (26)-(32) 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.

Appendix E. Supplemental figures and tables for the empirical analysis

In this appendix, I include figures and tables that facilitate empirical analyses in the main text above. Figure A.1 shows that the data (of survey round 1) matches the theoretical model broadly well. Figure A.2 shows that households who were initially credit-constrained had similar demographics as those who were initially credit-unconstrained. Figure A.3 shows distributions of predicted credit-constrained probabilities before and after matching.

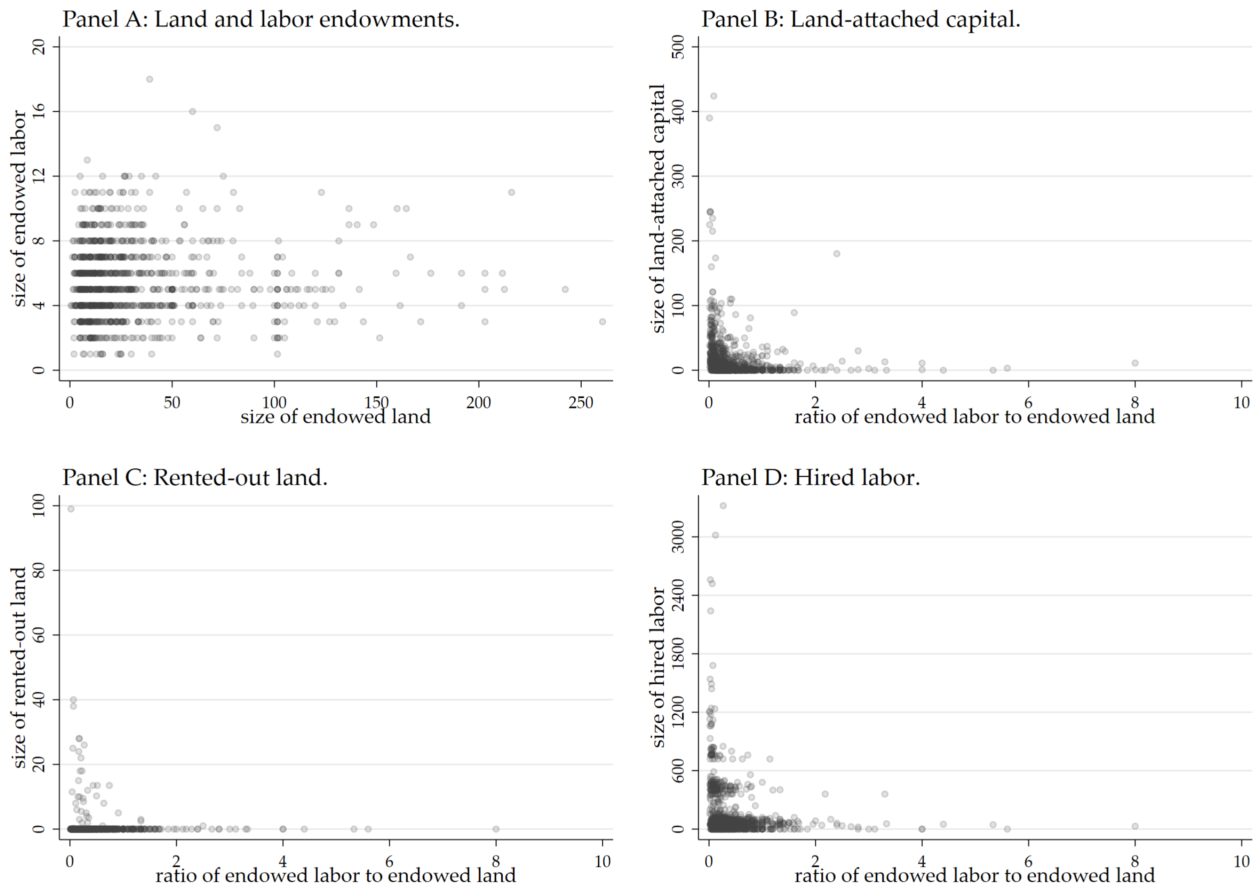

Figure A.1: Patterns of Household-level Attached Capital, Land Rental, and Hired Labor Sizes.

As follows, let me illustrate Figure A.1 in detail. 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 capital (Panel B). This is 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. As shown by Panel D, households having larger land endowments or equivalently smaller ratios of labor to land endowment did hire more labor as predicted by the model.

Although not shown here, households who invested more in land-attached capital 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 capital 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 capital and rented-out land before and after participating in security improvement programs in the main text above.

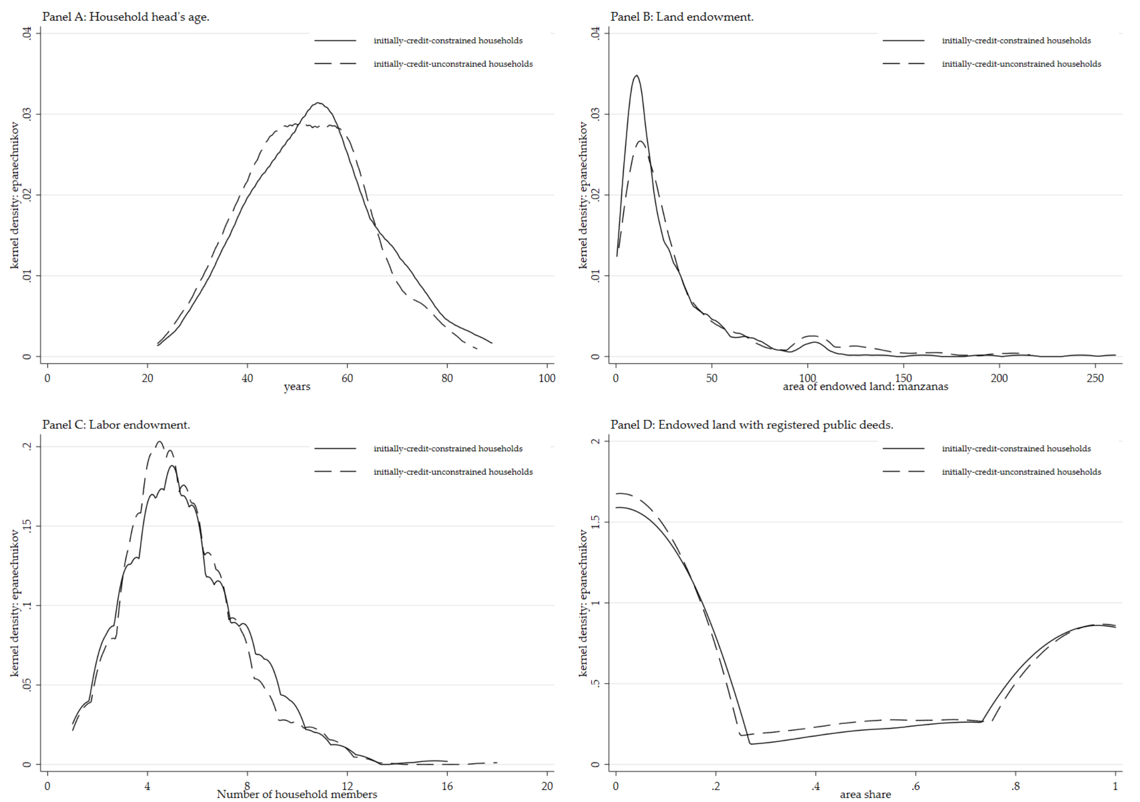

Figure A.2: Distributions of Households' Demographics by Initial Credit Constraint Status.

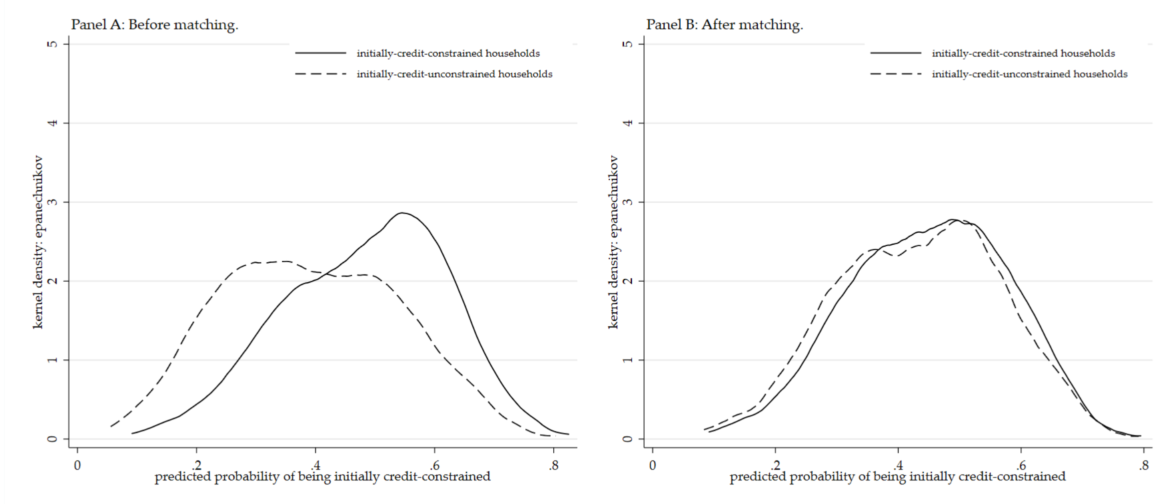

Figure A.3: Predicted Probabilities of being Initially Credit-constrained.

Note: I used households' socioeconomic demographics to predict their probabilities of being initially credit-constrained, based on a standard Logit regression model. Results show that apart from the residential community, the area of the household's endowed land, the area share of endowed land with registered public deeds, the age of a household head, and whether a household hired labor or not are four statistically significant predictors for households' initial credit constraint status. Regression results are available upon request. Then, I matched pairs of initially-credit-constrained and -unconstrained households within each community when their differences in predicted credit-constrained probabilities are no larger than 0.03. In the end, 530 out of 1004 households are successfully paired in 54 out of 56 communities. The two subfigures above show the distributions of predicted probabilities of being initially credit-constrained for initially credit-constrained and -unconstrained households before and after paring.