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Economic Impacts of Land Security Improvements:

Investment Incentives versus Rental Incentives.

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Abstract

Improving the security of land property rights often enhances incentives of making land-attached investments and renting out land. However, the literature has shown that both landlords and tenants prefer to invest in the owner-cultivated land, especially under short-term rental contracts. To study how they may counteract each other and the associated policy implications, this paper firstly builds up a novel land rental model that incorporates investment and rental incentives and credit access associated with land security in addition to the agency cost of hired labor—the essential efficiency argument for pro-smallholder land policies. Comparative statics indicate that a landowner tends to invest more attached capital in the land to be self-cultivated relative to the land to be rented out in response to higher land security because of the capital depreciation rate gap between them induced by barriers to long-term rental contracts other than land insecurity, leading to the counteraction between investment and rental incentives in terms of land rental supply. Then, I parameterize and calibrate the model closely to the rural context of Nicaragua, one of the poorest countries in Latin America and the Caribbean, where the size and security distributions of land endowment have been highly unequal and legal restrictions on the duration of land rental contracts have been historically in place. Numerical results from comprehensive multi-agent simulations indicate that the aforementioned counteraction can largely attenuate potential gains from land security improvements on land in rental and wage rate but not necessarily land-attached investments or agricultural output. Counterfactual analyses suggest that policymakers need to remove barriers to long-term rental contracts together with improving land security to achieve the great potential of reducing rural poverty by facilitating land access for the poor through land rental market. The counteraction also helps explain why Nicaragua witnessed a large increase in land-attached investments but a small expansion of land rental market after salient land titling and registration in the 1990s.

Keywords: land property rights; land rental market; contract duration; land-attached investments; agency cost of hired labor; rural poverty.

1 Introduction

Improving the security of land property rights often enhances incentives of making land-attached investments (e.g. Feder et al., 1988; Besley, 1995; Jacoby et al., 2002; Fort, 2007), incentives of renting out land (e.g. Carter and Yao, 2002; Macours et al., 2010; Chari et al., 2021), and sometimes improves credit access as well (e.g. Feder and Onchan, 1987; Carter and Olinto, 2003). Among them the enhancement of rental incentives is supposed to bring about a more equitable distribution of economic benefits from land security improvements since the land-poor usually cannot materialize the enhanced investment incentives due to various forms of credit rationing (e.g. Carter, 1988; Boucher et al., 2008). In particular, it has long been used to justify the poverty reduction strategy of improving land security to facilitate land access for the rural poor through land rental market so that they can utilize their labor endowment more efficiently by cultivating the rented land (e.g. de Janvry et al., 2001; Deininger, 2003).

The critical assumption behind such poverty reduction strategy is that land rental supply will increase after the security improvement since landowners will face a lower risk of losing the land to be rented out and thereby be more likely to rent out (more) land. Then, the rural poor, who usually have little land endowment in an unequal agrarian society, can rent in (more) land and earn higher incomes generated from the family management of farm operations in the competitive equilibrium (Boucher et al., 2005). However, investment and rental incentives may counteract each other as both landlords and tenants prefer to invest in the owner-cultivated land, especially under short-term rental contracts (Bandiera, 2007; Jacoby and Mansuri, 2008), which may attenuate and even reverse the potential of improving land security to increase land rental supply and hence limit income gains for the rural poor. Their counteraction may also attenuate gains on land-attached investments and thus agricultural output as the inefficient labor input (see details below) may dampen land-attached investments through the complementarity between them. This paper studies their counteraction through the lens of land rental market and demonstrates how the counteraction may affect economic impacts of land security improvements for an unequal agrarian economy.

I start with building up a novel land rental model based on seminal works on the agency cost of hired labor—the essential efficiency argument for pro-smallholder land policies (e.g. Eswaran and Kotwal, 1986; Frisvold, 1994). The agency cost of hired labor would increase the marginal cost of the efficiency-adjusted labor input facing landowners who have relatively abundant land endowment if they self-cultivated all the endowed land. They can get around this efficiency loss in labor input by renting out part of the endowed land to the land-poor who have relatively abundant labor endowment. However, they will hesitate to do so if land property rights are insecure. Specifically, insecure land property rights induce costs of protecting the raw land and its attached capital invested by the landowner. The associated protection cost rate will be higher if the land is rented out. Thus, they face a trade-off between improving the efficiency of labor input and paying a higher protection cost rate.

Higher land security reduces the two protection cost rates and the gap between them and hence enhances investment and rental incentives simultaneously. It also improves credit access for landowners who have enough endowed land to meet the minimum collateral requirement, i.e. the leverage ratio of the accessible credit to the size of land collateral is increasing in land security. The enhanced rental incentives, namely the lower protection cost rate gap between the rented-out and self-cultivated land, would induce landowners who have relatively abundant land endowment to rent out (more) land if there were no barrier to long-term rental contracts (other than land insecurity). To capture such barriers, I introduce the capital depreciation rate gap between the rented-out and self-cultivated land into the model. In principle, the shorter the rental contract duration is, the larger the depreciation rate gap will be due to the moral hazard from the tenant who may overexploit or use the attached capital recklessly. In the extreme case landowners will not invest in the land to be rented out regardless of land security. Then, the enhanced investment incentives will only materialize in the land to be self-cultivated for landowners having access to credit and thereby counteract the enhanced rental incentives. So will the improved credit access for landowners being investment-constrained in prior.

Comparative statics below demonstrate that the degree of their counteractions depend on the size of the capital depreciation rate gap when landowners will also make some attached capital investments in the land to be rented out. The larger the depreciation rate gap is, the more attached capital investments they will make in the land to be self-cultivated relative to the land to be rented out in response to higher land security. The economic mechanism behind it is that a larger depreciation rate gap renders a larger difference in the marginal cost of attached capital input between them and thereby incentivizes landowners having land security improvements to increase attached capital investments more in the land to be self-cultivated relative to the land to be rented out because of the diminishing marginal return of attached capital input, holding other things constant.

Next, I study equilibrium impacts of improving land security on resource allocation and social welfare, since security improvement programs like land titling and registration often apply to the whole agrarian economy and thus cause additional effects through price adjustments. Importantly, laborers can only benefit from land security improvements through the increase in wage rate induced by the increase in the attached capital input that complements labor input and/or the increase in land under tenant-cultivation that demands a higher intensity of labor input than owner-cultivation (due to the agency cost of hired labor). This is also the case for tenants under the C.R.S. production technology as they (are assumed to) only contribute labor input on the rented land and thereby earn wages. The land rental rate for any given intensity of attached capital, however, will decrease as wage rate increases because land, attached capital, and labor are gross complements for each other. The decrease in land rental rate schedule will then discourage renting out land and the increase in wage rate itself will dampen attached capital investments.

To make the matter concrete, I calibrate the land rental model closely to the rural context of Nicaragua, one of the poorest countries in Latin America and the Caribbean (LAC), that largely represents many low-income countries in LAC where improving land security has been supposed to have the great potential of reducing rural poverty (e.g. de Janvry et al., 2001; Díaz et al., 2002; Deininger, 2003). In this agrarian economy, the size and security distributions of land endowment are highly unequal and there is one third of agents that are landless. Half of landowners have no credit access due to quantity-rationing as they do not have enough endowed land to meet the minimum collateral requirement. In the multi-agent simulations below, landowners who have access to credit will choose to rent out land while landowners who do not have access to credit will choose not to do so in any competitive equilibrium.

In simulation exercises, I strategically manipulate the leverage ratio of credit access (linear in land security) and the capital depreciation rate gap between the rented-out and self-cultivated land to demonstrate their critical roles in the effect of higher land security on individual land rental supply (indicated by comparative statics) and explore the associated implications for the impacts of improving land security on resource allocation and social welfare for the unequal agrarian economy considered above. In addition, I introduce a specific structure for the protection cost rate gap between the rented-out and self-cultivated land that can reflect the empirical findings in Nicaragua that higher land security significantly increases the probability of renting out land but not making attached capital investments unless the improved land security is sufficiently high (Deininger et al., 2003; Deininger and Chamorro, 2004). Its implications for economic impacts of improving land security are also investigated.

Numerical results are threefold for the impacts of land security improvements on resource allocation—land in rental and attached capital investments—and social welfare—wage rate and agricultural output. These impacts are all positive provided no capital depreciation rate gap; contexts with better credit access (a larger maximum leverage ratio) will witness larger gains as the improvement in credit access will be larger and thereby previously-constrained landowners will make more land-attached investments. However, the depreciation rate gap arising from short-term land rental contracts triggers the counteraction between investment incentives (and credit access) and rental incentives that can largely attenuate gains on land in rental and wage rate while it may not have sizable negative effects on increases in attached capital investments and agricultural output. For instance, when the depreciation rate gap is sufficiently large, land rental market may decrease after land security improvements and hence render a negligible increase in wage rate. Even without the depreciation rate gap, gains on land in rental and wage rate may still be limited if the protection cost rate gap follows the specific pattern in land security described above.

The numerical evidence above corroborates the long-standing statement that land security improvements have the great potential to reduce rural poverty by facilitating land access for the poor through land rental market (e.g. de Janvry et al., 2001; Deininger, 2003). However, the capital depreciation rate gap between the rented-out and self-cultivated land that comes from barriers to long term rental contracts can largely attenuate that potential. To achieve the maximum potential, policymakers should eliminate these barriers together with improving land security. Using numerical simulations, I clearly show that removing these barriers can bring us sizable extra gains from land security improvements, especially on land in rental and wage rate.

The analyses in this paper also shed light on the "puzzling" empirical findings that Nicaragua, one of the poorest countries in LAC, witnessed a large increment of land-attached investments but a small expansion of land rental market after salient land security improvements in the 1990s (Deininger and Chamorro, 2004; Boucher et al., 2005). Based on the simulated economic impacts of improving land security, I find that both the capital depreciation rate gap and the specific structure of the protection cost rate gap described above can notably reduce the gain on land in rental relative to the gain on attached capital investments. Besides the latter, the former was also present in Nicaragua to some extent in the 1990s, e.g. land rental contracts could not be more than 10 years long (Díaz et al., 2002). Unlike Boucher et al. (2005) who emphasize on the land rental demand side, this paper provides alternative explanations from the land rental supply side and thereby complements their work.

Finally, this paper contributes to the extensive literature on economic impacts of securing land property rights by introducing the counteraction between investment incentives (and credit access) and rental incentives and demonstrating how it may adversely affect land rental supply and other economic outcomes in response to the improvement in land security. Admittedly, researchers have studied their interactions. To my knowledge, the most-related is the gains-from-trade theory proposed by Besley (1995) in which higher land security lowers the transaction cost of establishing and enforcing land rental contracts (incentives of renting out land) and thereby incentivizes landowners to make more land-attached investments (investment incentives) as they will benefit more from renting out the land in the future when a negative productivity shock happens to them. Note that they make those attached investments in the self-cultivated land as they have not rented out the land. Also, they may not rent out the land in the future, especially when they do not receive any negative productivity shock. Thus, the theory outlined in this paper does not contradict but complements Besley's.

The rest of the paper proceeds as follows. First, I introduce the land rental model in section 2, where I also present the comparative statics about how land security generally affects individual land rental supply and explain the role of the counteraction between investment incentives (and credit access) and rental incentives. Then, I define the competitive equilibrium for land rental and labor markets in the agrarian economy in section 3, including land rental rate schedule. Section 4 moves to simulation exercises that provide thoughtful numerical evidence about how improving land security will affect resource allocation and social welfare for an unequal agrarian economy in various scenarios. Based on these simulation results, I discuss potential gains from removing barriers to long-term land rental contracts and plausible explanations for the aforementioned "puzzling" empirical findings in Nicaragua in section 5. Finally, I conclude the paper and outline future research in section 6.

2 The Theoretical Model

In this section I introduce the theoretical model that I parameterize later in section 4 to numerically explore equilibrium impacts of improving land security on resource allocation and social welfare for an unequal agrarian economy. First, I outline model assumptions in subsection 2.1. Then, I set up the utility maximization problem facing individual agents and explain the first-order conditions for the optimal resource allocation in subsection 2.2. Finally, in subsection 2.3 I use the comparative statics of individual land rental supply with respect to land security to illustrate model predictions about impacts of improving land security on land rental market.

2.1 Model assumptions

The agrarian economy considered below consists of two sectors—the production sector and the service sector. The service sector, comprised of lawyers and policemen who get paid to protect the raw insecure land and the attached capital invested in that land (if applicable), is an auxiliary sector. In the production sector landless and landed agents, whose resource allocation and welfare are of interest in this paper, engage in the C.R.S. agricultural production that uses land, attached capital, and labor as inputs. Attached capital consists of natural capital that is embedded in the raw land and artificial capital that is invested later on. They are perfect substitutes for each other, e.g. access to surface water or rainfall and groundwater wells.

The agency cost of hired labor raises the marginal cost of the effective labor input (defined below) above wage rate when hired labor is employed for land cultivation, motivating agents who have relatively abundant land endowment to rent out part of the land to agents who have relatively abundant labor endowment. But insecure land property rights impede this productive land transfer as renting out land induces higher protection costs. When barriers to long-term land rental contracts (e.g. legal restrictions on the contract duration) are also in place, the depreciation rate of the artificial capital for the rented-out land will be higher than that for the self-cultivated land while the embedded natural capital does not depreciate.[1] This depreciation rate gap adds an extra impediment to land rental supply. The detailed and other model assumptions are outlined below.

[1] Admittedly, land insecurity could also be an important barrier to long-term land rental contracts as landlords tend to provide short-term contracts to reduce the risk of tenants occupying the rented land (e.g. de Janvry and Sadoulet, 2002). However, for simplicity I assume that landlords only expend resource like money in this model to protect land ownership as the other landed agents do.

Preferences: Each agent has the same risk neutral preferences for income flow over the infinite production periods.[2] They allocate labor, land, and credit (if applicable) to maximize their discounted incomes and share the same discount factor β.

Endowments: labor and land.

(i) *Labor*: Landless and landed agents are all 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 land of size, A_e, and security level, $S_e \in [0,1]$. Larger S_e means higher security of land property rights and $S_e = 1$ refers to the full security, i.e. no ownership risk. Landed agents are heterogeneous in land endowment while the same intensity of natural capital k_n is embedded in all the land.

Technologies: agricultural production and effective labor.

(i) *Production technology*: Each agent has access to the same C.R.S. production technology $F(A,K,L)$ that is strictly increasing, concave, and twice-continuously differentiable in its three inputs—land A, attached capital K, and effective labor L.[3] Attached capital has two sources—natural capital (endowment) and artificial capital (investment)—and they are perfect substitutes. All the inputs above are ordinary and strict gross complements for each other. Also, the marginal output of each input, evaluated at zero, goes to positive infinity given nonzero other inputs.

(ii) *The effective labor extraction technology under the agency cost of hired labor*: Hired labor is an imperfect substitute for family labor as hired labor tends to shirk and needs to be supervised (e.g. Eswaran and Kotwal, 1986). Thus, land cultivators will use family labor first before hiring in labor. When hired workers are employed, they

[2]For simplicity, I do not consider the utility of leisure in addition to income as Eswaran and Kotwal (1986) do. Adding it will not change but strengthen the upward pattern of the marginal cost of the effective labor input defined below as the marginal utility of leisure is usually decreasing. It will become clear later that the utility of leisure is not essential for this model and incorporating it will only introduce unnecessary complexity.

[3]For simplicity, I do not incorporate any intermediate input in the production technology above. Movable capital like machines and other farming equipment are not considered either. See related discussions in section 5.

use family labor to 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): (i) $L(L_f, 0) = L_f, \forall L_f \geq 0$, i.e. family labor is used as the numeraire for the effective labor; and (ii) $\frac{\partial L}{\partial L_h} \in (0,1), \frac{\partial^2 L}{\partial L_h^2} < 0, \forall L_h \geq 0, L_f > 0$, i.e. hired labor is less efficient than family labor and its effectiveness decreases as more hired labor is used.[4]

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

(i) *Land rental market*: Land rental contracts are all of fixed rent.[5] Holding prices constant, as shown in the next subsection, landlords will choose to keep renting out land by consecutively renewing or signing new contracts.[6] They provide each tenant with the full security to cultivate the land and collect fruits during contract periods by securing land ownership through the protection service (see details below). However, they may or may not invest attached capital in the rented-out land depending on the cost of the artificial capital (including credit interest, protection cost, and depreciation cost, see details in subsection 2.3) while tenants do not invest in the rented-in land.[7] Each agent faces the same land rental rate schedule $r(k)$ determined in the competitive equilibrium, where k denotes the intensity of natural capital cum the artificial capital invested by landlords (if applicable).

(ii) *Labor market*: Each agent faces the same wage rate w determined in the competitive equilibrium when they allocate labor.

[4]The reason is that the supervision intensity, namely L_f/L_h, decreases as more hired labor is employed.

[5]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).

[6]As shown in subsection 3.1, changing tenants does not affect land rental rates received by landlords and hence their resource allocation. Also, the literature has shown that it is the contract duration but not the duration of the rental relationship that matters for land-attached investments (Bandiera, 2007; Jacoby and Mansuri, 2008).

[7]I do not allow tenants to invest attached capital in the rented-in land since they would otherwise use all the accessible credit to invest in the rented-in land anyway given the full security provided by landlords, which contradicts common sense. This ad hoc assumption seems innocuous for an unequal agrarian society like rural areas in LAC like Nicaragua where it is often the landlord that provides attached investments (e.g. Bandiera, 2007).

(iii) *Attached capital market*: Each agent faces the same exogenous price of (artificial) attached capital when they make investment decisions in the initial production period. Such price is normalized to one, i.e. attached capital is the numeraire in this economy.
(iv) *Credit market*: Credit, the only source of investment fund, requires land collateral. Landed agents whose sizes of land endowment are below a certain threshold, say A_e^m, will be quantity-rationed and thus have no access to credit.[8] Non-rationed landed agents have access to credit up to $A_e\theta(S_e)$ with the leverage ratio $\theta(S_e) > 0$ and $\theta'(S_e) > 0$. Each agent faces the same exogenous interest rate i. Following Eswaran and Kotwal (1986), I set the discount factor β equal to $\frac{1}{1+i}$.
(v) *Output market*: The output price p is exogenously given by the outside market.[9]

Protection costs: Insecure land property rights bring about ownership risk and renting out land raises the risk exposure.[10] To protect the insecure land and its attached capital, landed agents periodically pay lawyers and policemen in the auxiliary sector service fees.[11] These payments translate into the protection costs below. Here, A_o and A_t^{out} denote sizes of the self-cultivated and rented-out land, respectively; k_o and k_t^{out} denote intensities of the attached capital invested in these two types of land, respectively. The associated cost rates are $c_o(S_e)$ and $c_t(S_e)$, respectively, with $c_t(S_e) > c_o(S_e) > 0, c_t'(S_e) < c_o'(S_e) < 0, \forall S_e \in [0,1)$ and $c_t(0) = c_o(0) = 0$.[12]
(i) The cost of protecting the raw land: $c_o(S_e)A_o r(k_n) + c_t(S_e)A_t^{out} r(k_n)$.
(ii) The cost of protecting the invested capital: $c_o(S_e)A_o k_o + c_t(S_e)A_t^{out} k_t^{out}$.

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

[9] There is no way to endogenize output price given the preferences over income flows above. We may take p as the global agricultural output price that is not affected by local supply in the agrarian economy.

[10] The increased ownership risk comes from either tenants who may try to occupy the rented land or non-tenants for whom it may be easier to occupy the land under tenant-cultivation.

[11] To distinguish the variable labor input from the fixed attached capital input that is directly affected by land insecurity, I deviate from the conventional way of modelling the insecurity of land property rights in which landowners passively lose land and its attached capital cum output with some positive probability (e.g. Feder et al., 1988; Besley, 1995), and introduce this alternative approach in which landowners actively use resources like money in this model to protect land ownership such that land insecurity only indirectly affects labor input through attached capital input. Nevertheless, this new approach still implies that improving land security will enhance investment and rental incentives as shown by the structure of protection cost rates outlined above.

[12] We may interpret $c_o(S_e)$ and $c_t(S_e)$ as per-period probabilities of losing ownership of the land to be self-cultivated and rented out, respectively, provided no protection. In this sense, the protection costs above are the same as the expected losses of the raw land and the invested capital in market values.

Depreciation costs: Artificial capital depreciates over production periods while natural capital does not. The depreciation rate of the artificial capital invested in the rented-out land d_t may be higher than that of the artificial capital invested in the self-cultivated land d_o, i.e. $d_t \geq d_o > 0$. This depreciation rate gap will show up due to the moral hazard of tenants under short-term land rental contracts.[13] Landlords will conduct regular maintenance and renovation to keep the artificial capital invested in the self-cultivated and rented-out land unchanged across production periods, i.e. their per-period depreciation costs are $d_o A_o k_o$ and $d_t A_t^{out} k_t^{out}$, respectively.[14]

Working capital requirement: Agents pay for hiring in labor, renting in land, and protecting land ownership after harvest except making attached capital investments.

2.2 The utility maximization problem

Given the model assumptions above, we have the following cash flows over the infinite production periods. Here, A_t^{in} and k_t^{in} denote the size of the rented-in land and the intensity of the attached capital in that land invested by the landlord, respectively. L_o and L_t^{in} denote effective labor inputs on the self-cultivated and rented-in land, respectively; L_h^{out} and L_h^{in} denote amounts of labor hired out and in, respectively.

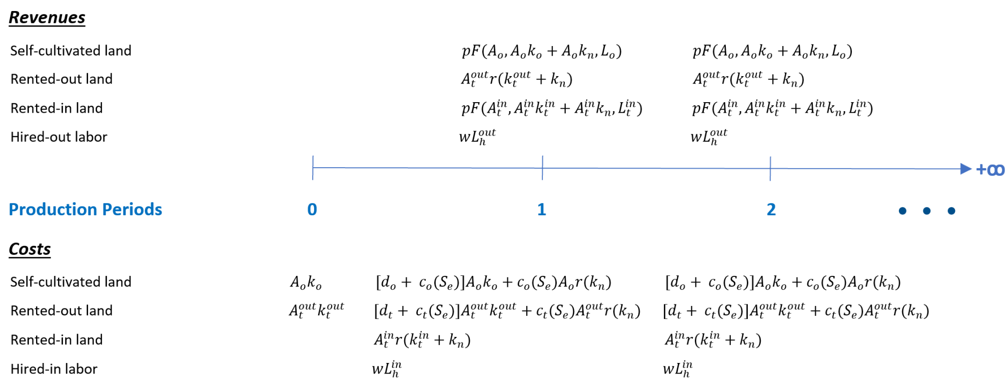

Figure 1: Cash Flows over Production Periods.

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

[14] That, intensities of land-attached capital input will remain unchanged over the infinite production periods. So are land and labor inputs as shown above in Figure 1.

Each agent makes resource allocation to maximize the discounted incomes over the infinite production periods. Thus, individual agent will face the following utility maximization problem (UMP) with CVS denoting the set of choice variables.

$$
\begin{aligned}
max_{\{CVS\}} \frac{\beta}{1-\beta} \Big\{ & pF(A_o, A_o k_o + A_o k_n, L_o) - [d_o + c_o(S_e)]A_o k_o - c_o(S_e) A_o r(k_n) \\
& + A_t^{out} r(k_t^{out} + k_n) - [d_t + c_t(S_e)] A_t^{out} k_t^{out} - c_t(S_e) A_t^{out} r(k_n) \\
& + pF(A_t^{in}, A_t^{in} k_t^{in} + A_t^{in} k_n, L_t^{in}) - A_t^{in} r(k_t^{in} + k_n) \\
& + wL_h^{out} - wL_h^{in} \Big\} - (A_o k_o + A_t^{out} k_t^{out}) \\
s.t. \quad & A_o + A_t^{out} = A_e, \\
& A_o k_o + A_t^{out} k_t^{out} \leq I_{\{A_e > A_e^m\}} A_e \theta(S_e), \\
& L_o + L_t^{in} = L(L_f, L_h^{in}), \\
& L_f + L_h^{out} = 1, \\
& CVS : \{A_o, A_t^{out}, A_t^{in}, k_o, k_t^{out}, k_t^{in}, L_o, L_t^{in}, L_f, L_h^{out}, L_h^{in}\} \geq 0.
\end{aligned}
$$

Note that attached capital investments are made in the initial production period and the investment fund comes from the accessible credit that equals $A_e\theta(S_e)$ for non-rationed landed agents ($A_e > A_e^m$) but zero for rationed landed agents ($A_e \leq A_e^m$). Once invested, attached capital will remain invariant across production periods thanks to regular maintenance and renovation made by the landowner. Then, land and labor allocations will also remain unchanged holding prices and land security constant. In this model, the rental contract duration directly affects attached capital investments through the depreciation rate gap and indirectly affects land and labor allocations through the complementary relationships among these three production inputs.

To proceed, let us set up the following Lagrangian for the UMP above, with λ, μ, ν, ξ, ζ's, δ's, χ's, ψ, ϕ, and η denoting Lagrangian multipliers (see details below).

$$\mathcal{L} = \frac{\beta}{1-\beta}\Big\{pF(A_o, A_o k_o + A_o k_n, L_o) - [d_o + c_o(S_e)]A_o k_o - c_o(S_e)A_o r(k_n)$$

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

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

$$+ wL_h^{out} - wL_h^{in}\Big\} - (A_o k_o + A_t^{out} k_t^{out})$$

$$- \lambda(A_o + A_t^{out} - A_e)$$

$$- \mu[A_o k_o + A_t^{out} k_t^{out} - I_{\{A_e > A_e^m\}} A_e \theta(S_e)]$$

$$- \nu[L_o + L_t^{in} - L(L_f, L_h^{in})]$$

$$- \xi(L_f + L_h^{out} - 1)$$

$$+ \zeta_o A_o + \zeta_t^{out} A_t^{out} + \zeta_t^{in} A_t^{in}$$

$$+ \delta_o k_o + \delta_t^{out} k_t^{out} + \delta_t^{in} k_t^{in}$$

$$+ \chi_o L_o + \chi_t^{in} L_t^{in} + \psi L_f + \phi L_h^{out} + \eta L_h^{in}.$$

Denote F^o and F^t for outputs on the self-cultivated and rented-in land, respectively. Then, the first-order optimality conditions for individual resource allocation can be written as follows.

(1) $\frac{\partial \mathcal{L}}{\partial A_o} : \frac{\beta}{1-\beta}\Big\{p\frac{\partial F^o}{\partial A} + p\frac{\partial F^o}{\partial K}(k_o + k_n) - [d_o + c_o(S_e)]k_o - c_o(S_e)r(k_n)\Big\} - k_o - \lambda - \mu k_o + \zeta_o = 0;$

(2) $\frac{\partial \mathcal{L}}{\partial k_o} : \frac{\beta}{1-\beta}\Big\{p\frac{\partial F^o}{\partial K}A_o - [d_o + c_o(S_e)]A_o\Big\} - A_o - \mu A_o + \delta_o = 0;$

(3) $\frac{\partial \mathcal{L}}{\partial L_o} : \frac{\beta}{1-\beta}p\frac{\partial F^o}{\partial L} - \nu + \chi_o = 0;$

(4) $\frac{\partial \mathcal{L}}{\partial A_t^{out}} : \frac{\beta}{1-\beta}\Big\{r(k_t^{out} + k_n) - [d_t + c_t(S_e)]k_t^{out} - c_t(S_e)r(k_n)\Big\} - k_t^{out} - \lambda - \mu k_t^{out} + \zeta_t^{out} = 0;$

(5) $\frac{\partial \mathcal{L}}{\partial k_t^{out}} : \frac{\beta}{1-\beta}\Big\{r'(k_t^{out} + k_n)A_t^{out} - [d_t + c_t(S_e)]A_t^{out}\Big\} - A_t^{out} - \mu A_t^{out} + \delta_t^{out} = 0;$

(6) $\frac{\partial \mathcal{L}}{\partial A_t^{in}} : \frac{\beta}{1-\beta}\Big[p\frac{\partial F^t}{\partial A} + p\frac{\partial F^t}{\partial K}(k_t^{in} + k_n) - r(k_t^{in} + k_n)\Big] + \zeta_t^{in} = 0;$

(7) $\frac{\partial \mathcal{L}}{\partial k_t^{in}} : \frac{\beta}{1-\beta}\Big[p\frac{\partial F^t}{\partial K}A_t^{in} - r'(k_t^{in} + k_n)A_t^{in}\Big] + \delta_t^{in} = 0;$

(8) $\frac{\partial \mathcal{L}}{\partial L_t^{in}} : \frac{\beta}{1-\beta}p\frac{\partial F^t}{\partial L} - \nu + \chi_t^{in} = 0;$

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

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

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

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

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

(14) $\nu \geq 0, L_o + L_t^{in} = L(L_f, L_h^{in});$

(15) $\xi \geq 0, L_f + L_h^{out} = 1;$

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

The first three conditions above are for the optimal production on the self-cultivated land and conditions (6)-(8) are for the optimal production on the rented-in land. Note that the same (per-period) shadow price of the effective labor input, namely $\frac{1-\beta}{\beta}\nu$, applies to both productions. Given the effective labor extraction technology, the other three labor allocation conditions (9)-(11) say that an individual agent will not hire out labor unless $\frac{1-\beta}{\beta}\nu$ equals wage rate w and will not hire in labor unless $\frac{1-\beta}{\beta}\nu$ is sufficiently larger than w. On the other hand, as shown below in subsection 3.1, tenants only earn the market return of labor from cultivating the rented-in land (during each production period), namely $p\frac{\partial F^t}{\partial L} = w$, given that the production technology is C.R.S. and they only contribute labor input. Put it into the condition (8), this implies that an individual agent will not rent in land unless $\frac{1-\beta}{\beta}\nu$ equals w. In sum, landed agents will neither hire out labor nor rent in land if self-cultivating the endowed land delivers the marginal return of the endowed labor that is higher than wage rate.

As shown below in subsection 3.2, landed agents will always self-cultivate all the endowed land unless the shadow price of the effective labor input is sufficiently higher than wage rate. Then, the critical question becomes how land security affects their choices of renting out land. Intuitively, when self-cultivating all the endowed land consumes all the endowed labor and/or involves hired labor input, renting out land will bring about higher efficiency of labor input as tenants only use family labor to cultivate the rented land. However, renting out land will also bring about higher protection cost and/or depreciation rates. Thus, landed agents for whom self-cultivating all the endowed land will raise the shadow price of the effective labor input above wage rate face the trade-off above while other landed agents will not have this dilemma as renting out land will not bring them any efficiency gain in labor input.

2.3 Comparative statics

In this subsection I explain how land security affects individual land rental supply holding prices constant. To proceed, denote A_e^{out} for the threshold of renting out land (in terms of the size of land endowment) that may vary across land security S_e. As shown below in subsection 3.2, landed agents will only rent out land provided $A_e > A_e^{out}$. Also, denote A_o^* for the optimal size of the self-cultivated land. In the following I will use their comparative statics with respect to land security to formalize the trade-off facing landlords at extensive and intensive margins, respectively, based on the definitive condition below for both A_e^{out} and A_o^* derived from the first-order conditions above and the land rental rate schedule defined below in subsection 3.1:[15]

$$p\frac{\partial F^o}{\partial A}|_{k=k_o+k_n}+p\frac{\partial F^o}{\partial K}|_{k=k_o+k_n}k_n-c_o(S_e)r(k_n)=p\frac{\partial F^t}{\partial A}|_{k=k_t^{out}+k_n}+p\frac{\partial F^t}{\partial K}|_{k=k_t^{out}+k_n}k_n-c_t(S_e)r(k_n),$$

where F^t now stands for the output on the rented-out land.

The equation above says that the net marginal return of the endowed land under owner-cultivation equals that under tenant-cultivation for landlords at extensive and intensive margins. Here, the net marginal return of the endowed land is the (per-period) marginal return of the endowed land (including its embedded natural capital) minus its (per-period) marginal protection cost. Recall that landed agents have the motivation to rent out land when self-cultivating all the endowed land raises the marginal cost of the effective labor input above wage rate, i.e. the net marginal return of the endowed land under tenant-cultivation would be higher than that under owner-cultivation if

[15]On the one hand, we can obtain μ from the condition (2) if $k_o > 0$. Plug it into the condition (1) and then obtain λ given $A_o > 0$. We will obtain λ in the same formula from the condition (1) if $k_o = 0$. On the other hand, using the same procedure we can obtain λ from conditions (4) and (5) given $r(k_t^{out}+k_n) = p\frac{\partial F^t}{\partial A}|_{k=k_t^{out}+k_n} + p\frac{\partial F^t}{\partial K}|_{k=k_t^{out}+k_n}(k_t^{out}+k_n)$ and $r'(k_t^{out}+k_n) = p\frac{\partial F^t}{\partial K}|_{k=k_t^{out}+k_n}$ that come from the land rental rate schedule defined below in subsection 3.1. These two λ's should equal each other at the optimum for landlords at extensive and intensive margins.

there were no cost difference in other inputs between the two modes of land cultivation. However, renting out land will raise protection cost and/or capital depreciation rates, leading to a higher cost of protecting the endowed land and a lower intensity of or no attached capital investments (see details below). This tends to make the net marginal return of the endowed land under tenant-cultivation lower than that under owner-cultivation. Thus, landed agents for whom self-cultivating all the endowed land will raise the shadow price of the effective labor input above wage rate face the trade-off described above.

To provide thoughtful discussions on how land security affects individual land rental supply, let us focus on landed agents who have access to credit and assume that they will make attached capital investments.[16] Note that the (per-period) marginal cost of attached capital input for the self-cultivated land, namely $d_o + c_o(S_e) + i$, is always lower than that for the rented-out land, namely $d_t + c_t(S_e) + i$, due to gaps between depreciation and protection cost rates. Thus, I assume that they will always invest in the land to be self-cultivated while they may not invest in the land to be rented out.[17] Accordingly, I will present comparative statics of the threshold of renting out land A_e^{out} and the optimal size of the self-cultivated land A_o^* with respect to the land security level S_e below for the two sets of landlords who make some or no attached capital investments in the rented-out land.

A. The Extensive Margin: $\frac{\partial A_e^{out}}{\partial S_e}$

When landlords at the extensive margin have no attached capital investments in the first unit of the rented-out land, say due to a large depreciate rate gap, higher land security will not necessarily lead to a smaller threshold of renting out land. Higher land security means lower protection cost rates and thus higher incentives of making attached capital investments ($c_o'(S_e) < 0$ and $c_t'(S_e) < 0$) and renting out

[16]The other landed agents have no credit to invest and hence will be always more likely to rent out (more) land as higher land security lowers the cost of protecting the land to be rented out relative to the land to be self-cultivated.

[17]Explicitly, I assume $d_o + c_o(S_e) + i < p\frac{\partial F^o}{\partial K}|_{k=k_n}$ so that landed agents who have access to credit will make attached capital investments in the land to be self-cultivated. However, they will not invest in the land to be rented out if it is not profitable to do so, for instance $d_t + c_t(S_e) + i \geq p\frac{\partial F^t}{\partial K}|_{k=k_n}$.

land ($c_t'(S_e) - c_o'(S_e) < 0$). However, the former only materializes in the self-cultivated land as investing in the rented-out land is unprofitable. Hence, as shown below in the second row of Table 1, investment incentives will counteract rental incentives for unconstrained landlords at the extensive margin. For constrained landlords at the extensive margin who have access to credit, higher land security will still bring about offsetting effects on the threshold of renting out land as it enhances credit access ($\theta'(S_e) > 0$) and thus more credit will be used for attached capital investments in the self-cultivated land.

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

k_t^{out}	investment-unconstrained	investment-constrained
$k_t^{out} = 0$	$I_e^{uc}[-c_o'(S_e)] - R_e^{uc} r(k_n)\{-[c_t'(S_e) - c_o'(S_e)]\}$	$I_e^{c}\theta'(S_e) - R_e^{c} r(k_n)\{-[c_t'(S_e) - c_o'(S_e)]\}$
	$I_e^{uc} > 0, R_e^{uc} > 0$	$I_e^{c} > 0, R_e^{c} > 0$
$k_t^{out} > 0$	$\tilde{I}_{e,1}^{uc}[-c_o'(S_e)] - \tilde{R}_e^{uc} r(k_n)\{-[c_t'(S_e) - c_o'(S_e)]\}$	$\tilde{I}_{e,1}^{c}\theta'(S_e) - \tilde{R}_e^{c} r(k_n)\{-[c_t'(S_e) - c_o'(S_e)]\}$
	$-\tilde{I}_{e,2}^{uc} k_t^{out}[-c_t'(S_e)]$	$-\tilde{I}_{e,2}^{c} k_t^{out}\theta'(S_e)$
		$-\tilde{I}_{e,3}^{c} k_t^{out}\{-[c_t'(S_e) - c_o'(S_e)]\}$
	$\tilde{I}_{e,1}^{uc} > 0, \tilde{I}_{e,2}^{uc} = \tilde{R}_e^{uc} > 0$	$\tilde{I}_{e,1}^{c} > 0, \tilde{I}_{e,2}^{c} > 0, \tilde{I}_{e,3}^{c} = \tilde{R}_e^{c} > 0$

Note: (i) Landlords at the extensive margin will not invest attached capital in the first unit of the rented-out land when the marginal cost of the invested capital, namely credit interest and depreciation and protection cost rates, is sufficiently higher for the rented-out land than that for the self-cultivated land. (ii) Using the implicit function theorem, I obtain all the I's and R's above from the first-order optimality conditions above. (iii) The comparative statics above are obtained under the condition that hired labor is employed. Similar comparative statics can be obtained when hired labor is not employed.

When landlords at the extensive margin have some attached capital investments in the first unit of the rented-out land, the ambiguous effects above maintain to some extent. Admittedly, the enhanced investment incentives and credit access now also materialize in the rented-out land in addition to the enhanced rental incentives, which will further increase the net marginal return of the first unit of the rented-out land. For instance, the enhanced credit access will relax the budget constraint of investing attached capital in the self-cultivated land and thereby decrease the shadow price of the accessible credit μ. Then, landlords at the extensive margin will have higher intensities of attached capital investments in the first unit of the rented-out land as the effective (per-period) marginal cost of the invested capital $d_t + c_t(S_e) + i + \mu i$ becomes smaller. It will still be the case even when landlords at the extensive margin are not investment-constrained in prior since the protection cost rate $c_t(S_e)$ will decrease anyway as land security improves.

As shown above in the third row of Table 1, however, the positive effect of the lower protection cost rate $c_t(S_e)$ on the marginal return of the first unit of the rented-out land through its attached capital investments tends be smaller under the investment constraint. The reason is that the lower protection cost rate $c_o(S_e)$ will increase attached capital investments in the self-cultivated land and thereby increase the shadow price of the accessible credit μ, partially offsetting the positive effect of the lower protection cost rate $c_t(S_e)$ on the effective marginal cost of the attached capital invested in the rented-out land. Nevertheless, regardless of the investment constraint status, the size of the extra gain on the net marginal return of the first unit of the rented-out land almost monotonically depends on the intensity of attached capital investments in the rented-out land that is less responsive to changes in the effective marginal cost of the invested capital at low levels due to the diminishing marginal return of attached capital input. It implies that the depreciation rate gap can still attenuate the potential of improving land security to incentivize more landowners to rent out land as landowners tend to invest more attached capital investments in the land to be self-cultivated relative to the land to be rented out.[18] Simulation results in subsection 4.2 largely corroborate this theoretical prediction.

B. The Intensive Margin: $\frac{\partial A_o^*}{\partial S_e}$

As shown below in Table 2, land security has similar ambiguous effects on the optimal size of the self-cultivated land A_o^* for a landlord at the intensive margin. The essential difference appears only for constrained landlords who have attached capital investments in the rented-out land. Note that constrained landlords at the extensive margin allocate all the accessible credit to the self-cultivated land, which will then affect attached capital investments in the first-unit of the rented-out land through the shadow

[18]Figure A.1 in the Appendix provides an intuitive presentation about the mechanism behind it.

price of the accessible credit μ as described above. However, a constrained landlord at the intensive margin rents out land of a non-negligible size. So, the aforementioned increment of attached capital investments in the self-cultivated and rented-out land would otherwise surpass the increment of credit if this constrained landlord did not reduce investments in them or reallocate credit between them.

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

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

Note: (i) Landlords at the intensive margin will not invest attached capital in the rented-out land when the marginal cost of the invested capital, namely credit interest and depreciation and protection costs, is sufficiently higher for the rented-out land than that for the self-cultivated land. (ii) Using the implicit function theorem, I obtain all the I's and R's above from the first-order optimality conditions above. (iii) The comparative statics above are obtained under the condition that hired labor is employed. Similar comparative statics can be obtained when hired labor is not employed.

The investment adjustments above add another layer to the effects of higher land security on the optimal size of the self-cultivated land for constrained landlords at the intensive margin. Nevertheless, as shown above in the third row and column of Table 2, the overall effect of lower protection cost rates or enhanced investment incentives on attached capital investments favors the rented-out land as the protection cost rate for the rented-out land $c_t(S_e)$ decreases more than the protection cost rate for the self-cultivated land $c_o(S_e)$. Simulation exercises below in section 4 indicate that the depreciation rate gap can still attenuate the potential of improving land security to increase land rental supply at the market level, although mathematically there is no clear pattern about its impact on the effect of higher land security on the land rental supply from an investment-constrained landlord at the intensive margin.

3 The Competitive Equilibrium

The comparative statics above do not tell us how land security affects resource allocation for agents other than landlords. In particular, as shown below in subsection 3.1, landless agents can only benefit from land security improvements through the increase in wage rate. Landed agents for whom self-cultivating all the endowed land does not consume all the endowed labor can also benefit from the increase in wage rate while they may not materialize the enhanced investment incentives as they may be quantity-rationed in the credit market due to small sizes of land endowment. Indeed, security improvement programs like land titling and registration often implement throughout the agrarian economy and thereby should have price effects. Therefore, exploring equilibrium impacts of improving land security is warranted.

Before jumping into simulation exercises below in section 4, I define the competitive equilibrium in subsection 3.3. In subsection 3.1, I derive and illustrate the properties of land rental rate schedule that have been widely utilized in previous subsections. In subsection 3.2, I formally introduce thresholds of renting in land and renting out land, which are relevant for aggregate land and labor allocations and hence provides us a comprehensive picture about the economic content of this model and its predictions on economic impacts of land security improvements.

3.1 Properties of land rental rate schedule

First of all, when there are some attached capital investments in the rented-in land made by the landlord, namely $k_t^{in} > 0$, we can rewrite first-order conditions for the production on the rented-in land, namely (6)-(8), as follows:

(17) $p\frac{\partial F^t}{\partial A}|_{k=k_t^{in}+k_n} + p\frac{\partial F^t}{\partial K}|_{k=k_t^{in}+k_n}(k_t^{in}+k_n) - r(k_t^{in}+k_n) = 0;$

(18) $p\frac{\partial F^t}{\partial K}|_{k=k_t^{in}+k_n} - r'(k_t^{in}+k_n) = 0;$

(19) $p\frac{\partial F^t}{\partial L}|_{k=k_t^{in}+k_n} - \frac{1-\beta}{\beta}\nu = 0.$

Together with the C.R.S. production technology, conditions (17) and (19) imply that tenants will just earn the return of the effective labor input on the rented-in land as they only provide labor input, i.e. $pF(A_t^{in}, A_t^{in}k_t^{in} + A_t^{in}k_n, L_t^{in}) - r(k_t^{in} + k_n)A_t^{in} = p\frac{\partial F^t}{\partial A}A_t^{in} + p\frac{\partial F^t}{\partial K}[A_t^{in}(k_t^{in} + k_n)] + p\frac{\partial F^t}{\partial L}L_t^{in} - r(k_t^{in} + k_n)A_t^{in} = p\frac{\partial F^t}{\partial L}L_t^{in} = \frac{1-\beta}{\beta}\nu L_t^{in}$.[19]

In terms of input intensities, the condition (17) is equivalent to $pF^t(1, k_t^{in} + k_n, l_t^{in}) - pF_l^t(1, k_t^{in} + k_n, l_t^{in})l_t^{in} = r(k_t^{in} + k_n)$. Then, the intensity of the effective labor input l_t^{in} is solely determined by the intensity of the attached capital on the rented-in land, namely $k_t^{in} + k_n$, as the value of left-hand-side terms is strictly decreasing in l_t^{in} for any given $k_t^{in} + k_n$. So is the marginal return of the effective labor input on the rented-in land $pF_l^t(1, k_t^{in} + k_n, l_t^{in})$. In the following I will demonstrate that the marginal return of the effective labor input on any type of the rented-in land (in terms of the intensity of the attached capital) should equal wage rate in the competitive equilibrium, i.e. $p\frac{\partial F^t}{\partial L}|_{k=k_t^{in}+k_n} = \frac{1-\beta}{\beta}\nu = w, \forall k_t^{in} \geq 0$ given the condition (19).

Without loss of generality, suppose that both land rental and labor markets are active, i.e. both markets have positive supply and demand in the competitive equilibrium. If the marginal return of the effective labor input on some type of the rented-in land, in terms of the intensity of attached capital input, is smaller than wage rate, then no agent will rent in that land as the marginal cost of the effective labor input is no less than wage rate. That is, the rental rate for that land will have to decrease to reach the competitive equilibrium. If the marginal return of the effective labor input on some type of the rented-in land is larger than wage rate, then all laborers will change to rent in that land instead of hiring out labor. That is, the rental rate for that land will have to increase to reach the competitive equilibrium. In sum, the marginal return of the effective labor input on any type of the rented-in land should equal wage rate in the competitive equilibrium where both land rental and labor markets are active. As shown below in subsection 3.3, this property also holds true for other competitive equilibria where either land rental market or labor market is inactive.[20]

[19] For $k_t^{in} = 0$, conditions (17) and (19) still hold true while the non-essential condition (18) does not.

[20] Since the agrarian economy has landless agents who either hire out the endowed labor or use it to cultivate the rented-in land, land rental and labor markets can not be inactive at the same time in any competitive equilibrium.

3.2 Renting regimes over the size of land endowment

Fix wage rate and land rental rate schedule in this subsection. On the one hand, the agency cost of hired labor raises the marginal cost of the effective labor input above wage rate when hired labor is used. On the other hand, the marginal return of the effective labor input on the rented-in land always equals wage rate due to the C.R.S. production technology as shown above. Hence, landed agents will not rent in any land if self-cultivating part of or all the endowed land can deliver returns of the endowed labor that are higher than wage rate.

Landed agents will not rent out land either if self-cultivating all the endowed land does not consume all the endowed labor, i.e. the associated marginal cost of the effective labor input equals wage rate. Under this condition renting out land will only bring them higher protection and depreciation costs of attached capital investments (if applicable) and a higher cost of protecting the raw land but not higher efficiency of labor input. As a corollary, landed agents will use the endowed labor to cultivate the endowed land first.[21] Thus, for any given land security there exits a unique size of land endowment, defined as the threshold of renting in land A_e^{in}, at which self-cultivating all the endowed land will just consume all the endowed labor.

When the size of the endowed land surpasses A_e^{in}, self-cultivating all the endowed land will consume all the endowed labor and even involve hired labor input.[22] Then, as the size of the endowed land increases, the marginal cost of the effective labor input would keep increasing due to the agency cost of hired labor if no endowed land were rented out. The rising marginal cost of the effective labor input would then keep reducing the marginal return of the endowed land under owner-cultivation, while

[21] When land property rights are fully secure and the depreciation rate gap disappears given long-term land rental contracts, landed agents will be indifferent between self-cultivating and renting out the endowed land if the marginal return of the endowed labor input on the endowed land under owner-cultivation equals wage rate. They are then assumed to use the endowed labor to cultivate the endowed land first. It will become clear later that this assumption does not affect equilibrium prices and hence outcomes of interest defined below in subsection 4.1.

[22] Admittedly, when self-cultivating all the endowed land does not consume all the endowed labor, landed agents will be indifferent between hiring out the rest of the endowed labor and using it to cultivate the rented-in land. I assume that they will then rent in land and hire out labor at the same time following some regularity rule introduced below in subsection 3.3. It will become clear later on that that labor allocation assignment does not affect outcomes of interest defined below in subsection 4.1.

the accessible credit does not play a role here as it is either zero or perfectly linear in the size of land endowment. However, it will not motivate landed agents to rent out land immediately after the size of the endowed land surpasses A_e^{in}, given that renting out land will bring about higher protection and depreciation costs of attached capital investments in the land (if applicable) and a higher cost of protecting the raw land. Hence, for any given land security level the threshold of renting out land A_e^{out}, above which landed agents will start to rent out land, is generally larger than the threshold of renting in land A_e^{in}.[23]

Now, let us get back to the ignored scenario where landed agents who have no credit access also rent out land. Higher land security reduces their costs of protecting the raw land while the reduced costs of protecting attached capital investments are irrelevant to them as they have no money to make land-attached investments. As before, higher land security always reduces the cost of protecting the raw land added by renting out the land. Hence, the threshold of renting out land A_e^{out} or equivalently the optimal size of the self-cultivated land A_o^* for them will always decrease for higher land security. However, the threshold of renting in land A_e^{in} for them will remain unchanged as they do not invest any attached capital that complements labor input.

3.3 The definition of the competitive equilibrium

Before defining the competitive equilibrium, let us revisit the properties of land rental rate schedule derived above in subsection 3.1: (i) $r(k_t^{in} + k_n) = p\frac{\partial F^t}{\partial A}|_{k=k_t^{in}+k_n} + p\frac{\partial F^t}{\partial K}|_{k=k_t^{in}+k_n}(k_t^{in} + k_n)$; (ii) $r'(k_t^{in} + k_n) = p\frac{\partial F^t}{\partial K}|_{k=k_t^{in}+k_n}$; and (iii) $p\frac{\partial F^t}{\partial L}|_{k=k_t^{in}+k_n} = w$. First of all, these properties will maintain when either land rental market or labor market is inactive in the competitive equilibrium. For instance, we can define the shadow price of family labor input on the rented-in land as wage rate when labor market is inactive.[24] Similarly, we can still define the land rental rate schedule such that it have

[23] When land property rights are fully secure and the depreciation rate gap disappears given long-term land rental contracts, we will have A_e^{out} being equal to A_e^{in} instead.

[24] Agents will not hire in labor at this wage rate due to the agency cost of hired labor. At the same time, tenants will not switch to hiring out labor either. Therefore, introducing this wage rate does not alter the competitive equilibrium.

properties (i)-(iii) when land rental market is inactive.[25] Secondly, these properties uniquely define land rental rate schedule given wage rate, i.e. wage rate is the essential factor price in the competitive equilibrium characterized below. As shown later in simulation results, land rental rate is decreasing in wage rate for a given intensity of attached capital. To proceed, I introduce the following notations for individual optimal labor allocations given wage rate w.

The optimal labor allocations of a landed agent:

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

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

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

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

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

The optimal resource allocation of a landless agent: $\varnothing$ denotes no land endowment.

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

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

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

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

Recall that like the landless landed agents for whom self-cultivating all the endowed land does not consume all the endowed labor are indifferent between hiring out the rest of the endowed labor and using it to cultivate the rented-in land as they deliver the same labor return, namely wage rate. To pin down their optimal labor allocations at any given wage rate, I assign the endowed labor excluding the part used to self-cultivate all the endowed land (if applicable) to cultivate the rented-in land and work on others' farms following some endogenous regularity rule. Denote $HLDO(w)$ and $FLDT(w)$

[25]Landed agents will not rent out any land at this land rental rate schedule as it is unprofitable to do so. Then, laborers can not rent in any land as there is no land rental in supply. In fact, they do not have incentives to rent in land as cultivating the rented-in land gives them the same return of labor input as wage rate. Thus, introducing this land rental rate schedule does not alter the competitive equilibrium.

as the aggregate hired labor demanded on the self-cultivated land and the aggregate family labor demanded on the rented-out land, respectively. Then, the endogenous labor allocation rule can be outlined in the following way.

The optimal labor allocation for a landless agent:
(i) $L_h^{in}(w;\emptyset) = 0, L_h^{out}(w;\emptyset) = \frac{HLDO(w)}{HLDO(w)+FLDT(w)}$; and
(ii) $L_t^{in}(w;\emptyset) = L_f(w;\emptyset) = \frac{FLDT(w)}{HLDO(w)+FLDT(w)}$.
The optimal labor allocation for a landed agent who self-cultivates all the endowed land and self-cultivation does not consume all the endowed labor: $A_e < A_e^{in}$.
(i) $L_h^{in}(w;A_e,S_e) = 0, L_h^{out}(w;A_e,S_e) = \frac{HLDO(w)}{HLDO(w)+FLDT(w)}[1 - L_o(w;A_e,S_e)]$; and
(ii) $L_t^{in}(w;A_e,S_e) = L_f(w;A_e,S_e) - L_o(w;A_e,S_e) = \frac{FLDT(w)}{HLDO(w)+FLDT(w)}[1 - L_o(w;A_e,S_e)]$.

Finally, when it comes to the context where there is no depreciation rate gap for the invested capital between the rented-out and self-cultivated land, I assume that landed agents whose endowed land is fully secure still use the endowed labor to cultivate the endowed land before hiring it out or using it to cultivate the rented-in land. Nevertheless, this assumption does not affect their incomes as they would invest the same intensities of attached capital in the endowed land if part or all of it were rented out and thus earn the same returns of the endowed land and the invested capital attached to it as that under owner-cultivation. Also, it does not affect the aggregate resource allocation and thereby equilibrium prices. These statements also apply to the endogenous labor allocation rule above. Hence, neither of them will affect equilibrium outcomes of interest described below in subsection 4.1.

Denote the distribution of the size and security level of the endowed land as $GH(A_e,S_e)$. Also, denote the ratio of the population of landless agents to the population of landed agents as RLL. Given the labor allocation rule above, the competitive equilibrium can be characterized by the following clearance condition for labor market that determines the equilibrium wage rate w and thereby land rental rate schedule $r(k)$.

The clearance condition for labor market: the clearance condition for land rental market is implicitly incorporated in the endogenous labor allocation rule above.

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

4 Numerical Simulations

In this section I conduct simulation exercises to provide numerical evidence of equilibrium impacts of improving land security for an unequal agrarian economy. I calibrate the model closely to the rural context of Nicaragua that largely represents low-income countries in LAC as one of the poorest countries. Subsection 4.1 outlines the simulation design in detail. Notably, I strategically manipulate the leverage ratio for credit, the depreciation rate gap for the invested capital, and the cost rate gap for protecting land ownership to provide insights about the critical roles of credit access, depreciation rates, and protection cost rates in economic impacts of land security improvements as shown above by the comparative statics in subsection 2.3.

In subsection 4.2, I use the aforementioned well-designed simulations to explore the direction in which and the extent to which the three critical factors above may affect impacts of improving land security on resource allocation and social welfare for the unequal agrarian economy considered. Numerical results suggest that better credit access generally enlarges economic gains from land security improvements in every aspects. However, the depreciation rate gap between the rented-out and self-cultivated land can largely attenuate gains from land security improvements on land in rental and wage rate but not necessarily land-attached investments or agricultural output. In extreme cases improving land security may dampen land rental supply and thereby substantially attenuate the policy potential of improving land security to reduce rural poverty as the increase in wage may become negligible. The structure of the protection cost rate gap between them may also matter (see details below).

4.1 The simulation design

In this subsection I parameterize the land rental model above in subsection 2.1 and specify the treatment of improving land security and the associated treatment effects for the economic outcomes of interest. The former involves the landless rate, the size and security distributions of land endowment, production and effective labor extraction technologies, credit and output markets, depreciation and protection cost rates, and the intensity of natural capital attached to the raw land. As discussed above, I leave the leverage ratio $\theta(S_e)$, the depreciation rate gap $\frac{d_t}{d_o}$, and the protection cost rate gap $c_t(S_e) - c_o(S_e)$ not (fully) specified for exploratory simulation exercises. The detailed simulation design is outlined below.

Land Endowment: the landless rate and the size and security distribution of the endowed land.

Firstly, I set the ratio of the population of landless agents to the population of landed agents RLL equal to $\frac{1}{2}$, i.e. the landless rate is about 33%, close to the 38% landless rate of rural Nicaraguan households in 1998 (Corral and Reardon, 2001).

Secondly, following Eswaran and Kotwal (1986), a landed agent is indexed by the proportion, $z_e \in (0,1]$, of landed agents who own smaller sizes of land than it does; the proportion, $G(z_e) \in (0,1]$, of land that is held by all landed agents with $z_e' \leq z_e$ follows a Pareto C.D.F, i.e. $G(z_e) = 1-(1-z_e)^a, a \in (0,1)$. Here a controls the degree of the equality of the size distribution of land endowment, i.e. the larger it is, the more egalitarian the size distribution of land endowment among landed agents is. I set a equal to $\frac{1}{9}$, which implies that the Gini coefficient of land endowment (in size, including landless agents) is about 0.87, almost the same as that for rural areas of Nicaragua in 1998 (Davis and Stampini, 2002).

Thirdly, the security level of the endowed land, $S_e \in [0,1]$, has the following conditional C.D.F: $H(S_e|z_e) = {S_e}^{b_1 z_e + b_2}, b_1 > 0, b_2 \geq \frac{\sqrt{5}-1}{2}$. Here b_1 controls the strength of the positive correlation between the size and security level of land endowment. Specifically, the conditional mean of land security, namely $\frac{b_1 z_e + b_2}{b_1 z_e + b_2 + 1}$, is strictly increasing in the product of b_1 and the land size indicated by z_e, i.e. the larger b_1 is, the higher the average land security for large landed agents will be relative to that for small landed agents. The inequality condition for b_2, on the other hand, guarantees that the conditional variance of land security is strictly decreasing in land size, which implies that the dispersion of land security levels is smaller among large landed agents than that among small landed agents. I set b_1 and b_2 equal to $\frac{\sqrt{5}+3}{2}$ and $\frac{\sqrt{5}-1}{2}$, respectively. This means that averages of conditional land security levels range from 0.38 to 0.76, which is in line with land security conditions in rural Nicaragua before (major) land titling and registration programs implemented in the 1990s (Boucher et al., 2005).[26]

Technologies: agricultural production and effective labor.

(i) *Agricultural production*: A hybrid C.E.S. function $F(A,K,L) = A^{\alpha}\left[(\alpha_k K^{\rho} + \alpha_l L^{\rho})^{\frac{1}{\rho}}\right]^{1-\alpha}$ with $\{\alpha, \alpha_k, \alpha_l\} \in (0,1)$, $\alpha_k + \alpha_l = 1$, and $\rho < 1-\alpha$, is employed for the C.R.S. agricultural production technology. Here α and $1-\alpha$ can be interpreted as output shares contributed by the pure land (excluding natural capital attached to it) and other inputs (including the natural capital), respectively. On the other hand, ρ controls the degree of substitution between land-attached capital and labor, i.e. the elasticity of substitution between them equals $\varepsilon = \frac{1}{1-\rho}$.[27] The inequality condition, $\rho < 1-\alpha$, reflects the

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

[27] When ρ approaches 0, we have $F(A,K,L) = A^{\alpha}K^{\alpha_k(1-\alpha)}L^{\alpha_l(1-\alpha)}$, a Cobb-Douglas production function. Then, α_k and α_l can be interpreted as relative output shares between land-attached capital and labor.

assumption that land-attached capital and labor inputs are strictly gross complements. For simplicity, I set $\alpha = \rho = \frac{1}{3}$ and $\alpha_k = \alpha_l = \frac{1}{2}$.

(ii) *Effective labor*: The effective labor extraction function is a modified version of the labor effort model proposed by Frisvold (1994)—$L = (L_f + L_h)\left(\frac{L_f}{L_f+L_h}\right)^{\gamma}$ with $\gamma \in (0,1)$.[28] Here γ controls the effectiveness of hired labor relative to family labor, i.e. the smaller it is, the more effective hired labor is. Considering possible advancement in supervising labor, I set γ equal to 0.2 instead of 0.24, an estimate for the rural India context in the early 1980s (Frisvold, 1994) .

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

(i) *Credit market*: Considering the important role of land security in credit access (e.g. Feder et al., 1988; Carter and Olinto, 2003), I set the leverage ratio $\theta(S_e)$ equal to $\theta\left(\frac{1}{2} + \frac{1}{2}S_e\right)$ with $\theta > 0$ for landed agents who have access to credit. Landed agents whose sizes of land endowment are below the median are set to be quantity-rationed (A_e^m equals the median size of land endowment) and hence have no credit access, which is corroborated by some descriptive evidence about the status of credit access for rural Nicaragua agricultural producers in 1999 (Boucher et al., 2005). The half-half design about the relative role of land size and security in credit access is also in line with the empirical findings in rural Nicaragua that relative to no title or document, on average, having a registered title or document (the full security) increases land values by 100% in the 1990s (Deininger and Chamorro, 2004).[29] For the interest rate i, I set it equal to 10%, the average real commercial loan rate for Nicaragua in 1996 (Jonakin and EnrÃquez, 1999).

(ii) *Output price*: For simplicity, I set output price p equal to 1.

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

[29] According to their estimates about effects of land security on land values for rural Nicaraguan households in the 1990s, having an agrarian reform title or sales receipt increases land values by 70% on average and having them registered increases land values further by 30%.

Depreciation and protection cost rates

(i) *Depreciation rates*: I strategically set the depreciation rate of the attached capital invested in self-cultivated land d_o equal to 10%, the same as the interest rate i. Also, I set the depreciation rate gap $\frac{d_t}{d_o} \geq 1$, i.e. the depreciation rate of the attached capital invested in rented-out land is no less than d_o. This design ensures that depreciation rates and interest rate, the two components of the (per-period) marginal cost of attached capital input, namely depreciation and protection cost rates and interest rate, are reasonably comparable to each other.

(i) *Protection cost rates*: Due to the same reason described above, I strategically set the protection cost rate for the self-cultivated land $c_o(S_e)$ equal to $c(1-S_e)$ with $c = 10\%$ as the protection cost rate is the other component of the marginal cost of attached capital input. For the protection cost rate for the rented-out land $c_t(S_e)$, I set it equal to $c_o(S_e) + c(1-S_e^\tau)$ with $\tau \in (0,1]$. That is, the protection cost rate gap or the protection cost rate added by renting out land $c_t(S_e) - c_o(S_e)$ equals $c(1-S_e^\tau)$ which will be the same as $c_o(S_e)$ provided $\tau = 1$.

For $\tau < 1$, however, it means that relative to the protection cost rate for the self-cultivated land the protection cost rate gap between the rented-out and self-cultivated land decreases faster at low security levels but slower at high security levels as land security increases. As shown below in subsection 4.2, this design enables us to incorporate the empirical findings in Nicaragua that having land titles significantly increases the probability of landowners renting out land but awarding them land titles does not effectively increase their investments in land-attached capital unless titles are also registered (Deininger et al., 2003; Deininger and Chamorro, 2004).

Natural capital: The intensity of natural capital attached to the raw land k_n satisfies the definitive condition that the marginal return of attached capital input on the land under owner cultivation equals the sum of depreciation and interest rates provided no invested capital and labor inputs, i.e. $p\frac{\partial F}{\partial K}|_{k=k_n,L=0} = d_o + i$ or $\frac{1}{6}k_n^{-\frac{1}{3}} = 0.2$. That is, I set k_n equal to 1.2^{-3} or about 0.6. Importantly, this implies that a landed agent who has access to credit will always invest attached capital in the self-cultivated land if land ownership is fully secure, since labor and attached capital inputs are strictly gross complements for each other. In the simulation results below, all landed agents who have access to credit have some attached capital investments in the self-cultivated land while some or all landlords among them do not invest in the rented-out land under some conditions.

Table 3 below summarizes all the model parameterization above.

Treatment: land security improvements, i.e. to freely improve land security to the highest level for all landed agents. Then, there will be no ownership risk or equivalently no cost of protecting the raw land and the attached capital invested in any land (if applicable) after the treatment. However, the depreciation rate gap between the rented-out and self-cultivated land remains unchanged since land security improvements per se do not remove barriers to long-term land rental contracts (other than land insecurity) like legal restrictions on the length of land rental contracts.

Treatment effects: Economic outcomes of interest for the agrarian economy considered above have the following two parts for agents in the agricultural production sector. Treatment effects are measured by their changes before and after the treatment.
(i) Resource allocation: sizes of land rental market and attached capital investments.
(ii) Social welfare: the aggregate agricultural output and wage rate.

The aggregate agricultural output just equals the gross income as the output price is one. Hence, it measures the overall welfare for all agents during each production period given the risk-neutral preferences over income. By definition, it also measures the degree of food security for the agrarian society. Wage rate, on the other hand, measures the income of landless agents. As discussed above in subsection 3.1, cultivating the rented-in land just delivers the market return of labor input for tenants given the C.R.S. production technology and the competitive land and labor markets. Thus, the gain on wage rate largely represents the size of the income gain from land security improvements for the poor who are landless and land-poor in this model. Admittedly, the land-poor also benefit from the cost reduction of protecting the raw land, although they have no credit to make investments due to quantity-rationing.

Since the total size of land endowment is fixed, I measure the size of land rental market by the percentage of land in rental following the literature (e.g. Boucher et al., 2005). Similarly, I measure the size of attached capital investments by the percentage of the maximum aggregate accessible credit—the product of the total size of land endowment and the maximum leverage ratio θ—used for those investments. Differences in these percentages before and after the treatment or their percentage points represent the treatment effect on resource allocation. On the other hand, I use percentage changes of the aggregate agricultural output and wage rate before and after the treatment to measure the treatment effect on social welfare.

Free parameters: θ, d_t, and τ. As shown above by the comparative statics, they all play important roles in the effects of higher land security on individual land rental supply. So do they in the treatment effects of land security improvements above. To explore their critical roles, I strategically discretize them in the following way.

(i) *The maximum leverage ratio*: $\frac{\theta}{k_n} \in \{2, 4, 5, 6, 8\}$. As shown below in simulation results, before the treatment landlords will be almost all investment-constrained and investment-unconstrained for $\theta = 2k_n$ and $\theta = 8k_n$, respectively, provided no depreciation rate gap ($d_t = d_o$) and no difference between the protection cost rate increased by renting out land and the protection cost rate for the self-cultivated land ($\tau = 1$). Under the same condition, about 20%, 50%, and 80% of them will be investment-unconstrained for $\theta = 4k_n$, $\theta = 5k_n$, and $\theta = 6k_n$, respectively. That is, the larger θ is, the more landlords will be investment-unconstrained before the treatment. Importantly, the larger θ is, the larger the improvement in credit access for landed agents who are investment-constrained in prior will be given $\theta'(S_e) = \frac{1}{2}\theta$ so that they will have more credit to make more attached capital investments after the treatment. Simulation results below suggest that a larger θ will lead to larger gains from land security improvements on both resource allocation and social welfare when there is no depreciation rate gap between the rented-out and self-cultivated land.

(ii) *The deprecation rate gap*: $\frac{d_t}{d_o} \in \{1, 2, 3, 4, 5\}$. Simulation results below show that regardless of the value of the maximum leverage ratio, before the treatment no landlord will make attached capital investments in the rented-out land at $d_t = 5d_o$ while all landlords will do that at $d_t = d_o$. Also, the larger the depreciation rate gap is, the lower the intensity of attached capital investments in the rented-out land will be relative to that in the self-cultivated land before the treatment, which tends to favor self-cultivating the endowed land rather than renting it out in response to land security improvements as shown above by the comparative statics.

(iii) *The protection cost rate gap*: $c_t(S_e) - c_o(S_e) = c(1 - S_e^{\tau}), c = 10\%$ with $\tau \in \{1, 0.8, 0.6, 0.4, 0.2\}$. Recall that the protection cost rate increased by renting out land, the protection cost rate gap here, is similar to the protection cost rate for the self-cultivated land, namely $c_o(S_e) = c(1 - S_e)$, in magnitude as they share the same c, e.g. they will be exactly the same provided $\tau = 1$. However, the smaller τ is, the larger the marginal reduction of $c_t(S_e) - c_o(S_e)$ will be relative to the marginal reduction of $c_o(S_e)$ when land security improves at low levels. The opposite will be true when land security improves at high levels. The comparative statics above will then predict that higher land security will be more likely to favor renting out land at low levels relative to high levels. As shown below in simulation results, the smaller τ is, the smaller the expansion of land rental market will be after the treatment, as on average agents endowed with larger sizes of land have higher land security in prior.

To explore their roles separately, I firstly set $d_t = d_o$ and $\tau = 1$ and vary the maximum leverage ratio θ to explore the treatment effects of improving land security under different levels of credit access. These treatment effects are then taken as the benchmark economic impacts of land security improvements that will be compared with the treatment effects in scenarios when we have either $d_t > d_o$ or $0 < \tau < 1$. The differences between them will reflect the roles of depreciation and protection cost rate gaps in economic impacts of land security improvements.

Table 3: The Model Parameterization.

	value/feature	reasons/references
Panel A: Technologies.		
production		
$F(A,K,L) = A^{\alpha}\left[(\alpha_k K^{\rho} + \alpha_l L^{\rho})^{\frac{1}{\rho}}\right]^{1-\alpha}$	$\alpha = \rho = \frac{1}{3}$	for simplicity
	$\alpha_k = \alpha_l = \frac{1}{2}$	for simplicity
effective labor		
$L(L_f, L_h) = (L_f + L_h)\left(\frac{L_f}{L_f+L_h}\right)^{\gamma}$	$\gamma = 0.2$	Frisvold (1994)
Panel B: Markets.		
labor	competitive	for simplicity
land rental	competitive	for simplicity
attached capital	price fixed at 1	numeraire
credit		
interest rate	$i = 10\%$	Jonakin and EnrÃquez (1999)
rationing threshold	A_e^m = median size	Boucher et al. (2005)
leverage ratio	$\theta(S_e) = \theta\left(\frac{1}{2} + \frac{1}{2}S_e\right)$	Deininger and Chamorro (2004)
maximum leverage ratio	$\theta > 0$	free values*
output	$p = 1$	for simplicity
Panel C: Agents.		
preferences		
discount factor	$\beta = \frac{1}{1+i}$	Eswaran and Kotwal (1986)
endowments		
labor	1	Eswaran and Kotwal (1986)
landless rate	$\frac{1}{3}$	Corral and Reardon (2001)
C.D.F. of land size		
$G(z_e) = 1-(1-z_e)^a, z_e \in (0,1]$	$a = \frac{1}{9}$	Davis and Stampini (2002)
C.D.F. of land security		
$H(S_e \mid z_e) = S_e^{b_1 z_e + b_2}, S_e \in (0,1]$	$b_2 = \frac{\sqrt{5}-1}{2}$	variance decreases in land size
	$b_1 = \frac{\sqrt{5}+3}{2}$	Boucher et al. (2005)
natural capital	$MRPK\|_{k=k_n, L=0} = d_o + i$	small and
	i.e. $k_n = 1.2^{-3}$, about 0.6	unrelated to equilibrium prices
Panel D: Depreciation and Protection Costs.		
capital depreciation rates		
self-cultivated land	$d_o = 10\%$	comparable to interest rate i
rented-out land	$d_t \geq d_o$	free values*
protection cost rates		
self-cultivated land	$c_o(S_e) = c(1-S_e), c = 10\%$	comparable to interest rate i
rented-out land	$c_t(S_e) - c_o(S_e) = c(1-S_e^{\tau})$,	comparable to $c_o(S_e)$
	$\tau \in (0,1]$, nonlinear	free values*, Deininger et al. (2003)
	provided $\tau < 1$	+ Deininger and Chamorro (2004)

Note: *I strategically choose some discrete values for each of the three free parameters above to explore the critical roles of credit access, depreciation and protection costs in the treatment effects of land security improvements. See choices of their values and reasons in the text above.

4.2 Simulation results

In this subsection I use simulation results to illustrate the differential roles of depreciation and protection costs and credit access in the impacts of land security improvements on resource allocation and social welfare for the unequal agrarian economy specified above. The numerical evidence below indicates that better credit access will enlarge the positive effects of land security improvements provide no depreciation rate gap. However, the presence of the depreciation rate gap tends to attenuate such desirable economic impacts. In particular, land rental market may even witness a shrinkage after land security improvements when the depreciation rate gap is sufficiently large. The protection cost rate gap induced by renting out land will also have negative effects on economic impacts of land security improvements if it has a specific structure under which at margin higher land security favors renting out land more at lower initial land security levels (see details below).

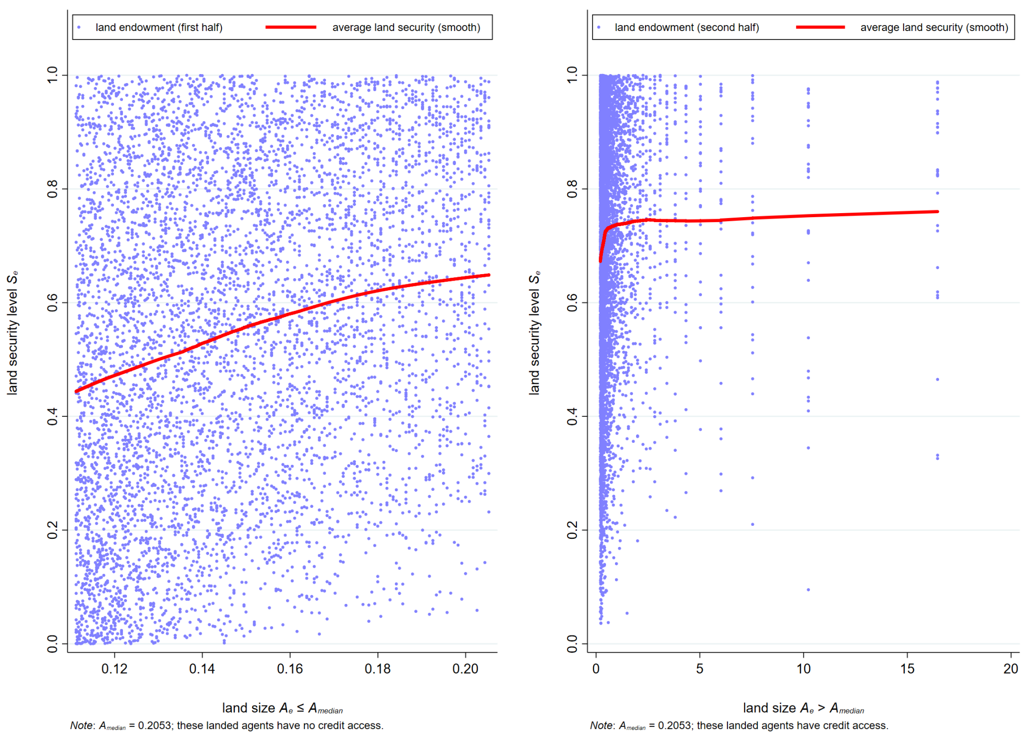

Figure 2: The Size and Security Distributions of Land Endowment.

Before moving to the treatment effects of improving land security defined above, let us go over common features of the simulated agrarian economies in different scenarios.

First of all, they share the same size and security distributions of land endowment as shown above in Figure 2. On average, the larger land size is, the higher land security level is. The average land security level for the largest landed agents are close to 2 times of that for the smallest landed agents. On the other hand, most landed agents endow with small sizes of land while a few landed agents own most land. For instance, the median land size is around 0.2 which is only about 1/80 of the largest land size. Agents whose sizes of land endowment are below the median only own about 1% of land in total. Moreover, they do not have credit access due to quantity-rationing while the other half of landed agents have. In fact, landlords are of the latter group in all the simulated scenarios below. Last but not least, as shown below in Figure 3 land rental rate schedule is decreasing in wage rate in any simulated scenarios as a higher cost of labor input reduces the return of the raw land and its attached capital (if applicable).

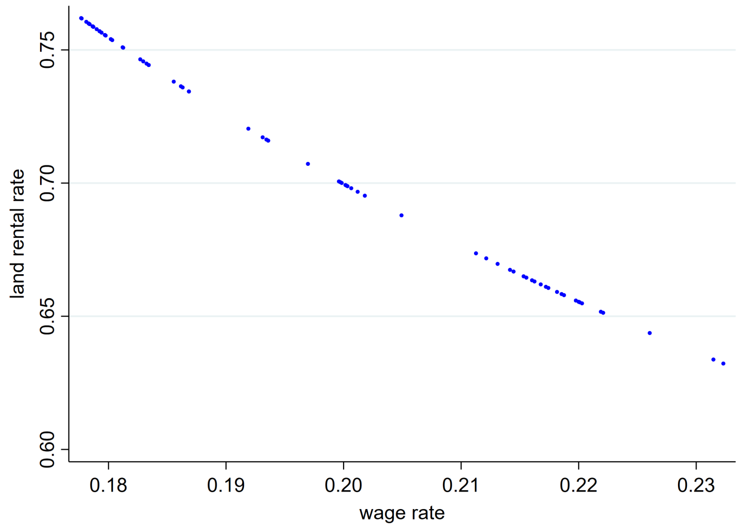

Figure 3: Land Rental Rates for the Raw Land.

Note: The land rental rates above are obtained from competitive equilibria before and after land security improvements in all the scenarios considered below. The higher the intensity of attached capital is, the higher the land rental rate will be for any given wage rate, although this pattern is not shown here.

A. The Role of Credit Access

To study the role of credit access for treatment effects, I set $d_t = d_o$ and $\tau = 1$ so that the attached capital invested in the self-cultivated and rented-out land depreciate at the same rate and renting out land simply doubles the protection cost rate at any land security level. Then, I vary the maximum leverage ratio θ to explore the equilibrium effects of land security improvements on resource allocation and social welfare at different levels of credit access. As shown below in Panel A of Figure 4, the higher level the credit access is, the more landlords will become unconstrained in making attached capital investments before the treatment.

Note that at any levels of credit access every landlord will always invest attached capital in the rented-out land before the treatment because there is no depreciation rate gap, although they will always make more attached capital investments in the self-cultivated land due to the protection cost rate gap. The level of credit access almost does not affect the overall investment gap either, indicated by the stable average intensity ratio of attached capital investments in the rented-out land to that in the self-cultivated land weighted by sizes of the rented-out land. Nevertheless, it does affect individual land rental supply, for instance at the extensive margin as shown below by the variant threshold of renting out land in Panel B of Figure 4.

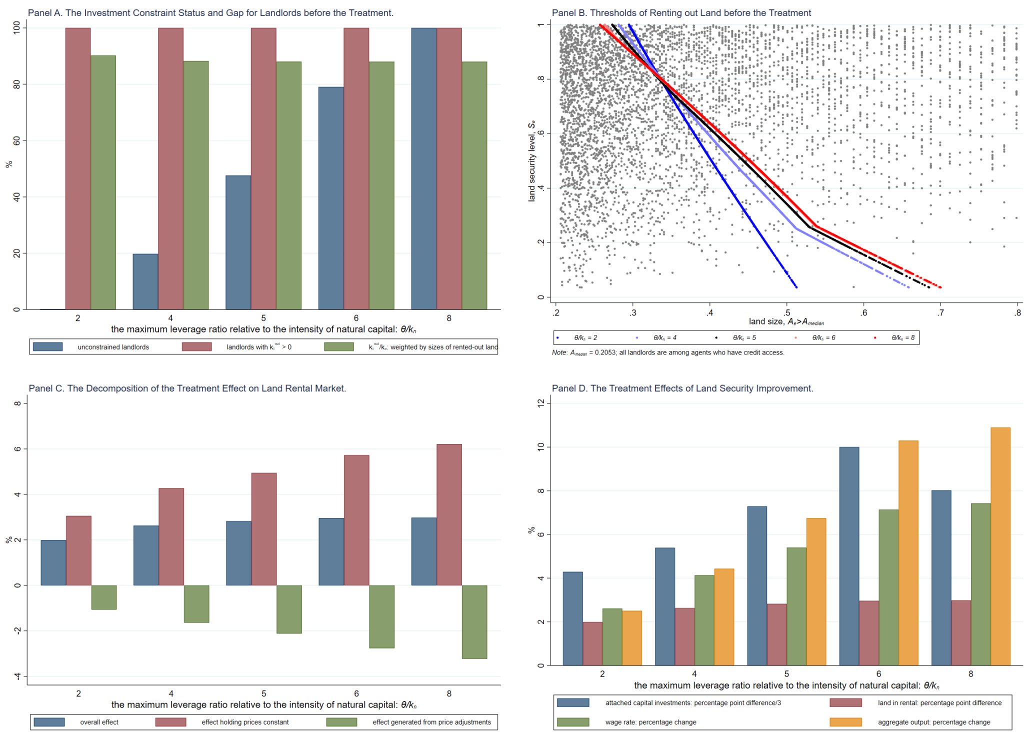

Figure 4: The Role of Credit Access in the Treatment Effects.

Note: Here, we have $d_t = d_o$ and $\tau = 1$ with other model parameters listed above in Table 3.

Before the treatment a higher level of credit access brings about a larger relaxation in the investment constraint facing landlords who demand high investment intensities at high land security levels. Hence, thresholds of renting out land at sufficiently high security levels, say close to 1 (almost no land ownership risk), decrease since more attached capital input requires more labor input and thereby the associated landed agents rent out land at smaller sizes of land endowment. However, this is less likely to be the case for other landed agents as they face less severe and even no investment constraint (e.g. at sufficiently low land security levels). In fact, most of them rent out land at larger sizes of land endowment since a higher level of credit access additionally raises wage rate through the complementarity between attached capital and labor inputs and thus lowers land rental rate schedule. As a result, thresholds of renting out land become flatter for landed agents as a whole.

Note that the thresholds of renting out land above are all downward-sloping in land security level, which is in line with the comparative statics above in subsection 2.3 that higher land security tends to favor renting out land when the investment gap between the self-cultivated and rented-out land is small (a large k_t^{out}). Together with these thresholds being flatter, it implies that more land will be rented out after land security improvements for a higher level of credit access, holding prices constant. However, a higher level of credit access will bring a larger increase in wage rate after the treatment and thereby a larger decrease in the land rental rate schedule, which will lead to a larger reduction of land rental supply holding other things constant. As shown above in Panel C of Figure 4, the net treatment effect is that land rental market expands more for a higher level of credit access.

After the treatment attached capital investments also increase more for a higher level of credit access until landed agents who have credit access are all investment-unconstrained in prior. Investing more land-attached capital and renting out more land after the treatment lead to a higher wage rate in the competitive equilibrium as they raise the labor demand and the efficiency of labor input, respectively. So do they for the aggregate agricultural output as shown above in Panel D of Figure 4. In the following, I compare the treatment effects in scenarios where we have either $d_t > d_o$ or $0 < \tau < 1$ with the treatment effects above to investigate how depreciation and protection cost rate gaps affect economic impacts of land security improvements.

B. The Role of the Depreciation Rate Gap

As shown above by the comparative statics in Table 2, there is no clear pattern about how the depreciation rate gap affects the land rental supply from investment-constrained landlords at the intensive margin. To get around this uncertain effect, I focus on the scenarios where landlords are all investment-unconstrained before and after the treatment, i.e. $\theta = 8, \tau = 1$. Intuitively, a larger depreciation rate gap will lead to a larger investment gap between the self-cultivated and rented-out land and even no attached capital investment in the rented-out land. As shown below in Panel A of Figure 5, this is exactly the case for landlords before the treatment.

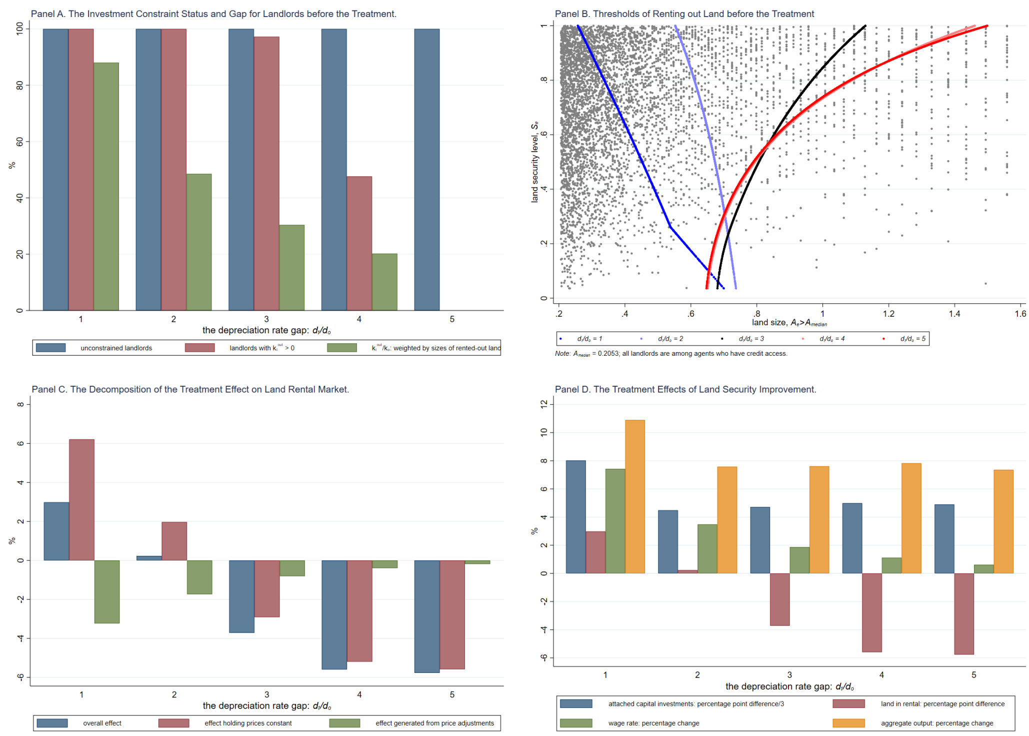

Figure 5: The Role of the Depreciation Rate Gap in the Treatment Effects.

Note: Here, we have $\theta = 8$ and $\tau = 1$ with other model parameters listed above in Table 3. See Figure A.2 below in the Appendix for the treatment effects under alternative values of θ.

The comparative statics for individual land rental supply in subsection 2.3 indicate that a larger investment gap means a lower intensity of attached capital invested in the rented-out land k_t^{out} and hence higher land security will be less likely to favor renting out land. In fact, as shown above by the thresholds of renting out land in Panel B of Figure 5, it will even favor self-cultivating the endowed land at any land security levels for sufficiently large depreciation rate gaps. Holding prices constant, land rental market will then change from expansion to shrinkage after the treatment as the depreciation rate gap increases.

On the other hand, wage rate will still increase thanks to the increased labor demand resulting from the increased attached capital investments after the treatment, although its increment will be smaller for a larger depreciation rate gap as a smaller expansion or shrinkage of land rental market brings about a smaller efficiency gain or efficiency loss in labor input. As before, land rental rate schedule will decrease after the treatment, dampening incentives of renting out land. The net effect on the size of land rental market will then turn to be negative when the depreciation rate gap is large enough, as shown above in Panel C of Figure 5.

Interestingly, a larger depreciation rate gap, will attenuate the positive treatment effect on attached capital investments only when the depreciation rate gap is relatively small as shown above in Panel D of Figure 5. This is due to the fact that the intensity of attached capital investments in the self-cultivated land is always higher than that in the rented-out land. Admittedly, a larger depreciation rate gap will lead to a smaller increase in attached capital investments after the treatment, holding land rental statuses unchanged. But more and more land will switch from being rented-out to being self-cultivated after land security improvements for a larger and larger depreciation rate gap when the depreciation rate gap surpasses some certain level. It will then result in an increase in attached capital investments, offsetting the aforementioned decrease. This also explains why the aggregate agricultural output follows a similar pattern.

Finally, as shown below by Figure A.2 in the Appendix, only the patterns of the treatment effects on attached capital investments and the aggregate agricultural output above change at low levels of credit access. Specifically, these two outcomes of interest will instead witness larger increases after the treatment as the depreciation rate gap increases from a low basis. Note that at low levels of credit access most landlords will be investment-constrained even after the treatment and thereby they cannot fully materialize the enhanced investment incentives, i.e. they would increase more attached capital investments if they did not face the investment constraint after the treatment. As the depreciation rate gap increases, however, more of them will become investment-unconstrained after the treatment, although the marginal cost of attached capital input on the rented-out land increases at the same time. The gain from the treatment on attached capital investments will then firstly increase and then decrease as the depreciation rate gap increases. So will the gain from the treatment on the aggregate agricultural output.

C. The Role of the Protection Cost Rate Gap

First of all, let us focus on the scenarios where landlords are all investment-unconstrained before and after the treatment, i.e. $\theta = 8, d_t = d_o$. To investigate how the structure of the protection cost rate gap affects the treatment effects of land security improvements, I vary the parameter τ in the protection cost rate gap $c(1 - S_e^{\tau})$ that differs from the protection cost rate for the self-cultivated land $c(1 - S_e)$ provided $\tau \neq 1$. Recall that higher land security tends to significantly enhance incentives of renting out land but not incentives of making land-attached capital investments unless the improved land security is sufficiently high, according to the empirical findings about the effects of land security on land rental supply and attached capital investments in Nicaragua (Deininger et al., 2003; Deininger and Chamorro, 2004). Therefore, I only consider alternative scenarios where the marginal reduction of the protection cost rate added by renting out land is larger than that for the self-cultivated land at low land security levels, namely $0 < \tau < 1$.

As shown below in Panel A of Figure 6, all landlords invest attached capital in the rented-out land before the treatment as there is no depreciation rate gap. As expected, the investment gap between the self-cultivated and rented-out land is small. Moreover, it decreases as the parameter τ decreases. Note that the smaller τ is, the smaller the protection cost rate gap will be at high land security. Then, landlords will invest more attached capital in the rented-out land before the treatment as they enjoy high land security in prior.

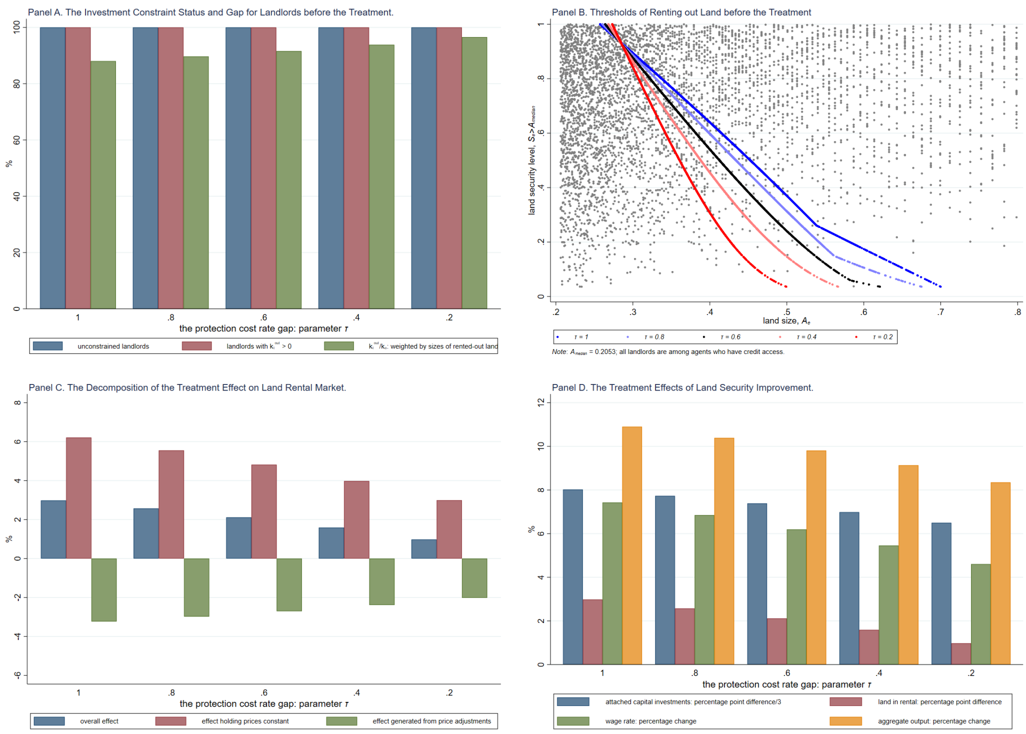

Figure 6: The Role of the Protection Cost Rate Gap in the Treatment Effects.

Note: Here, we have $\theta = 8$ and $d_t = d_0$ with other model parameters listed above in Table 3. See Figure A.3 below in the Appendix for the treatment effects under alternative values of θ.

The treatment effects, however, will evolve in the opposite direction. For instance, land rental market will witness a smaller expansion after the treatment along with the decrease in the parameter τ, as shown above in Panel D of Figure 6. The reason is that at a smaller τ more landed agents will become less responsive to land security improvements in terms of land rental supply as most of the involved landed agents enjoy relatively high land security before the treatment. This is reflected by the inward rotations of thresholds of renting out land as shown above in Panel B of Figure 6.[30] As

[30] Before the treatment differences in wage rate are relatively small for different τ's, although wage rate is higher for a smaller τ thanks to the smaller investment gap between the self-cultivated and rented-out land. Hence, before the treatment the threshold of renting out land almost remains unchanged at the

before, the pattern of the net treatment effect of land security improvements on land rental market is driven by the effect holding prices constant, as shown above in Panel C of Figure 6.

Likewise, the attached capital investments in the rented-out land will also become less responsive to land security improvements for a smaller value of the parameter τ. The smaller positive treatment effects on resource allocation above induce smaller increases in wage rate and the aggregate agricultural output as shown above in Panel D of Figure 6. Furthermore, Figure A.3 in the Appendix shows that the patterns of all the treatment effects described above remain the same at different levels of credit access.

5 Discussions

In the previous section, I have shown that the capital depreciation rate gap between the rented-out and self-cultivated land has undesirable impacts on the treatment effects of improving land security. In principle, we can remove the depreciation rate gap by encouraging and enforcing long-term rental contracts, e.g. eliminating legal restrictions on rental contract durations or protecting benefits of landlords and/or tenants in long-term rental contracts, although we cannot modify the structure of the protection cost rate gap to enlarge the potential of improving land security to boost agricultural productivity and reduce rural poverty. This could be particularly relevant in Latin America and the Caribbean where many countries have put legal restrictions on the length of land rental contracts in history (Díaz et al., 2002).

Figure A.4 below in the Appendix shows that removing the depreciation rate gap can bring us sizable extra gains from land security improvements. Notably, most of these gains are larger than the treatment effects of improving land security alone presented in section 4, especially on land in rental and wage rate. These numerical results suggest that policymakers need to eliminate barriers to long-term land rental contracts together with improving land security to achieve the great potential of reducing rural poverty by facilitating land access for the poor through land rental market.

highest land security level for different τ's as shown above in Panel B of Figure 6.

Now, let us revisit the "puzzling" empirical findings in Nicaragua: land titling and registration in the 1990s increased land-attached investments sizably while land rental market only expanded mildly (Deininger and Chamorro, 2004; Boucher et al., 2005).[31] Can the depreciation rate gap or the specific structure of the protection cost rate gap explain this phenomenon somehow? The answer is yes. For instance, the Panel A of Figure A.5 in the Appendix shows that the depreciation rate gap can substantially enlarge the gap between the treatment effect on the size of land rental market and the treatment effect on the size of attached capital investments, measured by their ratio, even when the level of credit access, measured by the maximum leverage ratio, is relatively low. Such ratio also decreases when the protection cost rate gap between the rented-out land and self-cultivated land has the specific structure under which at margin higher land security favors renting out land more at lower land security, as shown below in Panel B of Figure A.5 in the Appendix.

Admittedly, the ratio above is pretty small, about 10%-15%, even without the presence of the depreciation rate gap or the undesirable structure of the protection cost rate gap. So it might be just the case that the treatment effect of improving land security on attached capital investments tends to be substantially larger than the treatment effect on the size of land rental market for an unequal agrarian economy anyway. Nevertheless, there has been some legal restriction on rental contract durations in Nicaragua, i.e. land rental contracts cannot be longer than 10 years (Díaz et al., 2002). Also, the protection cost rate gap seems to exhibit the pattern that at margin higher land security favors renting out land more at lower land security in Nicaragua given that having a land title significantly increases the probability of renting out land but not the probability of making land-attached investments unless the land title is also registered (Deininger et al., 2003; Deininger and Chamorro, 2004).

[31] Nicaraguan households whose land was titled and/or registered in the 1990s on average increased land-attached investments by 4600C$ that is more than 50% of the average land-attached investments 8800 C$ (Deininger and Chamorro, 2004). However, the proportion of land in rental only increased from 2% to 5% while land security improvements almost covered the whole spectrum of the landownership distribution (Boucher et al., 2005).

6 Conclusion

This paper examines the economic impacts of improving the security of land property rights within the agriculture sector through the lens of land rental market, concerning that investment incentives (and credit access) may counteract rental incentives in terms of land rental supply as both landlords and tenants prefer to make attached investments in the owner-cultivated land (Bandiera, 2007; Jacoby and Mansuri, 2008). Based on two seminal works on the agency cost of hired labor (Eswaran and Kotwal, 1986; Frisvold, 1994)—the essential efficiency argument for pro-smallholder land policies, I firstly build up a noval land rental model that additionally incorporates investment and rental incentives and credit access associated with land security. The model captures barriers to long-term rental contracts (other than land insecurity) by the capital depreciation rate gap between the rented-out and self-cultivated land that enlarges their difference in the marginal cost of attached capital input.

As shown above by the comparative statics about individual land rental supply, the depreciation rate gap incentivizes landowners to invest more attached capital in the land to be self-cultivated relative to the land to be rented out in response to higher land security because of the diminishing marginal return of attached capital input. This investment bias towards the self-cultivated land causes the counteraction between investment incentives (and credit access) and rental incentives as landowners for whom self-cultivating all the endowed land will raise the marginal cost of the effective labor input above wage rate will face a trade-off between self-cultivating land to make more profitable attached capital investments and renting out land to reduce the efficiency loss in labor input after land security improvements. The larger the depreciation rate gap is, the severer their counteraction will be and landowners will then be less likely to rent out (more) land as land security improves. They may even self-cultivate more land in response to higher land security when the depreciation rate gap is sufficiently large.

The numerical results from multi-agent simulations in various scenarios demonstrate that the counteraction above can largely attenuate the potential economic gains from land security improvements for an unequal agrarian economy like Nicaragua, especially on land in rental and wage rate, although increases in attached capital investments and the aggregate agricultural output might still be sizable. In fact, land rental market may even witness a shrinkage when the depreciation rate gap is sufficiently large, which can substantially reduce the size of the gain on wage rate. Thus, policymakers will need to eliminate barriers to long-term land rental contracts together with improving land security to achieve the maximum potential of reducing rural poverty by facilitating land access for the poor through land rental market when the context considered, for instance Latin America and the Caribbean where the land ownership distribution is quite unequal and rural poverty is severe, have notable restrictions on the length of land rental contracts in place (Díaz et al., 2002).

Policymakers may also need to recognize that the size of the potential of improving land security to reduce rural poverty depends on the structure of the protection cost rate gap between the rented-out and self-cultivated land. For instance, this paper shows that the gain on wage rate from land security improvements for an unequal agrarian economy may be limited even without barriers to long-term land rental contracts, when at margin higher land security favors renting out land more at lower land security. The reason is that most landowners who are current and potential landlords may enjoy relatively high land security in prior so that land security improvements only mildly enhance rental incentives for them given this specific structure of the protection cost rate gap. This also helps explain the "puzzling" empirical findings that Nicaragua witnessed a large increase in land-attached investments but a small expansion of land rental market after salient land titling and registration in the 1990s (Deininger et al., 2003; Deininger and Chamorro, 2004; Boucher et al., 2005), in addition to the capital depreciation rate gap between the rented-out and self-cultivated land.

Admittedly, the land rental model in this paper does not incorporate several relevant features of the modern agriculture. For instance, machine, a salient agricultural input even in developing countries that often substitutes labor and favors large farms due to economies of scale (e.g. Sheng et al., 2019; Foster and Rosenzweig, 2022), is completely missing in the current model. Importantly, it may induce a U-shape relationship between the return of land and land size and thus change the set of landowners who will rent out land, e.g. landlords will be only among landowners endowed with medium-to-large sizes of land but not those who have sufficiently large sizes of land endowment. Then, land security improvements may bring about limited gains on the size of land rental market and wage rate as the donor pool of landowners who may rent out (more) land in response to higher land security is small.

Adding the input of mechines, however, will not alter the nature of the counteraction between investment incentives (and credit access) and rental incentives. The reason is that land security improvements will still incentivize landowners to make more attached capital investments in the land to be self-cultivated relative to the land to be rented out provided the depreciation rate gap, although it may induce landowners who are previously investment-constrained to change the portfolio of land-attached capital and movable capital like mechine (Carter and Olinto, 2003). Similar arguments apply to the modern value chain in which larger farms face higher output prices (e.g. Henderson and Isaac, 2017).

Last but not least, I do not consider other channels through which land security improvements affect the agriculture sector. One important channel is the sectoral occupation choice studied in recent literature (e.g. Lagakos and Waugh, 2013; De Janvry et al., 2015; Chen, 2017 Gottlieb and Grobovšek, 2019). Specifically, after land security improvements, landowners who have the comparative advantage doing non-agricultural work may opt out of farming in the agriculture sector by renting out land without fear of losing it and switch to jobs in the non-agriculture sector to earn higher income. The associated adjustments in sectoral outputs will then change the price of agricultural goods relative to non-agricultural goods given non-homothetic preferences. Ultimately, the economic impacts of improving land security will largely depend on the distribution of sectoral skills and its correlation with the size and security distributions of land endowment, which I leave for future research.

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Appendix

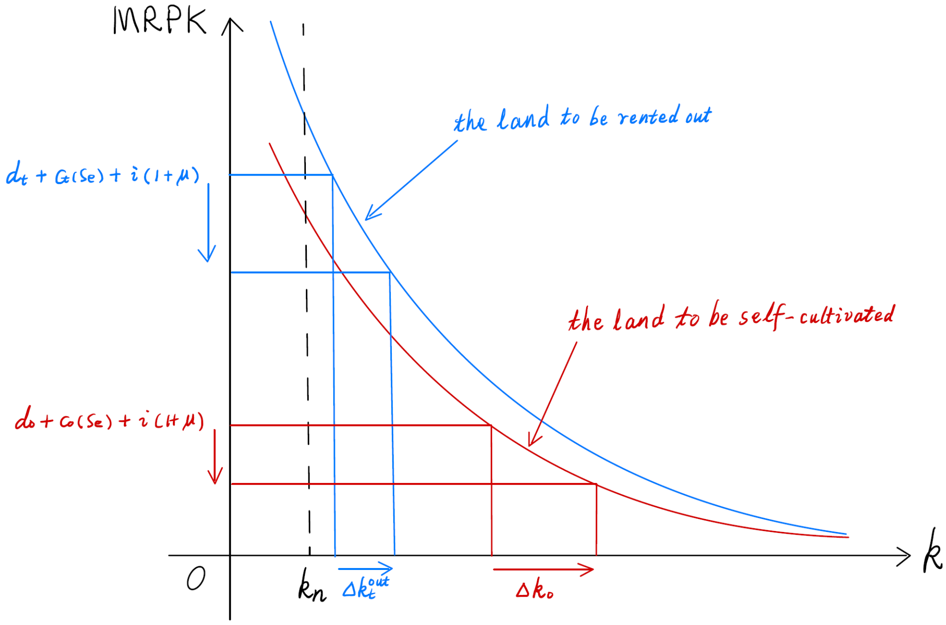

Figure A.1. The Marginal Return of Attached Capital Input.

Note: The per-period marginal return of attached capital input, denoted by $MRPK$, is higher for the land to be rented out relative to the land to be self-cultivated at any given intensity k since the intensity of the labor input in the former is generally higher than that in the latter and labor input strictly complements attached capital input in the production. At the same time, the per-period marginal cost of attached capital input in the former, namely $d_t + c_t(S_e) + i(1+\mu)$, is generally higher than that in the latter, namely $d_o + c_((S_e) + i(1+\mu)$, due to the protection cost rate gap and/or the depreciation rate gap, although they share the same shadow price of the accessible credit $i(1+\mu)$ where μ will change from zero to be positive if the landowner faces the investment constraint. A landlord will invest in the land to be rented out unless its per-period marginal cost of attached capital input $d_t + c_t(S_e) + i(1+\mu)$ is sufficiently high such that its optimal intensity of attached capital input is below or equal to the intensity of natural capital attached to the land k_n.

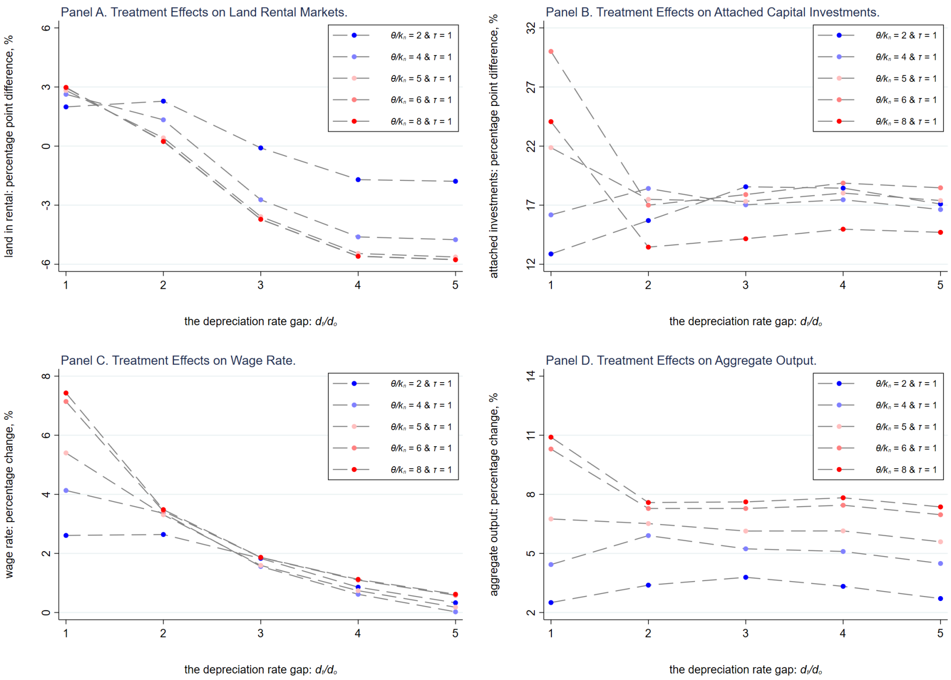

Figure A.2. The Role of the Depreciation Rate Gap in the Treatment Effects (Comprehensive).

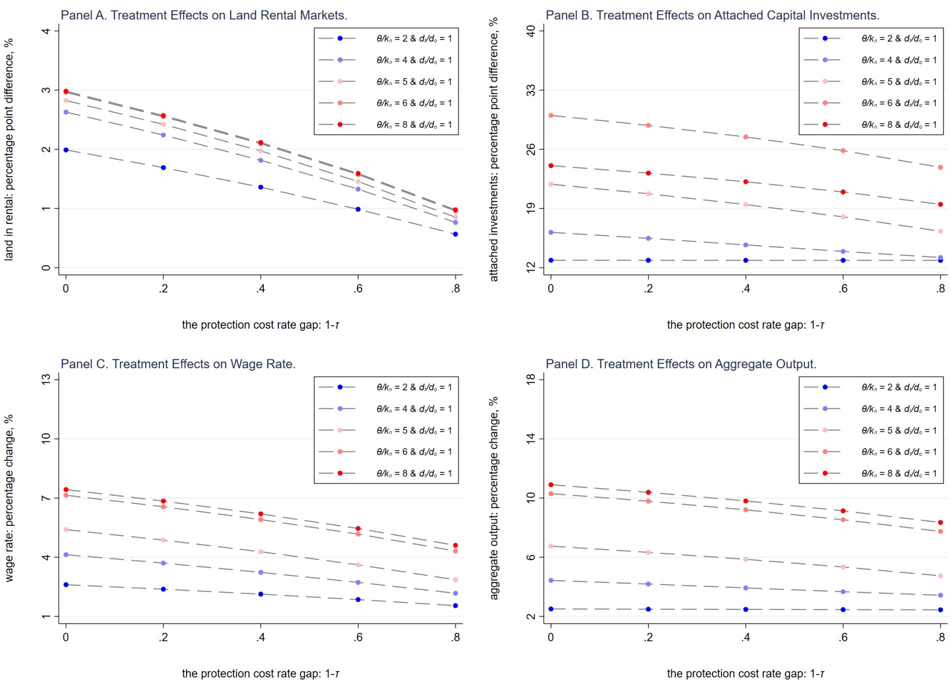

Figure A.3. The Role of the Protection Cost Rate Gap in the Treatment Effects (Comprehensive).

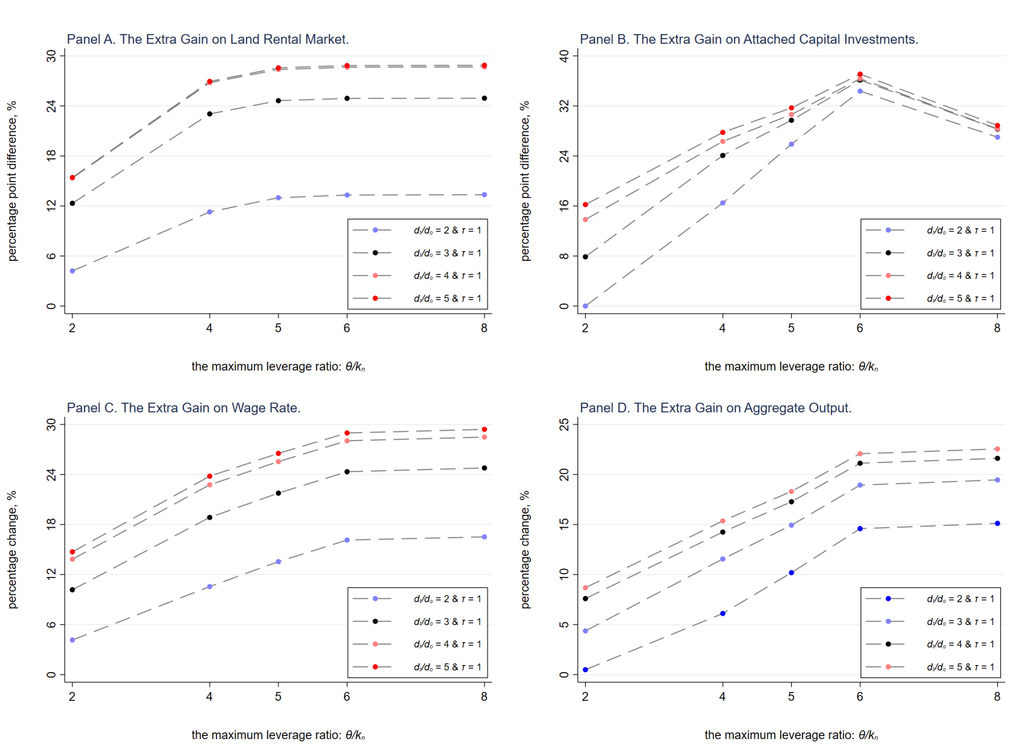

Figure A.4. The Extra Gain from Removing the Depreciation Rate Gap.

Note: The extra gain for each outcome of interest above is defined as the difference between the treatment effect of removing the depreciation rate gap together with improving land security and the treatment effect of improving land security alone. Thus, their values are directly comparable to the latter treatment effects in subsection 4.2.

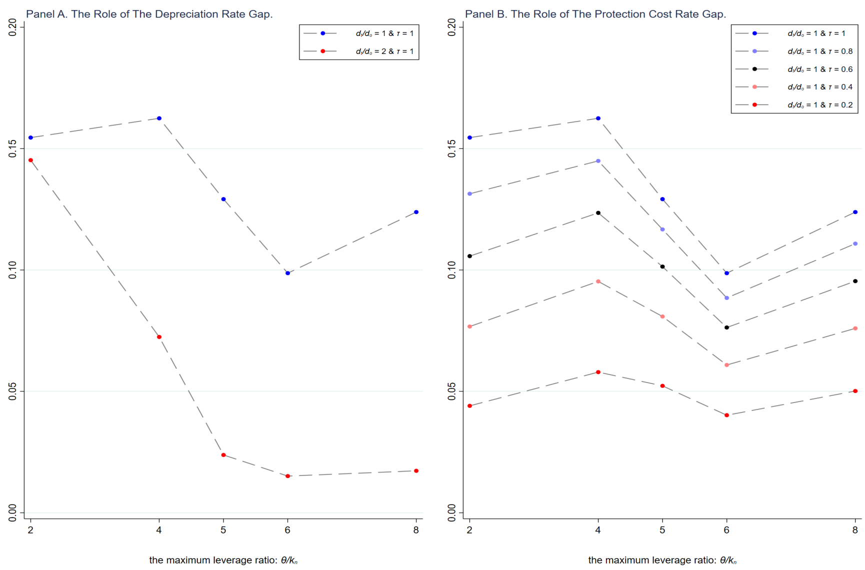

Figure A.5. The Treatment Effect on Land in Rental Relative to Attached Capital Investments.

Note: To make the ratios above meaningful, I only consider scenarios where the treatment effects of land security improvements on land in rental and attached capital investments are both positive.