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Do property rights promote investment but cause deforestation? Quasi-experimental evidence from Nicaragua

Zachary D. Liscow

Yale Law School, 127 Wall St., New Haven, CT 06511, USA

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ABSTRACT

Many policymakers argue that property rights decrease deforestation. Some theoretical papers also make this prediction, arguing that property rights decrease discount rates applied to a long-term investment in forestry. However, the effect is theoretically ambiguous. The paper takes a novel instrumental variables approach based on Nicaragua's agrarian reform to test for the effect, using a new dataset—Nicaragua's 2001 agricultural census. It finds that property rights significantly *increase* deforestation. The model, supported by the data, suggests a likely mechanism for this relationship: property rights increase investment, increasing agricultural productivity and therefore the returns to deforestation.

1. Introduction

As property rights have spread, promoted by organizations like the World Bank, it has become increasingly important to understand the consequences of improved property rights (see e.g., [14]). It is widely argued in the economic literature that property rights and the institutions that undergird them are essential for creating the incentives necessary for economic growth [1,51].[1] Many economists argue that property titling is one of the most effective ways to improve the lives of the poor, who often lack property rights [8,17,53].[2]

One important area on which property rights may have an impact is on tropical deforestation, which is spreading rapidly and is viewed by scientists as one of the world's greatest environmental problems [22,57].[3] For example, Nicaragua, the subject of this study, lost half of its forest cover between 1983 and 2000 [5], as shown in Fig. 1.

Deforestation confers largely private benefits, while reducing the positive externalities that forests provide to society. Because of this asymmetry between private and social benefits, rational individuals will deforest, despite the social harm. Additionally, the global nature of many of the social benefits reduces incentives for national governments to legislate to unify social with private good

In particular, deforestation is problematic for several reasons. One global external cost is its contribution to climate change, with estimates that approximately one fifth of current anthropocentric carbon dioxide emissions are thought to come from land transformation [34,44]. The recent interest in Reducing Emissions from Deforestation and Forest Degradation (REDD) reflects this concern. Deforestation also contributes to species extinction, which is especially important in Nicaragua, given its designation as a "biodiversity hotspot" with high rates of endemism and habitat loss

E-mail address: zachary.liscow@yale.edu

[1] See also Deininger and Chamorro [23], Field [33], and Hornbeck [41] for recent empirical studies on the effects of property rights.

[2] However, see Besley and Ghatak [14] for a balanced view of the issue and Besley and Ghatak [15], which shows that the benefits of titling may be over-stated. See also Jacoby et al. [42], which argues that reducing expropriation risk can have large effects on investment but little effect on welfare.

[3] For a review of literature on the causes of deforestation, see Barbier and Burgess [10]. The growth in deforestation has been linked with growth in income, population, and road building, as well as changes in agricultural returns, logging returns, and institutional factors (e.g., [52]).

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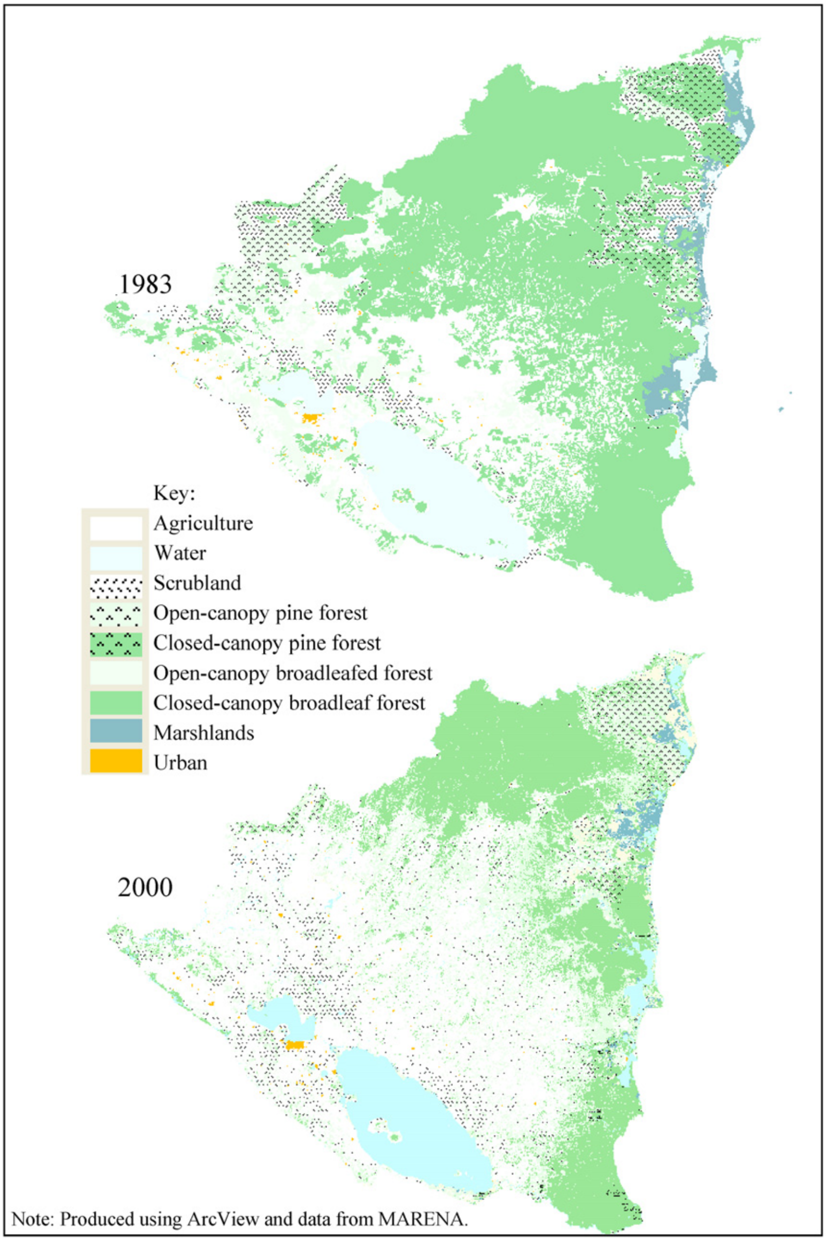


Fig. 1. Land Use in Nicaragua in 1983 and 2000.

[50]. Deforestation also has local externalities, removing protection for watersheds; reducing neighbors' soil fertility; harming air quality through fires; harming fisheries through increased runoff; and thereby exacerbating droughts, floods, and landslides by reducing land's absorptive capacity [57]. For example, many believe that deforestation was an important contributor to the flooding and landslides from Hurricane Mitch in 1998.

The impact of property rights on deforestation is unclear because property rights could affect forest cover in two different ways with opposite implications. First, as much of the environmental economics theory and cross-country analysis concludes, property rights could lead landholders[4] to discount the future less and reap the long-term benefits of forestry instead of the short-term benefits of agriculture [11,18,47]. Thus, since the returns to forestry are further in the

[4] Throughout this paper, I will use the term "landholder" to refer to an agent in possession of a piece of land, but not necessarily "owning" in the sense of having a title.

future than those of agriculture, titling will increase the value of forest relative to agriculture and will *increase forest cover*. For the sake of clarity I term this view, also held by many in policy circles,[5] the "conservation effect."

On the other hand, I build on the work of Farzin [31] to develop a model which includes another possibility: more secure property rights increase investment in land, increasing the value of agriculture relative to that of forest. This theory predicts that property rights may *decrease forest cover*. A few regional-level or small individual-level case studies in the development literature have found this result [4,37,60]. The theory developed here suggests that, since income from forestry is essentially unaffected by investment and agriculture becomes substantially more valuable through intensification, titling may increase the returns to deforestation and therefore decrease forest cover. Investment increases for two reasons: (1) landholders can use their land as collateral for credit, allowing investment, and (2) landholders have a greater ability to recoup future returns, encouraging investment. That is, since maximizing profits—not minimizing costs for a fixed output—is the landholders' goal, investments that increase yield could raise production area. For the sake of clarity, I term this the "investment effect."

This question is part of the broader forest transitions literature on the evolution of forest stocks as countries develop [12,46]. Does titling, which spurs investment and economic development, harm or help forest cover? For deforestation, how reconcilable are development and environmental quality?

On the question of the effect of property rights on deforestation, this paper makes several innovations to the existing cross-country evidence [16,18] and small correlational studies [37,60].[6] Existing empirical studies suffer from the risk that omitted variables at the country level (e.g., political or regulatory factors) or individual level (e.g., education) drive both property rights and forest cover or that forest cover itself drives the demand for property rights by affecting one's ability to lay claim to land. Improving upon the existing literature, this study introduces a new individual-level dataset, the entire 2001 Agricultural Census, which has rich data on land use. Its size—three orders of magnitude larger than previous datasets—allows precise estimates. Its coverage of the entire country makes it more representative; in particular, it includes non-frontier regions that are rarely included in deforestation studies but contain a substantial amount of the country's forest. Second, unlike previous work (e.g., [37]), this study has direct measures of tenure status, rather than constructed proxies; it is a study of formal tenure, not a mix of informal and formal tenure.[7]

Most importantly, to address the problem of tenancy security's endogeneity, the study's instrumental variables approaches take advantage of the natural policy experiment which took place in Nicaragua in the 1980s.[8] I use two specific policies implemented during Nicaragua's agrarian reform: (1) an arbitrary division between areas in which expropriation was differentially difficult and (2) a policy of increasing redistribution in areas with large amounts of war to maintain the loyalties of the people in those regions. Those regions with larger amounts of redistribution have a legacy of insecurity today.

Using the same methodologies described above, I also add new evidence to the literature on the effect of property rights on agricultural investment decisions (e.g., [13]). These effects suggest the mechanism controlling the relationship between forest cover and property rights and are also independently interesting. Like Goldstein and Udry [38] and others, I find that property rights have a large effect on agricultural investment, for both fallowing and other dimensions.

This study finds that tenancy insecurity substantially increases forest cover. Specifically, the results suggest that titling decreases the fraction of a landholding as forest by 14 percentage points. I also find that the owners of titled land receive more credit, use more fertilizer, and practice more resource-intensive forms of agriculture, suggesting that property rights increase the returns to deforestation, encouraging landholders to reduce the forest cover on their land.

2. Property rights in Nicaragua

Following decades of land concentration among the wealthy, the leftist Sandinista insurgency triumphed over the Somoza dynasty in 1979 and implemented a land expropriation and redistribution program. As detailed in Table 1, over the ensuing decade while they were in power, the Sandinistas confiscated much of the country's agricultural land. In particular, they expropriated the Somozas' holdings—amount to approximately 20 percent of the country's agricultural land—and landholdings over a minimum size that the Sandinistas considered abandoned, underused, or mismanaged. The Sandinistas also purchased some land. The Sandinistas then distributed land to multi-family and extended-family cooperatives, individuals, and indigenous communities.

The agrarian reform expropriated land from wealthy individuals and redistributed it to the landless poor. The Sandinistas ostensibly had two sometimes contradictory goals with the redistribution: promoting equality and production [21]. The first was consistent with their goal of maintaining their base of support among the poor and the second was consistent with their larger goal of promoting economic development and maintaining the creation of foreign exchange using the country's dominant sector, agriculture. To achieve these goals with the redistribution, the government conducted

[5] For example, Brazil's environment minister in 2009 said, "Land regularization is of fundamental importance for halting deforestation" [29].

[6] Bandiera [9] studies planted trees, which are discussed at the end of this paper as having a different incentive structure from primary or secondary forest due to the larger investment involved.

[7] Depending on the setting, either formal or informal tenure could be more important. Isolating one type of tenure makes the policy relevance of the results clearer.

[8] Both Miceli et al. [49] and Alston et al. [2] document the endogeneity of titling.

Table 1
Summary of land redistributed in 1980s.

Means of acquisition	No. of properties	Area (1000 acres)
1979—Decrees 3, 38, 329: Confiscating land of Somoza and associates	2000	2422
1981—Agrarian Reform Law (Decree 782): Confiscate underused or poorly-managed land	1200	1419
1981—Decree 760: Confiscate abandoned land	252	32
1980s—Purchases by Sandinista Government	1050	339
1980s—De facto occupations	510	519
1980s—Other means	860	154
	5968	5317

Note: Due to poor record-keeping, many of these numbers are estimates. Adapted from Stanfield [54].

substantial research efforts on the productivity of various types of land, seeking to distribute land of equivalent value to the peasants, while maintaining high agricultural productivity.

Nearly all of the land that the Sandinistas redistributed, either implicitly through permitting land occupations or explicitly after expropriation or purchase, was either given a provisional title or no title at all; this led to the insecure tenancy which persisted at the time of this study. The state simply lacked the resources to administer such a massive program, especially after the Contra War started mid-decade. For example, about 3750 properties, or 70 percent of the total procured from private owners by the Sandinistas, were never legalized as holdings of the state; title was never officially awarded [54]. If title was issued, it was usually issued provisionally because the state did not have legal possession of the land. Even if provisional title was awarded, most of the provisional titles still could not easily be recorded in public registers, since the boundaries and areas of the properties were often not described with sufficient precision, given the hasty nature of the redistribution. Of properties investigated in a 1993 study, 78 percent remained under the name of the former owners [48]. Finally, even if provisional title was awarded *and registered*, it could still be challenged by previous owners in courts set up after 1990, when the Sandinistas were voted out of power. These challengers included the former owners of the 1600 properties which were purchased by the Sandinistas, claiming that they were purchased under duress. Thus, the combination of challenges, lack of recording in the public registers, and simply untitled land led to a high degree of tenure insecurity on this land.

As a result of all these conflicts, by 1995 roughly 40 percent of the country's households found themselves in conflict or potential conflict over land tenure [54]. With the large number of expropriations and redistributions, in 2001, when the data used here were collected, Nicaragua's small judicial system was still sorting through the problems created by the agrarian reform for those seeking secure tenure. Many others were deterred from obtaining tenure because of the often high costs involved, including multiple visits to Managua, lawyer's fees, and time in court, without guarantee of success.[9] Even though the government, with the aid of NGOs and United Nations organizations, had been haphazardly establishing titling programs across the country, insecure tenure resulting from the Sandinistas' land redistribution remained a large problem in Nicaragua at the time of the study.[10]

3. Theory

In this section, I present a model that shows that the effect of tenancy insecurity on forest cover is ambiguous and can be disaggregated into two opposite effects, the conservation effect and the investment effect. The previous modeling work of Mendelsohn [47] and Barbier and Burgess [11] assume that, relative to agriculture, forest cover's returns are disproportionately in the future; their result is that that tenancy insecurity reduces forest cover. I include this assumption, but also include the effect of tenure security on agricultural investment and productivity, yielding ambiguous theoretical results. In doing so, I adapt the insights of the Farzin [31] model from his context—the relationship between the interest rate and the rate of exhaustion of an exhaustible resource before switching to a substitute—to this setting, of choosing the allocation between two land uses.

I assume a rational, profit-maximizing landholder with full information. He maximizes the net present value of his future stream of profits (P). Following Stavins and Jaffe [55], the landholder lives on a heterogeneous piece of land. The landholding is of fixed size. Following Zwane [61], potential purchasers of the land value it the same as the current landholder does, so decisions are unaffected by the possibility of selling the land in the future. Land is either agricultural or

[9] For example, I talked to some ranchers from the middle of the country who had made the trip three times to receive an uncontested title and still had not received it [32].

[10] Of the tens of thousands of households without a secure, uncontested title in 1995, only around 2500 were granted provisional titles by 1997 which were honored by subsequent governments [26]. By June 1999, approximately 10,000 rural properties were being reviewed under a 1997 arbitration law [27]. By July 2001, nearly 8500 were on appeal or pending resolution [28]. In addition, many did not even enter the judicial system.

forested; there is no urbanization pressure.[11] The fraction of land as agriculture is α (with $0 \le \alpha \le 1$), and the fraction of land as forest is $1-\alpha$.

There are two periods; one can think of each as corresponding to five years. The landholder allocates land between forest and agriculture at the beginning of period one; land allocation stays the same in both periods. The landholder discounts the second period because he faces some probability of eviction (ρ) from the government or other landholders.[12] The model could also have included an additional discount factor, but this leaves the results the same, so I exclude it.

The landholder begins with all agricultural land. This is a plausible assumption in this context, since 86 percent of all forest is secondary in the primary sample used here, suggesting that landholders have converted from forest to agriculture, reaping the benefits of timber removal and paying the costs of conversion to agriculture.

The profits from agriculture (A)—cropland, planted forest, and pastureland—are available in both periods. Profits from agriculture are a function of: (1) the effective units of agricultural land (Q), which can be thought of as the sum of a quality index rating due to geographical characteristics (but not investment) for each unit of area; and (2) investments (I) in inputs (like fertilizer) and infrastructure (like irrigation systems), given current market conditions. Agricultural profits are increasing in land quality $(\partial A/\partial Q) > 0$ and in investment $(\partial A/\partial I) > 0$. Effective units of agricultural land (Q) increases with more land devoted to agriculture (α), so that $(\partial Q/\partial \alpha) > 0$.

Investment (I) is a function of the probability of eviction, with $(\partial I/(\partial(1-\rho))) > 0$. This could function through four channels. First, many landholders are credit-constrained[13]; if landholders can demonstrate that they have secure tenure, they can use their land as collateral, which will allow more investment. Second, some investments have liquidity constraints or high transaction costs, especially on a short time scale. For example, if someone were to be removed from his landholding, the liquidity constraints on a barn or soil that he invested in protecting would be almost complete, while the transaction costs of quickly selling a tractor may also be high. Third, a landholder with a higher probability of eviction will choose to invest less because he devalues the future benefits that an investment will bring while valuing relatively higher the costs of the investment. Finally, a landholders with higher probability of eviction will spend time and money on defensive tactics, rather than more productive activities,[14] which will reduce investable surplus—often all that is available for investment to a small landholder in a poor country.

Profits from forest cover have three features. First, unlike agricultural land, forested land yields profits only in the second period. Note that this framework is robust to harvesting half of the forest at a time (to maintain windbreaks, for example).[15] The key point is that the landholder must wait for the returns.

Second, profits from forest cover are linear in $(1-\alpha)$, equaling a parameter $t > 0$ times the amount of land devoted to forest cover $(1-\alpha)$. In a given area, while agricultural productivity may be highly affected by local geographical conditions, forest productivity is less likely to be affected because forests create their own micro-environments, which make geographical conditions less important.

Third, profits from forest cover are not a function of investment. Although investments can be made in forests (e.g., costly but advertise-able ecofriendly forest management), these investments are substantially less important than those for agriculture. Perhaps the most important non-land input into forestry, labor with chainsaws for timber extraction, can easily be "rented" for a portion of the profits from the tree-cutting [7]. In contrast, agricultural land can be improved with investments like fertilizer, irrigation systems, and more intensive crops.

Fig. 2 summarizes the time line.

Thus, the landholder will optimize his land use choice according to the following equation:

$$\max_{\alpha} P = \max_{\alpha} A\big(Q(\alpha),\ I(1-\rho)\big) + (1-\rho)[A\big(Q(\alpha), I(1-\rho)\big) + (1-\alpha)t] \tag{1}$$

where all functions are twice continuously differentiable. Also, assume that an interior solution exists. This setup yields two propositions, both of which are applications of the Monotone Selection Theorem and have proofs in Appendix A.

Proposition 1. *The effect of property rights on forest cover, $\frac{\partial \alpha^*}{\partial(1-\rho)}$, is of ambiguous sign, since $\frac{\partial^2 A}{\partial Q \partial I}$, the degree of substitutability or complementarily between land quality and investment, is of unclear sign.*

Proposition 2. *If $\frac{\partial \alpha^*}{\partial(1-\rho)} > 0$, then $\frac{\partial^2 A}{\partial Q \partial I} > 0$. If improving property rights increases equilibrium agricultural cover, total land quality, Q, and investment, I, are complements.*[16]

[11] Nicaragua has little urban area relative to agricultural area, so this is a reasonable assumption.

[12] Note that ρ is taken as exogenous to α, which may not be the case if certain land uses decrease the likelihood of eviction.

[13] Credit constraints are especially prevalent in Nicaragua due to the history of bank failures in the country after the Sandinistas left power in 1990; some cities with as many as 30,000 people have no bank. Many still fear putting money in the bank, having lost much of their savings a decade earlier [39].

[14] For example, a landholder may spend time patrolling rather than planting crops. Likewise, conflict with others, which can sometimes turn violent, can also be a substantial cost. See Alston et al. [3].

[15] The forest may also provide non-timber resources (like palm leaves and fruits), but those are assumed to be small in the first period.

[16] Note that an analogous result is not possible for $\frac{\partial^2 \alpha^*}{\partial(1-\rho)} < 0$, since that would depend upon a sufficient, not a necessary, condition on the relationship between $\frac{\partial^2 A}{\partial Q \partial I}$ and $\frac{\partial^2 P}{\partial \alpha \partial(1-\rho)}$.

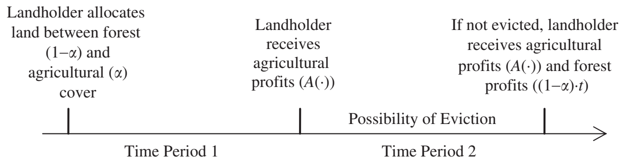


Fig. 2. Timing.

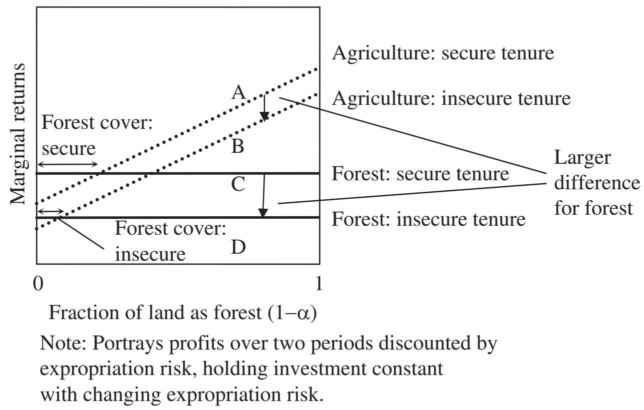


Fig. 3. Conservation effect.

To gain insight into these results, consider the following cross-partial derivative for how tenancy security affects the returns to having agriculture instead of forestry:

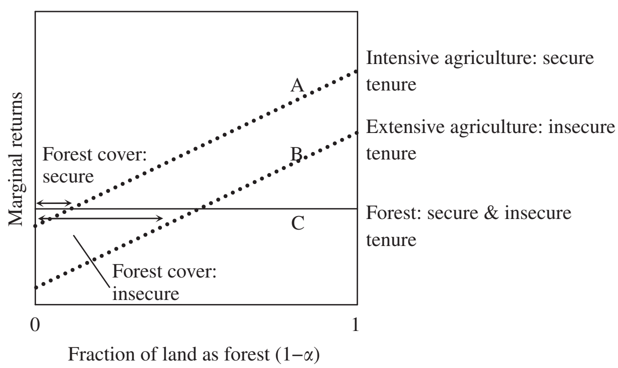
$$\frac{\partial^2 P}{\partial\alpha\partial(1-\rho)} = \underbrace{\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial \alpha} - t}_{(i)} + \underbrace{(2-\rho)\frac{\partial^2 A}{\partial Q \partial I}\frac{\partial Q}{\partial \alpha}\frac{\partial I}{\partial(1-\rho)}}_{(ii)} \tag{2}$$

The two terms in (2) have conflicting implications for the effect of tenancy insecurity on forest cover. First, a high probability of eviction will disproportionately devalue forestry because forests' returns are disproportionately in the future. Thus, high eviction rates will decrease forest cover. Adopting the language of Farzin [31], this is the "conservation effect," the view found in Mendelsohn [47] and Barbier and Burgess [11] and represented by term (*i*) in (2), $\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial \alpha} - t$. This term must be negative for interior solutions, since the per-period returns must be higher for forestry (t) than for agriculture $\left(\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial \alpha}\right)$. Thus, if $\frac{\partial I}{\partial(1-\rho)} = 0$, improving property rights must make increasing forest cover more valuable.

Fig. 3 presents the conservation effect, in which α^* is determined by the point at which the line for the marginal returns from forest cover crosses that for agricultural cover. Because forestry's returns are disproportionately in the future, higher effective discount rates disproportionately discount forest's value, with agriculture's value decreasing from line A to line B with greater insecurity, but forest cover's marginal value decreasing a larger amount from line C to line D. Thus, forest cover is more attractive in a secure-tenancy regime, demonstrated below by the larger amount of forest with higher marginal returns than agriculture (more of C over A than B over D) with secure tenancy than with insecure tenancy. This theory predicts that landholders with insecure tenure, or a high risk of expropriation, will have *less* forest.

However, a high probability of eviction will also *change the composition* of agriculture, discouraging investment, making agriculture less valuable relative to forestry, which is unaffected by investment. This is the "investment effect" (again adopting language similar to that of Farzin), term (*ii*) in (2). Since all terms are positive except for $\frac{\partial^2 A}{\partial Q \partial I}$, the sign of the investment effect depends upon this term. If $\frac{\partial^2 A}{\partial Q \partial I} < 0$, then the investment effect is negative, the same as the conservation effect. If $\frac{\partial^2 A}{\partial Q \partial I} > 0$, then the investment effect is positive, the opposite of the conservation effect.

Fig. 4 shows the investment effect when investment and land quality are complements $\left(\frac{\partial^2 A}{\partial Q \partial I} > 0\right)$. Unlike the conservation effect, which assumes that the type of agriculture stays the same regardless of tenancy security, this diagram looks precisely at this change in the composition of agricultural land. Because of the greater likelihood of capturing future benefits from investment in a secure-tenancy regime, landholders will invest more, increasing agricultural productivity by changing from more extensive to more intensive agriculture—increasing agricultural returns from line B to line A. Returns to forest, on the other hand, are not directly affected by investment and are the same in both high-risk and low-risk regimes, at line B. Thus, increases in agricultural productivity increase the returns to agriculture—and, therefore, deforestation. The investment effect predicts that landholders with insecure tenure, or a high risk of expropriation, will have *more* forest.



Note: Portrays term (i) of equation (2), profits over two periods discounted by expropriation risk, allowing investment to change with changing expropriation risk.

Fig. 4. Investment effect.

Past models of the effect of property rights on deforestation have ignored the effects of investment and found that property rights increase forest cover by reducing discounting. Because the effect of agricultural investment on forest cover can more than offset this effect, the direction of the sign remains an empirical question, to which we now turn.

4. Data

Outcome variables come from Nicaragua's 2001 Agricultural Census. The National Institute of Statistics and Censuses (INEC) and the Ministry of Agriculture and Forestry (MAG-FOR) conducted the census on the agricultural year from May 1, 2000 to April 30, 2001. All agricultural holdings in the country were surveyed, excluding kitchen-gardens in urban areas, resulting in 199,549 landholdings covering 6,254,514 ha. These landholdings—cooperatives, commercial enterprises, and individual landholdings—constitute a little over half (52 percent) of Nicaragua's land area. The dataset does not include timber concessions, national parks, or indigenous communities using slash-and-burn agriculture. The survey includes 75 percent of total land area for non-frontier areas and 40 percent for frontier areas. Importantly, landholdings are geocoded to the municipal level. Observations are constructed by combining parcels for the same landholder and removing cooperatives and communal enterprises.

Those census questions relevant to this study include: tenure, size of holding, education, investment in various farm technologies and agricultural inputs, and land use (forest cover, type of crop, type of grazing, etc.). Those labeled here as having no secure title have no title at all, are in the process of legalizing their title, or have a provisional agrarian reform title. The census also disaggregates forest cover by type: natural, secondary, and planted.

The census was a well-funded effort (with half of the funding provided by the European Union) conducted over a one-month period, in March 2001. Answers consisted of responses to in-person interviews. Enumerators were trained to use consistent definitions. Each enumerator was given detailed maps based on the 1995 Census of Population, with an area containing from 70 to 90 landholdings to cover. The enumerator talked to the "producer" who makes land use decisions and returned if he was not present, to ensure that someone intimately knowledgeable with the landholding answers the questions. If the respondent seemed hesitant, the enumerator was told to emphasize the confidentiality of the answers. After the interview, with the producer still present, the enumerators reviewed the answers to check for incorrect entries. Both the emphasis on confidentiality and the review should serve to reduce bias and measurement error. After the census was completed, INEC conducted a survey on a sample of farms to measure under- and over-counting and found these to be relatively small.[17]

This study also uses Geographical Information Systems (GIS) data associated with the Ministry of Environment and Natural Resource's 2004 "Atlas Forestal." The atlas provides high-resolution geographical data on elevation, slope, precipitation, soil texture, and average yearly temperature. It also provides socio-economic information on poverty levels in the year 2000 and road density in the mid-1990s. Finally, the atlas contains forest cover data resolved to 30 m^2 for 1983 and 2000, a useful check of the quality to the census forest cover data as well as measure of initial conditions.[18] This data was processed using Arc geographical software and divided into Nicaragua's municipalities; the data that appear in the

[17] See a description of the survey methodology at http://www.inide.gob.ni/cenagro/conceptosdefini.htm and the Census Manual at http://www.inide.gob.ni/cenagro/anexos/manualempadronamiento.pdf.

[18] Aggregating to the municipal level the total forest cover measure in this dataset and correlating it with LANDSAT satellite data yields a correlation of 0.80, suggesting that the data is of high quality. This correlation is especially high, given that the two measures are of different things—all land for the satellite data and only agricultural land for the census.

Table 2
Summary statistics.

	Obs	Mean	Standard deviation	Min	Max
Dependent variables					
Fraction total forest	18,969	0.035	0.101	0.000	1.000
Receipt of credit (1=yes, 0=no)	18,969	0.168	0.374	0.000	1.000
Use of fertilizer (1=yes, 0=no)	16,884	0.622	0.485	0.000	1.000
Ownership of tractor (1=yes, 0=no)	18,969	0.092	0.289	0.000	1.000
Ownership of warehouse (1=yes, 0=no)	18,969	0.054	0.227	0.000	1.000
Cropland/(cropland+pastureland)	18,502	0.544	0.376	0.000	1.000
Fraction cropland	18,969	0.372	0.320	0.000	1.000
Permanent cropland / total cropland	17,033	0.062	0.202	0.000	1.000
Fraction pastureland	18,969	0.338	0.324	0.000	1.000
Planted pastureland/total pastureland	12,544	0.282	0.406	0.000	1.000
Fraction fallow	18,969	0.168	0.251	0.000	1.000
Independent variable					
Fraction with title	18,969	0.614	0.476	0.000	1.000
Instrument					
Western side	18,969	0.496	0.500	0.000	1.000
Controls: individual-level					
Area (acres)	18,969	70.721	220.095	0.017	8650.000
Log area (acres)	18,969	3.130	1.473	−4.057	9.065
No education	18,969	0.450	0.497	0.000	1.000
Can read and write	18,969	0.055	0.229	0.000	1.000
Primary education	18,969	0.384	0.486	0.000	1.000
Secondary education	18,969	0.066	0.248	0.000	1.000
Post-secondary education	18,969	0.044	0.206	0.000	1.000
Controls: municipal-level					
Precipitation (m/year)	18,969	1.162	0.293	0.862	1.709
Elevation (km)	18,969	0.458	0.289	0.104	1.067
Temperature (°C)	18,969	24.080	1.402	21.250	26.167
Slope/100 (percent)	18,969	0.291	0.101	0.121	0.561
Fine sandy soil	18,969	0.561	0.270	0.118	0.981
Clay soil	18,969	0.019	0.067	0.000	0.264
Sandy soil	18,969	0.110	0.125	0.000	0.431
Heavy clay soil	18,969	0.228	0.188	0.000	0.515
High poverty	18,969	0.236	0.400	0.000	0.996
Distance from managua (deg.)	18,969	1.077	0.309	0.495	1.907
Rural population density (1000 persons/km^2 1995)	18,969	0.030	0.010	0.012	0.055
Urban population density (1000 persons/km 1995)	18,969	0.029	0.039	0.001	0.122
Road density (km road/km^2)	18,969	0.016	0.020	0.000	0.060
1983 forest cover	18,969	0.452	0.198	0.105	0.969

Notes: The sub-sample used is that for the main specifications in the paper, as explained in the methodology section. See sources in text.

regression are constructed by multiplying the proportion of a municipality's land covered by a particular value (like an annual rainfall of 1000 mm) by the value, and then adding these products together.

Finally, I also incorporate municipal-level data on rural and urban population density in 1995, as well as geographical coordinates, from INEC [43].

See Table 2 for summary statistics for the main sample used. The average landholding has only 3.5 percent forest cover. The measure of property rights, fraction of land with title, is continuous between 0 and 1 (though usually 0 or 1), since landholders can have multiple parcels with different types of tenure; the average landholding is 61 percent titled. The majority of landholders use fertilizers, but not credit, tractors, or warehouses. Close to half of landholders have no education, while 38 percent have a primary school education.

5. Methodology

There are two primary concerns with an OLS regression of land use choices on having a property title. First, there are several reasons that to expect omitted variables bias. Individual characteristics may be related to both title and forest cover. For example, an unmotivated individual may neither cut down trees nor attain title. Or an individual may be myopic, cutting down every tree since he cares none for the future, while not investing in a title. Additionally, unobserved micro-geographic variables may cause both less titling and less forest. For example land that is dry or on a hillside may not be desirable for farming, so a landholder may leave the trees. However, because of the land's lower value, he may not bother attaining a title.

Second and perhaps more importantly, forest cover and tenancy security may simultaneously cause each other. For example, at some points in Nicaragua's past, before the 1980s, the government granted title partly dependent upon demonstrating use of the land through clearing the forest. Thus, deforestation may increase the availability of secure tenure on the supply side. Alternatively, deforestation may increase the demand for titling on the demand side. Receiving tenure can be a costly process, especially in areas with conflicts over ownership. For example, it may require long trips to Managua, with the possibility of failure. Landholders with forest are more vulnerable to land invasions from neighbors since their land looks underutilized; recognizing that they lack the informal tenure security provided by agriculture, they may have a higher demand for a formal title [3].

To find a relevant instrument, I take advantage of Nicaragua's agrarian reform in the 1980s. The 1981 Agrarian Reform Law led to expropriations of 1.42 million acres of "underused or poorly-managed" land. The law limited expropriations to farms of over 865 acres on the Pacific coast, the traditional population center of the country where there were many landless peasants, and twice as large (1730 acres) in the rest of the country. This created a greater pool for expropriation and redistribution—and therefore more tenure insecurity—on the Pacific. As described above, those areas with larger amounts of land redistribution in the 1980s have a legacy of decreased security in 2000 because of cost and legal disputes [54,28].

The western and eastern regions of the country differ markedly. The Pacific regions have higher population density and less poverty. They also have a lower elevation and warmer temperatures than the center of the country. Thus, in the country as a whole, one's location in the western or eastern region is not exogenous to land use decisions.

However, the precise line of demarcation between the eastern and western regions likely is, to a considerable degree, exogenous to land use choices. As can be seen from Fig. 5, the division between the western and eastern regions is around the transition from the coastal lowlands to the mountainous uplands. However, the line does not precisely follow the topography. Additionally, the line has almost no administrative meaning, since control has been centralized throughout Nicaraguan history [45,30] there are also not cultural or historical discontinuities at the line between the regions.

Thus, since characteristics relating to land use are different in the eastern and western parts of the country, but likely roughly similar along the line separating the two regions, I take landholdings from the seventeen municipalities which directly abut the regional dividing line as my sample (the "east–west boundary sample"). I then instrument with the side of the line the municipality is on, as shown in Fig. 6, which outlines in bold the municipalities along the border included in the analysis. The figure also graphically shows the first stage: the municipalities to the west of the boundary have less titling.

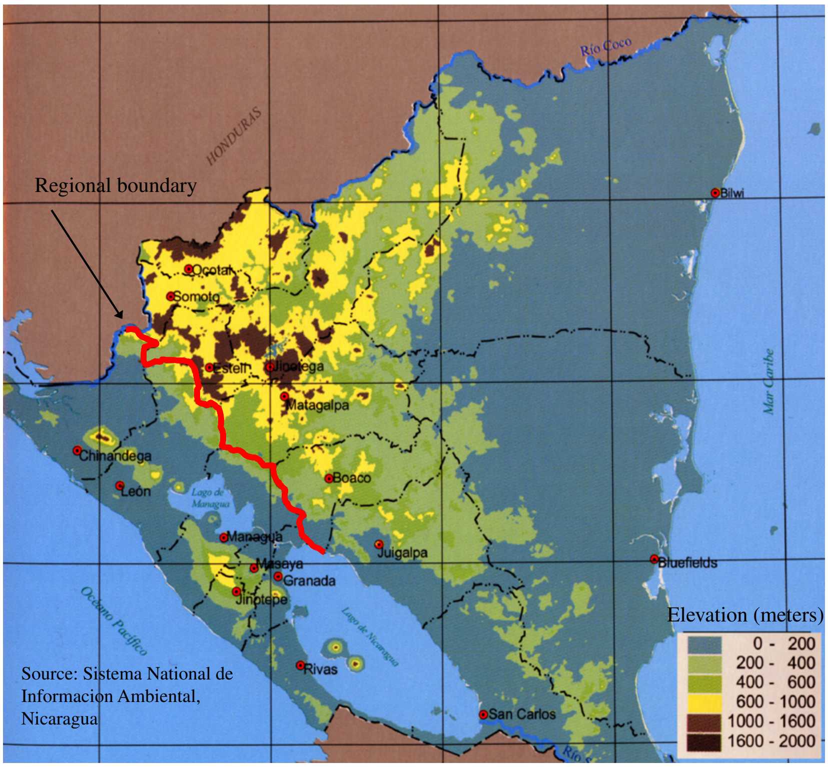


Fig. 5. Elevation with regional boundary.

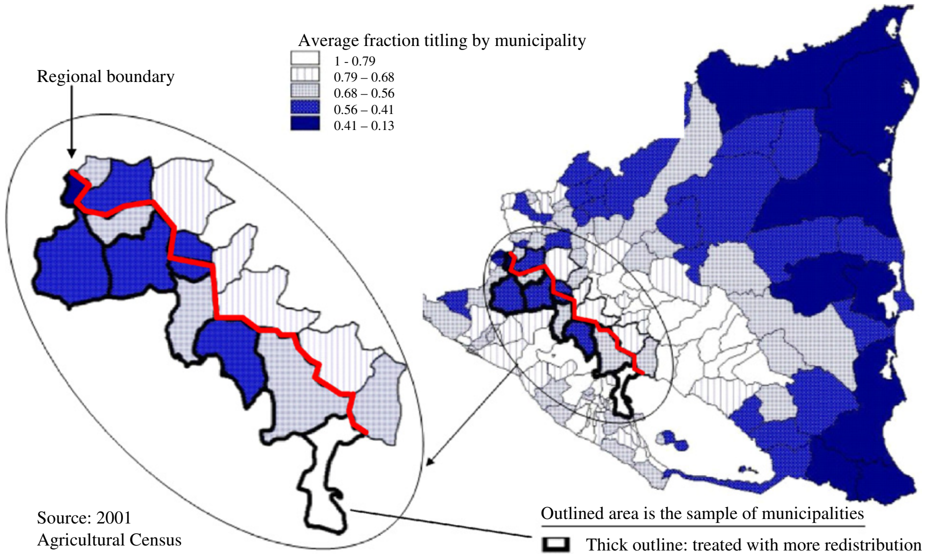


Fig. 6. Titling by municipality with outline around sampled municipalities.

There are two key identifying assumptions required for the exclusion restriction to be valid. First, conditional on covariates, the treated areas are not differentially favorable to forest cover. Second, conditional on covariates, those to whom land is redistributed do not differ in deforestation behavior from those who did not receive redistributed land.[19]

The second-stage regression that I run is then:

$$f_i = \alpha + \beta w_i + \delta c_m + \gamma d_i + \varepsilon_i \quad (3)$$

where the unit of observation is a landholding, f is the fraction of land covered by forest in 2000, w is the fraction of a landholding with title (usually 0 or 1, but possibly between if the landholder has multiple parcels), c is a vector of control variables at the municipal level, d is a vector of individual-level control variables, and ε_i is an i.i.d. error term. Municipal-level controls are elevation, mean annual temperature, slope, soil quality, precipitation, poverty level, distance from the capital Managua, rural and urban population density, and road density, which reduce concerns about differences between the municipalities to the east and west of the dividing line.[20] Individual-level controls are educational status and a spline in log area of landholding and are largely meant to be proxies of socio-economic status, helping to address the concern that individuals with a certain propensity to deforest received redistributed land during the agrarian reform.

The fraction of the land with a title is then instrumented with a binary variable for being on the west side. The identifying assumption is that this variable is unrelated to ε_i.

Using a similar methodology—replacing the left-hand-side variable of (3)—I then also study the effect of property rights on various measures of investment. Using instrumented probit regessions, I look at four potential avenues of agricultural intensification, important under the "investment effect" described above: credit, use of fertilizer, ownership of a tractor, and ownership of a warehouse. I also run linear regressions with four constructed variables: (1) fraction of agricultural land (crops and pasture) that is crops, (2) fraction of crops which is permanent, or more intensive, (3) fraction of pasture which is planted, or more intensive, and (4) fraction of total land that is fallow.

Table 3 compares the mean values for each of the two regions. The eastern side has somewhat more forest. The intensification measures are not uniformly higher in either region. A substantially larger number of landholders on the eastern side have title: 67 percent versus 55 percent, suggesting a strong first stage. There are not economically significant

[19] The fact that much of the land that was redistributed was expropriated on the basis of its being "underutilized" may arouse suspicion that "underutilized" equated with being covered by more trees than most agricultural land. This could mean that the instrument would pick up the effect only of redistributing marginal or highly tree-covered land. To see how significant this concern should be, I interviewed the Minister of Agrarian Reform during the 1980s, Jaime Wheelock Ramon. When asked, "Was the land that was expropriated and then redistributed more or less likely to have forest?" Wheelock responded, "No. Generally, the land that was underutilized was brushland that had only a few cattle on it, but not more trees" [59]. Often underutilized plots were adjacent to plots of intensive agriculture with the same land qualities. The owners had just left because of the war, and the land was likely farmed relatively recently.

[20] Although the poverty and density variables are not strictly exogenous, since they could have been affected by the land redistribution itself, the benefits of including them outweigh the costs, since these are factors which increase economic opportunity and potentially affect both forest cover and the desire or ability to gain title. For example, although I am unaware of disproportionate migration to areas with more redistribution [58], controlling for population density should also help alleviate potential concerns about migration induced by the greater availability of land in areas with more redistribution.

Table 3
Variable means: west versus east.

	West	East	*t*-value		West	East	*t*-value
Individual-level variables							
Independent variable				*Dependent variables*			
Fraction with title	0.55	0.67	−17.62	Fraction total forest	0.032	0.038	−4.06
	(0.49)	(0.46)			(0.09)	(0.11)	
Controls				Receipt of credit	0.14	0.19	−9.38
					(0.35)	(0.40)	
Area (acres)	79.30	62.24	5.30	Use of fertilizer	0.66	0.59	10.23
	(256.00)	(177.21)			(0.47)	(0.49)	
Log area (acres)	3.22	3.04	8.16	Ownership of tractor	0.10	0.08	5.42
	(1.51)	(1.44)			(0.30)	(0.27)	
No education	0.43	0.46	−4.07	Ownership of warehouse	0.04	0.07	−7.55
	(0.50)	(0.50)			(0.20)	(0.25)	
Can read and write	0.06	0.05)	3.41	Cropland/(cropland + pastureland)	0.54	0.55	−2.68
	(0.24)	(0.22)			(0.38)	(0.37)	
Primary education	0.38	0.38	−0.04	Fraction cropland	0.36	0.39	−6.12
	(0.49)	(0.49)			(0.32)	(0.32)	
Secondary education	0.07	0.06	4.13	Permanent cropland/total cropland	0.07	0.05	7.96
	(0.26)	(0.23)			(0.23)	(0.17)	
Post-secondary education	0.05	0.04	1.33	Fraction pastureland	0.34	0.34	0.56
	(0.21)	(0.20)			(0.33)	(0.32)	
				Planted pastureland/total pastureland	0.37	0.20	29.63
					(0.43)	(0.36)	
				Fraction fallow	0.18	0.16	6.06
					(0.26)	(0.24)	
Municipal-level variables							
Precipitation (m/year)	1.33	1.00	2.76	Heavy clay soil	0.28	0.18	1.08
	(0.28)	(0.20)			(0.19)	(0.17)	
Elevation (km)	0.28	0.64	−3.26	High poverty	0.01	0.46	−2.75
	(0.14)	(0.28)			(0.01)	(0.46)	
Temperature (°C)	24.96	23.21	3.27	Distance from Managua (deg.)	1.06	1.10	−0.28
	(0.97)	(1.21)			(0.40)	(0.18)	
Slope/100 (percent)	0.25	0.33	−1.81	Rural population density	0.03	0.03	−0.17
	(0.10)	(0.08)		(1000 persons/km^2)	(0.01)	(0.01)	
Fine sandy soil	0.57	0.55	0.13	Urban population density	0.03	0.03	0.10
	(0.32)	(0.21)	0.13	(1000 persons/km^2)	(0.04)	(0.04)	
Clay soil	0.04	0.00	1.26	Road density (km road/km^2)	0.02	0.02	0.03
	(0.09)	(0.00)			(0.02)	(0.02)	
Sandy soil	0.06	0.16	−1.94				
	(0.07)	(0.14)					

Note: Standard deviation in parentheses. The *t*-value is for the difference in the means. For the individual-level variables, the west has 9431 observations and the east has 9538 (the east–west boundary sample). For the municipal-level variables, the west has 9 observations and the east has 8. See sources in text.

differences in education levels between the two areas. The east is higher, cooler, wetter, and more impoverished, suggesting the value of municipal-level controls.

6. Results and interpretation

6.1. First stage

Table 4 presents the first-stage results for the effect of being on the west on the fraction of land with title. Column (1) presents the results without any individual level controls, column (2) adds a spline in the log area of the landholding, and column (3) adds education controls. The first stage results are little-changed with the addition of the individual-level controls. Column (3) yields a coefficient of −0.210, meaning that—controlling for other factors—being on the west side of the discontinuity, where more redistribution happened, reduces the fraction of land with title by 21 percentage points. Note that this is the same sign as, but larger than, the unconditional difference of −0.12 (0.55 for the West versus 0.67 for the East) in Table 3. The first stage is strong, with an F-statistic of 29 in column (3).

Some of the results for covariates are worth noting as well. As one might expect, locations further from Managua, which were settled more recently and from which attaining title is more costly, are less likely to have title. The coefficient in column (3) implies that moving one degree (approximately 110 km) from the capital reduces the probability of having a title by 17 percentage points. Road density is positively related to having title, perhaps because of the greater ease of attaining it or the greater value of the land. Those living in areas with a higher rural population density are less likely to have title. Among the

Table 4
First stage—fraction of land with title.

	(1)	(2)	(3)
West side of discontinuity	−0.231***	−0.214***	−0.210***
	(0.039)	(0.039)	(0.039)
Precipitation (m/year)	−0.144***	−0.197***	−0.198***
	(0.055)	(0.054)	(0.054)
Elevation (km)	−0.180***	−0.145**	−0.139**
	(0.064)	(0.062)	(0.062)
Temperature (°C)	−0.013	−0.016	−0.017
	(0.016)	(0.015)	(0.015)
Slope (fraction)	1.280***	1.236***	1.215***
	(0.291)	(0.285)	(0.285)
Distance from Managua (deg.)	−0.197***	−0.170***	−0.174***
	(0.027)	(0.027)	(0.027)
Rural population density (1000 persons/km^2)	−4.910***	−5.468***	−5.376***
	(0.685)	(0.675)	(0.675)
Urban population density (1000 persons/km^2)	−0.899*	−0.225	−0.464
	(0.480)	(0.476)	(0.477)
High poverty status	−0.326***	−0.325***	−0.327***
	(0.032)	(0.032)	(0.032)
Road density (km/km^2)	3.712***	3.669***	3.644***
	(0.407)	(0.402)	(0.402)
No education			−0.147***
			(0.019)
Can read and write			−0.097***
			(0.013)
Primary school			−0.097***
			(0.013)
Secondary education			−0.072***
			(0.016)
Constant	0.554	−0.499	−0.349
	(0.378)	(0.375)	(0.418)
Log area spline		X	X
Adjusted *R*-squared	0.072	0.109	0.111
Observations	18,969	18,969	18,969

Note: Robust standard errors in parentheses. All regressions include municipal-level controls for precipitation, temperature, soil type, elevation, slope, road density, high poverty status, rural population density, and urban population density. Regressions use the east–west boundary sample. See sources in text.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

geographic variables, precipitation and elevation are both negatively related to having title, while slope is positively related. Socioeconomic status is negatively related to having title; areas with high poverty, landholders with less education (relative to the excluded education group of having a post-secondary education), and landholders with smaller landholding size (in unreported results) are less likely to have a title. For example, according to column (3), those with no education are the least likely to have title, at 15 percentage points less likely than those with a post-secondary education. The negative relationship between socioeconomic status and having a title could result from the poor's paltry resources for attaining title, their tendency to squat on land, or the small value of attaining title on the lower-quality land that they may occupy.

6.2. Main results

Table 5 presents the main results of the paper, the effect of land title on forest cover. Columns (1)–(3) present the OLS results, and columns (4)–(6) present the IV results, with columns further to the right adding in individual-level controls. The OLS results are statistically, but not economically, significant; they are very close to 0.

In contrast, the IV results are large in magnitude and highly statistically significant. They are little-changed by the inclusion of individual-level controls.[21] The most important result in the paper, the coefficient on fraction with title in column (6), is −0.137, suggests that titling a landholding decreases the fraction of forest cover by 13.7 percentage points,

[21] In addition, controlling for 1983 forest cover from LANDSAT satellite data does not qualitatively change the results. With this control, the coefficient on fraction with title is −0.240 (SE=0.063). Likewise, including as control the measures of capital use from Table 6, both individually and together, affects the results little.

Table 5
Fraction of land with forest cover.

	OLS			IV		
	(1)	(2)	(3)	(4)	(5)	(6)
Fraction with title	0.004**	−0.004***	−0.004***	−0.131***	−0.135**	−0.137***
	(0.002)	(0.001)	(0.001)	(0.042)	(0.044)*	(0.045)
Precipitation (m/year)	0.030***	0.014***	0.014***	−0.027	−0.046**	−0.046**
	(0.005)	(0.005)	(0.005)	(0.018)	(0.020)	(0.021)
Elevation (km)	0.042***	0.046***	0.046***	0.023	0.031**	0.032**
	(0.013)	(0.013)	(0.013)	(0.016)	(0.016)	(0.016)
Temperature (°C)	0.001	0.001	0.001	−0.010**	−0.010**	−0.010**
	(0.002)	(0.002)	(0.002)	(0.004)	(0.004)	(0.004)
Slope (fraction)	0.142***	0.150***	0.148***	0.139***	0.155***	0.152***
	(0.034)	(0.034)	(0.034)	(0.043)	(0.042)	(0.042)
Distance from Managua (deg.)	−0.008*	−0.003	−0.003	−0.024***	−0.015**	−0.016**
	(0.004)	(0.004)	(0.004)	(0.007)	(0.007)	(0.007)
Rural population density (1000 persons/km^2)	−0.755***	−0.988***	−0.978***	−1.469***	−1.748***	−1.735***
	(0.125)	(0.123)	(0.123)	(0.260)	(0.289)	(0.291)
Urban population density (1000 persons/km^2)	−0.129	0.071	0.072	−0.168	0.114	0.082
	(0.096)	(0.095)	(0.096)	(0.113)	(0.112)	(0.112)
High poverty status	0.016**	0.014**	0.014**	−0.020	−0.021	−0.022
	(0.006)	(0.006)	(0.006)	(0.013)	(0.014)	(0.014)
Road density (km/km^2)	0.273***	0.291***	0.282***	0.631***	0.643***	0.639***
	(0.074)	(0.073)	(0.073)	(0.141)	(0.146)	(0.149)
No education			0.004			−0.016*
			(0.006)			(0.009)
Can read & write			−0.005			−0.018***
			(0.005)			(0.007)
Primary school			−0.005			−0.018***
			(0.005)			(0.007)
Secondary education			−0.001			−0.011
			(0.006)			(0.007)
Constant	0.150**	0.052	0.057	0.403***	0.262	−1.667**
	(0.067)	(0.065)	(0.075)	(0.105)	(0.452)	(0.784)
Log area spline		X	X		X	X
Observations	18,969	18,969	18,969	18,969	18,969	18,969

Note: Robust standard errors in parentheses. All regressions include soil type indicators and use the east–west boundary sample. See sources in text.
* Significant at 10%.
** Significant at 5%.
*** Significant at 1%.

Table 6
Instrumented probit regressions of intensification mechanisms (1 = Yes, 0 = No): average marginal effects.

	Receipt of credit (1)	Fertilizer use (2)	Tractor ownership (3)	Warehouse ownership (4)
Fraction with title	0.320***	0.370***	0.451***	0.089
	(0.090)	(0.109)	(0.086)	(0.091)
Individual-level controls	X	X	X	X
Observations	18,969	16,884	18,969	18,969

Note: Robust standard errors in parentheses. All regressions include county-level controls for precipitation, temperature, soil type, elevation, slope, road density, high poverty status, rural population density, and urban population density. Individual-level controls are education and a log area spline. Regressions use the east–west boundary sample. See sources in text.
*** Significant at 1%.

larger than the results in earlier correlational studies and large compared to the average forest cover of 3.5 percent. In the context of the model, these results suggest that land quality and investment are complements and that the investment effect dominates the conservation effect.

Given the large number of landholdings with no forest (79 percent), for additional interpretation, I run an instrumented Tobit regression with the same controls as in column (6), censoring fraction forest cover at 0. The coefficient on fraction with title is −0.264 with a standard error 0.121. I then simulate the average effect of titling using the existing distribution of titling and forest cover, taking into account censoring. These results suggest that titling reduces forest cover by an average of 82 percent.

Table 7
Instrumented linear regressions on land use: fraction of total landholding.

	Crops/(crops and pasture) (1)	Permanent crops/crops (2)	Planted pasture/pasture (3)	Fallow (4)
Fraction with title	0.358***	0.306***	0.855***	0.176**
	(0.123)	(0.071)	(0.330)	(0.087)
Individual-level controls	X	X	X	X
Observations	18,502	17,033	12,544	18,969

Note: Robust standard errors in parentheses. All regressions include municipal-level controls for precipitation, temperature, soil type, elevation, slope, road density, high poverty status, rural population density, and urban population density. Individual-level controls are education and a log area spline. Regressions use the east–west boundary sample. See sources in text.
** Significant at 5%
*** Significant at 1%.

One possible violation of the exclusion restriction is that the land redistribution affected forest cover in ways other than through property rights. For example, those who received redistributed land may have characteristics (e.g., poverty) which make them unlikely to have either a title or a large amount of agricultural cover. One way to evaluate the magnitude of this is to compare the results with and without the individual-level controls for the size of the landholding and educational attainment. As can be seen in Table 5, adding controls in both OLS and IV results in changes which are not of an economically significant magnitude. If anything, the controls makes the coefficient on title *more* negative, suggesting that—if omitted socioeconomic controls are like landholding size and educational attainment—their omission may be biasing the results *toward* zero.[22] To the extent to which these are good controls, these results suggest that this source of bias may be relatively unimportant.

The fact that the IV results are so much more negative than the OLS results suggests that previous studies may have substantially underestimated the extent to which property rights reduce forest cover. One potential explanation is unobserved characteristics of the land. For example, someone more distant from market has less of an incentive to gain title because he likely has fewer abutters; he would also be less likely to value firewood, which is very bulky and has a low value per unit of mass or volume compared to agricultural goods; since forest would be less valuable, the landholder would choose agriculture over forestry more. This would create a bias toward zero on the uninstrumented coefficient on tenure insecurity.

A second explanation for why the IV results are so much more negative is that the instrument may correct for the simultaneity in the system, which tends to bias results toward zero. Forest cover may increase demand for title. If local market conditions are such that there is high demand for forest products, agricultural producers will have more forest. For example, in areas with the appropriate soil, brick-makers demand large amounts of firewood, which may increase forest cover on surrounding landholdings [35]. Forest cover decreases a landholder's *informal* property rights, since the land appears less used. Landholders may therefore demand more formal property rights to compensate. In other words, formal property rights through titling may be a substitute for agricultural production, which confers informal property rights.

6.3. *Other covariates*

There are several notable results among the covariates. Many coefficients are what one might have expected ex ante; for example, areas with steeper slopes and higher elevations, where land may be less valuable for agriculture, are associated with more forest cover. Areas with higher population density—and therefore a higher labor/land ratio which could reduce the cost of agriculture—have less forest cover. Others may be less expected. For example, road density has a large positive coefficient, perhaps because, conditional on rural population density, roads are placed to open up forested areas to agriculture.

There are also several shifts from OLS to IV. Across the board, standard errors increase—turning the coefficient on high poverty status insignificant, for example. Likewise, the road density variable becomes substantially more positive in the IV regressions. This is because, in OLS, the title variable picks up some of the positive relation between forest cover and road density. Once the title variable is effectively purged of its portion correlated with the error term, road density can take on its appropriate magnitude. Similarly, for the distance from Managua and precipitation variables, OLS allows the coefficient on the title variable to pick up an extra negative loading due to its joint correlation with the error term and the covariates. It should be noted that the coefficients for both of these variables are rather small in magnitude; increasing precipitation

[22] For example, the effect of title is more positive in columns (1) and (4) than columns (2) and (5), respectively, because having title is positively related to area, which is in turn positively related to forest cover. So, in the absence of the log area spline, the title variable is picking up some of the positive effect of landholding area.

by one standard deviation (0.29 m/year) decreases forest cover by 1 percentage point. Increasing the distance to Managua by one standard deviation (0.31°) decreases forest cover by 0.5 percentage points. By comparison, increasing the title variable by one standard deviation (0.48) increases forest cover by 7 percentage points.

6.4. Property rights and investment

I turn now to results on the effect of property rights on investment. Table 6 presents the average marginal effects of instrumented probit[23] regressions on having land title, showing that, with a title, the probability of receiving credit increases by 0.32, using fertilizer increases by 0.37, and owning a tractor increases by 0.45. These are all consistent with the investment effect. The coefficient on warehouse ownership is insignificant.

Table 7 presents IV regressions where the outcome is the intensity of land use. In columns (1) to (3), the outcome variable has the more investment-intensive form of land use in the numerator and a larger category of land use in the denominator. The number of observations varies, since some landholdings have a zero in the denominator. The table shows that titled land has more cropland as a fraction of agricultural land, more permanent cropland as a fraction of cropland, and more planted pastureland as a fraction of pasture, all as predicted by the investment effect. Titling also increases fallow land. A plausible explanation is that land is left land fallow as an *investment*, allowing soils to regenerate. This would conform to the investment effect, as consistent with Goldstein and Udry [38].

7. Alternative instrumental variables strategy

7.1. "War instrument" IV strategy

As a test of robustness, I develop an alternative instrument with a different source of variation. I take advantage of the fact that the Sandinistas responded to the Contra War by increasing the amount of land redistribution in more conflict-prone areas to maintain the support of the locals and discourage them from aiding the rebels [58,24]. These areas with high levels of military activity were in the north and south of the country, near the borders from which the insurgents attacked. For example, in Esteli, one of the northernmost regions and an active war zone, state farms were distributed to such an extent that the state-controlled area was reduced to only 6 percent of the total agricultural land in the region, while the national average was 19 percent [20]. As above, the new owners of this redistributed land were either given provisional titles or no titles at all. Land that was expropriated but not redistributed could easily be returned to former owners, while land that was redistributed entered into a limbo status—with either provisional or no titling, with insecurity lasting until the time of the study. Since the insurgency was mounted from Nicaragua's borders, I have two instruments as good measures of the extent to which the war affected the municipality: presence in a department adjacent to the southern border and also the northern border, where *less titling* is expected than the rest of the country due to the agrarian reform.[24] Because this instrument takes advantage of geographic variation largely unrelated to the first instrument, it provides an especially valuable second test.

The key identifying assumption of the "war instrument" approach is that the direct effect of the war on forest cover is gone over a decade after the end of the war, while—because of constraints on gaining title—the effect on land titles is not gone. Given the sign of the results, what would be most concerning would be if war led to increased forest cover, since areas with war also had increased redistribution, reduced property rights, and more forest cover. However, historical accounts suggest that, if anything, the war led to increased defoliation and burning, as the Contras set fire to agricultural land while attacking coffee plantation workers and exploding munitions damaged forests [36,25].

To increase the strength of these regional-level variables and permit multiple endogenous variables, I interact location adjacent to the northern and southern borders with the landholder's educational status. Educational status is relevant to titling status because those who received land during the agrarian reform were primarily those who were in need of land, the poor. Those who had political connections may also have received more land. Since my measure of socio-economic status is educational status, I would expect the least amount of redistribution among the rich, those with post-secondary degrees. Depending on whether the effect of political connections or the effect of need matters most, I would expect either the lower socio-economic group (without any education) or the intermediate group (primary or secondary education) to have the most redistribution—and, therefore, tenancy insecurity. Since I also separately control for education, the identifying assumption is that educational attainment is related to forest cover the same in border and non-border areas, except as education relates to differential probability of having insecure tenure resulting from the agrarian reform.

One benefit of technically having eight instruments is the ability to instrument several endogenous variables. This is especially valuable given that war likely increased damage to infrastructure, which could discourage agricultural intensification—and thereby decrease the returns to deforestation. In fact, state farms were a primary target of the

[23] See [6, p. 197–205], for an explanation of instrumented probit regressions.

[24] One potential concern is the presence of political or cultural differences between the border and center of the country. Aside from the English and indigenous presence on the Caribbean coast, the country is largely unified, with boundaries between departments mattering little [30,48].

Table 8
War instrument—first stage regressions.

	Fraction land with title (1)	Log area (2)	Warehouse ownership (3)
Northern border × no education	−0.127***	−0.096***	−0.019***
	(0.004)	(0.012)	(0.002)
Northern border × primary education	−0.114***	−0.240***	−0.02***
	(0.004)	(0.012)	(0.002)
Northern border × secondary education	−0.098***	−0.355***	−0.014**
	(0.009)	(0.033)	(0.007)
Northern border × postsecondary education	−0.029***	0.083*	0.021*
	(0.009)	(0.046)	(0.012)
Southern border × no education	−0.031***	0.018	0.014***
	(0.005)	(0.015)	(0.002)
Southern border × primary education	−0.006	−0.258***	0.002
	(0.005)	(0.016)	(0.003)
Southern border × secondary education	0.006	−0.608***	−0.032***
	(0.011)	(0.041)	(0.008)
Southern border × postsecondary education	0.028**	−0.681***	−0.015
	(0.013)	(0.074)	(0.017)
Education controls	X	X	X
F statistic on instruments	187.99	112.64	39.48
R-squared	0.08	0.30	0.06

Note: Robust standard errors in parentheses. All regressions include municipal-level controls for precipitation, temperature, soil type, elevation, slope, road density, high poverty status, rural population density, and urban population density. The sample is the whole country and has 195,637 observations. See sources in text.

* Significant at 10%.

** Significant at 5%.

*** Significant at 1%.

Table 9
War instrument—instrumented regressions on land use: fraction of total landholding.

	OLS			IV		
	(1)	(2)	(3)	(4)	(5)	(6)
Fraction with title	−0.022***	−0.022***	−0.030***	−0.300***	−0.180***	−0.158***
	(0.001)	(0.001)	(0.001)	(0.011)	(0.022)	(0.042)
Warehouse ownership		X	X		X	X
Log area			X			X
Education controls	X	X	X	X	X	X
Passes test of over-identifying restrictions?				Yes	Yes	Yes

Note: Robust standard errors in parentheses. All regressions include municipal-level controls for precipitation, temperature, soil type, elevation, slope, road density, high poverty status, rural population density, and urban population density. The sample is the whole country and has 195,637 observations. The eight instruments are n./s. border∗educational attainment. See sources in text.

*** Significant at 1%.

counterinsurgents [20]. Consequently, given that it is possible that this infrastructure damage lasted until 2000 in the war-ridden areas, I include a measure of infrastructure (warehouse ownership) as an endogenous variable. Since redistribution also affected land size, this variable is instrumented as well.

I use the same specification as before, except for controlling for log area linearly to permit it to be instrumented. The control for the distance from Managua is particularly important here, since border areas are more recently settled, increasing forest cover and reducing titling. Looking at a national map of Nicaragua's forest cover (see Fig. 1), it becomes readily apparent that the agricultural frontier forms a semi-circle with Managua as its center. Controlling for distance from Managua means that the instrument, rather than working along a strict north-south axis, works outwardly in concentric circles radiating from Managua.

Table 10
War instrument—instrumented regressions on land use: fraction of total landholding.

	Total forest (1)	Natural forest (2)	Secondary forest (3)	Planted forest (4)
Fraction with title	−0.158***	−0.089***	−0.066***	0.008**
	(0.042)	(0.026)	(0.018)	(0.003)
Education controls	X	X	X	X
Passes test of over-identifying restrictions?	Yes	Yes	Yes	Yes

Note: Robust standard errors in parentheses. All regressions include municipal-level controls for precipitation, temperature, soil type, elevation, slope, road density, high poverty status, rural population density, and urban population density. The sample is the whole country and has 195,637 observations. The eight instruments are n./s. border × educational attainment. Other endogenous variables are log area and warehouse ownership. See sources in text.

** Significant at 5%.

*** Significant at 1%.

Appendix Table A1 compares the mean values for departments adjacent to and not adjacent to the borders. Approximately 50 percent more landholdings have title in non-border regions than border ones. Landholdings are somewhat larger in border areas. The non-border regions have substantially less forest and higher population densities. The two regions have different soil types, and the border areas are wetter and cooler. The landholders in the non-border areas have somewhat higher educational attainment.

7.2. First-stage results

Table 8 presents the first-stage regressions for the endogenous variables on the instruments and shows that the coefficients have the expected sign. For fraction of land with title, the effect of being in the north or south is generally negative, as expected, since there should have been more redistribution in those regions—and therefore tenancy insecurity. Also, the effect generally becomes more negative for those with less education: the poorest benefited the most from the agrarian reform. Likewise, coefficients from column (2), with log area as the outcome are negative and generally more negative to less educated groups, reflecting the tendency of redistribution to decrease the size of landholdings. Finally, border areas tend to have less warehouse ownership, possibly reflecting the effects of the war. In all three cases, the instruments are powerful, with joint F statistics over 100 for land titling and log area and over 30 for warehouse ownership.

7.3. IV Results

Table 9 presents results OLS [columns (1) to (3)] and IV [columns (4) to (6)] for the effect of title on forest cover. The first column in each set contains the municipal-level and education controls, the second adds warehouse ownership, and the third further adds log area. All regressions pass a test of over-identifying restrictions. As with the first instrument, OLS results are close to 0, and IV results are large and negative. The inclusion of warehouse ownership reduces the magnitude of the coefficient, suggesting that it may be an important endogenous variable to include. Column (6), the IV regression with both log area and warehouse ownership, has a coefficient of −0.158, remarkably similar to the preferred specification with the first instrument, which has a coefficient of −0.137. This similarity between strategies using related, but different, sources of variation helps validate the results.[25]

Unlike with the first IV approach, which covered areas which were nearly all secondary forest, the second IV approach includes areas with substantial amounts of natural and planted forest. Table 10 presents results disaggregated by forest type. With a title, the fraction of land as natural forest, which accounts for approximately half of all forest, decreases by 0.089, while the fraction as secondary forest, most of the other half, decreases by 0.066.[26] This effect is larger for natural forest perhaps because the conservation effect is likely larger for secondary forest: more of the returns to secondary forest are more distant in the future because it is gradually regrowing and becoming more productive, leading to a greater impact of discounting on the value of secondary forest under insecure tenancy regimes relative to natural forest. The fraction of land as planted forest, on the other hand, *decreases* with lack of title. This result is expected, since planted forest is more like agriculture—a permanent intensive crop—than atural or secondary forest [9].[27]

[25] Using an instrument only a binary variable for being in a border or non-border region yields similar results, with a specification like that in column (6) having a coefficient of −0.129 (SE=0.012).

[26] The division into natural and secondary forest should be taken cautiously, since the war could have affected whether areas were left as natural forest.

[27] Municipal-level regressions with the outcomes of 2000 forest cover from the census, 2000 forest cover from satellite data, and the percent change in forest cover between 1983 and 2000 from satellite data give results that are of the same sign as the results here, but are not statistically significant.

Table A1
Means for border and non-border departments for war instrument.

	Non-border	Border	*t*-value
Dependent variables			
Fraction total forest	0.04	0.09	−65.83
Fraction natural forest	0.01	0.04	−64.70
Fraction secondary forest	0.03	0.05	−34.45
Fraction planted forest	0.004	0.002	16.11
Endogenous independent variables			
Fraction with title	0.70	0.54	−79.54
Log area	2.26	2.69	−57.30
Warehouse ownership	0.07	0.06	16.04
Mechanisms			
Receipt of credit	0.15	0.15	1.65
Use of fertilizer	0.56	0.41	66.73
Ownership of tractor	0.09	0.07	17.71
Cropland/(cropland + pastureland)	0.62	0.62	2.81
Fraction cropland	0.44	0.41	22.10
Permanent cropland/total cropland	0.29	0.28	4.81
Fraction pastureland	0.29	0.27	9.26
Planted pastureland/total pastureland	0.25	0.32	−37.72
Fraction fallow	0.14	0.17	−26.81
Labor characteristics: individual-level			
Members of household working	2.91	3.29	−37.58
Permanent workers	0.63	0.47	12.65
Temporary workers	2.25	2.83	−9.68
Area (mz)	38.38	44.61	−12.28
Controls: municipal-level			
Precipitation (m/year)	1.45	1.77	−4.94
Elevation (km)	0.40	0.44	−0.96
Temperature (°C)	24.24	23.74	2.98
Slope/100 (percent)	0.29	0.28	0.62
Fine sandy soil	0.37	0.18	5.78
Clay soil	0.06	0.02	2.81
Sandy soil	0.35	0.66	−6.83
Heavy clay soil	0.10	0.05	3.07
High poverty	0.38	0.67	−5.62
Distance from Managua	0.99	1.76	−10.49
Rural population density	78.11	26.71	2600.49
Urban population density	99.39	15.02	4178.88
Road density	0.02	0.01	3.70
1983 forest cover	0.44	0.69	−9.50
Controls: individual level			
No education	0.40	0.45	−22.62
Can read and write	0.05	0.06	−11.11
Primary education	0.39	0.41	−5.23
Secondary education	0.09	0.06	26.60
Post-secondary education	0.07	0.03	44.39

Notes: The *t*-value is for the difference in the means. See sources in text. There are 94,240 non-border observations and 102,658 border observations.

8. Conclusion

This study offers evidence that, contrary to many theoretical predictions, tenancy insecurity protects forests. "The tragedy of the commons" does not appear to occur in this case; rather, the opposite seems to happen for forests [40]. This research supports the results of at least two small-scale correlational case studies, using a larger number of observations and a more credible, instrumental variables strategy. It contradicts previous country-level studies and theoretical results, and develops a theoretical framework to explain the results. The study suggests that previous theoretical studies over-emphasize the effect of tenancy insecurity on discounting future forest returns and ignore what appears to be more important—the effect of tenancy insecurity on investment and agricultural productivity.

This research suggests that, as Besley and Ghatak [14] note, assigning property rights is not a complete panacea for the environment and development. Rather, problems with tenancy security may have unintended positive consequences for the local and global environment. This result reveals the costs of creating better markets for land titling without creating markets for the positive externalities provided by forests. Most importantly, these results should raise a cautionary note:

titling land may exacerbate deforestation, further necessitating the adoption of effective forest policies that align private with public preferences. As markets for land titles are increasingly created, similar markets could be created for the protection of forests: perhaps a subsidization scheme for forest preservation. At least in Nicaragua, where land use regulations are regularly flouted,[28] these results suggest that the daunting challenge of preserving the country's forests may be even more difficult than was previously recognized.

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Appendix A. Proofs

Proof of Proposition 1. The following result shows conditions with which to show that the sign is ambiguous: by the Monotone Selection Theorem, (A) if $\frac{\partial^2 P}{\partial\alpha\partial(1-\rho)} > 0$, then $\frac{\partial\alpha^*}{\partial(1-\rho)} \geq 0$; and (B) if $\frac{\partial^2 P}{\partial\alpha\partial(1-\rho)} < 0$, then $\frac{\partial\alpha^*}{\partial(1-\rho)} \leq 0$.[29] Hence, determining the sign on $\frac{\partial\alpha^*}{\partial(1-\rho)}$ depends critically on the sign of $\frac{\partial P}{\partial\alpha\partial(1-\rho)}$. I now show that theory cannot give clear predictions on the sign of $\frac{\partial P}{\partial\alpha\partial(1-\rho)}$ (See Table A1).

Taking the cross-partial of (1) yields:

$$\frac{\partial^2 P}{\partial\alpha\partial(1-\rho)} = \underbrace{\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial\alpha} - t}_{(i)} + \underbrace{(2-\rho)\frac{\partial^2 A}{\partial Q\partial I}\frac{\partial Q}{\partial\alpha}\frac{\partial I}{\partial(1-\rho)}}_{(ii)} \tag{A1}$$

We know that term (*i*) of (A1) is positive, since taking the first-order condition of (1) and rearranging yields:

$$t = \frac{(2-\rho)}{(1-\rho)}\frac{\partial A}{\partial Q}\frac{\partial Q}{\partial\alpha} \tag{A2}$$

Since $\rho < 1$, we know that $t > \frac{\partial A}{\partial Q}\frac{\partial Q}{\partial\alpha}$. This makes sense because per-period marginal profits from forestry ought to be higher to compensate for only being available in the second period.

However, term (*ii*) of (A1) has an unclear sign, since there is no assumption on the cross-partial term $\frac{\partial^2 A}{\partial Q\partial I}$. Different assumptions on $\frac{\partial^2 A}{\partial Q\partial I}$ will then yield different signs on $\frac{\partial^2 P}{\partial\alpha\partial(1-\rho)}$ (and hence on $\frac{\partial^2\alpha^*}{\partial(1-\rho)}$, by the Monotone Selection Theorem).

Part (A) of the Monotone Selection Theorem result requires that:

$$\frac{\partial^2 A}{\partial Q\partial I} > \frac{t-(\partial A/\partial Q)(\partial Q/\partial\alpha)}{(2-\rho)(\partial Q/\partial\alpha)(\partial I/\partial(1-\rho))} \tag{A3}$$

which is found by setting the right-hand-side of (A1) as greater than zero. Since $t > \frac{\partial A}{\partial Q}\frac{\partial Q}{\partial\alpha}$ and the denominator of (A3) is greater than 0, we know that $\frac{\partial^2 A}{\partial Q\partial I} > 0$ is a necessary (but not sufficient) condition for part (A). Thus, $\frac{\partial^2 A}{\partial Q\partial I} > 0$, the equivalent of Q and I being complements, implies that $\frac{\partial^2 P}{\partial\alpha\partial(1-\rho)} > 0$. This occurs with Cobb–Douglas functions, for example.

Likewise, part (B) of the Monotone Selection Theorem result requires that:

$$\frac{\partial^2 A}{\partial Q\partial I} < \frac{t-(\partial A/\partial Q)(\partial Q/\partial\alpha)}{(2-\rho)(\partial Q/\partial\alpha)(\partial I/\partial(1-\rho))} \tag{A4}$$

which is found by setting the right-hand-side of (A1) as less than zero. Since, as before, the right-hand-side is positive, we cannot assign a sign to $\frac{\partial^2 A}{\partial Q\partial I}$. Thus, $\frac{\partial^2 A}{\partial Q\partial I} < 0$ is a sufficient (but not necessary) condition for (B) to be satisfied. If Q and I are substitutes or even complements such that (A4) is satisfied, then (B) will be satisfied. □

[28] Torrez, Juan [56].

[29] P ought technically to be redefined as a function only of $(1-\rho)$ and α; however, for clarity of exposition, I am keeping the same function. The statement of the theorem requires that $P(\alpha,(1-\rho))$ has increasing differences, which is equivalent to the conditions on the cross-partial, assuming continuous differentiability. Likewise, the theorem's result is that $(1-\rho) > (1-\rho)'$ implies that $\alpha \leq \alpha'$ at equilibrium values of $\alpha*$, which is equivalent to $\frac{\partial\alpha^*}{\partial(1-\rho)} \geq 0$, assuming continuous differentiability. These results reverse for the negative; this can be seen by noting that all the result for increasing differences applies when simply taking the negative of $(1-\rho)$.

Proof of Proposition 2. Taking the contrapositive of part (B) of the Monotone Selection Theorem result yields: if $\frac{\partial^2 \alpha^*}{\partial(1-\rho)} > 0$, then $\frac{\partial^2 P}{\partial\alpha\partial(1-\rho)} \geq 0$. By reasoning similar to that above, we know that

$$\frac{\partial^2 A}{\partial Q \partial I} \geq \frac{t-(\partial A/\partial Q)(\partial Q/\partial\alpha)}{(2-\rho)(\partial Q/\partial\alpha)(\partial I/\partial(1-\rho))} > 0, \quad \text{(A5)}$$

which shows that $\frac{\partial^2 A}{\partial Q \partial I} > 0$ if $\frac{\partial^2 P}{\partial\alpha\partial(1-\rho)} \geq 0$. □

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