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Property rights, production technology, and deforestation: cocoa in Cameroon

Harounan Kazianga[a,*], William A. Masters[b]

[a] *Earth Institute, Columbia University, 2910 Broadway, B-19 Hogan Hall, New York, NY 10025, USA*
[b] *Department of Agricultural Economics, Purdue University, 403 W State Street, West Lafayette, IN 47907, USA*

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Abstract

In this article, we use a vintage-capital model with risk of eviction to assess cocoa farmers' response to changes in their tenure security and to the introduction of a new, faster-maturing cocoa variety. The model is calibrated with data from Cameroon in calendar year 2000, and then used to simulate the effects of institutional and technical change on farmer welfare and deforestation rates. Our findings can be summarized in three points. First, improved tenure security over cocoa fields increases farmers' consumption and welfare, but at the expense of more deforestation. Second, the introduction of new cocoa varieties with faster maturity and higher input response also unambiguously raises farmers' consumption and welfare. Doing so increases deforestation under insecure land tenure, but slows down deforestation under secure land tenure. Third, when introducing the two innovations together (more security and also new varieties), there is both an increase in welfare and a decline in deforestation. In sum, the availability of new cocoa cultivars calls for stronger tenure security, to accommodate investment in the new technology without increasing deforestation.

JEL classification: Q15, Q16

Keywords: Cameroon; Tree crops; Land tenure; Forest use

1. Introduction

About 70% of the world's cocoa is produced by smallholders in West and Central Africa (FAO, 2002). The typical production system involves clearing virgin forest to plant new trees, and later replacing old cocoa plantations with food crops (Ruf, 1995). The future of such cocoa-led deforestation is an urgent question for both environmentalists and for the cocoa industry, as forest resources become increasingly scarce and valuable.

Once planted, cocoa trees can have a productive life of more than 30 years, with yields per tree that rise gradually and eventually fall as the tree grows older. Breeding programs have generated new varieties that can grow faster and be more responsive to soil fertility and pest control, providing a kind of "Green Revolution" for tree crops.[1] Offering a higher and faster payoff could induce farmers to produce more intensively on less land and thus reduce deforestation rates, but might make it even more profitable to clear new lands.

Technology influences deforestation rates, but so do institutions. Many researchers have focused on property rights over the forest before it is cleared. Here we focus on property rights over the cocoa fields after they have been planted, which could have a particularly important influence on farmers' decisions to maintain or replant those fields over time. While the subject has received little attention from economists, it has generated substantial research in other disciplines (e.g., Awanyo, 1998; Berry, 1988; Chauveau and Léonard, 1996; and Hill, 1963 among others).

Our central hypothesis is that investment levels and deforestation rates depend on the *interaction* of technology with institutions: in particular, we ask whether the availability of faster-maturing varieties might raise farmers' incentive to clear virgin forests when property rights are weak, but have the opposite effect when the farmer's rights are secure. If so, then the exogenous arrival of the new variety calls for institutional change, with higher potential payoffs calling for greater security of tenure. Such interactions are receiving increasing attention from environmental and institutional economists (e.g.,

*Corresponding author. Tel.: 212-854-7977; fax: 212-854-0274.
E-mail address: hk2252@columbia.edu (H. Kazianga).

[1] The genetic improvements documented in this article result from the breeding and multiplication of new planting materials over several decades, complemented by newer techniques that have not yet been deployed on a large scale, e.g., Surujdeo-Maharaj et al. (2004).

Angelsen and Kaimowitz, 2001a; 2001b), but most previous work focuses on either technology (e.g., Gotsch and Burger, 2001; Gotsch and Wohlgenant, 2001), or tenure arrangements (e.g., Hill, 1963; Ruf and Zadi, 1998). Our innovation is to specify the nature of possible interactions in an explicit model, which we then calibrate to observed data.

We use a dynamic programming model capturing the vintage of trees, with a survival function capturing the risk of tenure loss, calibrated with survey data from Cameroon. This approach is motivated by the stylized facts described in Section 2 of the article; then Section 3 presents the model, Section 4 describes the data and parameters, Section 5 summarizes our results, and Section 6 concludes.

2. Migration, property rights, and cocoa farming in West Africa

Conflicts over the ownership of cocoa fields often involve disputes between migrants who come to plant cocoa and indigenous forest dwellers with pre-existing land use traditions. New cocoa regions have traditionally been developed by migrants, largely because of the dramatic increase in labor per hectare associated with the conversion from forest to cocoa. Migration and investment lead to new rules for land tenure (Chauveau, 2000), often distinguishing between the rights of migrants and those of indigenous people. Our model is motivated by this distinction, but could also accommodate other kinds of expropriation risk such as those that arise from conflicts within families, as documented by Hill (1963).

In the context of Cote d'Ivoire, Ruf and Zadi (1998) argued that migrant cocoa farmers were more concerned for faster and higher returns to their investments than their indigenous counterparts, while indigenous farmers' more secure property rights gave them a greater incentive to preserve land quality over time. Our own survey in Cameroon (Kazianga and Sanders, 2002) found that cocoa plantations are larger and less shaded in high-migration regions, which is likely to lead to more soil erosion and shorter-lived trees, as argued by Wood and Lass (1985) and Willson (1999), who find that zero-shade cocoa farms have higher yields in the short run but have shorter lifespan than shaded farms.

Tree planting is often used by migrants to assert land ownership. In Cameroon, Losch et al. (1991) noted that migrants in the frontier region of the Mbam and Kim district appeared to be pursuing a land accumulation objective, while indigenous farmers were pursuing current income. In Cote d'Ivoire, to encourage both immigrants from Sahelian countries and internal migrants to settle the southern forest zone, a 1967 presidential decree stated that "land belongs to the person who brings it into production, provided that exploitation rights have been formally registered" (Koudou and Vlosky, 1998, p. 4). The formal registration requirement is often overlooked, as states' power to implement and enforce formal registrations of any kind has been limited. More than 30 years later, government officials are still calling for improved land tenure in migration regions (Abanda, 1999). Customary tenure rules remain dominant in part because of their effectiveness in dealing with inheritance and other frequently encountered land transactions (Degrande and Duguma, 2000). Thus, expansion of cocoa area has proceeded under unclear property rights, and as land becomes scarcer the frequency of conflicts has increased (Chauveau, 2000).

3. Theoretical framework

Our analysis builds on Jacoby et al. (2002), using a capital accumulation model augmented to account for expropriation risk associated with insecure property rights. The consumption side of the model is similar to the standard setup of dynamic consumption used in various applied studies, e.g., Dercon (1998) and Malchow-Moller and Thorsen (2000). The production side is a neoclassical investment model with costs of adjustments and vintage structure as in Akiyama and Trivedi (1987), extended to allow interaction with other activities. The farm household maximizes time additive expected utility over an infinite planning horizon, defined over aggregate consumption.

Farm output consists of cocoa and an aggregate of all other goods, which includes both food crops and off-farm activity. The cocoa plantation requires long-term investment, with two to six years of gestation followed by a rise and then fall in yield over several decades, during which period the farmer may have insecure property rights. The aggregate other activity is conducted entirely under a secure property right regime. The two activities compete for the farmer's capital and labor.

Based on the literature on perennial crops (e.g., Bellman and Hartley, 1985; Akiyama and Trivedi, 1987), cocoa production can be described as follows:

$$y_t^c = \sum_v y_{tv}(x_{tv}, a_{tv}), \tag{1}$$

where y_t^c is total cocoa production in year t, y_{tv} is cocoa production of vintage v in year t, which is function of vintage v area (a_{tv}), and variable inputs applied on vintage v, (x_{tv}). Each year, the area planted in new vintage (a_{t1}) is either replanted (r_t) or newly cleared (n_t)

$$a_{t1} = r_t + n_t. \tag{2}$$

Once planted, trees remain unless uprooted or killed by disease

$$a_{t+1,v} = a_{t,v} - u_{tv} - d_{tv}, \tag{3}$$

where u_{tv} is the area in vintage v uprooted in year t, and d_{tv} is the area of land occupied by the trees that died in year t.[2] Each year, the area replanted in year t (denoted r_t) is constrained by the sum of the area uprooted, and the area of dead trees. For simplicity, we assume that this area, if not replanted in the same

[2] The tree death formula follows Gotsch and Wohlgenant (2001) and is given by

year, becomes no longer available for cocoa. This constraint is written as follows:[3]

$$r_t \leq \sum_v u_{tv} + \sum_v d_{tv}. \tag{4}$$

Trees that are replanted in an existing field typically have somewhat slower growth than those planted in new forest; we capture this in our model through a two-year delay, so that at period $t + 2$ trees planted in new forest will be in vintage 2 while trees replanted in cultivated fields will be in vintage 0. Given that, in year t, profit from cocoa production is

$$\pi_t^c = p_t^c y_t^c - w_t^c x_t^c - w_t^n n_t - w_t^r r_t, \tag{5}$$

where π_t^c is the profit, p_t^c is the cocoa price, w_t^c is the variable input price, $x_t^c = \sum_v x_{tv}$ is total variable input, w_t^n are the unit costs of new planting including costs of purchasing the new forest, and w_t^r are the unit costs of replanting.

The aggregate alternative activity, denoted f for food crops, yields immediate profits in each year of

$$\pi_t^f = p_t^a y\big(l_{at}, x_t^a\big) - w_t^a l_{at}^h, \tag{6}$$

where π_t^f is the profit, p_t^a is price level, y is production function defined over labor used l_{at} and land x_t^a, w_t^a is the labor cost, and l_{at}^h is the hired labor in the production process.

Property rights over cocoa land are not fully secure. We describe the farmer's continued ownership as a random variable, whose realization is discovered by the farmer each year. Hence there are two states of nature; under state s_1 the farmer continues to control his or her plot and under s_2 he or she loses control. State s_2 is irreversible in the sense that lost plots are not recovered. In other words, expropriation may occur at some random time τ. Drawing from the duration literature (Lawless, 1982; Gourieroux and Josiak, 2001), one can define a survivor function, $S(t) = P(\tau \geq t)$, denoting the probability that the farmer keeps control of the plot (i.e., stays under state of nature s_1) until at least period t. Conversely, $(1 - S(t))$ is the probability that the farmer is in state s_2 in year t, given that he or she was in state s_1 previously. The corresponding hazard function of eviction is defined as

$$h(t) = f(t)/S(t), \tag{7}$$

where $f(t)$ is the probability function of land tenure. The hazard function can be interpreted as the instantaneous probability of losing control over a plot, given that it has been owned for t periods. Given a risk of expropriation at each period t, and a density function $f(t)$ for land tenure, $S(t)$ is derived from (7). Next, the expected utility is defined over the two states of nature based on $S(t)$, so that the farmer's problem is

$$Max \int_{t=0}^{\infty} \left\{U_{s1}(c_t) S(t) e^{-\delta t}\right\} dt + \int_{t=0}^{\infty} \left\{U_{s2}(c_t)(1 - S(t)) e^{-\delta t}\right\} dt, \tag{8}$$

subject to

$$c_t + r_t^c x_t^c + r_t^f x_t^f + I_t \leq \pi_{t-1}^c + \pi_{t-1}^f, \quad \text{under } s_1, \text{ and} \tag{9}$$

$$c_t + r_t^f x_t^{fa} \leq \pi_{t-1}^f, \quad \text{under } s_2 \tag{10}$$

and (1) to (7), where U is a well-behaved utility function (e.g., twice differentiable, strictly concave) defined over aggregate consumption c_t, and δ is a discount factor. In our particular application, we implement U as a power function: $U(c) = \frac{c^{1-\rho}}{1-\rho}$, where ρ is the relative risk aversion coefficient. Equation (8) represents expected utility defined over the two states of nature s_1 and s_2 (e.g., Gjerde et al., 1999; Kamien and Schwartz, 1971). With secure property rights, $S(t) = 1$, for all t, and the objective reduces to the first term of Eq. (8).

4. Model parameterization

Our parameterization of the model uses survey data from Cameroon. Key parameters for cocoa production are tree yields over time, costs and labor requirements for establishment and maintenance, plus initial tree stock distribution and the probability of expropriation when land tenure is not fully secure, and expected prices of both cocoa and food crops. For the aggregate food crop activity, we need annual labor requirement and yield, and for consumption decisions, we need a time discount rate and a risk aversion coefficient.

Cocoa yields over time for the baseline technology are estimated using experiment station data covering 12 years of trials in southern Cameroon. We use spline regression with these data to recover the yield profile of existing varieties, and then modify the regression parameters to project the yield profile of a potential new technology. Fig. 1 shows the resulting estimates, based on regression specifications and results presented in an appendix available from the authors on request. The modification of parameters to obtain the profile of a hypothetical new variety is grounded on two arguments. First, we consider the hypothesis made by Gotsch and Burger (2001) who argue that a combination of traditional breeding research and biotechnology may lead more resistance to known pests. Second, we use field observations that indicate that crop losses due to pest damage in Cameroon vary between 35 and 65% (Varlet and Berry, 1997; Nyasse, 1997); these losses are due to two main pests, the

$$d_v = \frac{1 - e^{\left(\frac{-1}{\rho\mu}\right)}}{1 + e^{\left(\frac{\mu - v}{\rho\mu}\right)}},$$

where d_v is the fraction of trees of vintage v which die in year t, ρ is the speed by which tree death rate increases as they grow older and μ is the age at which half of the trees of vintage v are dead. The parameters ρ and μ are obtained through calibration using our survey. Note that we use the exogenously given parameters to account for tree death rates while uprooting is endogenously determined in the model.

[3] Note that replacing old cocoa plantations with food crops or replanting with cocoa are the most current "strategies" but not the only ones. Conditional on access to markets, old cocoa plantations can also be replaced with other tree crops (e.g., oil palm, citrus, or rubber, etc.). For simplicity and also due to data availability, we only consider cocoa and food crops.

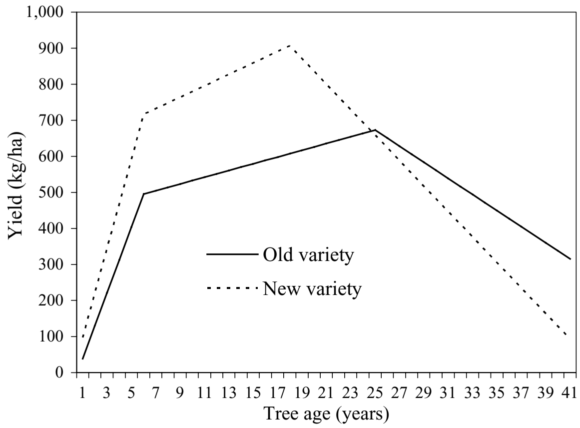


Fig. 1. Yield over time for old and new cocoa varieties.

capsid flying bug (*Heteroptera: Miridae*) which feeds on pods, leaves, and stems, and the fungus *Phytopthora* which causes black pod disease. Assuming a moderate level of pest resistance, we postulate a yield increase of 30%, in addition to the shorter gestation period that has been a longstanding target of cocoa breeding.

The establishment costs for new cocoa trees come from our field survey (Table 1), while the maintenance costs and labor for standing cocoa (Table 2) have been constructed using our survey plus data from Wyeth (1994) and Temple (1995). Using the new variety results in lower maintenance costs but higher fertilizer use, associated with their higher yields and greater uptake of soil nutrients. On balance, the cost of inputs decreases by 10%, which is similar to the estimate used by Gotsch and Burger

Table 1
Revenue and cash expenses associated with the establishment of new cocoa plantations (CFA)

	Year 1	Year 2	Year 3	Year 4
Revenues				
Revenue from cocoa (at CFA 400/kg)			4,000	30,000
Revenue from plantain		600,000	400,000	200,000
Revenue from cocoyam		250,000	250,000	250,000
Costs				
First clearing	15,000			
Tree felling	20,000			
Holing for plantain	24,000			
Cuttings of plantain	30,000			
Cuttings of cocoyam + planting	20,000			
Planting plantain	6,000			
Clearing	54,000	45,000	45,000	45,000
Planting cocoa	12,000			
Total cost	181,000	45,000	45,000	45,000
Cash flow	−181,000	805,000	609,000	435,000

Source: Survey data and estimates detailed in text.
Note: When cocoa upper canopy covers, plantain could be replaced by sweet banana; cost estimates do not include the value of forest land, which might cost CFA 25,000 to 100,000 depending on location.

Table 2
Annual labor requirement and cash expenditure required for maintenance of standing cocoa plantations

	Cash expenditure (CFA/ha)	Labor (man days/ha)
0–2 years		100
3–5 years		78
6–25 years	53,000	70
26–39 years	30,000	60
40+ years	25,000	60

Source: Survey data and estimates detailed in text.

(2001). Annual labor requirements are assumed to be the same for existing and new varieties, as the added labor needed for harvesting a larger yield is offset by the lower labor needs for pest control.

The labor requirements and yield for food crops are constructed using a survey conducted by the International Institute for Tropical Agriculture (IITA). The common practice in Cameroon is to mix up to five species (groundnuts, cassava, maize, cocoyam, and plantain) on a single plot. For tractability, these five have been converted into an aggregate food crop.

At $t = 0$, the area distribution is defined as in Table 3 and is chosen for each village so that the average yield is replicated by the average yield-age profile. Next, in the absence of detailed data, we assume that each age class is represented by trees at the midpoint of the age interval. For example, we assume that trees in the first age class are one-year old on average. Throughout the study, an average tree density of 1,200 per hectare is assumed, farm size is normalized to one hectare of standing cocoa, and there is no constraint placed on the access of virgin forest to be cleared conditional on the opportunity cost for clearing this forest. Thus, our model refers to a representative hectare of standing cocoa and an open forest frontier, rather than a representative household or particular farm. The opportunity cost of clearing each forest hectare is fixed at FCFA 62,500 (about 86 US$, at an exchange rate of 730 FCFA per US$), which corresponds to the average land cost observed in the frontier region of Cameroon in 2001.

On average, we assume that the probability of the incumbent farmer losing a given hectare is 0.01. In other words, on average each year one in a hundred plots is lost by the planter in a tenure dispute. This magnitude of probability seems consistent with

Table 3
Initial area and tree distribution per hectare

Age class	Area (ha)	Trees (no.)	Representative age
0–2 years	0.041	49	1
3–5 years	0.059	70	4
6–25 years	0.184	221	16
26–39 years	0.272	326	33
40+ years	0.445	534	40

Source: Authors' field survey.

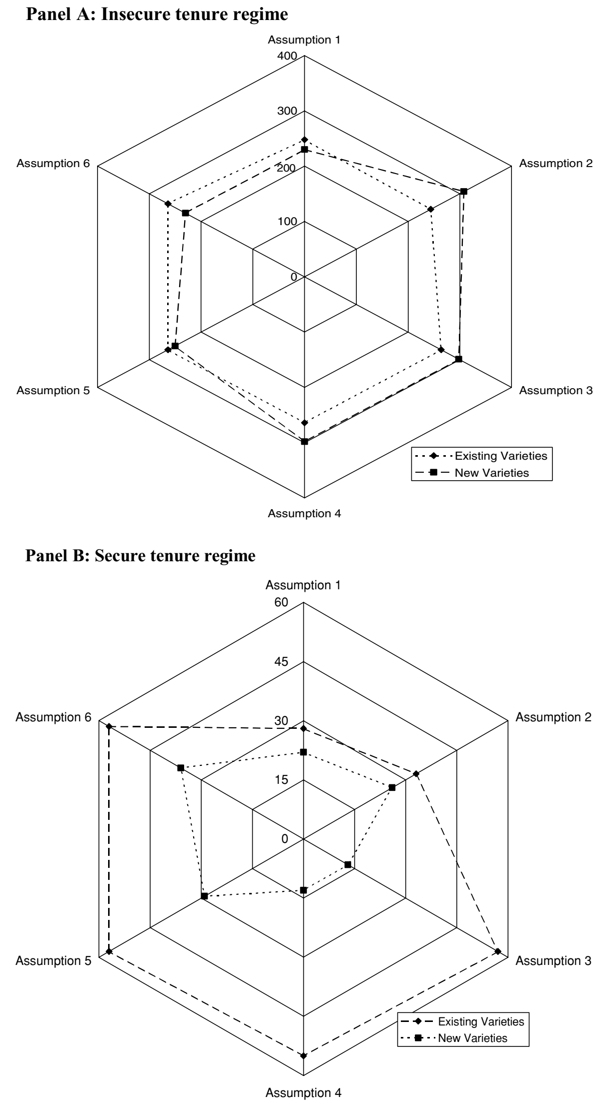
casual accounts (e.g., Chauveau, 2000; Degrande and Duguma, 2000). Though the probability of being expropriated at any given period is low, the cumulative effects over time are substantial. Finally, where risk aversion is considered we use a coefficient of 0.2, and for the discount rate we use sensitivity analysis around 10%, which is the rate used in previous studies of the cocoa sector in Cameroon (e.g., Wyeth, 1994), with a low of 5% and a high of 15%. These rates are all consistent with those used elsewhere for resource economics and in the evaluation of new technologies (Goeschl and Swanson, 2002; Alston et al., 1995). With a long-lived agent (as in our model) and any of these discount rates, the terminal value of the tree stock has little influence on investment choices, so it is not included.

To get expected prices of cocoa and food crops, we estimate a vector autoregressive system of these two price series, and then use the resulting parameters and the variance–covariance matrix to predict prices over the planning horizon, where the starting value are observed prices of cocoa and food crop in 2000. The estimated VAR form, the estimation results and the impulse-response function are presented in an appendix that is available on request.

5. Simulation results

The aim of the model is to assess smallholder response to exogenous shocks in both technology and tenure regime, over the long run. Our particular interest is in the extent to which farmers will replant old trees or clear new lands as the new cocoa varieties become available, under alternative property rights regimes and the possibility of significant risk aversion. To validate the model for this purpose, we used it to predict the number of replanted trees, the vintage composition, and the average yield in the two surveyed villages where such observations were available, and found that the model adequately simulates both new plantings and replanting (validation results are available on request).

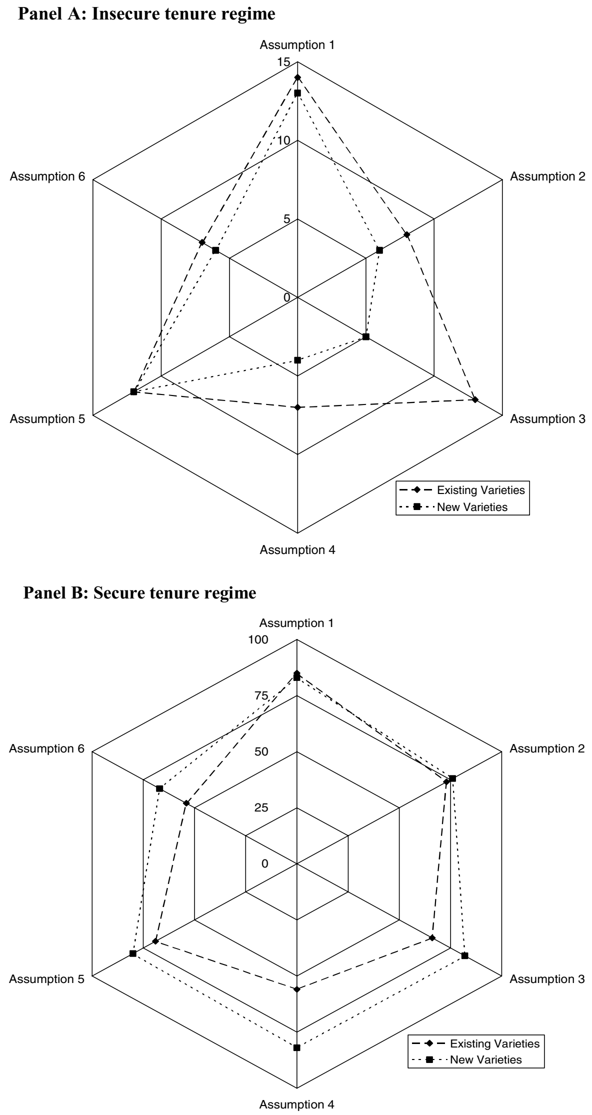
The main simulation results are provided in Table A.1, and summarized in Fig. 2 (for the deforestation rate) and Fig. 3 (for the frequency of replanting). The two figures are constructed in a similar way, but the scales differ. There are six assumptions (the combinations of three levels of discount rate on the one hand, the presence or absence of risk aversion on the other hand). Each edge of the web diagram corresponds to one of these hypotheses. The rates of deforestation in Fig. 2 are expressed as a percentage of the initial cocoa area. With insecure tenure (panel A), deforested area more than triples (that is, increases by more than 200%) over the 30 years, and tends to rise or stay high when the new variety is introduced. In particular, under assumptions 2 (5% discount rate and risk aversion), 3 (10% discount rate without risk aversion), and 4 (10% discount rate with risk aversion), introducing new varieties increases deforestation. With secure tenure (panel B), the rate of deforestation is much lower and it declines when the new variety is introduced, from 30–50% of the initial area to 15–40%.



Assumption 1: Discount rate 5%, no risk aversion
Assumption 2: Discount rate 5%, with risk aversion
Assumption 3: Discount rate 10%, no risk aversion
Assumption 4: Discount rate 10%, with risk aversion
Assumption 5: Discount rate 15%, no risk aversion
Assumption 6: Discount rate 15%, with risk aversion

Fig. 2. Projected deforestation over 30 years (percent increase over current cocoa area).

Table A.1, in the column labeled [a], provides the underlying data in decimal form as the number of additional hectares that are cleared over the 30-year period, in addition to the initial representative hectare of already-planted cocoa. The column labeled [b] of the Table A.1 shows the total number of hectares that are ever *re*planted over the 30-year period. Note that in a few cases, the area replanted is more than one hectare, as farmers have replanted not only their original hectare but also some of the land cleared during the forecast period. Combining the two columns allows us to compute the fraction of cocoa land that is ever replanted over the 30 years, which is shown in Fig. 3.



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Assumption 4: Discount rate 10%, with risk aversion
Assumption 5: Discount rate 15%, no risk aversion
Assumption 6: Discount rate 15%, with risk aversion

Fig. 3. Projected cocoa replanting over 30 years (percent of cocoa ever replanted).

This variable is always less than one, and is much larger when tenure is secure (panel B) than when it is insecure (panel B). Introducing the new variety when tenure is secure tends to raise the already-high level of replanting, while introducing it when tenure is insecure tends to reduce its already-lower level.

Table A.1, in its last two columns, also shows the welfare results of the model, first in terms of discounted aggregate consumption (expressed in CFA 10,000) and then in terms of the utility level. Introducing the new variety always raises farmers' welfare, as a direct consequence of the characteristics of the new technology. Its yield profile and cost structure are such that it is always more profitable than the old variety. Once it becomes available, all further plantings are in the new variety, gradually replacing the old. The resulting welfare gain is between 31 and 36% in terms of the net present value of long-run consumption, and slightly smaller in terms of utility when there is risk aversion, which reduces the gain to between 25 and 29%.

Our finding is an example of the complex interaction between technology and tenure systems discussed by Angelsen and Kaimowitz (2001b). In the Cameroon case, we find that, if insecurity persists, then introducing the new variety will raise the already-high deforestation rates, as its earlier payoff makes land clearing relatively more attractive. On the other hand, strengthening property rights when the new variety arrives would accommodate higher levels of investment through replanting rather than expansion, dramatically lowering the rate of deforestation. We emphasize that these results refer to property rights over cocoa after the forest is cleared, not access rights to the forest itself, which in both cases we assume is available for clearing at a fixed marginal cost per hectare.

6. Conclusions

This article uses a vintage-capital model with risk of eviction to assess cocoa farmers' response to changes in their tenure security and to the introduction of a new, faster-maturing cocoa variety. The model is calibrated with data from Cameroon in calendar year 2000, and then used to simulate the effects of institutional and technical change on farmer welfare and deforestation rates.

Simulation results can be summarized as follows. First, increasing farmers' land tenure security unambiguously raises their consumption and welfare, by supporting higher investment rates. But with traditional cocoa varieties, this increased investment takes the form of a relatively high rate of deforestation, because investing in existing plantations offers a relatively lower payoff than clearing new forest.

Second, introducing new cocoa varieties with faster maturity and higher input response also unambiguously raises farmers' consumption and welfare, by raising the payoff to all investment. But doing so under a relatively insecure rights regime further raises the deforestation rate. In contrast, doing so under a fully secure regime has the opposite effect, reducing the deforestation rate, as the new variety raises the relative payoff to further investment on existing plots.

Third, when introducing the two innovations together (more security and also new varieties), there is a large increase in welfare and, on balance, a decline in deforestation. Thus, the benefits from the development of new cocoa cultivars for both farmers and the environment (in terms of slowing down deforestation) will be the largest if policies leading to more secure tenure over cocoa lands are implemented.

Finally, our conclusions must be interpreted in the perspective of some of the assumptions we have maintained. First, we assumed constant yield for the food crop and constant opportunity costs for clearing the new forest. In reality, land pressure and decreasing land fertility may contribute to increase new forest opportunity costs and decrease food crop yields over time—although simulation results not shown here indicate that our results do not change significantly if food crop yields decrease at the rate of 1% per year and opportunity costs of new forest increase at the rate of 2.5% per year. Second, discarded cocoa land can be used for food crops, an aspect we rule out in the model. Third and perhaps more importantly, the model assumes fixed number of farmers, thus ruling out the possibility that more secure land rights may attract more migrants, thus resulting into more new clearing. Extension of our model to consider these and other changes could be very helpful, and provide further insight into the interaction between technology and institutions. Additional work might focus particularly on our central finding that the introduction of higher-productivity techniques can sharply raise the payoff to stronger property rights.

Acknowledgments

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Appendix

Table A.1
Impact of new variety by tenure status, risk aversion, and discount rate

Coefficient of relative risk aversion	Tenure status	Investment levels				Household welfare	
		Clearing of new forest areas (ha) [a]	Replanting of cocoa trees (ha) [b]	Total area planted or replanted (ha) [a+b]	Replanting rate (%) b/[a+b]	Discounted consumption (CFA'0000)	Utility level
			Lower discount rate (5%)				
Old variety only							
0	Secure	0.28	1.63	1.91	85	85.7	85.7
0	Insecure	2.48	0.41	2.90	14	77.5	77.5
0.2	Secure	0.33	0.90	1.23	73	85.7	50.4
0.2	Insecure	2.44	0.21	2.65	8	77.4	46.4
Old and new varieties							
0	Secure	0.22	1.03	1.25	83	112.2	112.2
0	Insecure	2.30	0.34	2.65	13	102.9	102.9
0.2	Secure	0.26	0.82	1.07	76	112.2	62.6
0.2	Insecure	3.08	0.21	3.28	6	102.9	58.5
			Medium discount rate (10%)				
Old variety only							
0	Secure	0.57	1.12	1.69	66	474.9	474.9
0	Insecure	2.64	0.39	3.03	13	418.3	418.3
0.2	Secure	0.55	0.69	1.25	56	474.8	270.0
0.2	Insecure	2.64	0.21	2.84	7	418.3	244.0
Old and new varieties							
0	Secure	0.13	0.58	0.71	82	629.7	629.7
0	Insecure	2.98	0.14	3.12	5	568.0	568.0
0.2	Secure	0.13	0.58	0.71	82	629.7	338.9
0.2	Insecure	2.98	0.14	3.12	4	568.0	312.3
			Higher discount rate (15%)				
Old variety only							
0	Secure	0.57	1.26	1.83	69	309.7	309.7
0	Insecure	2.64	0.36	3.00	12	275.1	275.1
0.2	Secure	0.57	0.67	1.24	54	309.7	178.5
0.2	Insecure	2.64	0.20	2.84	7	275.1	162.2
Old and new varieties							
0	Secure	0.29	1.15	1.44	80	415.6	415.6
0	Insecure	2.50	0.33	2.83	12	375.3	375.3
0.2	Secure	0.36	0.72	1.08	67	415.6	226.1
0.2	Insecure	2.30	0.14	2.44	6	375.3	208.6

Source: Model simulations, as detailed in the text.

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