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**Property Rights, Production Technology and Deforestation:
Cocoa in West Africa**

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Property Rights, Production Technology and Deforestation: Cocoa in West Africa

Abstract

In this paper, 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 accelerate investment and reduce deforestation.

Property Rights, Production Technology and Deforestation:

Cocoa in West Africa

1. Introduction

About seventy percent of the world's cocoa is produced by West African smallholders (FAO 2002). The typical production system involves clearing virgin forest to plant new trees, and later replacing old cocoa plantations with food crops (Ruf, 1994). The future of such cocoa-led deforestation is an urgent question for both environmentalists and for the cocoa industry, as West Africa's 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 then fall as the tree grows older. Recent research 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. 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. Here we focus on property rights over the cocoa fields, which could have a particularly important influence on production because the trees are such long-lived, irreversible investments. Faster maturity could help make investment less sensitive to expropriation risks, but their higher potential payoff might make raise the stakes and increase that sensitivity.

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.

Previous work has focused on either the effects of new cocoa technology (e.g. Gotsch and Burger, 2001; Gotsch and Wohlgenant, 2001), or the longstanding problem of tenure over trees (e.g. Hill, 1963, Ruf and Zadi, 1998). Our innovation is to examine their interaction. 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 two of the paper; then section three presents the model, section four describes the data and parameters, section five summarizes our results, and section six 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.¹ 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 leads to new rules for land tenure (Chauveau, 2000), often distinguishing between the rights of migrants and those of

¹ Other kinds of conflict also arise, of course, even within families. For example, Hill (1963) focuses on conflicts in which land is collectively owned but individuals have private rights over the trees. Our model is motivated by the migrants' problem, but can accommodate other kinds of expropriation risk.

indigenous people. Ruf and Zadi (1998) argued that, in Cote d'Ivoire, the 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 (1987) and Wilson (1999), who find that zero-shade cocoa farms have higher yields in the short run but have shorter lifespans than shaded farms.

In many contexts, tree planting is 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). But states' power to implement and enforce formal registrations has been limited, and 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 analytical approach uses 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 set-up 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 either cocoa or an aggregate of all other goods, that includes both food crops and off-farm activity. The cocoa plantation requires long-term investment, with 2 to 6 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.

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

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):

$$a_{t1} = r_t + n_t \quad (2)$$

Once planted, trees remain unless uprooted or killed by disease:

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

Where u_{tv} is area in vintage v uprooted in year t , and d_{tv} is area of land occupied by the trees that died in year t . Each year, the area replanted in year 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 year, becomes no longer available for cocoa. This constraint is written as follows:

$$r_t \leq \sum_v u_{tv} + \sum_v d_{tv} \quad (4)$$

In year t , profit from cocoa production is:

$$\pi_t^c = p_t^c y_t^c - w_t^c x_t^c - w_t^n n_t - w_t^r r_t \quad (5)$$

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

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

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

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 controls his plot and under s_2 he loses control over the plot. 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; Gouieroux and Jasiak, 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 farmers finds himself in state s_2 , in year t , given that he has been in state s_1 previously. The corresponding hazard function of eviction is defined as:

$$h(t) = f(t)/S(t) \quad (9)$$

where $f(t)$ is the probability function of land tenure. The hazard function can be interpreted as the instantaneous probability of loosing 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 (9). Next, the expected utility is defined over the two state of nature by using the $S(t)$, so that the farmer problem is:

$$\text{Max} \int_{t=0}^{\infty} \{U_{s_1}(c_t)S(t)e^{-\delta t}\} dt + \int_{t=0}^{\infty} \{U_{s_2}(c_t)(1-S(t))e^{-\delta t}\} dt \quad (10)$$

Subject to:

$$c_t + r_t^c x_t^c + r_t^f x_t^f + I_t \leq \pi_{t-1}^c + \pi_{t-1}^f, \quad \text{under } s_1, \text{ and} \quad (11)$$

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

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.

Equation (10) 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), and in our particular application we implement U as a power function:

$$U(c) = \frac{c^{1-\rho}}{1-\rho}, \text{ where } \rho \text{ is the relative risk aversion coefficient.}$$

With secure property rights, $S(t) = I$, for all t , and the objective reduces to the first term of 10. Jacoby et al. have used a similar model to evaluate land expropriation rate effects on farm investments in China in an econometric framework.

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. 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 tree yield over time (cf. figure 1). The estimated parameters are then modified to get the age yield profile of a potential technology (figure 1), following the assumptions by Gotsch and Burger (2001) who argue that a combination of traditional breeding research and biotechnology may lead to a yield increase in the order of 30 percent along with more resistance to known pests. The yield profile of the new technology reflects the historical focus of cocoa breeding, which has been to develop

a higher yielding tree with a shorter gestation period. However, the yield decline for such trees has been faster than the traditional variety.

The establishment costs come from our field survey (table 2), and the labor requirements and production costs for cocoa have been constructed using survey data, and also data from Whyeth (1994) and Temple (1995). The labor requirements and yield for food crops are constructed using a survey conducted by the IITA. The common practice in Cameroon is to mix up to five crops (groundnuts, cassava, maize, coco yam, and plantain) on a single plot. For tractability, these five crops have been converted into an aggregated crop as explained in the appendix.

At $t = 0$, the area distribution is defined as in table 1 and is chosen for each village so that the average yield is replicated by the average yield-age profile. Next, in absence of detailed data, we assume that each class age is represented by the average age between the two extremes of the interval. In the first class, for example we suppose that trees of this class are one year old on average. Throughout the study, an average tree density of 1200 per hectare is assumed, and farm size is normalized to one hectare of standing cocoa, and one hectare of virgin forest that may or may not be cleared. The opportunity cost of clearing that hectare is fixed at FCFA 62500² (about US\$86), 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 his plot 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 casual accounts (e.g. Chauveau 2000, Degrande and Duguma, 2000). Though the probability of being expelled at any given period is low, the cumulative effects over time are substantial.

² The exchange rate adopted is US \$ 1= FCFA 730

Finally, where risk aversion is considered we use a coefficient of 0.2, and for the discount rate we use 10 percent, which is the rate used in previous studies of the cocoa sector in Cameroon (e.g. Wyeth, 1994). With an infinitely living agent (as in our model) and such a high discount rate, the terminal value of the tree stock has little influence on investment choices, so it is not included.

5. Simulation results

The aim of the modeling is to assess smallholder response to exogenous shocks in 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, given alternative property right regimes and the possibility of significant risk aversion. To validate the model, 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 summarized in table 3 (with only the existing variety) and in table 4 (when the new variety becomes available). The three first columns in the tables refer to investments in terms of clearing of new forest and replanting existing fields over the planning horizon (i.e. 30 years). The last three columns refer to welfare, in terms of discounted aggregate consumption (expressed in FCFA 10,000 and in US dollars) or utility level.

Results in table 3, representing cocoa planters' choices when only the old variety is available, show that making their land claims fully secure increases their discounted

consumption from 8.44 to 9.27 million FCFA, or from US\$11,565 to \$12,708 (a gain of almost 10 percent) in the absence of risk aversion, and this result is robust to increasing the relative risk aversion coefficient from 0 to 0.2. Increasing tenure security over cleared land does, however, raise the rate of deforestation, as farmers slightly increase the rate at which they prepare new lands from around 0.92 of the one hectare assumed to be available, to 0.97 or 0.99 (depending on their level of risk aversion).

The impact of introducing the new tree varieties is shown by comparing table 4 to table 3. Consumption and utility levels rise by about 25%, or 2.3 million FCFA (or US\$3,151) in the absence of risk aversion, and this gain is insensitive to change in relative risk aversion from 0 to 0.2. More interestingly, when the tenure regime is fully secure, introducing the new variety will cause farmers to reduce their land-clearing rates by about 6 percent (from 0.969 to 0.906 of the available hectare without risk aversion, or from 0.997 to 0.937 with risk aversion). But when land tenure is insecure, introducing the new variety causes precisely the opposite effect, as the earlier maturity makes clearing relatively more attractive and farmers clear the entire one hectare available—an increase in deforestation of about 8 percent. Introducing both together (increasing security at the same time as the new variety arrives) reduces land clearing rates by about 1.5 percent, from 0.921 to 0.906 of the available hectare without risk aversion, or from 0.920 to 0.937 with risk aversion at the 0.2 level.

Our finding that the introduction of faster-maturing and higher-yielding varieties causes a decrease in deforestation under secure tenure, and an increase in deforestation under an insecure regime, is an example of the complex interaction between technology and tenure systems discussed by Angelsen and Kaimowitz (2001). In the Cameroon case,

we find that, if insecurity persists, then introducing the new variety will raise 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 reduce deforestation, by increasing farmers' incentive to invest in existing lands. This result is robust to risk aversion, but does depend crucially on the technological characteristics of the innovation.

6. Conclusions

This paper 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, since 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.

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Table 1. Initial area and tree distribution per hectare.

age class	Area	Trees	Age
0 to 2 years	0.041	49	1
3 to 5 years	0.059	70	4
6 to 25 years	0.184	221	16
26 to 39 years	0.272	326	33
more than 40	0.445	534	40

Figure 1: Age yield profile for old and new cocoa varieties, kg/ha

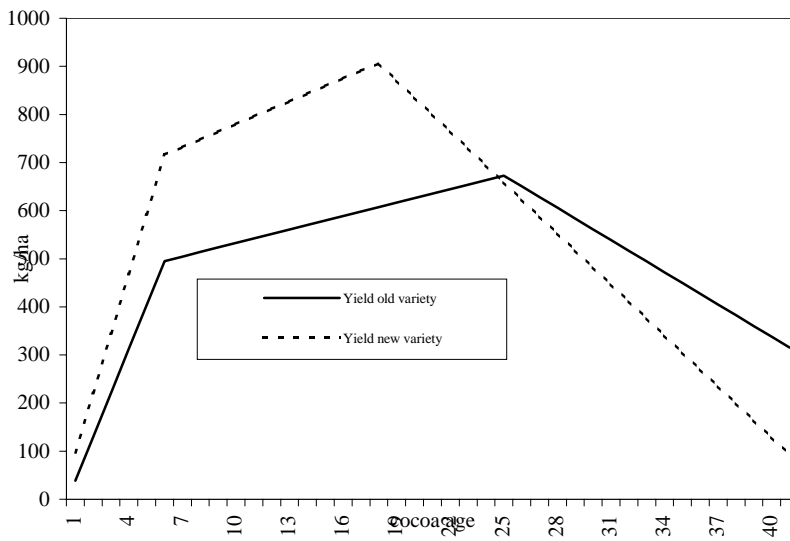


Table 2 establishment and production costs

	Year 1		Year 2		Year 3		Year 4		
	Qty	unit	Cost in FCFA	Qty	unit	Cost in FCFA	Qty	unit	Cost in FCFA
Revenue from cocoa (CFA 400 /kg)			0			4000			30000
Revenue from plantain			0			400000			200000
Revenue from cocoyam			0			250000			250000
First clearing	1		15000						
Tree Falling	1		20000 (keep some tress for shade)						
Holing for plantain	1200	unit	24000						
Cuttings of plantain	1200		30000						
Cuttings of cocoyam+plantain			20000						
Planting plantain	1200		6000						
Clearing	3	unit	54000	3	unit	45000	3	unit	45000
Seed bed	1200								
Planting cocoa	1200		12000						
Harvesting plantain									
Harvesting cocoyam									
Operating costs	0		0			0			0
Phytosanitary Harvest	0		0			0			0
Pruning	0		0			0			0
Fungicides	0		0			0			0
Pesticides	0		0			0			0
Harvest, transport and drying	0		0			0			0
Costs			181000			45000			45000
Cash Flow			-181000			809000			435000

* When cocoa upper canopy covers, plantain could be replaced by sweet banana

* An ha of forest costs FCFA 25 000 to 100 000 depending on the location (near a road or not for example)

Table 3: Summary of results with only old variety

		Old variety only					
		Investments			Welfare		
		Clearing	Replanting	Rep. Rate	Dis. Cons	Dis. Cons ^a	Utility
R. Risk av.	Tenure						
	0.0 Secure	0.969	1.383	0.588	927.67	12707.74	927.67
	0.0 Insecure	0.921	0.957	0.510	844.24	11564.92	844.24
	0.2 Secure	0.997	1.356	0.576	927.65	12707.56	460.45
	0.2 Insecure	0.920	0.947	0.507	844.23	11564.82	427.40

a: Discounted consumption evaluated in US \$ (\$ 1= FCFA 730)

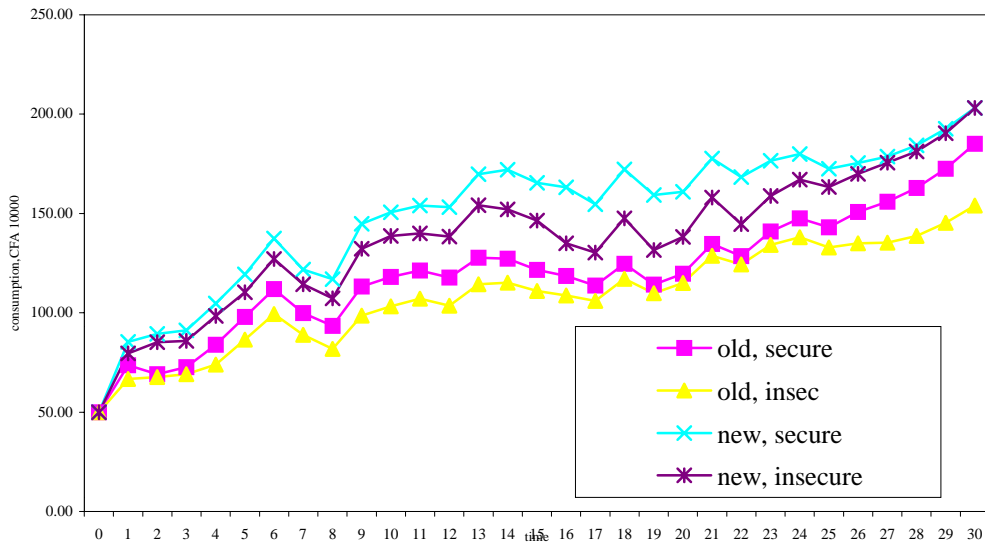
Table 4: Summary of results when new variety is made available

		Old and new varieties					
		Investments			Welfare		
		Clearing	Replanting	Rep. Rate	Dis. Cons.	Dis. Cons ^a	Utility
R. Risk Av.	Tenure						
	0.0 Secure	0.91	1.08	0.544	1160.98	15903.79	1160.98
	0.0 Insecure	1.00	1.41	0.586	1065.87	14600.97	1065.87
	0.2 Secure	0.94	1.09	0.538	1160.96	15903.55	549.92
	0.2 Insecure	1.00	1.41	0.585	1065.87	14600.96	514.12

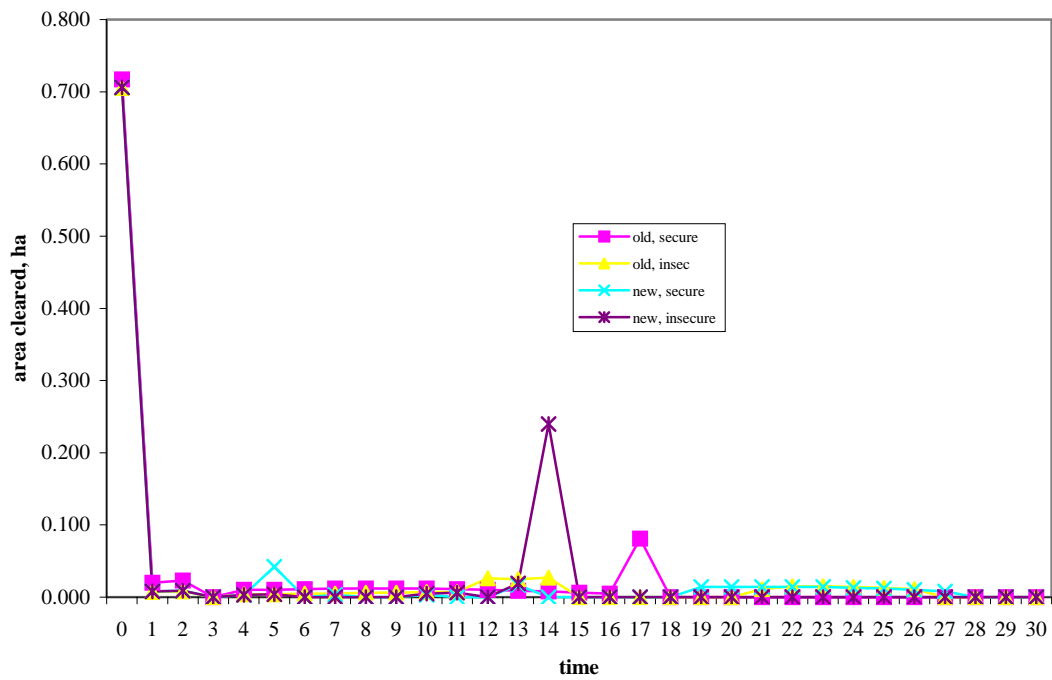
a: Discounted consumption evaluated in US \$ (\$ 1= FCFA 730)

Graphs of selected optimal plan (secure property rights)

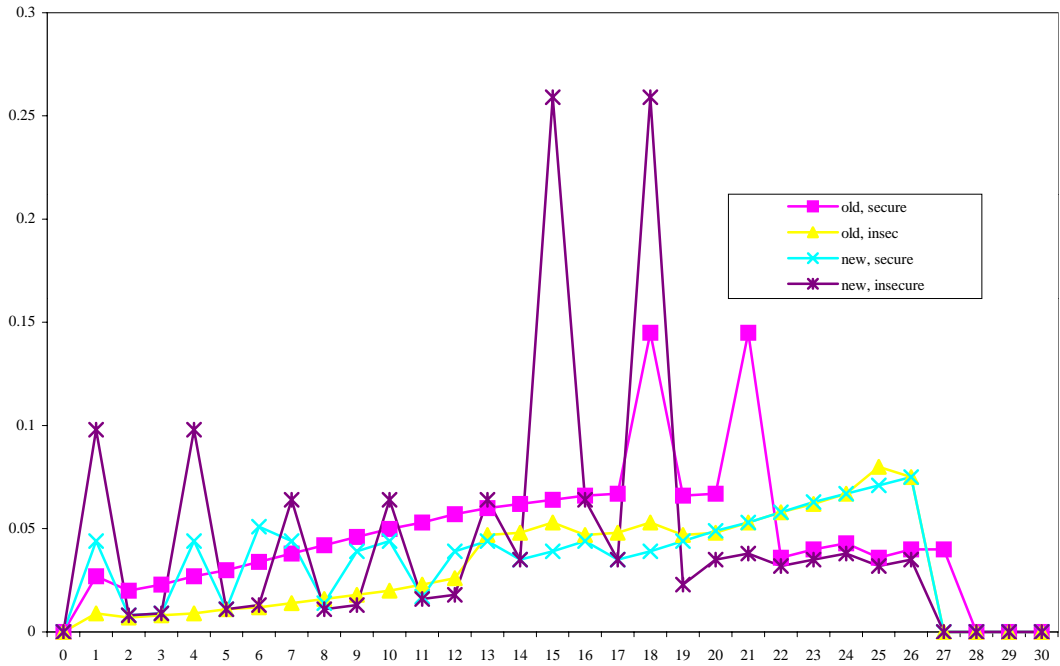
Graph 1: Aggregate consumption over time



Graph 2: New forest clearing over time



Graph 3: Replanting over time



Note: Replanted trees replace area left vacant due to uprooting and exogenous tree deaths

Graph 4: Area uprooted (and replanted) over time

