10 Coffee, Pastures, and Deforestation in the Western Brazilian Amazon

A FARM-LEVEL BIOECONOMIC MODEL

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Tropical moist forests are disappearing every year, and much clearing is driven by the demand for agricultural land. This conversion of forest to agriculture carries with it costs and benefits. The costs include soil degradation, deterioration in water quality and availability, biodiversity loss, and conflict with traditional forest dwellers. The benefits, production of food and fiber for consumption and sale, can also be considerable for inhabitants of forest margin areas and populations depending on agricultural exports from these areas, but large gaps in assessments of environmental and poverty dimensions prevent an evaluation of the overall impact of forest conversion. Activities at many levels (e.g., the Biodiversity Convention, Kyoto Protocol, Amazon Treaty Organization, Pilot Program to Conserve the Brazilian Rain Forest, and national-level movement to protect extractive reserves in Brazil) that seek to mitigate further deforestation via some kind of government intervention respond to a scenario in which, at the private level, the benefits of clearing land outweigh the costs of land conversion, and social costs of deforestation are higher than the benefits.

In the past, economists paid attention mainly to external drivers of deforestation such as distorting macro policies and Amazon settlement subsidies (e.g., Hecht 1985; Binswanger 1987). Most of these policies have been stopped, yet deforestation continues. This suggests that external drivers apart from policies may be at work, but more importantly, that internal drivers—factors within the region—may play an important role. Recent analyses of these internal drivers failed to integrate production systems effectively into either a whole-farm view or into current socioeconomic conditions of small-scale farmers in the western Brazilian Amazon

(Vosti et al. 2002). In their review of economic models of deforestation, Kaimowitz and Angelsen (1998) found that national models failed to account for internal drivers.

Although some believe that improving yields on already cleared land in forest margin areas will take pressure off the remaining forest, and promoting perennial and agroforestry systems will alleviate some ecological damage caused by deforestation, responses by resource users to technology and policy changes are not necessarily straightforward. This chapter looks at those responses, which ultimately will determine the impacts of forests and rural inhabitants on policy and technology change.

In part to fill this gap, a Farm Level Bioeconomic Model (FaleBEM) was built to study how various policies and technology interventions affect land use decisions of small-scale farmers in the western Brazilian Amazon. The western Brazilian Amazon is home to much of the world's remaining tropical moist forests and to more than 500,000 small-scale farmers whose annual decisions to deforest (or not) will have a large influence on the ultimate fate of the forest. For instance, an average small-scale farmer in the settlement project of Pedro Peixoto, Acre, slashed and burned 2.46 ha of forest per year (Lewis et al. 2002), annually emitting 367 t of carbon contained in this forest (Palm et al. 2002; Lewis et al. 2002). Using linear programming to simulate consumption-maximizing behavior of farm households, the FaleBEM incorporates farm-level objectives and constraints to production; can be adjusted to fit the heterogeneity of land, labor, and farm household characteristics prevalent in the area; and tracks the income, soil productivity, carbon stock, and forest depletion impacts of current and proposed technology or policy experiments.

The FaleBEM helps structure thinking about these issues and replaces "I think" statements with "if–then" statements through policy experiments. It differs from purely economic models in that it simulates biophysical processes and economic activities based on optimization algorithms. What differentiates this BEM from most BEMs applied to developed countries, such as those of Shortle (1984), Ellis et al. (1991), Dosi and Moretto (1993), and Carpentier et al. (1998), is the feedback of soil fertility depletion and regeneration on agricultural production and deforestation. The FaleBEM effectively links deforestation decisions to production decisions on the cleared land. Also, FaleBEM overcomes criticisms of many linear programming models by approximating nonlinear production and damage functions with linear segments (Barbier and Bergeron 1998).

For this chapter, the model was used to predict the effect of changes in input and product prices, particularly that of coffee (*Coffea canephora* Pierre ex Fröhner L.), between 1994 and 1996 in the state of Acre. Model simulations of land use for the 1994 baseline for the settlement project of Pedro Peixoto in Acre are compared with simulations of 1996 with more favorable coffee prices.

METHODS

The Model

The FaleBEM, a dynamic mathematical programming model written and solved in GAMS (Brooke et al. 1992), was developed to model the decisions of representative small-scale subsistence-oriented settlers in the Pedro Peixoto project in the western Brazilian state of Acre. It simulates the typical farmer's responses to a wide range of policy, technology, and project interventions. The model incorporates all the important biophysical and economic factors thought to affect farmers' decisions about land use and deforestation (see Lewis et al. 2002, for a more detailed description of the model).

The model assumes that farmers maximize the discounted value of their household consumption over a 15-year time horizon, but it is not a utility-maximizing model because it values consumption but not leisure time. However, this maximization is subject to serious labor constraints. Previous work has shown that labor availability is the major factor in slowing deforestation (Lewis et al. 2002).

Although the model has a 15-year planning horizon, it is solved recursively at 5-year intervals. If one updates all the constraint values for each solution, a series of moving 15-year farm plans are obtained that can be used to track much longer periods of time than the initial 15-year period. This is especially useful for exploring long-term changes in land use and the sustainability aspects of different farming practices. The results presented in this chapter are based on a 25-year period and were derived from five recursive runs of the model for each policy experiment.

There are also minimum consumption constraints that must be met each year for food, clothes, and farm implements. The model allocates farm income each year to consumption and on-farm investments. When income is invested it increases future production potential, and hence future consumption, but at the expense of current consumption. Income is generated in the model by the production of products for home consumption or sale. Production choices are subject to an array of resource and technology constraints, including seasonal land, labor, and cash flow constraints. For example, in keeping with local restrictions on markets, milk sales are constrained by quotas, and the maximum amount of hired labor that can be acquired in any given month is restricted to 15 worker-days. In addition to agricultural production, the household can engage in extractive activities in the forest (e.g., harvesting Brazil nuts [*Bertholletia excelsa* Humb. & Bonpl.]) and can sell household labor off farm. It can also hire nonfamily labor to work on the farm. Because the region is only a small producer of most products, all output prices are fixed in the model. This assumption is less defensible for nontimber tree products because these products have limited marketing outlets. But the model produces such small quantities that the impact on consumption of any price effects can reasonably be ignored. Potential general equilibrium effects on the input side, especially labor and wages, were addressed through sensitivity analyses. Because the model does not include risk, and land cannot be rented, purchased, or sold, results must be interpreted in light of these realities: Would risk and land markets change the land use patterns shown here? These issues are addressed in this chapter.

The model also tracks soil fertility and soil nutrient balances, and these influence future productivity levels within the planning period of the model. Soil fertility can be improved by adding inorganic fertilizers, by changing the cropping pattern, by putting land into fallow, or opening new areas to production (deforesting). Soil nutrients in the forest, fallow, and cultivated areas are tracked and linked to crop nutrient demands and yields; this provides a link between deforestation decisions and production decisions on the cleared land. This link is modeled by allowing farmers to choose between growing the crops with all the nutrients needed to achieve the average yield for a given soil type and crop or using fewer nutrients and suffering the yield consequences depicted in figure 10.1. Choosing to produce with nutrient deficiency (*c*) has a yield reduction effect (*b*) calculated as $y-(b/c\,\mathrm{ND})$, where y is the yield when nutrient requirements are met, and ND is the level of deficiency chosen by the model. The model approximates each land use's yield response function by dividing and linearizing the nutrient yield–response function into three sections (O 1–3 in figure 10.1) and measuring yield reductions based on the slope of the curve at the chosen level of deficiency, ND. Agronomic and soil productivity decline and buildup,

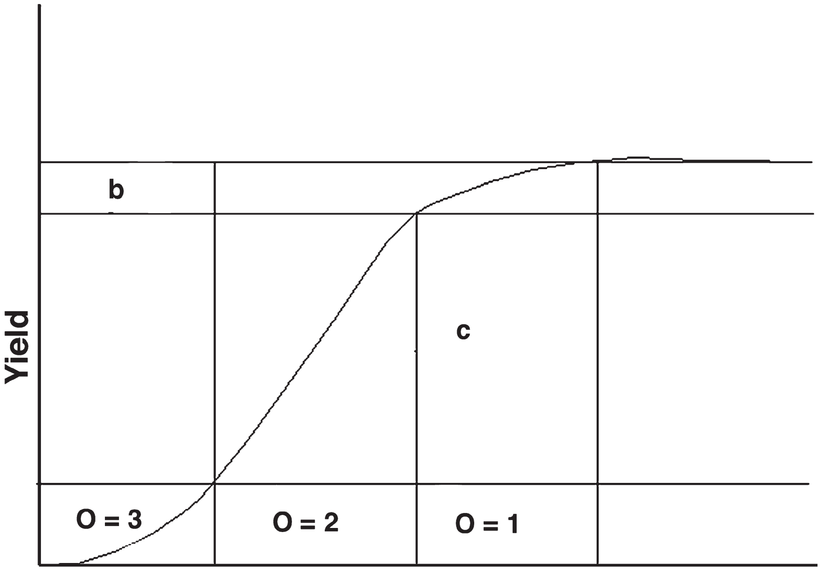

Figure 10.1 Hypothetical crop yield response to varying soil nitrogen levels. Point *b* is the decrease in crop yield expected for a given nitrogen deficiency in the soil of *c;* O = threshold levels of nutrients.

as well as crop yield responses, were modeled using local crop and soil expert opinion and published data.

The FaleBEM also keeps track of how many hectares of forest and of each cleared land use are on the farm in any year and the age of these land uses. Using this information, the farm's carbon stock in any year is determined. The FaleBEM can be used to perform carbon policy experiments, such as mandating a minimum amount of carbon that must be maintained in any year or allowing farmers to be paid for carbon stocks or flows (Carpentier et al. 2000). Estimates of carbon stocks by land use are from Lewis et al. (2002) and from chapter 2 of this volume.

Other agronomic constraints restrict land use dynamics and thus the long-term composition of the farm. Pasture is least restricted in that it can be planted after any land use and on all soil types. Annual and perennial crops can be planted only after other crops, burned forest, or fallow areas. In the absence of added inputs, the number of consecutive years crops can be planted on the same plot of land is limited by the decline in yields that accompanies the exhaustion of nutrients left after the burn and subsequent planting. In the model, farmers can choose to apply commercial fertilizer or to face smaller yields. Observed and reported yields declined over the years after the burn because most farmers do not use prohibitively expensive commercial fertilizers. After 2 years of annual cropping, farmers reported switching to pastures, fallow, or perennials because without adding fertilizers annual crop yields would be too low.

Economic activities and associated land uses affect soil productivity, which in turn affects future land uses and yields. The long-term effects of these interactions are taken into account in FaleBEM using a discretely dynamic modeling approach in which the state of the economic and environmental resources at the end of year $t = 1$ becomes the initial condition for decision-making in year $t = 2$.

More specifically, forest and other stocks are carried over from one production year to the next to become the initial natural resource stock for the next year. This discretely dynamic model is initiated in the first year of simulation with a set of initial conditions describing a farm and farmer's family characteristics in 1994 that were derived from field surveys for a group of farmers well situated vis-à-vis markets (see Witcover and Vosti 1996). These include characteristics such as hectares in different land uses, forest remaining, and on-farm labor (family composition). Basically, this model presents the farmer with the complete set of land use options and intensity levels available in the area, and some experimental ones, and then performs several "reality checks" that constrain farmer decisions, such as input availability, reversibility of land use decisions, and profitability. Financial returns for each activity are the product of the activity's yield and output prices minus input costs. With all this information in hand, the model selects, from all possible land use paths (over a 15-year period), the one that maximizes the discounted sum of consumption that results from yearly allocation of income to investment or consumption discounted to the present using a 9 percent discount rate.

Land use activities can be modeled at three levels of technology, V1, V2, and V3, each with associated input and output technical coefficients. V1 is the dominant traditional production system for small farmers in the area. It is land and labor intensive and uses limited external inputs. V3 is the recommended technology package of the state branch of the national agricultural research agency, Empresa Brasileira de Pesquisa Agropecuária (Embrapa). The intermediate technology level, V2, uses some improved management and commercial inputs but not necessarily at recommended levels. This level reflects the way small-scale farmers adopt new technology packages incrementally, instead of whole packages at once. As the level of technology intensifies from V1 to V3, management (controlled burning, increased weeding, spacing, control breeding, and herd rotation) generally improves, reliance on commercial inputs (seeds, fertilizers, pesticides, vaccines, feed supplements) increases, and the quality of these inputs (seeds, bulls, and cows) increases. Labor may decrease or increase depending on the activity. Generally, farmers using V3 technology apply commercial fertilizers and pesticides, whereas those using V1 and V2 do not. The V1 technology implies use of seeds kept from previous years, whereas V2 and V3 imply use of commercial seeds. Perennials are grown with technology V1 or V3; that is, farmers usually adopt the recommended technology package or keep their traditional practices. Perennials cannot be stored because they are highly perishable; they are sold in the month in which they are harvested (in Rondônia, 20 percent of output is consumed by the family or spoiled [Oliveira 1998]).

Data

The model was built using economic parameters collected during fieldwork, such as input (including monthly labor) and output levels. Parameters for the model were generated through statistical analysis of detailed farm surveys conducted in Pedro Peixoto with eighty-one farmers in 1994 and sixty-two of the same farmers in 1996. Prices were drawn from secondary data supplemented by fieldwork. Our fieldwork revealed that farmers form their expectation of this year's prices based on last year's, mainly harvest, prices. Because the model tries to replicate the 1994 (1993–1994) and 1996 (1995–1996) land use decisions, 1992–1993 and 1994–1995 prices are used for all crops and livestock for the 1994 and 1996 simulations, respectively. Brazil nut prices are an exception to this rule; 1994 and 1996 prices were used because families can observe current prices before deciding whether to gather Brazil nuts. Together, these factors determine financial returns to activities undertaken at different scales. The preliminary results of the model were calibrated by groups of experts.

BACKGROUND DATA AND MODELING RESULTS

Characteristics of Acre and the Pedro Peixoto Settlement Project

Nine percent of the state of Acre (15.25 million ha) has been deforested (chapter 12, this volume). Most of the deforested area is under pasture (900,000 ha), followed by annual crops (108,000 ha), fallow land (64,000 ha), and banana (*Musa* X *paradisiaca* L., 8000 ha) (IBGE 1996). Cattle herd size in 1996 was 794,307 head and has now reached 1.2 million (chapter 12, this volume). In 1996, 36 percent of these animals were on small farms of less than 100 ha, and this number is expected to have grown to 50 percent by 2000 (Valentim, pers. comm. 2002). Pests and insects are common and cause sporadic damage. Because of agronomic constraints coupled with economic viability, most cleared land eventually is planted to pasture. Most farmers use extensive pasture systems with minimum management and thus labor, which results in substantial amounts of pasture. Valentim (1989) reports that in 1989 an estimated 70 percent of the 600,000 ha of pasture in Acre was degraded or in the process of being degraded. Traditional pastures can degrade quickly. However, with better management (including past and present stocking rates, quality of the initial forest burn, frequency of pasture burning, and the quality and adaptability of the grass planted, as well as soil improvements), the decrease in pasture carrying capacity can be reduced.

Table 10.1 summarizes land uses of the farms surveyed in Pedro Peixoto in 1994 and 1996. In 1994, farm size averaged 91.1 ha, 70 percent of which was still forested, 58 percent of their cleared land was in pasture, and more than 90 percent of farmers had some pasture. The forest, annual crop, and fallow areas decreased between 1994 and 1996; pasture areas increased, as did mixed crops and perennials, with high growth rates but in extremely small areas. According to Fujisaka et al. (1996), after 2 years of annual crops, 64 percent of farmers in Pedro Peixoto in 1994 planted their land to pasture, 36 percent let it go into fallow, and none planted it to perennials or annuals.

Banana and coffee are the main perennial crops in Pedro Peixoto, although they are grown at very limited levels. Annuals and perennials are labor intensive, few herbicides are applied, and no animal traction or mechanical implements are used. On average, farmers had 0.37 ha of coffee in 1996 and a total of 1.3 ha of perennials, including banana. Bananas are integrated into agroforestry systems to shade young trees, planted in monoculture, or used in farm gardens. Although coffee is common

Table 10.1 Area in Different Land Uses and Percentage Land Use Change for Farms Sampled in the Pedro Peixoto Project in 1994 and 1996

Land Uses	**1994 (ha)**	**1996 (ha)**	**Change (%)**
Forest	61.5	55.6	–9.5
Annuals	4.6	2.5	–45.7
Perennials	0.9	0.6	–33.3
Mixed annual and perennial crops	0.1	0.7	+600
Fallow	5.9	4.5	–23.7
Pasture	17.8	19.5	+9.5
Total	90.8	83.4	–8.2
Number of farms surveyed	70	122	

Source: Field survey, 1994 and 1996.

in the neighboring state of Rondônia, it was just beginning to appear in Acre in 1994, when most coffee plants were too young to be productive. Coffee usually is planted in association with corn (*Zea mays* L.), followed by bean (*Phaseolus vulgaris* L.), and has a productive life of 5 to 9 years, depending on management practices.

The farm household modeled combines subsistence and market-oriented activities. Among the surveyed farmers, more than 90 percent keep their own seeds of annual crops from one year to the next instead of buying certified seeds. The model allows farm households to store grains for seeds and feed themselves. Seeds and grain for consumption can also be bought. Similarly, extra labor can be sold off farm, and labor can be hired on farm. Production systems were characterized by extensive land uses with low or nonexistent external inputs. For example, out of the 124 Acre farmers interviewed in 1996, 2 used chemical fertilizers, 15 insecticides, and 17 herbicides.

Among the major shifts in prices between the harvest years of 1994 and 1996 was an increase of 36 percent in common (V1) livestock prices, a milk price increase of 11 percent, and a decrease in animal care of 20 percent (table 10.2). Rice (*Oryza sativa* L.) prices decreased by 26 percent, whereas corn prices increased by 13 percent and bean prices by 2 percent. Coffee prices increased by 411 percent, and banana prices increased by 123 percent. Input prices such as pesticides and fertilizers decreased by 10 percent, and wages increased by 43 percent. Coffee yields in the model are the expected yields given average weather for each technology level and soil type. A medium-quality soil's peak coffee yield is 970 kg/ha with V1 technology and 3400 kg/ha with V3 technology.

From field data collected in 1994, farms were grouped on the basis of characteristics deemed to be exogenous to farmers' land use decisions as characterized by the model (e.g., soil type, distance to market, and age of settlement of land). Several groups emerged, each of which can be taken to represent a farm type. There were two main groups: smaller, well-situated farms, and bigger farms further from the market. The average farm and household characteristics for well-situated farms, in terms of access to markets, were used as the model's initial conditions. This group was dominated by soil types of medium quality, that is, with some fertility problems, mild slopes, or rockiness. The 60-ha farm's initial land uses are 2.5 ha of annuals, 1.5 ha of perennials, 4 ha of fallow, 9 ha of pasture, and 43 ha of forest. There are 10,067 t of total carbon stock over all land uses, 89 percent of it in the forest.

Baseline Simulation Results

The baseline explicitly includes one forestry policy that prevents small-scale farmers from harvesting timber products from their forested land. Although technically permissible by law, the bureaucratic obstacles to obtaining official permission to sustainably harvest timber products in farmers' legal reserves have been insurmountable in practice and have made on-farm timber extraction difficult (see chapter 8, this volume). Another forestry law mandating that no more than half of any farm be cleared

Table 10.2 Farmgate Prices in 1994 and 1996

Prices	Farmgate Prices (in 1996 reais [R])		
	1994	1996	Change (%)
Commodity Prices			
Rice, kg	0.27	0.20	–26
Corn, kg	0.15	0.17	+13
Bean, kg	0.51	0.52	+2
Coffee, kg	0.28	1.43	+411
Banana, bunch	0.87	1.94	+123
Brazil nut, 18 kg	2.60	3.20	+23
Timber, m^3	110	120	+9
Calf, per head (V1 tech.)	102	134	+31
Cow, per head (V1 tech.)	214	290	+36
Beef, per head (V1 tech.)	350	364	+4
Milk, L (all technologies)	0.36	0.40	+11
Input Prices			
Rice seeds, kg	1.74	1.80	+3
Corn seeds, kg	1.72	2.40	+40
Bean seeds, kg	2.27	2.40	+6
Coffee seedlings, each	1.00	0.30	–70
Grass seeds, kg (V2 tech.)	2.36	2.36	0
Kudzu seeds, kg (V2 tech.)	11.60	10	–14
Sacks, each	0.85	0.65	–24
Pesticides, kg	24	21.60	–10
Nitrogen fertilizer, kg (V3 tech.)	1.21	1.08	–11
Chainsaw (purchase price)	1441	841	–42
Oxen + cart (purchase price)	1525	1120	–27
Chainsaw + operator rental rate	37	50	+35
Fence cost, km (V1 tech.)	302	307	+2
Animal care (R/animal unit/m, V1 tech.)	5.18	4.14	–20
Wage rate, June	7	10	+43
Bull, purchase price (V1 tech.)	823	823	0
Timber transport (R/m^3)	15	10	–33
Truck rental (round trip to market)	91	100	+10

The price vectors labeled 1994 and 1996 are the vectors of prices judged to influence 1994 and 1996 land uses and reflect market prices for the agricultural years 1992–1993 and 1994–1995. All prices reflect values for average-quality products and inputs for that region; regional product quality is not high by national standards, especially for coffee.

Source: Banco da Amazonia, 1994, 1995, 1996, semester report and farming supply store survey.

for agricultural purposes (the 50 percent rule) was excluded because this law was not actively enforced in the 1994–1996 period.

Figure 10.2 depicts land uses (including forest, and therefore implicitly deforestation) generated by the model for a 25-year time span for this typical small-scale farm in the settlement project of Pedro Peixoto, Acre.

There are several results from this baseline simulation. The amount of forest retained declines over time, finally disappearing in about year 25, despite the small but positive revenue provided by the extraction of Brazil nuts (an activity undertaken by about 50 percent of sample farms in 1996). At the same time, cattle production eventually occupies about 85 percent of the farm. In addition, the survey results suggest that farmers do not plant V1 pasture, so the baseline results do not include any degraded pasture. The level of annual crop area is constant, and this activity occupies about 8 percent of the farm throughout the 25-year time horizon. Manioc (*Manihot esculenta* Crantz) takes up about 1 ha throughout the 25-year horizon (manioc is included in the perennial category for modeling purposes because it spans more than 1 year, although it is not a perennial). Young fallow up to 4 years in age weaves into and out of the baseline to support annual crop production, becoming more significant as the forest disappears completely. When baseline simulations are extended to 35 years, area in fallow continues to increase at approximately 0.2 ha every 2 years, to reach 5.5 ha in year 35. Finally, no coffee or bananas were grown under 1994 conditions (the only pseudo-perennial is manioc). Farm incomes plateau at about year 13, at a level of approximately R9000 per year (as all prices, in 1996 reais). The net present value of consumption over the 25-year period is R50,688. The other farm type is characterized

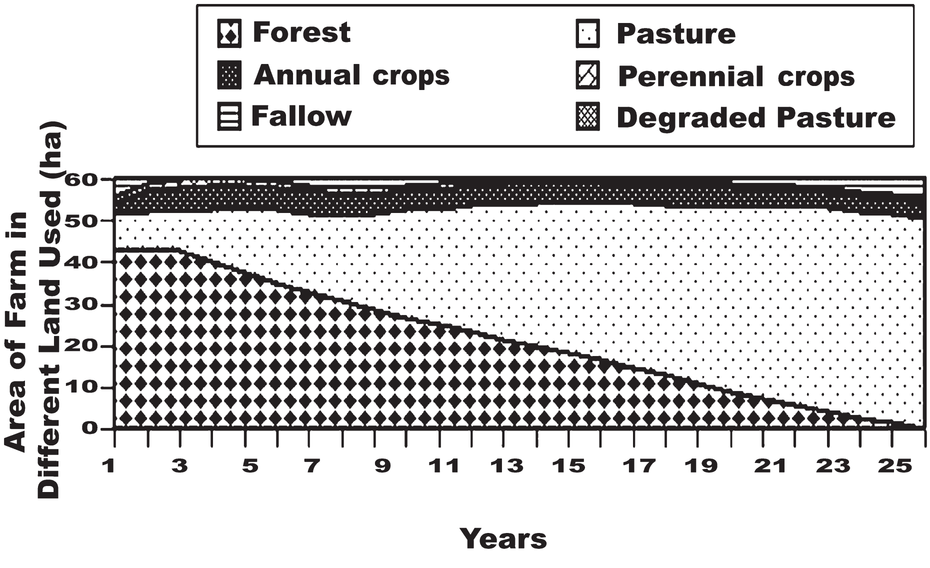

Figure 10.2 Area (ha) of a typical farm in different land uses during the 25-yr time line of the baseline simulation using 1994 prices.

by farms further away from market, with 90 ha and less household labor. Vosti et al. (chapter 17, this volume) report that deforestation rate on these farms is lower, resulting in slightly less than half the area still forested after 25 years. For this farm type too, however, pasture is the dominant cleared land use.

POLICY EXPERIMENT SIMULATION RESULTS

Some key product and input prices varied substantially between 1994 and 1996. A baseline simulation, using the medium-quality soils and 1996 prices, was run to assess the impact of some dramatic changes in relative prices since 1994, especially for coffee (a 411 percent increase) and labor (a 43 percent increase).

Figure 10.3 depicts land uses for a 25-year horizon using 1996 rather than 1994 prices (with adoption unaffected with risk factors such as price volatility). Comparing land use distributions on a farm with the baseline scenario (figure 10.2), the following results emerge. Deforestation rates slow somewhat, primarily because of the reallocation of labor (family and hired) to the establishment and especially the maintenance of coffee. Note that higher wages have a more significant impact on activities that depend on hired labor, such as coffee. The impact of increased labor needs for coffee (primarily during harvesting) is reflected in the rapid decline in deforestation after about year 7, when the substantial coffee area established during years 1 to 6 comes into full production and must be harvested in June, the time when new forest is usu-

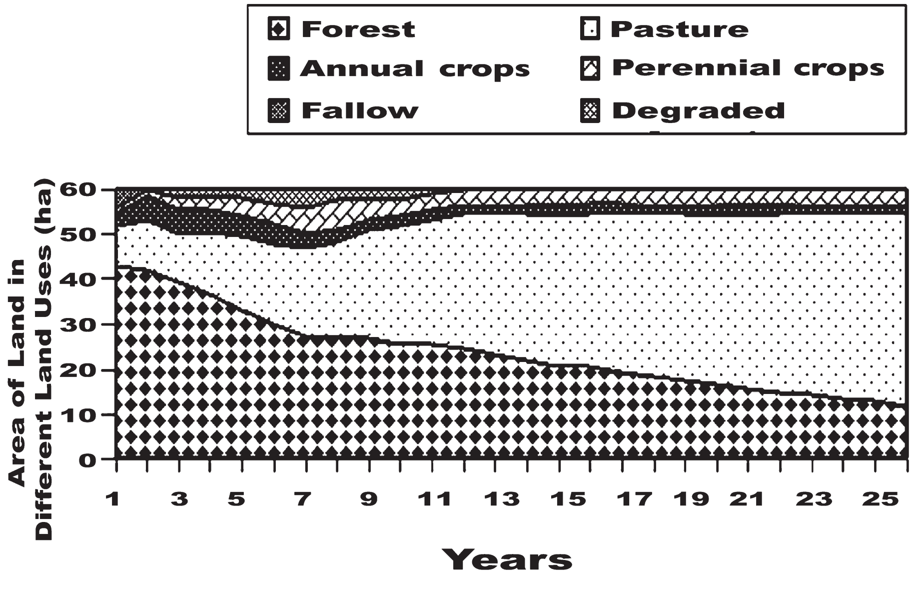

Figure 10.3 Area (ha) of a typical farm in different land uses during the 25-yr time line of the policy experiment simulation using 1996 prices.

ally cleared. That said, at year 25, forest is 12 ha and still declining, whereas pasture increases and perennials remain stable. Land dedicated to annual crops declines, and area in secondary fallow drops to zero. Finally, family-discounted consumption for the 25-year period increases substantially under the 1996 price scenario to R71,305, R20,617 more than in the baseline and mostly from coffee.

Under current economic and policy conditions, simulation results suggest that a large tradeoff exists: Deforestation will continue until the forest is exhausted on small farms, but incomes will rise. Results suggest that changes in relative prices such as those occurring between 1994 and 1996 would substantially raise farm household income. The quadrupling of coffee prices, in particular, would have a braking effect on deforestation, delaying by about 5 years the total depletion of the forest. In the simulation, the use of cleared land is significantly affected, with more land dedicated to coffee and less to annuals and fallow. However, the amount of land in pasture remains constant with the baseline, and the typical farm is still dominated by pasture.

CONCLUSION AND POLICY IMPLICATIONS

Four conclusions relevant for policy emerge from this modeling experiment. First, although farmers face constraints, these constraints do not shield farmers from major changes in product prices; therefore farmers are likely to respond to such large changes as occurred between 1994 and 1996, when input prices to establish coffee plummeted and the returns to this activity dramatically improved. Second, price changes between 1994 and 1996 led to substantial increases in farm income and a dramatic increase in the proportion of income coming from coffee. Third although overall deforestation was slowed by the shift in relative prices, it did not stop. In fact, if the time horizon for the 1996 simulation were extended by 5 years or so, forest retained on the farm would fall to zero. However, the gains in forest cover evaluated at year 25 are substantial when compared with the baseline, with 12 ha compared with none in the baseline, primarily because labor is reallocated from deforestation activities to coffee harvesting, activities that overlap in the annual agricultural calendar (although simulations suggest similar braking effects of total labor bottlenecks, even if in other seasons). Fourth, and perhaps most importantly for land use policy, area in pasture did not change much in the face of a dramatically changed set of relative prices for other commodities. Instead, adjustments in cleared area to establish coffee came at the expense of annual crops and fallow areas.

Two policy implications arise from these results. First, although major changes in input and product prices would be expected to affect land use practices and areas based on revised profitability, not all land uses necessarily will be significantly affected. For example, although increases in coffee prices would be expected to cause an increase in the area dedicated to coffee production, simulations show that this occurs at the expense of annual and fallow land rather than pasture. In this labor-scarce environment, farmers respond to favorable coffee prices initially by switching out of other labor-intensive activities rather than activities that use less labor per land unit (pasture, in this case). This also means that the price shift would not be expected to make a tremendous difference in deforestation rates. That livestock systems demand labor throughout the calendar year (rather than labor demand peaking, as it does for coffee, particularly at harvest time) only reinforces the propensity to stay with pasture if possible. Policymakers should not expect, then, that in the short to medium term (before the labor scarcity drew in more workers to the area), pricing policies aimed at establishing labor-intensive production systems would greatly affect the area dedicated to more extensive production systems. Because most agroforestry systems have a high overall labor demand and peak labor demands (as opposed to labor demands spread throughout the year), results obtained here for coffee are likely to apply for other perennial systems or simple or complex agroforests.

These results are so because the Linear Programming model sets out to capture a market setting in which farm households out to boost their consumption to the highest levels possible bump up against severe labor constraints, at least seasonally: They may have the money to buy more labor, but that labor is not available. This characterization of smallholder objectives and circumstances is one of several offered by Angelsen et al. (2001). Under these conditions, smallholders experiencing price changes are limited primarily by labor availability in the changes they can make to product mix or production technique. So, although price changes may greatly influence farm household incomes, changes in land and labor allocation across production activities in response to these prices can be concentrated among activities that compete seasonally for the most scarce factor: labor. This situation leaves pasture and deforestation unaffected. The good news is that the relationship is likely to be symmetric; as coffee prices fall, deforestation probably will not increase. Poorly functioning labor markets are an ingredient essential to both sides of this story; improvements in labor market performance will make the links between price changes and deforestation (via income) more direct and larger.

Second, some price changes, such as the shift in relative prices experienced between 1994 and 1996, simply cannot be managed by policymakers at any level. In this case, the supply and demand conditions of the international coffee market were chiefly responsible for the dramatic increase in coffee prices, and the private sector (with assistance for public sector research and extension) was responsible for much of the decrease in coffee establishment costs. Policymakers can influence the profitability of coffee production even though they cannot affect product prices by taking policy action focused on reducing costs, improving product quality, or discovering niche markets (e.g., organic coffee from the Amazon), but the effects (especially of the last option) probably will not be widespread.

Finally (these insights cannot be gleaned from the model in its current form), coffee is a perennial and as such can be managed more or less intensively—even to the point of abandonment—for a year or more while prices find their new low and begin to recover. A waiting period does not depend only on farmers' price expectations because converting land from coffee to pasture is not in itself costless: There are short-term constraints to herd expansion. Therefore it is unlikely that coffee will be converted to pasture immediately, although that will be the end result if return to profitability is delayed more than a couple of years. Also unlikely is any rush to convert more forest to pasture just because coffee prices have fallen because the seasonal nature of forest felling itself precludes hasty action, and the farmer still faces the short-term herd expansion constraints. That said, farmers might engage in other activities that require little investment and time commitment to cover livelihood needs and mitigate coffee losses; these could include off-farm employment or illegal logging.

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