

7 The Forest for the Trees

THE EFFECTS OF MACROECONOMIC FACTORS ON DEFORESTATION IN BRAZIL AND INDONESIA

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Since colonial times, the settlement of new frontiers has been undertaken to open access to land and other types of natural resources. In this chapter, we take the approach adopted by Findlay (1995) in which frontier movement is described as the process of incorporating a periphery into an economic center through a network of trade, investment, and migration. Adopting this perspective, the recent Indonesian and Brazilian cases of forest frontier expansion have many commonalities but also interesting distinguishing features. We assume that relative product prices, factor availability, and transportation costs are the main economic factors affecting the movement of a frontier.

In Brazil, macroeconomic policies, credit and fiscal subsidies to agriculture, and technological change in agriculture have all acted as push factors in the migration process to remote areas that are, to this date, still sparsely populated (2.7 inhabitants per square kilometer). In this respect, the Indonesian case is very different, with the island of Java having an average population density of 799 inhabitants per square kilometer and Sumatra having 77 inhabitants per square kilometer. This difference between the Latin American and the Southeast Asian situations is bound to have repercussions, through labor availability, on the adoption and impact of the technologies proposed in the Alternatives to Slash and Burn (ASB) matrices developed for the two regions. In Brazil, regional development policies have attracted economic resources to the Amazon through the expansion of the road network, colonization programs, and fiscal incentives to agropastoral projects (Binswanger 1991). The Sumatran case shares some of these characteristics: Annual population growth rate here has been the highest in Indonesia (3.1

percent annually) and is linked to the government transmigration program that has so far resettled 220,000 families (ca. 1 million people) to Sumatra. The land allocated to transmigrants is well mapped and totals 6 percent of Sumatra's land surface.

Continuing the comparison, if we assume that there are two interconnected components to deforestation, namely logging and land clearing for agricultural purposes, it is interesting to note that in Sumatra commercial logging concessions started in the 1970s and reached their peak in the 1980s. Of the total area of Sumatra, 30 percent is under active or passive logging concession today. In Brazil, deforestation is considered to be driven by land clearing for agricultural purposes with much of the timber extracted as a byproduct of land clearing (Mahar 1989). This may be an oversimplification, given the heterogeneity in productive activities in the Amazon; in fact, it has been estimated that logging has accounted for approximately 10 percent of total deforestation in the state of Pará (Watrin and Rocha 1994). Because of its selective nature, logging in the Amazon rarely leads to complete land clearing, but it appears to increase deforestation by facilitating access to forested areas for farmers (Uhl and Vieira 1989; Burgess 1993). Even so, one can safely state that logging, as a component of deforestation, is less predominant in the Amazon than in Sumatra.

High transportation costs between the Amazon and the rest of the country, leading to high agricultural input costs and limiting interregional trade, also affect deforestation rates. This is confirmed by Pfaff (1997), in which greater distance from markets south of the Amazon leads to less deforestation. Transportation costs are less likely to limit Sumatran development because almost all areas are within 20 km of a river and 50 km of a road.

The potential drivers of deforestation in both Brazil and Sumatra occur at different geographic scales, are linked to economic processes guided by different macroeconomic policies, and are conditioned by region-specific factors such as labor supply, technology, and land tenure regimes. Computable general equilibrium models generally are used to capture fundamental differences in factor endowments and economic structure and to assess the effects of changes in exogenous shocks (e.g., changes in exchange rates) on land use and deforestation.

The next section clarifies the modeling strategy considered appropriate for the problem at hand, describes the database, and presents the results of devaluation simulations. Later in this chapter we present the results of an in-depth analysis of Brazil to determine the relative importance of different drivers of deforestation. The chapter concludes with an overview of results and a discussion of their policy implications.

MODEL CHARACTERISTICS

Thiele (1994) and Wiebelt (1994) model deforestation in Indonesia and Brazil, respectively, using computable general equilibrium (CGE) models and consider deforestation to be driven by forest harvesting for logging purposes, following optimal intertemporal management practices (which assume replanting). The limitation of this approach

to deforestation in both countries is that in reality logging is more similar to an extractive process than a managed forest operation. Second, in the Amazon deforestation is driven mostly by clearing for agricultural purposes.

Our approach in both the Brazil and Indonesia models is centered on the role of land as a factor of production. Land is endowed with different characteristics that affect the profitability of agricultural activities. Economic agents know this and use these characteristics, among other things, to determine product mix and production technology on particular types of land. To better describe this approach, it is useful to define some terms and concepts. In both models, land is differentiated into land types on the basis of land cover. For example, there are three land types in Brazil: forested land, arable land, and grassland or pasture. There are two ways to switch from one land type to another. The first (important in Brazil but less so in Sumatra and hence not included in the Sumatra model) is via the biophysical process of land transformation brought about by certain agricultural activities. An example is the transformation of arable land cultivated for upland rice (*Oryza sativa* L.) into grassland or pasture by the extraction of soil nutrients. Land transformation processes were modeled as first-order stationary Markov processes, with land use entering as an exogenous variable (Van Loock et al. 1973; Baker 1989).

Second, land conversion describes a transition between two land types brought about intentionally by economic agents as an investment. Examples of land conversion included in the models are as follows: In the Brazilian case, farmers clear forest to obtain arable land; in the Sumatran case, land can be converted from secondary forest to arable land.

The modeling approaches taken in the Sumatran and Brazilian case studies were also different in several other respects. First, the geographic level of aggregation in the two cases was different. In Brazil, a multiregional approach was adopted in which the Brazilian Amazon was one of four Brazilian macroregions modeled. For Indonesia, instead of modeling the whole country and including a Sumatra component, a stand-alone regional model of Sumatra was developed. Second, because of model size and data constraints, the level of detail incorporated in the two models was quite different. The Brazil model had a simpler sectoral and factor disaggregation than the Sumatra model.

In both cases we modeled deforestation processes as realistically as possible. In the Brazil case, the model adopted builds on the approach introduced by Persson and Munasinghe (1995) for a study of Costa Rica. They include logging and squatter sectors and therefore markets for logs and cleared land. We extend their approach to include land degradation as a feedback mechanism into the deforestation process. For the Sumatra case, deforestation is computed as the sum of the land under logging and the expansion of the sectors that are known to drive deforestation for agricultural purposes (we did not include explicitly a squatter deforestation sector). A comprehensive review of CGE model applications to deforestation can be found in Kaimowitz and Angelsen (1998).

REPRESENTATION OF PRODUCTION: BRAZIL

The production activities considered in the Brazil model are presented in table 7.1, along with the factors used in production and the commodities produced by these activities.

For Brazil, agricultural production is disaggregated by region (Amazon, center-west, northeast, and rest of Brazil), activities (annuals, perennials, animal production, forest products, and other agriculture), and scale of operation (smallholder, large farm enterprise). Regional agricultural producers sell their products to a national commodity market. All factors used by agriculture are region-specific. Agricultural technologies are specified as two-level production functions, with the first level representing an agricultural activity's use of primary factors of production and intermediate inputs in producing output that is transformed and the second level divided into commodities according to smooth, concave transformation frontiers. Each agricultural activity produces several agricultural commodities. This specification of production allows farmers to consider certain agricultural commodities as substitutes, and others as complements, in the production process.

Table 7.1 Production Activities, Commodities, and Factors of Production in the Brazil Model

Production Activities	Commodities Produced	Factors of Production
Annual crop production	Corn, rice, bean, manioc, sugar, soy, horticultural goods, and other annual crops	Arable land, unskilled rural labor, skilled rural labor, agricultural capital
Perennial tree crop production	Coffee, cacao, other perennial tree crops	Arable land, unskilled rural labor, skilled rural labor, agricultural capital
Animal products	Milk, livestock, poultry	Grassland, unskilled rural labor, skilled rural labor, agricultural capital
Forest products	Nontimber tree products, timber, and deforested land for agricultural purposes	Forest land, unskilled rural labor, skilled rural labor, agricultural capital
Other agriculture	Other agriculture	Arable land, unskilled rural labor, skilled rural labor, agricultural capital
Food processing	Food processing	Urban skilled labor, urban unskilled labor, urban capital
Mining and oil	Mining and oil	
Industry	Industry	
Construction	Construction	
Trade and transportation services	Trade and transportation services	

Product mix and technology choice decisions are responsive to changes in relative prices (via own-price elasticities, which measure the percentage change in supply of a good associated with a change in its price) and are conditioned by technological constraints in transforming agricultural output from one commodity to another (via substitution elasticities, which measure the change in production of one commodity when the amount produced of another commodity changes). Values for substitution elasticities were obtained through expert interviews of researchers from the International Food Policy Research Institute (IFPRI) and Empresa Brasileira de Pesquisa Agropecuária (Embrapa). Degrees of cross-commodity substitution are summarized in table 7.2.

Given that deforestation for agricultural purposes appears to be important in the Brazilian Amazon, a regional deforestation sector was introduced in the model. The

Table 7.2 Cross-Commodity Substitution Possibilities in the Brazil Model

Commodity Category	Commodity 1	Commodity 2	Degree of Substitutability
Annual crops	Corn	Rice, bean	Low
	Corn	Manioc	Low–medium
	Corn	Sugar, soy, horticulture, other annuals	Medium–high
	Rice	Bean	Low
	Rice	Manioc	Low–medium
	Rice	Sugar, soy, horticulture, other annuals	Medium–high
	Beans	Manioc	Low–medium
	Beans	Sugar, soy, horticulture, other annuals	Medium–high
	Manioc	Sugar, soy, horticulture, other annuals	Medium
	Sugar	Soy, horticulture, other annuals	High
Perennials tree crops	Horticultural products	Other annual crops	Medium–high
	Coffee	Cacao	High
	Coffee	Other perennials	Medium
Animal products	Cacao	Other perennials	Medium–high
	Livestock	Milk	Medium
Forest products	Poultry	Livestock, milk	Medium–high
	Deforested land (agriculture)	Timber	Low–medium
	Deforested land (agriculture)	Nontimber tree products	High
	Nontimber tree products	Timber	High

Source: International Food Policy Research Institute and Embrapa expert interviews.

price for arable land produced by this sector, P_{ar} , is determined by the demand for agricultural land. In an infinite horizon framework, the flow return from an asset divided by the asset price must be equal to the rate of interest in the steady state. Deforesters, being the suppliers of arable land, are faced with this price, and the amount of land that will be deforested depends on P_{ar} and on the deforesters' profit-maximizing behavior and technology. The behavior of agents carrying out the land clearing can be differentiated according to whether forest is an open-access resource or whether property rights governing the use of the forest resource are well defined and enforced. In this chapter, forests are considered an open-access resource, so the returns from standing forest are not included in calculating the profits of deforesters. By assuming an infinite planning horizon when using arable land, we allow agents to acquire full property rights through deforestation.

We assume that deforesters provide agricultural land to be sold to whatever agricultural entity is expanding its cultivated area and that logging, though not directly causing deforestation, is a complementary activity to land clearing (the price of lumber therefore indirectly affects deforestation rates). We also assume that reductions in soil productivity caused by annual crop production and cattle (*Bos taurus*) grazing add substantially to pressure to clear forests.

REPRESENTATION OF PRODUCTION: SUMATRA

The production activities included in the Sumatra model, along with the commodities being produced by these activities and the specification of factor types, are presented in table 7.3. The emphasis in this case was on disaggregating the regional economy to capture all the sectoral linkages. Unlike in the approach taken for Brazil, each activity produces one commodity, allowing a more detailed description of the links between factor use and commodities produced but not permitting any representation of complementarity (or substitutability) in the production of different commodities between activities, as was done for Brazil.

Among the factors, labor is divided into ten categories according to location (urban or rural), skill level (skilled or unskilled), and employment relationship (hired or family). There are five land types, categorized according to the activities with which they are associated. Secondary forest sustains complex agroforestry systems; perennial land is used for monoculture rubber, oil palm, coffee, and other tree crop plantations; arable land permits the planting of annual crops; grassland sustains grazing; and aquaculture land is used only for fish or shrimp farming.

An important structural characteristic of production captured in model disaggregation is the distinction between smallholder and estate production of rubber and oil palm. This distinction is important because production techniques and land types used by smallholders and estate farms differ greatly.

Table 7.3 Production Activities, Commodities, and Factors of Production in the Sumatra Model

Production Activity	Commodities Produced	Factors of Production
Rice	Rice	Labor
Cassava	Cassava	
Soybean	Soybean	Rural agriculture, paid
Maize	Maize	Urban agriculture, paid
Horticulture	Horticulture	Rural agriculture, unpaid
Other food crop	Other food crop	Urban agriculture, unpaid
Estate rubber	Rubber	Rural production, machinery operator
Smallholder agroforestry rubber	Rubber	Urban production, machinery operator
Estate oil palm	Oil palm	Rural clerical and services
Smallholder oil palm	Oil palm	Urban clerical and service
Sugar cane	Sugar cane	Rural professional
Coffee	Coffee	Urban professional
Other estate crop	Other estate crop	
Livestock	Livestock	
Forestry	Forestry	Land
Fishery	Fishery	
Nonagriculture	Nonagriculture	Secondary forest
		Perennial crop
		Grass
		Arable
		Aquaculture
		Capital
Food processing	Food processing	Food crop
Mining	Mining	Tree crop
Other manufacturing	Other manufacturing	Livestock
Wood processing	Wood processing	Forestry
Chemical and rubber	Chemical and rubber	Nonagriculture
Services	Services	
Construction	Construction	
Trade and transportation	Trade and transportation	

MACROECONOMIC SHOCKS: CRISIS AND STRUCTURAL ADJUSTMENT

Beginning in August 1997, Indonesia suffered one of the greatest real exchange rate devaluations in recent economic history. In January 1999, Brazil followed suit when the widespread rumor that states might default on their debt to the Brazilian federal government sent foreign investors fleeing. Having to choose between making a stand for its overvalued currency or deciding not to intervene, the Brazilian government opted not to intervene and floated the exchange rate. The effect was an 80 percent nominal devaluation.

In this section we briefly review the mechanisms through which a devaluation can affect land use and deforestation, set out some basic assumptions regarding consumer, investor, and government behavior in the event of a devaluation, and present the

results of model simulations of devaluations ranging from 5 to 40 percent. Where welfare effects are identified, they are reported.

The effects of a large devaluation reverberate through an economic system by affecting relative prices. On the supply side, prices of export goods rise relative to those of nontraded goods sold domestically (e.g., services and construction). This prompts production shifts toward sectors that produce goods with a high export share. On the demand side, the rise in price of imported goods leads to a greater demand for domestic substitutes for the imported goods. Given enough microeconomic detail in the CGE model, it is possible to follow the reverberations of a macroeconomic shock throughout the economy, for example, to regional agricultural production sectors and logging.

The basic assumption is that the macroeconomic shock is transmitted through the price system to reach a new equilibrium in all markets; however, other assumptions must be made at the macroeconomic level for the price transmission mechanism to be complete. First, one has to specify the behavior of macroeconomic aggregates, such as the country's savings rate, which affects aggregate levels of consumption and investment. Second, one has to specify the mobility of factors of production, such as capital and labor, across sectors and regions. We will refer to the set of assumptions as macroeconomic closure rules.

Among the different possible specifications for savings and investment behavior, we define balanced adjustment to be a balanced contraction of demand under a financial crisis scenario associated with a flexible savings rate (government consumption and investment spending as fixed shares of total demand) and capital flight as the extreme case in which both the government and consumers do not respond to a crisis but maintain fixed savings rates, and the capital flight resulting from the crisis occurs completely on the investment side of demand. Regarding factor mobility, scenarios are distinguished by the time horizon of the adjustment process devaluation as either short run (this assumes that wages are rigid, so excess supply in the labor market is possible; we assume that in the short run migration of labor and capital between regions is not possible) or long run (which assumes wages are flexible and that inter-regional migration of factors is unobstructed).

Combining the closure rule assumptions listed earlier, we obtain four possible scenarios: balanced adjustment in the short run and in the long run and capital flight in the short run and in the long run. Because the mechanisms underlying equilibrium in the labor and capital markets are complex and the relationship between factor migration and differences in factor wages is uncertain, the results are presented as a range of possible outcomes. Where in this range of outcomes an economy will actually reestablish equilibrium depends on the speed of adjustment of factor markets, among other things. Where appropriate, brackets containing the results attributable to changes in critical model parameter values are included. In particular, we identify upper and lower boundaries in deforestation rates to highlight the wide range of parameter-specific outcomes that can occur.

DEVALUATIONS IN BRAZIL

In what follows we present the results for logging activities (table 7.4) and deforestation for agricultural purposes in the Amazon (figure 7.1) of model simulations of a range of devaluations under different model closure rules. Note that deforestation for agricultural purposes and logging react differently to devaluations, and the reaction depends on closure rules.

Logging in the Amazon (table 7.4) increases uniformly with the degree of devaluation in all simulations, with the capital flight scenario leading to slightly greater increases in logging than the balanced contraction scenario. This increase in logging arises from a substantial increase in the exports of processed wood products. From a policy standpoint, the only option to avoid this increase would be to place an export tax on processed wood products.

Deforestation to clear agricultural land (figure 7.1) is very sensitive to the aggregate behavior of the national economy and hence to model assumptions regarding aggregate responses to devaluation. The balanced contraction scenario, with a balanced reduction of private consumption, government demand, and investment, would lead to a reduction in deforestation that would be substantial in the short run, but the effect would be attenuated in the long run. The capital flight scenario, where government expenditures and household savings rates are left unchanged (meaning investment must decrease drastically), would lead, in the short run, to a small increase in deforestation for low levels of devaluation and a small decrease for higher levels. In the long run under the capital flight scenario, a substantial increase in deforestation rates would occur. Even with the uncertainty underlying the adjustment of factor markets to devaluation, the differences in these results underscore the importance of taking macroeconomic policy into account when analyzing deforestation: The types of policies adopted to address the shock are as important as the shock itself in understanding deforestation rates. For example, a 40 percent devaluation causes, in the long run, either a 12 percent increase or a 12 percent decrease in deforestation depending on policy variables; in absolute terms, this represents a difference of approximately 5000 km² in the amount of forest cleared.

The mechanism underlying the decrease in deforestation for the balanced contraction scenario is linked to the performance of Amazon agriculture relative to agri-

Table 7.4 Effects of Devaluation on Logging in the Amazon, by Model Scenario

Model Scenario Assumptions			Devaluation (%)			
			10	20	30	40
Percentage change in logging	Balanced contraction	Short run	3.9	8.0	12.3	17.0
		Long run	4.4	8.8	13.4	18.3
	Capital flight	Short run	4.5	9.4	14.8	21.1
		Long run	4.9	10.0	15.4	21.3

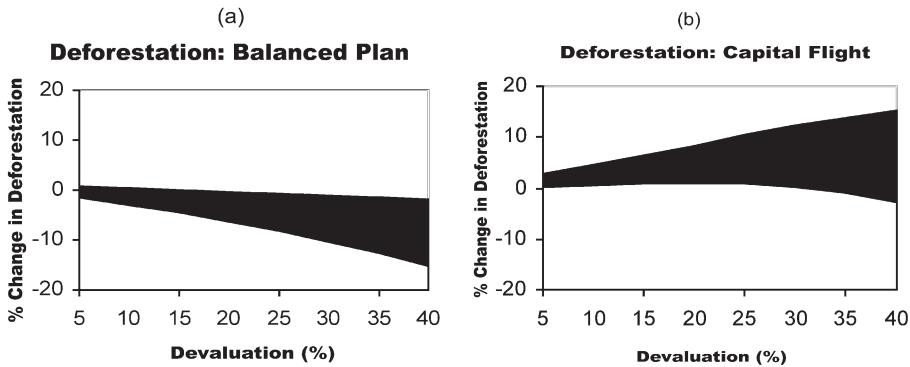


Figure 7.1 Effects of devaluation on deforestation in the Amazon, by model scenario: (a) balanced plan, (b) capital flight.

culture in the three other regions of Brazil. A devaluation usually is thought to favor agriculture because it produces exportable goods; therefore one would expect that the incentive to deforest for agricultural purposes would increase with the devaluation. This does not occur in the balanced contraction scenario for two reasons:

- The Amazon has a smaller share of its agricultural production allocated to exports; although agriculture as a whole does expand, Amazon agriculture reaps little benefit from the devaluation relative to the other regions of Brazil that produce a larger share of exportable agricultural products.
- Because the Amazon produces primarily for the domestic market, the contraction in private consumption affects Amazon agricultural production more than production in the other regions.

In the capital flight scenario, the main component of demand to be adversely affected is investment. This has two important implications: Demand for agricultural products is not as affected as in the balanced contraction case, and sectors producing investment goods (construction and industry) undergo a dramatic contraction, especially the sectors producing nontraded goods. The combined effect of these changes is to increase deforestation because although the Amazon is still less favored than other regions in producing exportable agricultural goods, agriculture as a whole performs better than in the balanced contraction scenario and, furthermore, the contraction in industry and construction leads to an increase in unemployment. This leads to a larger migrant pool of displaced workers who move into agriculture and thereby affect the movement of the agricultural frontier in the Amazon. That said, it is important to note that the effect on deforestation is extremely dependent on the migration flows; for example, a 30 percent devaluation combined with restricted urban–rural labor flows generates a decrease in deforestation of –5 percent, whereas the same devaluation in a scenario permitting urban–rural labor flows generates a 35 percent increase in the deforestation rate.

DEVALUATIONS IN INDONESIA

The first step in determining the impact of a devaluation on the Sumatran economy was to simulate the impact of the shock on the Indonesian economy as a whole using an already available CGE model for Indonesia. The devaluation results for Sumatra were then attained by imposing the commodity prices obtained from the national model as exogenous border prices for the Sumatran economy (conceptually similar to the world prices faced by sovereign countries).

The findings are less varied than in the Brazilian case, perhaps because of the absence in the models of feedback from Sumatra to the rest of the Indonesian economy. The change in deforestation rates, represented as the total increase in land under

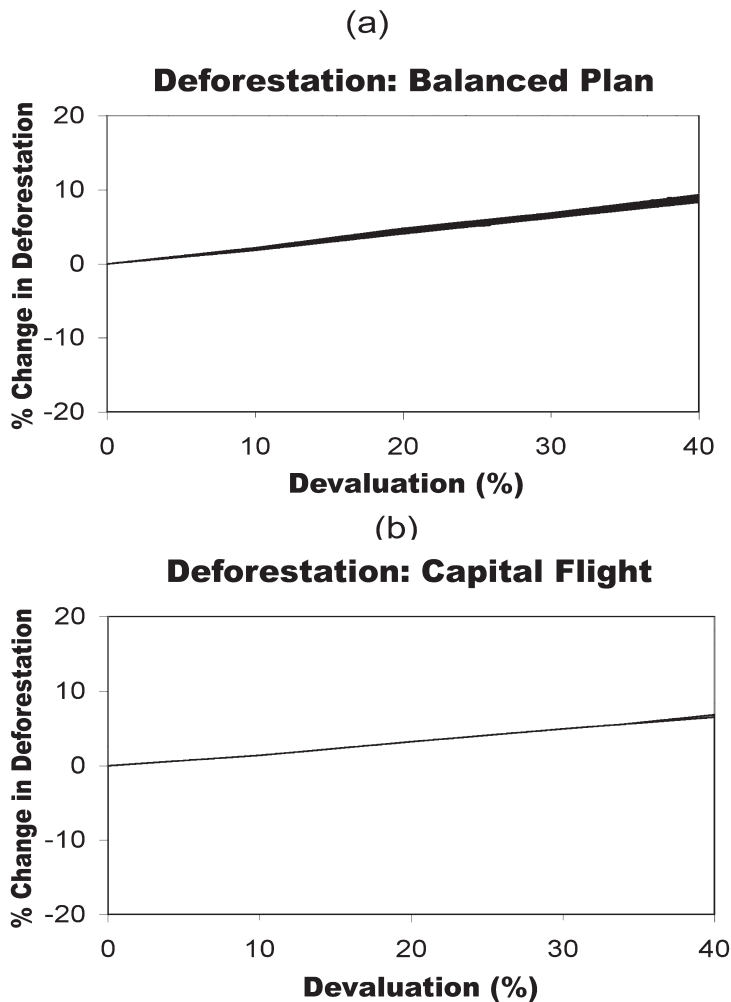


Figure 7.2 Effects of devaluation on deforestation in Sumatra, by model scenario: (a) balanced plan, (b) capital flight.

logging and estate farming, is presented for the different macroeconomic scenarios in figure 7.2. The area bounded by the short-run and long-run results is very small, implying that they are very similar to each other for both the balanced plan and the capital flight scenario. The reason for this narrow response range is the high population density in Sumatra; labor is not a binding constraint for deforestation and can actually substitute for other factors of production that are fixed in the short run.

In the capital flight scenario, deforestation is slightly lower because capital flight causes investment to fall. This leads to a slower growth in the logging sector that provides an output that serves as an input to construction, which is an important component of investment demand. Overall, the impact of devaluation on deforestation in Sumatra is comparable, in terms of percentage change, to the highest levels obtained in the Brazilian case.

THE EFFECTS OF CHANGES IN SOCIOECONOMIC CHARACTERISTICS ON DEFORESTATION IN BRAZIL

This section reports the results of the Brazil model simulations run to examine the effects on Amazonian deforestation of government investments in infrastructure, changes in land tenure regimes, and policy-induced changes in agricultural technology.

LINKS BETWEEN IMPROVEMENTS IN TRANSPORTATION INFRASTRUCTURE AND DEFORESTATION

Large investments in transportation infrastructure are once again under way in the Brazilian Amazon. For example, a road through the Amazon to the Pacific is under construction in Acre, and a recently completed port facility in Rondônia has dramatically reduced transport costs for soybean (*Glycine max* [L.] Merr.) and other products of the region. On the eastern side of the Brazilian Amazon, the “center-north multimodal transportation corridor,” including southeastern Pará, eastern Mato Grosso, and southern Maranhão will reduce the transportation costs of grains with investments in roads, railways, and waterways. The incentives that shape current deforestation rates and land use patterns in the area therefore may shift.

To assess the effects of these and other infrastructure investments, we assume that costs are reduced uniformly for all agricultural products of the Amazon. In all cases, a reduction in costs for transportation between the Amazon and the rest of Brazil increases deforestation rates (figure 7.3a). For small decreases in transport costs, one can ignore the uncertainty surrounding the elasticity of the response of the national commodity market to increased agricultural products from the Amazon. For large decreases in costs, though, it is important to know how the agricultural commodity markets react to such a shock. Because data to estimate such elasticities are not available, the results provided here are based on sensitivity analysis: Simulations were

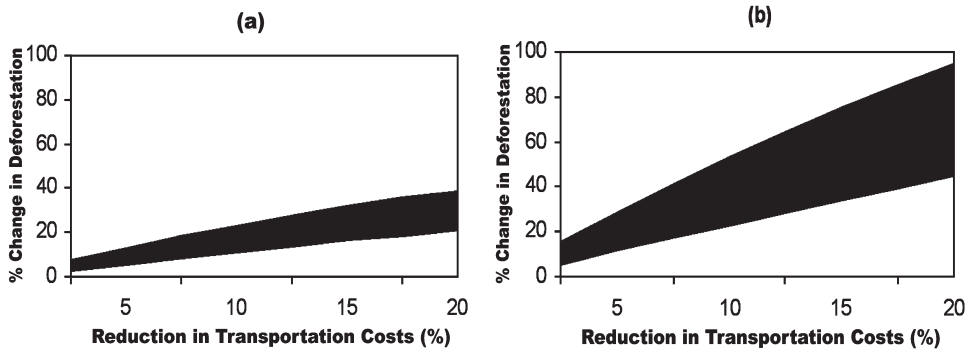


Figure 7.3 The effects of reduced transportation costs in the Amazon on deforestation (a) when deforestation and logging are complements in production and (b) when logging and deforestation are substitutes in production.

performed with values for these elasticities of between 1 and 12. Because similar agricultural products produced in different regions are generally good substitutes for one another, this range should bracket the true but unknown elasticity values. Model results indicate that a 20 percent reduction in transportation costs for all agricultural products from the Amazon causes an increase in deforestation in the range of 21 to 39 percent (figure 7.3a).

Therefore deforestation rates can be expected to increase as transportation costs in the region decline. However, the extent of increase in deforestation was found to depend on the degree of complementarity in production between logging and deforestation activities. In the base run (figure 7.3a) the two activities were assumed to be complementary (elasticity of transformation 0.3). If instead it is assumed that producers view these activities as substitutes (elasticity of transformation 2.0), in effect decoupling them in their productive decisions and reacting based only on their relative financial returns, the deforestation rate after the reduction in transportation costs increases dramatically (figure 7.3b). This is because the reduction in the gap between farmgate and market prices benefits agriculturalists more than loggers, so in the base simulation deforesters are constrained by their complementarity with a product for which costs are not decreasing. If this forced complementarity is removed, which would be the case if deforesters decided to burn the logs instead of marketing them, which they often do, increased returns to Amazon agriculture would translate into dramatic increases in deforestation.

In general, as agricultural production in the Amazon becomes more profitable, the price of arable land increases, thereby increasing the incentive to deforest. But this induced deforestation (the environmental implications of which are reported elsewhere in this publication) can have welfare implications. The increase in profitability leads, in the long run (with mobile agricultural labor and capital), to a 6 to 23 percent increase in production by smallholders and a 3 to 9 percent increase in production by large farms. However, welfare effects at the national level are very limited (rural

households at the national level gain only 0.5 to 0.9 percent in real income). This is because the increase in Amazon production, except for the share that is exported, replaces previous production from other regions; therefore, the positive regional welfare impact on Amazon development is offset by the negative welfare impact on other agricultural areas of Brazil.

The reduction in transportation costs scenario highlights how changes exogenous to the land use systems can dramatically affect deforestation by affecting the profitability of a single agricultural activity or, as in this case, the agricultural sector as a whole. Furthermore, the dampening effect of the complementary relationship between logging and land clearing for agricultural purposes stresses the importance of the wider context (of which a land use system is a component). The promotion of a specific land use alternative (e.g., one or more elements of the ASB matrix) may lead to unexpected results if the substitution and complementarity relationships it has with other productive activities have not been considered.

LAND TENURE REGIMES AND DEFORESTATION IN THE AMAZON

The economic literature linking deforestation to tenure regimes has adopted either a partial equilibrium approach (Mendelsohn 1994) or an econometric approach based on the explanatory power of measures of tenure security using cross-country data (Deacon 1994, 1999; Alston et al. 1996). The approach adopted here is similar to Mendelsohn's partial equilibrium description, but the context in our case is one of general equilibrium. Whereas in the partial equilibrium setting deforesters had the choice between sustainable forest uses and a destructive agricultural process with decaying physical output, in a general equilibrium framework, deforesters have an array of additional choices ranging from wage labor on large farms to migrating to urban areas to simply cultivating the already-cleared land.

The assumptions made in simulating changes in tenure regimes must be laid out. We assume in this chapter that deforestation is done exclusively to clear land for agriculture and that by doing so farmers acquire informal property rights to unclaimed land. The impact of a change in tenure regimes is simulated by making informal property rights less secure through eviction. This change can be represented in one of two ways: as an increase in the discount rate equal to the probability of eviction (Mendelsohn 1994) or as a decrease in the expected time of residence on the plot before eviction. In the analysis that follows, the latter option is adopted (see the appendix for details).

The results (figure 7.4) show the change in deforestation rate as a function of the expected time to eviction. The shaded area represents the range of discount rates (15 to 50 percent) believed to bracket the true discount rate of farmers in the Amazon. The lower boundary of the region occurs when the discount rate is 15 percent and shows a slow decrease in the deforestation rates that occur as a result of reducing the expected time of residence on the plot from 22 to 14 years (–18 percent) and a marked

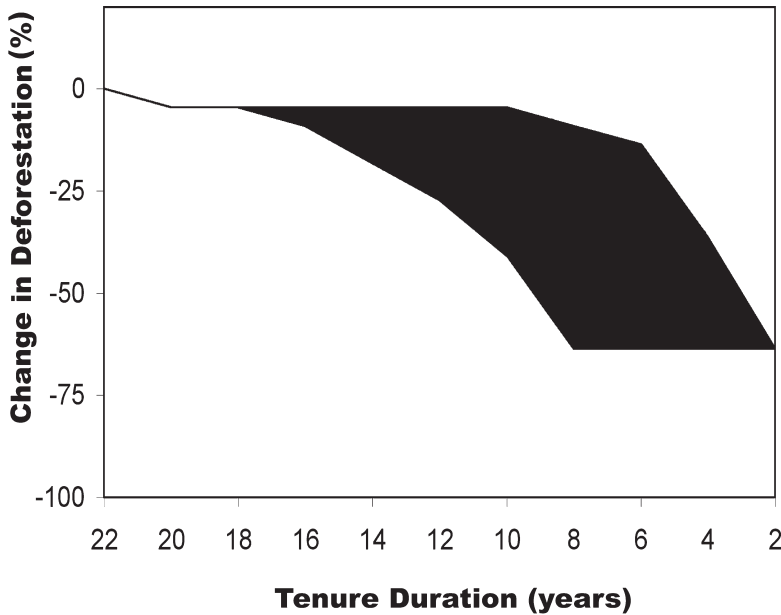


Figure 7.4 Effects of changes in land tenure on deforestation in Brazil.

decrease from there on (–27 percent for 12 years). The deforestation rate levels off at around 37 percent of its original value when the expected time of residence is reduced to 8 years.

The leveling off occurs because as the risk of being evicted increases it becomes more convenient to deforest previously tenured forest land rather than unclaimed land. A switch in behavior occurs from deforesting as capitalization on property right acquisition (even if unsecured) to deforesting solely for the value added that comes from agricultural activities. An optimal deforestation rate (given the 1994–1996 average) would be around 7400 km²/yr. This value, though far from arresting deforestation, is still much lower than the current trend, suggesting that the mode of tenure acquisition and its enforcement should be top priority issues. On the other hand, if the discount rate is higher than 15 percent, the leveling off will be reached for expected times lower than 8 years (the upper boundary, using a discount rate of 50 percent, reaches the leveling-off value at 2 years).

The assumption that all current deforestation occurs on unclaimed land may cause the results to overemphasize the impact of regulating tenure. If a share of the deforestation is already occurring on tenured land, then this will raise the floor in the deforestation rate because this component will not be affected by changing tenure regimes. Because by construction we begin from an equilibrium point, we can neither validate nor contradict the hypotheses that tenure leads to more deforestation (Vosti et al. 2002) or to less deforestation (Deacon 1999). All this analysis can say is that relative to the 1995 base structure of the economy, assumed as an equilibrium,

if unclaimed land is being deforested, then increasing the probability of eviction will decrease the deforestation rate to the point where it is profitable to clear only previously tenured land. In this respect, the results contradict the partial equilibrium results of Mendelsohn (1994), who stated that the possibility of eviction leads to destructive land uses.

The relevance of simulating the tenure regime modification is that it highlights how institutional issues may have to be pursued outside the domain of land use systems to reduce deforestation in certain areas of the tropics. It also reminds us that if a specific land use system is to be promoted, changes in tenure regimes could drastically alter its appeal to farmers. For example, with the possibility of eviction, few farmers will adopt technology involving perennial tree crops because the time gap between planting and fruit bearing can be beyond the expected presence on the farm of any one occupant.

TECHNOLOGICAL CHANGE IN AMAZONIAN AGRICULTURE

At the level of land use systems or specific production activities, much research has been done on technological change in agriculture in the Amazon. Different farming and cattle-raising systems have been analyzed (Serrão and Homma, 1993; Mattos and Uhl 1994; Almeida and Uhl 1995; Toniolo and Uhl 1995), paying particular attention to characteristics such as profitability, credit requirements, agronomic sustainability, and other factors that can influence adoption. We address the issue of technological change at the sectoral level and examine the effects of different types and degrees of technological change within and across broad geographic regions. Technological change is assumed to be exogenous to farmers but not to policymakers, and although the values of key parameters examined here represent a reasonable range of technology options, they are not based on case studies.

We simulate technological change in the production of annual crops, perennial tree crops, and animal products and distinguish between smallholder and larger-scale production systems. Different degrees and types of technological change are analyzed for each activity. Our reference simulation incrementally increases total factor productivity (TFP) by 70 percent equally across all factors of productions, a process known as disembodied technological change. Other simulations replicate these incremental levels of overall productivity increase but spread increases unevenly across factors of production, a process known as embodied technological change. In these cases, the extent of specific factor productivity increase is inversely proportional to that factor's value share in production. Comparisons across simulations of the different types of technological change are presented in the form of a TFP index (see the note to figure 7.5 for details of this index).

Table 7.5 shows the different types of technological change examined in the simulations. Because it is difficult to imagine innovations at the Amazon-wide level that are purely labor improving or capital improving, results represent a range of possibilities

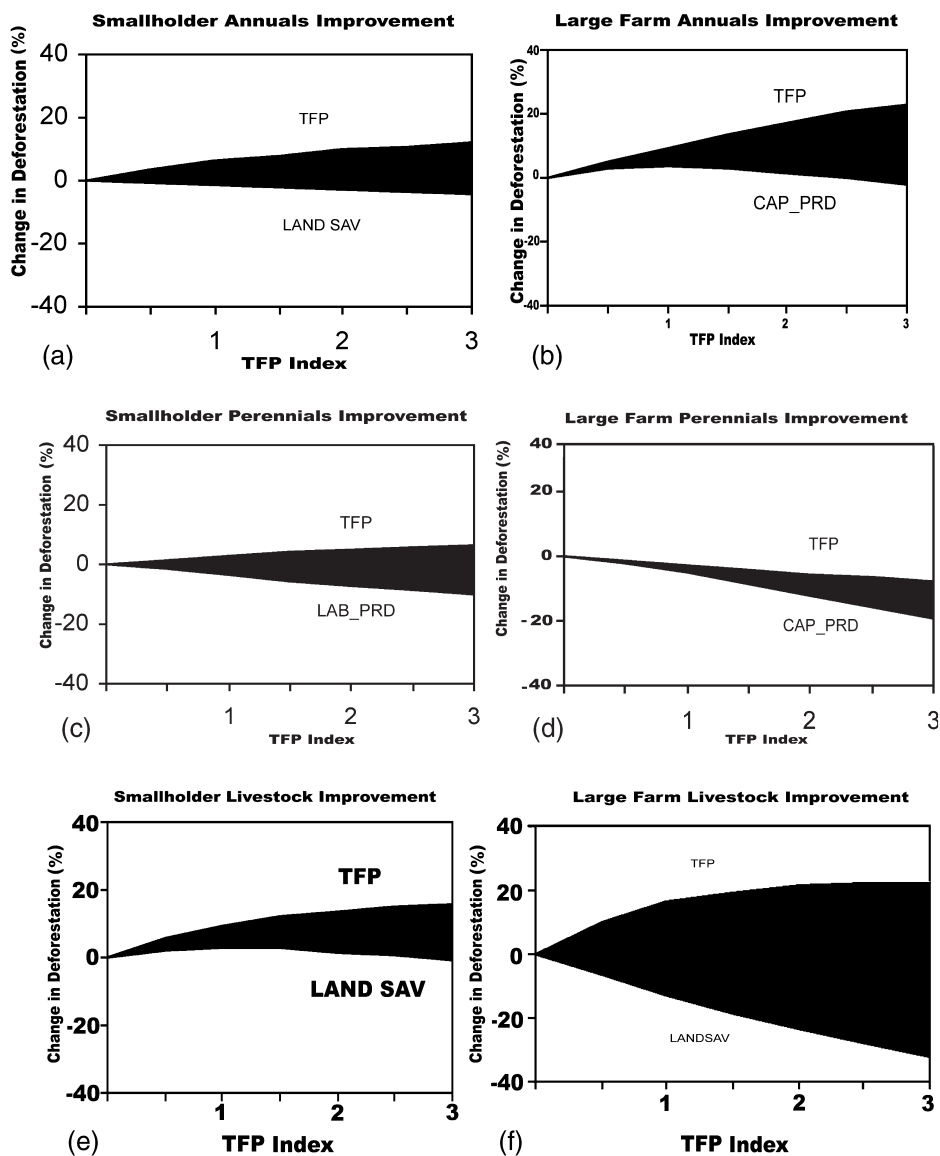


Figure 7.5 Short-run impacts of technological change on deforestation, by type of productivity improvement and scale of operation. CAP_PRD, improved productivity of capital; LAB_PRD, improved productivity of labor; LAND SAV, improvements in labor and capital productivity that increase the overall productivity of land. The TFP index associated with technical change embodied in factor f is defined as $\text{TFP index} = \Delta \text{productivity} / f$ (factor share).

Table 7.5 Types of Technological Change

Name	Comments	Acronym
Total factor productivity increase	Disembodied technological change: Improvements spread across all factors evenly.	TFP
Labor productivity increase	Improved labor productivity: Returns to labor increase.	LAB_PRD
Capital productivity increase	Improved capital productivity: Returns to capital increase.	CAP_PRD
Labor and capital productivity increase (land saving)	Replicates land intensification: Less land is needed to produce a unit of output.	LAND SAV

covering all four types of technological change and their combinations. We will not discuss in detail all the possible combinations of technological change; rather we will describe for each activity the innovations that lead to the best- and worst-case scenarios in terms of deforestation rates.

We carry out simulations for the short run (can be interpreted as 1 to 2 years), in which agricultural labor and capital are confined to their regions, and for the long run (5 to 8 years) by allowing these factors to migrate interregionally.

SHORT-RUN EFFECTS ON DEFORESTATION OF IMPROVING TECHNOLOGIES

Figure 7.5 presents the results over the short run of different types and degrees of product-specific technological change on deforestation for small-scale and large-scale production systems. The upper bound of each figure represents the results of balanced cross-factor productivity increases (TFP) for different production systems (annual crops, perennial tree crops, and livestock); the lower bounds of each figure represent the results of simulations that allowed some factors to benefit more than others from productivity gains and that were most forest-saving.

Increasing the productivity of annual crop production causes an increase in the deforestation rates of both smallholders and large farm enterprises, but especially the latter, which shift resources away from livestock into annual crops on their own farms and also force smallholders out of annual crops and into cattle production. Balanced technological change (the upper-bound, TFP cases in figure 7.5a and 7.5b) increases deforestation on large farms by more than 20 percent for high productivity gains (high TFP index readings). The lower boundaries of the shaded area in these figures represent types of technological change that are least disruptive to forests: for smallholders, land-saving technological change causes the least amount of forest loss; for large farms capital-intensive technological change actually reduced deforestation by attracting resources away from capital-intensive livestock.

Increasing productivity of perennial tree crop production in the short run generally reduces deforestation (figure 7.5d). Any technical change in production of perennials embodied in capital or labor has the effect of decreasing the demand for arable land, thereby allowing arable land to be used as pasture (lowering the price of pasture). The underlying cause of this shift is that perennials make intensive use of labor and capital per hectare cultivated (compared with annual crop production). This implies that as resources are drawn to perennials there will be less overall demand for arable land. A second reason for the decrease in deforestation is that perennials, as opposed to annuals, do not transform arable land to grassland. Therefore, there is a stock effect whereby the amount of available arable land increases, tending to reduce the demand for deforestation. Smallholders and large farms react differently to different types of technological change in perennials: Smallholders adopt innovations that are labor intensive, whereas large farms prefer capital-intensive changes. Thus, in figure 7.5c and 7.5d the lower boundaries of the shaded areas represent, respectively, labor-intensive innovation for smallholders and capital-intensive change for large farms.

The case of smallholders experiencing balanced technological change (figure 7.5c) appears to be the only exception to the decrease in deforestation associated with productivity gains in perennials. This occurs because the reduction in demand for arable land is offset by the increase in land productivity associated with a TFP improvement, which in turn raises the return to arable land. In practical terms, technological improvements in perennials will always have some positive spillover to land values. In any case, as long as the improvement in the productivity of land does not exceed the improvement in the productivity of the other factors, deforestation will decrease in the short run.

There is an expectation that improved pasture management and cattle production techniques in the Amazon will reduce deforestation by making more profitable and productive use of existing grasslands (Mattos and Uhl 1994; Arima and Uhl 1997). The model results presented in figure 7.5e and 7.5f suggest that the effects on deforestation depend on the type of technological change and the scale of operation. Almost all forms of technological change on small-scale farms increase deforestation; balanced TFP changes sharply increase deforestation rates, whereas no change in deforestation is evident in the land-saving scenario (figure 7.5e). The increase in deforestation rates can be traced back to the transfer of smallholder resources from annuals and perennials into livestock activities that use more land per unit value of output. Even arable land is converted to pasture as the livestock sector becomes more profitable. This is the least-cost solution in the short run; in fact, with a TFP index of 3, smallholder demand for arable land is reduced by 43 to 53 percent in all scenarios except the TFP case.

Technological improvement in cattle production systems operated by large farms appears to have great potential to reduce deforestation rates, especially if it is of the land-saving form (figure 7.5f). The difference vis-à-vis smallholders is that large farms already have large shares of their resources allocated to cattle production. By adopting new land-saving techniques, large farms reallocate resources between cattle and

pasture management activities, reducing their land needs. When this is combined with arable land being used in part for pasture and reductions in the value of grassland caused by excess supply, the incentives to deforest decrease. Only the balanced productivity gains scenario (TFP) causes an increase in deforestation.

LONG-RUN EFFECTS ON DEFORESTATION OF IMPROVING TECHNOLOGIES

Figure 7.6 presents the results over the long run of different types and degrees of product-specific technological change on deforestation for small-scale and large-scale production systems. The format of presentation of figure 7.6 is the same as that of figure 7.5.

Extending (to 5 years or more) the time horizon of analysis by allowing complete intersectoral and especially interregional migration of labor and capital generally causes all forms of technological change in agriculture to cause more deforestation than comparable short-term results. For example, technological improvements in annual crop production in the long run lead to higher deforestation rates than in the short-run case, especially for large farms (compare figure 7.5a with figure 7.6a and figure 7.5b with figure 7.6b). The basic tenet is that with all factors mobile land becomes the scarce factor. This implies that the returns to arable land are higher than in the short-run case, creating incentives to deforest.

Productivity gains in perennial tree crop production remain more likely to save forest than gains in other activities (figure 7.6c and 7.6d). For smallholders, the labor-intensive innovations save the most because producing more perennials leaves less labor for annual and cattle production activities. The underlying process is unchanged, but with migration there is no surplus arable land to be used as pasture; in fact, arable land increases in value. However, deforestation is still reduced by the dampening effect of lower returns to pasture land arising from factors shifting toward the production of perennials (which uses arable land). This dampening effect is also present in the TFP and the more capital-intensive scenarios, but it is not enough to offset the prospect of higher returns from arable land, so deforestation increases in the long run if smallholders adopt these types of innovations.

Increasing by whatever means the productivity of perennial tree crop production is a safe bet to reduce deforestation on large farms. The upper boundary in figure 7.6d is given by the capital-intensive innovation, which was also found to reduce deforestation in the short run. The lower boundary is now given by labor-intensive technological change scenario. The reason for this reversal is that in the short run labor is scarce and capital is abundant for large farms, so capital-intensive technological change is preferred by large farms. However, perennials are very labor intensive and therefore in the long run (i.e., when labor availability is no longer an issue) large farms favor labor-intensive innovations. In each case, the preferred option is the one that leads to the greatest expansion of perennials and a decrease in deforestation.

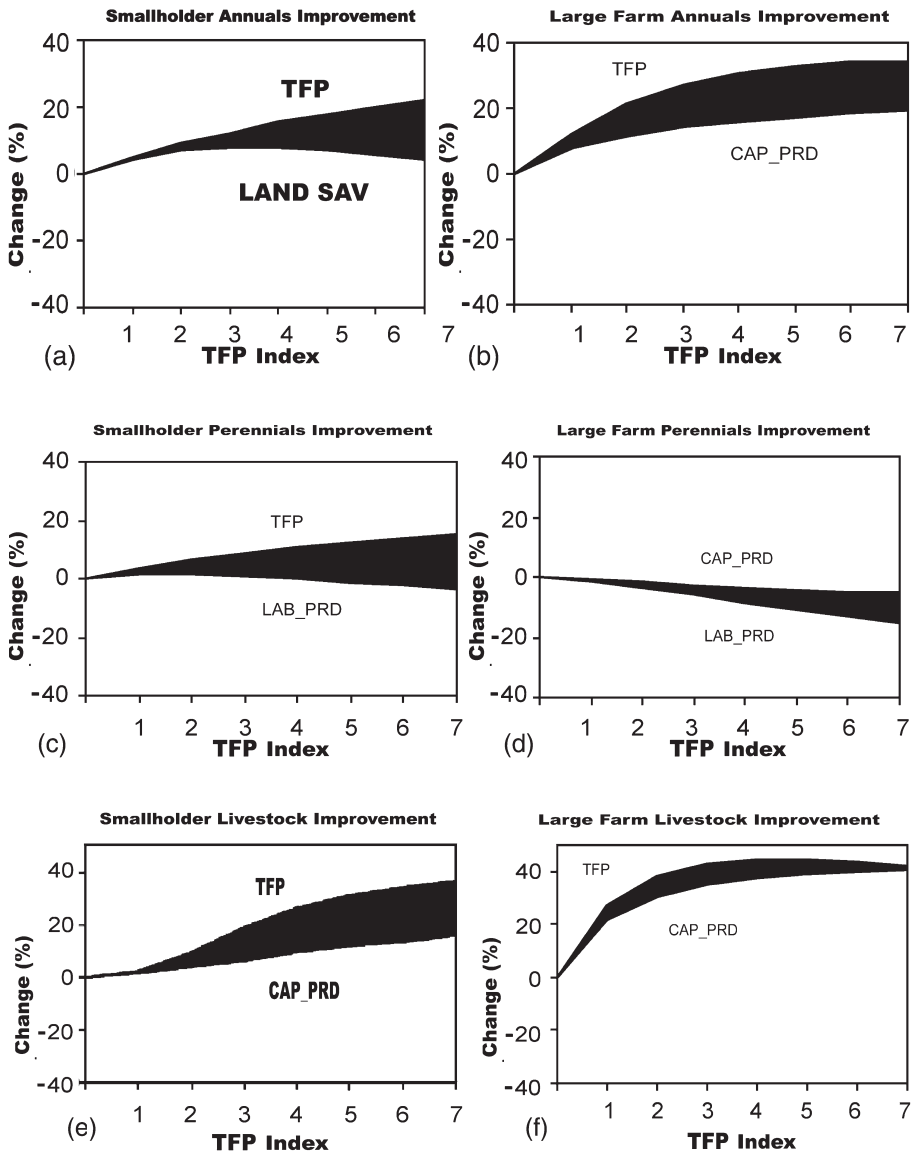


Figure 7.6 Long-run impacts of technological change on deforestation, by type of productivity improvement and scale of operation. (See figure 7.5 for abbreviations.)

The expectation or hope that improved cattle and pasture management techniques in the Amazon can reduce deforestation rates is supported only by some short-run scenarios. This short-run perspective does not take into consideration the long-term effects of a more profitable cattle-ranching sector in the Amazon. In the long run (figure 7.6e and 7.6f), as resources are allowed to flow from other regions to the Amazon, the increased demand for pasture is met by increased deforestation. In all of the long-run scenarios, improving livestock productivity by any means will substantially increase deforestation. The increase in deforestation rates is particularly strong if the adoption of technological change in the livestock sector is carried out by the large farms (figure 7.6f). The reason for this dramatic increase is that, in the case of large farm adoption, returns to pasture land increase substantially and the price of arable land increases. The increased price of arable land comes about because production of annuals leads to land degradation and subsequent use of the land as pasture; therefore, as keeping the land in pasture becomes more attractive, the demand for arable land increases in expectation that it will be used as pasture in the future. In fact, in all the long-run scenarios, production of annual crops increases alongside that of livestock (although at a lower rate). Perennial tree crop production, also pursued on arable land but not a cause of land degradation, does not expand and in some cases actually declined.

Summarizing the results of technological change scenarios, the best option for reducing deforestation is to promote technological change in perennial tree crop production. This option has the added benefit of increasing smallholder incomes relative to those of large-farm enterprises. However, from a purely revenue-driven perspective, cattle production is the best alternative for both small and large farms. This result is problematic because any form of technological improvement in livestock will lead to higher deforestation rates in the long run. Improvements in annual crop production are possible in some parts of the Amazon and would yield returns roughly equivalent to those of improvements in perennial systems, but the former probably would cause higher deforestation rates than the latter.

CONCLUSION

This chapter used economy-wide models of Brazil and Sumatra, Indonesia, to examine the effects of major currency devaluations on deforestation rates and then explored in detail the effects of infrastructure improvements and technological change in agriculture on deforestation in the Brazilian Amazon.

A major devaluation of the exchange rate can have an impact on deforestation that is similar in magnitude to that of technological change, but the direction of the effect of devaluations on deforestation cannot be known a priori. In the Sumatran case, devaluation leads unequivocally to higher deforestation rates because of the higher profitability of products exported by the agriculture and forest sectors. In the Brazil case, by contrast, policies adopted to address a major devaluation are

as important as the shock itself in determining the direction of effect on deforestation rates: In the long run, a 40 percent devaluation causes either a 12 percent increase or a 12 percent decrease in deforestation rates, depending on the policy response. Consequently, understanding the processes that lead to these different outcomes is important when evaluating the vulnerability of specific land use systems to such macroeconomic shocks; systems producing exportable commodities are least vulnerable. However, the overall performance of agriculture in specific regions can also powerfully influence farmers' choices of land use systems and production technologies.

In the Brazilian Amazon, where transportation costs for agricultural products are much higher than the national average, improving transportation infrastructure will lead to substantial increases in deforestation rates. That said, assessing the effects of reduced transportation costs on the use of cleared land will be more challenging; different products have different transportation costs per unit value, so across-the-board reductions in transportation costs can alter product mix and choice of production technique. The link between logging and deforestation solely for agricultural purposes also affects the impact of a reduction in transportation costs on deforestation rates, as does the potential for the national economy to absorb products produced in the Amazon.

Regarding regional policy, regulating and enforcing land tenure is the best option to reduce deforestation, assuming that current deforestation is in large part occurring at the hands of untenured deforesters who acquire tenure in the process. Regulating tenure far surpasses the impacts of any form of technological change in agriculture. Unfortunately, new tenure regimes are difficult to develop, implement, and enforce in a region the size of the Brazilian Amazon. However, this result supports initiatives that aim to create buffer zones with integrated participatory management, create clear property rights in these buffer zones, and discourage any encroachment into protected areas.

Most forms of productivity-enhancing technological change in the Amazon were found to increase deforestation rates, especially over the long run, when interregional flows of capital and labor migrated to the Amazon to take advantage of productivity gains. Improvements in cattle production systems were likely to cause the largest increases in long-run deforestation rates, especially if large-scale ranchers adopted improved technologies. These systems remained the most lucrative even after technological advances in alternative systems were taken into account.

Technological improvement in perennial tree crop production systems was the only case that led to reductions in deforestation; increased productivity and profitability of this labor-intense product could draw labor and capital away from extensive alternative systems, especially if adopted by large farms.

The striking difference in the effects on deforestation rates of technology change between the short run and the long run highlights the importance of interregional flows of labor and capital in determining the expansion of the agricultural frontier. This distinction is very important in evaluating the benefits of alternative land use systems: A given system may be expected to reduce deforestation because it is land saving

or because it diverts labor away from deforesting and activities that make extensive use of land; however, if this system is successful it may attract resources (labor or capital) from other regions and ultimately accelerate expansion of the agricultural frontier. Finally, the asset portfolios of agriculturalists mattered greatly in determining the links between technological change and deforestation; the behavior of smallholders often was quite different from that of large farms.

Unless deforestation is driven by subsistence needs in isolated areas, the transmission mechanisms from nonfrontier regions to the agricultural frontier are many and intertwined. Understanding these mechanisms is important in predicting the impact of policy changes and technological innovations on deforestation, something partial equilibrium analyses are not well equipped to do.

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APPENDIX: DATABASES AND KEY MODEL ASSUMPTIONS

BRAZIL

The data used in this model were drawn from Cattaneo (2002). The original sources used to construct the social accounting matrix were the 1995 Input–Output (IO) table for Brazil (IBGE 1997a), and the national accounts data (IBGE 1997b). These source were integrated with the agricultural census data for 1995–1996 (IBGE 1998) to yield a regionalized representation of agricultural activities. Household data were obtained from the national accounts and the household income and expenditure surveys. Total labor, land, and capital value added were allocated across the agricultural activities based on the agricultural census. Labor was disaggregated into agricultural and nonagricultural labor and further differentiated as skilled or unskilled. Gross profits in agriculture were allocated in part to land based on the return to land being used by the activity (FGV 1998) and the remaining part to capital.

Regional marketing margins were estimated by calculating the average distance to the closest market and using the ratio of these values relative to the industrial South to multiply the trade and transportation coefficients of each agricultural sector as obtained from transportation cost surveys (SIFRECA 1998).

Deforestation (in hectares) in 1995 was assumed to equal average deforestation between 1994 and 1996. The coefficients for deforestation technology were obtained from Vosti et al. (2002). Estimates of timber production were obtained from the agricultural census. The economic rent to timber was based on a technological specification proposed by Stone (1998). Elasticities of substitution between production factors for industry were taken from Najberg et al. (1995). For agriculture, the substitution elasticity between land and capital was set at 0.4 for smallholders and 0.8 for large farms. These values are judgment-based estimates, assuming large farms can substitute more easily between factors. The substitution elasticities in the production process of agricultural commodities were obtained through expert interviews. Arable land is assumed to sustain annual production for 4 years before being transformed into pasture or grassland. Livestock can be sustained for 8 years on pasture or grassland before degrading land completely. This implies that, on average, 25 percent of arable land in annuals and 12.5 percent of pastureland in livestock is transformed through biophysical processes.

We note two limitations in the data and model formulation. Because of the uncertainty surrounding the elasticities, the results of the simulations are meant to clarify the sign and order of magnitude of impacts of regime shifts and should not be interpreted as precise quantitative measures. For this reason, the results are presented as a range of possible outcomes given the range of possible parameters. Second, this chapter compares the impacts of policy shocks in a comparative static framework; the dynamics of adjustment processes are not considerations.

SUMATRA

The Sumatra model is based on Indonesia's 1990 intraregional IO table (BAPPNAS and JICA 1995) and on Indonesia's 1990 national social accounting matrix (BPS 1994). Complementary data allowed further disaggregation. For example, provincial crop production data for Sumatra for 1993 were used to disaggregate agricultural production. The 1993 population survey data were used to calculate factor payments to households. Disaggregated household consumption data were derived from the Sumatra household expenditure survey. For each household type, savings were calculated as a residual of income minus expenditures. Regional government revenue was derived from BPS (1996, 1997). Regional government savings were calculated as a residual of revenues minus expenses. A cross-entropy approach was used to balance the social accounting matrix (Robinson et al. 1998). The Sumatra model also adopted a comparative static framework.

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