Roads often trigger forest conversion to agriculture. This road was opened in Kalimantan, Indonesia as part of a 1980s transmigration program.

Incentives and Constraints Shape Forest Outcomes

Put yourself in the place of a farmer. You have some forest, or are thinking about claiming some forest. Should you log it? If so, should you extract as much as you can now, or plan for sustainable harvesting over the coming decades? Or should you simply clear cut the forest and replace it with crops, pasture, or tree plantations?

Your choices will be shaped by your constraints and abilities, the characteristics of the forest, your rights over it, and the wider social, economic, and political context. Your choices will affect your livelihood—as well as stream flows of your downhill neighbors and climates of people in distant lands. When your interests and other people's diverge, there could be a mediating role for public policy.

Understanding landholders' behavior is essential to understanding how policies and context affect deforestation and forest poverty. Attempts to understand the effects of sweeping policies (such as structural adjustment) on sweeping outcomes (such as aggregate forest loss in a country) are doomed to inconclusiveness. Policy changes typically pull many economic and social levers—changing prices and wages; stimulating one sector, dampening another. Each lever could have a distinctive impact on deforestation and forest poverty, and those impacts might differ between regions. At the national level these impacts might be difficult to disentangle. So this report's strategy is to try to understand how each potential lever works.

This chapter, which draws heavily on Angelsen (2006), offers a simple but powerful model of land use decisions at a particular point in space and time.[1] It then uses that model to examine how forest cover and poverty might evolve over time for entire regions.

The View from the Forest Plot: Comparing the Returns to Forestry and Agriculture

The International Tropical Timber Organization (2006, p. 46) describes the dilemma facing sustainable forest management: "alternative land uses, which usually involve a much more intensive use of the land, are more profitable or provide quicker returns." How and why does this dilemma arise?

Is Sustainable Forest Management Appealing to Landholders?

Culture and experience may impel long-time forest dwellers to maintain forest even if other land uses are potentially more lucrative. Shifting cultivators, for instance, have a long history of sustainable forest management, temporarily clearing small plots for agriculture and cycling over long periods through large tracts of forest. Some forest-owning Mexican communities harvest less than regulations permit or profits might dictate (Bray and others 2003). And cultures around the world protect sacred forest groves.

Still, economics is likely to intrude on the decisions of most forestholders. There are few long-cycle shifting cultivators left in the world—reflecting rising population densities, accelerating fallow cycles, and forests degrading into bush. Elsewhere, as markets approach, forestholders (or would-be forest claimants) balance returns from sustainable timber production against predatory extraction, followed by agricultural conversion.

Though there are exceptions, sustainable timber management is often less lucrative than other options. Exceptional cases involve forests with precious woods, many saleable trees, fast-growing trees, or soils unsuited to agriculture. For instance, sustainable management of Indian teak forests is estimated to confer a land value of more than $5,000 a hectare in net present value (World Bank 2005, vol. II, p. 76).[2] Coniferous forests in Mexico, where nearly all trees are commercially valuable, are another example.

But in old-growth rainforests with diverse, slow-growing species, biological and financial considerations could push landholders away from sustainability. An analysis of logging economics at a Brazilian site by Boltz and others (2001) illustrates a general pattern.[3] Reduced impact logging could net $128 a hectare from an initial selective harvest, leaving the residual forest in reasonably good condition. Left alone (without silvicultural treatment), the forest regenerates, but its value grows by just 2 percent a year—a bad investment. Another harvest is possible in 30 years, but the present value of that harvest, evaluated at a 20 percent discount rate (a reasonable approximation of the discount rate in many developing countries), is only $0.24 a hectare. Even low-return pasture or staple crops offer higher returns to landholders. Of course society, with a lower discount rate and a demand for forest environmental services, may view things differently.

Private Gains from Deforestation: Sometimes Minuscule, Sometimes Huge

How big are the private gains to deforestation? Knowing this is essential to assessing the economic and political costs of encouraging sustainable forest management. The answer—not surprising, but important—is that these gains vary tremendously between places, technologies, and land use systems. Profits from deforestation range from near zero to thousands of dollars a hectare.

Profits are the benefits to landholders from sales of timber and agricultural products, after costs of conversion and production, including labor. For smallholders dependent on unpaid family labor, this concept of profits can be interpreted as income above what family members could earn elsewhere. In other words, a strict measure of profit deducts the opportunity cost of family labor. The resulting measure of net profits per hectare is a convenient measure of the economic pressure for forest conversion—or of the opportunity cost of conservation. However, where labor markets are imperfect, workers and policymakers may consider labor absorption a benefit. So employment per hectare is another way of assessing the benefits of forest conversion.

It is challenging to document the value of forested land in the tropics. In a few places, mostly in Latin America, markets provide a clear indicator of the profitability of land. In theory, prices for pasture or prepared fields in these areas should reflect the net present value of future revenue from farming, including expected gains from road construction and improvements in tenure security.

Elsewhere in the developing world, where land, labor, and product markets are thin, estimates of profitability come from farm studies. The Consultative Group on International Agricultural Research's Alternatives to Slash and Burn (ASB) program has undertaken especially rigorous measurements of economic benefits and environmental impacts of forest conversion in Brazil, Cameroon, and Indonesia (Tomich and others 2005). These measurements, along with other reported land values from forested areas, appear in table 2.1.

Although the land values provide a useful benchmark, they typically overstate the private gains to forest conversion, for two reasons. First, it is necessary to account for the upfront costs of clearing logged-over forest and preparing the land for crops or pasture. In Bolivia, for instance, the cost of clearing and pasture establishment averages $480 a hectare, defrayed only in part by after-tax timber revenues of $227 (Merry and others 2002).[4] These upfront costs are factored into the ASB estimates, but they also need to be deducted from some of the others.

Second, most analyses that compute net present values adopt a 10 percent discount rate, which is lower than typical private discount rates—especially among poor people. At a higher discount rate, the returns to conversion would fall substantially. In Ninan and Sathyapalan (2005) increasing the assumed discount rate from 8 percent to 12 percent cut the net present value in half. Naidoo and Adamowicz (2006) present evidence supporting a discount rate of 15–25 percent for Paraguay; GEF (2006) suggests that discount rates in the developing world are typically even higher. For these reasons the net present values reported in table 2.1 might be two or three times greater than landholder perceptions of returns to forest conversion.

Some highlights from these studies:

- In some places there are huge incentives to degrade or convert forest. In Cameroon oil palm and intensive cocoa cultivation has a net present value of more than $1,400 a hectare. In Brazil's *cerrado* (savanna) region, converting native woodlands to soy results in land worth over $3,000 a hectare. India offers extraordinarily high values for land devoted to coffee cultivation in the Western Ghats, a biodiversity hotspot.
- In contrast, mean land values are just $400 a hectare in another hotspot, the Atlantic forest of Bahia, Brazil—one of the world's most important places for bio-

Table 2.1 Land Values in Forested Areas Vary Enormously

a. Studies Reporting Land Prices or NPV

Study	Location	Year(s)	Land use, type, or location	Price or net present value (per hectare)	Notes
Batagoda and others (2000)	Sinharaja, Sri Lanka	1995	Tea Timber potential	$4,281 $1,129	NPV at 8 percent
Chomitz and others (2005b)	Bahia, Brazil	2000	Median land value	$400	Price
Davies and Abelson (1996)	Bolivia	1992	Mechanized soybeans and maize Traditional farm excl. coca Traditional farm with coca	$1,500 $270 $385	NPV at 10 percent
FNP Consultoría & Agroinformativos	Goias, Brazil (various subregions)	2004	Cerrado (savanna) High-productivity agricultural land	$140–1,290 $1,950–3,150	Price
Fundacão Getulio Vargas	Brazil	2004	Pará Rondonia	$200 $318	Price of pasture
Grimes and others (1994)	Ecuador (Amazon region)	1987–91	Cattle ranching Timber Agriculture Land price	$57–287 $189 <$500 $50–220	NPV at 5 percent NPV at 5 percent NPV at 5 percent Price
Howard and Valerio (1996)	Costa Rica	1994	Cattle ranching Atlantic South North Bean crops South North Corn (Atlantic)	 $1,239 $1,433 $880 $2,716 $2,163 $2,281	NPV at 10 percent
Kazianga and Masters (2005)	Cameroon	2001	Land at the frontier	$86	Price
Kishor and Constantino (1993)	Costa Rica	1989	Cattle ranching Clear felling Plantations Managed forestry	$1,319 $1,292 $3,223 $854	NPV at 8 percent (without taxes and subsidies; includes timber revenue)

(continued on next page)

Table 2.1a (*continued*)

Study	Location	Year(s)	Land use, type, or location	Price or net present value (per hectare)	Notes
Merry and others (2002)	Bolivia	Not available	Pasture	$24–500	Price; range reflects accessibility
Ninan and Sathyapalan (2005)	Ghats, India	2000	Coffee on farm <2.5 acres 2.5–5.0 acres 5–10 acres >10 acres	$1,593 $1,819 $4,834 $8,280	NPV at 10 percent; small farms more likely to be in forests
Olschewski and Benitez (2005)	Ecuador	2001	Grazing land North Coast Nearest Quito	 $150–500 $400–1,000 $800–2,000	Price
Pinedo-Vasquez, Zarin, and Jipp (1992)	Peruvian Amazon	1988–89	Swidden agriculture (rice, cassava, plantains, fallow)	$1,627	NPV at 10 percent
Ricker and others (1999)	Veracruz, Mexico	1998	Pasture	$210–1,052	Price
Tomich and others (2005)	Brazil Amazônia	1996	Pasture	$2	NPV at 9 percent
Tomich and others (2005)	Cameroon	1990s	Food crop Cocoa Oil palm	$283–623 $424–1,409 $722–1,458	NPV at 10 percent
Tomich and others (2005)	Sumatra, Indonesia	1997	Rubber agroforestry Community forest management Oil palm Unsustainable logging	$1 $5 $114 $1,080	NPV at 20 percent
Wunder (2000)	Ecuador	1994–96	Deforestation cycle (wood, crops, cattle)	$1,721	NPV at 10 percent; includes initial timber revenue
Yaron (2001)	Cameroon	1997–98	Small farming Oil palm and rubber Sustainable timber production	$2,380–4,275 –$2,838 to $96 $45–470	NPV at 10 percent

Table 2.1 (*continued*)
b. Studies Reporting Annual Net Returns

Study	Location	Year(s)	Land use, type, or location	Annual net returns (per hectare)
Naidoo and Adamowicz (2005)	Uganda	1993–2001	Farming	$114
Norton-Griffiths and Southey (1995)	Kenya	1989–93	High potential zone Medium potential Per humid Arable	$151 $91 $38 $54
Olschewski and Benitez (2005)	Ecuador	2001	Cattle ranching North Coast Nearest Quito	 $25[a] $42[a] $110[a]
Zelek and Shively (2003)	Philippines	1994–96	Low-input maize	$260

NPV stands for net present value.
a. Returns are net of costs except labor.

diversity conservation. Only small fragments of forest remain in this long-settled region. The study also finds that remaining forest sells at a steep discount relative to other land with similar characteristics. This disparity may reflect the effect of laws, even though imperfectly enforced, against deforestation. It may also reflect relegation of the poorest-quality land to forest; after decades of occupation, most agriculturally suitable land has already been cleared. Both effects may be present in other biodiversity hotspots where forests have been heavily fragmented.

- At the Latin American frontier, forest is being converted to low-value uses that generate little employment. Conversion of forest to traditionally managed pasture in Amazônia yields pasture worth only a few hundred dollars a hectare. Pasture at the Ecuadorian frontier is worth $150–500 a hectare; at the Bolivian frontier, $24–500. After accounting for costs, ASB estimates that converting a hectare confers a net present value of only $2 and provides just 11 days of employment a year. But values are much higher near cities and on well-managed farms using improved production systems.

- Low-value land uses are also reported in Indonesia, Uganda, and the Cameroonian forest frontier.
- Sustainable forest management typically provides lower returns and employment than does commercial agriculture. In Sumatra, for instance, management for non-timber forest products employs 0.3 people a hectare per year and returns a net present value of just $5 a hectare—while oil palm cultivation employs 108 people a hectare per year and returns $114 a hectare. Agricultural returns outstrip those from sustainable forest management in Cameroon, Costa Rica, India, and Sri Lanka.

In summary, there is great variation across pantropical forest margins in the strength of incentives for deforestation. Where conditions are amenable to crops such as soybeans, oil palm, or cocoa, and where old-growth timber is still standing, deforesters are rewarded with thousands of dollars a hectare. On marginal lands, lands far from markets, or where agricultural technologies are unavailable, there may be little incentive beyond the ability to eke out a living at the going wage.

How Do Agroclimate, Prices, Technology, Tenure, and Other Factors Affect Deforestation and Income?

This section considers how the environmental, social, and economic context of a forest plot affects the relative returns to forest maintenance and agriculture. The discussion here helps in understanding how policy levers affect outcomes in the forest domains described in chapter 1. Table 2.2 summarizes the discussion.

Richer Farmers Are Better Able to Finance Deforestation

A poor household can't afford to clear much forest. In Bolivia clearance and land preparation costs range from $350–605 a hectare (Merry and others 2002); in Costa Rica clearance costs $78 a hectare (Howard and Valerio 1996). Sometimes these costs can be partly or fully defrayed by sales of timber; sometimes wealthy interests are willing to finance clearing by smallholders on their behalf. Where these markets are lacking, successful deforesters must be able to mobilize a lot of family or community labor—50 to 70 person-days

Table 2.2 Predictions of How Changes in Local Variables Will Affect the Environment and Welfare

Element	Effect on environment − Promotes deforestation + Inhibits deforestation	Effect on welfare − Reduces welfare + Enhances welfare
Access to credit markets; own assets	−	+
Lower discount rates	+ with exceptions	+
Good soils, moderate rainfall	−	+
Higher prices for extensive farm output	−	+
Higher prices for intensive farm output	+ Where labor markets are imperfect, could decrease deforestation by attracting labor away from extensive production − Where capital markets are imperfect, could increase deforestation by funding forest conversion	+
Higher prices for timber	− Spur deforestation of old-growth timber − Increase deforestation in open access areas + Encourage sustainable management of secondary forests where there is secure tenure + Spur reforestation in forest-poor areas	± Effect on local poverty depends on who extracts the timber and wider economic effects; poverty may increase if outsiders degrade forests on which locals depend
Higher off-farm wages	+ Where labor markets are imperfect or in-migration is limited, draw labor away from deforestation of marginal areas − Could fund deforestation	+
Higher-yielding agricultural technologies	− If labor and capital can migrate to forest margins + If marketwide effects lower prices + If technologies absorb labor and in-migration is limited	+ (though indirect negative effects are possible)
More secure land tenure	+ Reduces deforestation as a means of claiming land + Makes sustainable forest management more attractive − Makes investments in land improvements (including perennial crops) more attractive	+
Road extension or improvement	− Increases farmgate prices of outputs, lowers prices of inputs, makes in-migration more attractive	+ (unless outsiders displace locals)

a hectare—or to hire workers, chainsaws, and bulldozers. This point suggests that cash and credit constraints hamper smallholder deforestation. Relaxing those constraints—through transfers, stronger credit markets, and better opportunities for off-season employment—could increase both incomes and deforestation.

Good Land Is Cleared First

Soils, topography, and climate (agroclimate, for short) strongly affect land rents. Differences in soils and climates explain most county-level variations in land values in Brazil, India, and the United States (Mendelsohn, Dinar, and Sanghi 2001). In Bahia rural land prices increase with soil quality but decrease with slope, holding constant other characteristics such as road access (Chomitz and others 2005b).

Deforestation occurs more quickly on lands that offer higher rents. Studies of deforestation at the farm or local level generally find that deforestation rates are lower on hillsides, other things constant (appendix table A.1). These studies also find a strong correlation between soil quality and deforestation. In periurban areas of Latin America and Asia tree cover is about twice as high on the poorest soils as on the best soils for rainfed agriculture (see chapter 1).

High densities of saleable trees can also promote deforestation. Roads built by loggers and revenue from timber sales can help finance agricultural clearing. If the density is high enough, extraction can lead to deforestation even in the absence of agriculture. This is thought to be true in Southeast Asia, where lowland forests have high densities of valuable dipterocarp trees. For instance, logging is blamed for deforestation in sparsely populated, protected areas of Kalimantan, Indonesia (Curran and others 2004).

Deforestation skirts areas with high rainfall, which is inimical to cultivation of annual crops and discourages cattle ranching—especially when there is no dry season. A study of Brazilian Amazônia by Chomitz and Thomas (2003) found that, controlling for road access, higher rainfall is associated with lower deforestation, more land abandonment, and lower grazing densities.

Higher Prices for Farm Output Induce Forest Conversion and Benefit Farmers

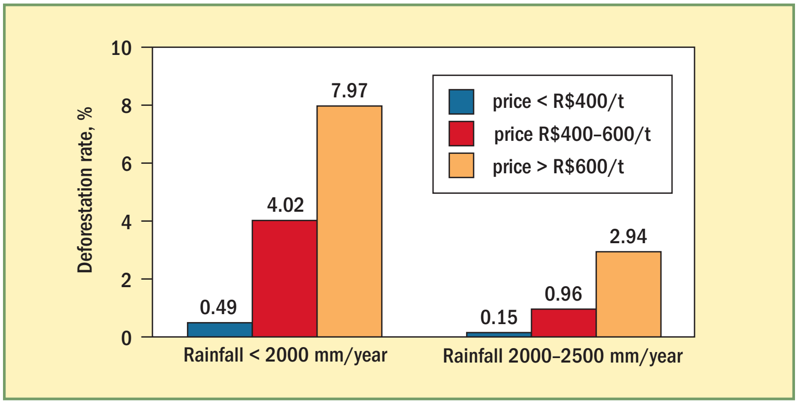
Other things being equal, higher prices for crops and lower prices for farm inputs will spur faster deforestation. This prediction is important because many policies can affect farmgate prices, including taxes, tariffs, subsidies, road improvements, and exchange rate policies.

The prediction can be tested by looking for variations in prices across the landscape within a country, between countries, or over time, and correlating prices with deforestation rates. Doing so is difficult. Within a country, at a single point in time, there may be little price variation. Comparisons between countries and over time are problematic because there are many other confounding influences, and because measurements of deforestation may be inconsistent. So there are only a few relevant studies.

Most of these studies find a strong link between higher agricultural prices and more rapid or extensive deforestation. The degree of price sensitivity varies but tends to increase with more localized measurements. For instance, an analysis of remote sensing data shows that, after controlling for other factors, deforestation rates in Brazilian Amazônia are closely linked to farmgate prices of beef (figure 2.1). This analysis focuses on unprotected lands (excluding land reform settlements) and shows the strong effect of rainfall levels and farmgate prices on deforestation rates. In areas with moderate rainfall (less than 2,000 millimeters a year) near roads, deforestation over 2001–03 was 8 percent where the beef price was above R$600 a ton, 4 percent where the price was R$400–600, and 0.5 percent where the price was below R$400.

In a study of Mexico, Deininger and Minten (1999) examined the relationship between deforestation and proximity to buyers of

Figure 2.1 Deforestation in Brazilian Amazônia Is Shaped by Rainfall and Farmgate Prices of Beef, 2001–03



Source: Authors' calculations; see Appendix B.
Note: Rate is deforested area/initial forest area.
Excludes protected areas and land reform settlements.

maize—the main forest-competing crop. Because maize is bulky, closer proximity translates into lower transport costs and higher farmgate prices. The authors found that an increase of one standard deviation in buyer density corresponded to a 40 percent increase in the deforestation rate. Barbier and Cox (2004) examined mangrove deforestation (due to shrimp farming) in Thai provinces and found that a 10 percent hike in shrimp prices would boost deforestation a modest 1.6 percent—while a similar hike in the price of ammonium phosphate (an input) would reduce deforestation by 4.5 percent. But not all studies find strong effects. Gbetnkom (2005), for instance, finds that changes in prices of coffee, cocoa, and food have negligible effects on forest clearance in Cameroon.

The impacts of price changes become more complicated when two other land uses compete with forest. Suppose that one use is extensive: long-fallow cultivation of a staple food (such as cacao, irrigated rice, or coca). Suppose that the other is much more intensive, using far more labor per hectare (say, shifting cultivation of maize, rice, or plantains). Suppose too that the labor supply is limited, and outsiders cannot easily move in to exploit new opportunities. Then, theory says, an increase in the returns to the intensive land use could absorb labor from the extensive one, at least in the short to medium run.

There is evidence that this happens. Coxhead and Demeke (2004), in a study of upland farmers in the Philippines, find strong cross-effects between vegetable and maize production. An increase in the price of vegetables, the more intensive crop, is predicted to slightly reduce the total area under cultivation.

Higher prices for farm products benefit land owners and increase employment. So in general, higher prices for outputs and lower prices for inputs will reduce rural poverty—with two exceptions. First, because farmers with tiny plots might be net buyers of food, higher food prices will hurt them. Second, substitution between crops could indirectly hurt poor people. For instance, higher prices for beef or soy—which use relatively little labor—could divert land away from more intensive cultivation.

Higher Timber Prices Put Pressure on Old-growth Forests but Create Incentives for New Ones

Do high timber values promote or undermine sustainable forest management? The answer depends on the state of the forest (von Amsberg 1998) and how it is regulated. New roads or new markets can confer enormous value on old-growth forests. Individual trees can be worth thousands of dollars.

In the absence of regulation, rising prices induce loggers to sweep deeper into old-growth forests, mining sellable trees (Stone 1998). But where societies are willing and able to require forest owners to practice sustainable forest management, higher timber prices make such regulation less onerous. And where forests have already been depleted, higher timber prices make it more attractive to raise trees—especially plantations of fast-growing ones—as a crop.

Higher Off-farm Wages Discourage Deforestation in Marginal Areas

Many, though not all, forest dwellers have opportunities to earn wages. The opportunities may be on neighboring farms or plantations, in nearby market towns, or in distant cities. As these opportunities become more lucrative, there is less incentive to use forest for subsistence or low-value crops. Kaimowitz and Angelsen (1998) found broad support for this proposition.

A dramatic long-run example of this is the abandonment of the hillsides of Puerto Rico. By 1950 almost all the island's hillside forests had been converted to coffee plantations or other agriculture, leaving only 9 percent of the island under forest. Subsequently, there was massive out-migration from the hillsides as people sought better-paying employment in San Juan and the United States. The result was regeneration of the deforested area: by 1990, 37 percent of the island was under forest (Rudel, Perez-Lugo, and Zichal 2000; Lamb, Erskine, and Parrotta 2005b).

Between 1994 and 2002 Coxhead and Demeke (2004) observed a wage rise of about 50 percent among hillside farmers in the Philippines, as transportation and communications improved. According to their analysis, this increase would by itself reduce land cultivation by about 20 percent. But wage increases can also affect deforestation in other ways. Barbier and Cox (2004) found that higher wages were associated with higher clearance of mangroves for shrimp farming in Thailand. They suggest that this was because shrimp growers, faced with higher wages, had ways of substituting land for labor. Wage increases can also increase the demand for fuelwood and food, spurring additional deforestation.

Whatever their effects on deforestation, increases in off-farm wages are essential to poverty alleviation. A growing literature documents the potential role of off-farm employment in alleviating rural poverty (Reardon, Berdegue, and Escobar 2001).

Agricultural Technology Promotes Growth —With Ambiguous Implications for Deforestation

Technological improvements in agriculture are crucial to raising rural welfare (through higher farm incomes) and consumer welfare (through lower food prices). But the gains from these improvements may be unequally shared. And except in special circumstances, technological improvements are likely to increase pressures on forest. To explain why, this section draws on Angelsen (2006) and Angelsen and Kaimowitz (2001).

To be adopted, a technical innovation generally has to save a farmer's time or increase farm output. But any innovation that makes farming more profitable is likely to prompt the expansion of farms into forests or attract new farmers to the forest frontier. And anything that reduces labor requirements could release unemployed farmers to search for new frontiers. For instance, Ruf (2001) claims that in Sulawesi, Indonesia, the introduction of herbicides and mechanical cultivators in lowland rice production released workers to engage in upland deforestation.

Consider too the impact of improved soybean varieties in Brazil's *cerrado* (savanna) region. The region's poor soils and short days had been unsuitable for cultivating traditional soy varieties. So EMBRAPA, the Brazilian agricultural research agency, bred varieties adapted to the region. As a result soy cultivation exploded—at the expense of pasture, biodiversity-rich *cerrado,* and, recently, dense forests. The area cultivated jumped from nearly zero in 1970 (Warnken 1999) to 117,000 square kilometers in 2004 (IBGE 2006). Soybean and soy product exports were $9.8 billion in 2004 (Economist Intelligence Unit 2005).

For a technological innovation to simultaneously increase farmer welfare and reduce forest pressure, one of the following conditions must apply:

- The innovation increases food production so much that food prices fall, easing pressure to convert forested uplands. This might happen in isolated locales cut off from markets. Or it might happen if the productivity increase is so large that it depresses national or even global markets. Some analysts think that the green revolution is an example, positing that improvements in irrigated rice yields reduced pressures for upland deforestation.

- The innovation boosts the productivity of subsistence farmers not closely linked to food markets. This could reduce their need for clearing and might occur in areas beyond the frontier.
- The innovation boosts both productivity and labor use per hectare. Moreover, labor supply is limited, either because of remoteness or because local residents have secure tenure over large amounts of land and prefer not to rent or sell to newcomers. In these conditions—more characteristic of frontier areas than mosaiclands—some intensive farming systems could absorb labor away from extensive, more forest-damaging ones. Holden (2001), Shively and Pagiola (2004), Shively and Martinez (2001), and Coxhead and Demeke (2004) present examples of how expansion of intensified land use systems can draw labor away from extensive, deforesting land uses. It is uncertain, though, whether over the long run inflows of labor might counteract this effect.
- The innovation stimulates nonfarm employment. Returning to the example of soy in Brazil's *cerrado,* the direct beneficiaries were soybean farmers, including large and industrial growers. But related growth in services, transportation, and processing has contributed to the rapid development of urban centers in the soybelt, and during the 1990s these cities accounted for substantial employment growth. However, the size of the link between soy expansion and urban employment has not been quantified.

Tenure Is Good for Landholders, but Has Uncertain Effects for Deforestation

Landholders with secure tenure are more likely to make physical improvements, invest in perennial crops, and plant and maintain forests. They worry less about defending their property and lives from thieves. They are better able to tap credit markets. And large landholders with secure tenure are more inclined to rent out land to tenants or sharecroppers, rather than keeping it idle or under pasture. For all these reasons, tenure security boosts incomes of rural landowners and workers (Deininger 2003).

Poorly defined tenure is generally bad for people and forests. In many parts of the world, governments have nominal control of forests but are too weak to effectively regulate their use. This can lead to a tragedy of the commons where forest resources are degraded.

The relationship between tenure and deforestation is more ambiguous. In frontier areas deforestation is a common way of laying claim to land and securing tenure, in both practice and law. This setup encourages a destructive race for property rights at the frontier (Schneider 1995), where land is prematurely deforested—that is, before it generates any economic rent—in speculation that roads or government will eventually confer value on it. And in countries with pressure for land reform, large landholders will feel pressured to deforest just to demonstrate "productive use" of the land and so avoid invasion or expropriation. That has been especially common in Brazil, where uncertainty over land rights has led to violent fights over forested properties.

But secure tenure does not guarantee that landowners will spare forests. As noted, landholders will likely first extract and sell large, mature, slow-growing trees. Landholders will then weigh the relative advantages of forest maintenance and cropping. With secure tenure, investments in perennial crops such as black pepper or oil palm may be more attractive.

Roads Provide the Path to Rural Development —and Forest Clearance

Providing road access is the most effective determinant of deforestation that is under policy control. The theoretical argument is strong: it says that road provision increases farmgate prices for outputs and decreases farmgate prices for inputs, with all the effects just reviewed. Property-level studies of land values in Nepal (Jacoby 2000) and the Atlantic forest area of Brazil (Chomitz and others 2005b) support this linkage. This means that improving access to a forest plot generally creates strong pressures to deforest it.

The theory allows for exceptions. In rural areas where tenure is strong and immigration is limited, better road access might allow residents to work in towns, or shift them from extensive production of subsistence crops to more intensive production of commercial crops. Deforestation might then fall as long as residents can and will exclude in-migrants. Road links to nearby towns might boost local wages more than farmgate prices, attracting farmers away from marginal lands. And where forests are already exhausted, better road access could trigger tree planting for poles, firewood, and timber.

But an extensive empirical literature strongly supports the proposition that roads tend to promote, rather than inhibit, deforestation. A major challenge for this literature is determining causality when road development and deforestation occur together. Did the roads facilitate deforestation? Or were they built in response to settlement that would have occurred in their absence?

One approach to answering these questions is through case studies of deforestation (for example, Arima and others 2005). One analysis of 152 case studies finds that road access was a driver of deforestation in 93 cases (Geist and Lambin 2001), and another metareview concurs on the importance of road access (Kaimowitz and Angelsen 1998).

Another approach uses spatial econometric analysis to relate the incidence of deforestation to road proximity. Investigators compare small geographical regions, or even individual points on the landscape, in order to account for confounding factors such as soil fertility, climate, slope, or elevation. This helps to control for the possibility that roads are a symptom rather than cause of deforestation. This report reviewed 33 such studies, most of them at the finest level of geographic analysis (appendix table A.1). Twenty-one found a statistically significant, positive relationship between road proximity and deforestation. Eight found complex or ambiguous patterns, for instance when several measures of remoteness were used, or when there were differential effects on different groups. The remainder were inconclusive.

Road access also facilitates hunting of large mammals. In central African forests this is a more severe environmental threat than deforestation, and a study in Gabon found fewer mammals near roads (Laurance and others 2006).

Rural roads are generally believed to raise rural incomes and alleviate poverty, for the same reasons our model suggests they promote deforestation: by raising farmgate prices, lowering prices of urban manufactured goods, and promoting more intensive demand for labor. Rural roads also facilitate access to nonfarm employment in towns, which is often crucial to alleviating poverty in rural areas. For these reasons rural road provision is a mainstay of rural development strategies.

Considering the importance of rural roads to development strategies, the literature on their impact is thin. This report reviewed 26 studies and two metareviews covering 56 others. Though they were almost unanimous in finding positive impacts, the magnitude of the impacts varies greatly. Few of the studies used rigorous, quasi-experimental evaluations of how roads affect income and welfare. One of the most rigorous evaluations compared Peruvian villages that had received rehabilitated road links with similar control villages (Instituto Cuanto 2005). After five years, male (but not female) wages in the villages with rehabilitated roads rose by 20 percent relative to the control villages. In subsequent hard economic times, poverty in the control villages increased by 4–6 percentage points more than in the villages with rehabilitated roads.

Two recent simulations are of particular interest because they examine countries with extensive forest cover. In Papua New Guinea a study assessed the impact of reducing to three hours the access time to a road of all households that required more time (Gibson and Rozelle 2003). This potentially expensive undertaking would cut the number of poor people by 12 percent. The other study found that providing all-season roads to the 50 percent of Laotians lacking them would release 5 percent of the population from poverty (Warr 2005).

Other studies involve econometric analysis of district or provincial data, attempting to control for other potentially confounding factors. Fan and Chan-Kang (2004) summarize some of these studies, reporting astounding returns to road investment—hundreds of percentage points—in China, Uganda, and rain-fed regions of India. Other reported returns are far more modest, but still positive (appendix table A.2).

The inconsistent relationship between rural roads and poverty alleviation reflects a variety of factors. First, it may be modulated by other policies and conditions. Finan, Sadoulet, and de Janvry (2005) find that rural Mexicans with both road access and primary education earn about 10 times more from an extra hectare of land than do those without either asset. Second, where immigration is possible, roads may cause an increase in workers rather than wages.

Forest Trajectories: Roads, Markets, and Rights Shape Outcomes for Environment and Income

Astronomers teach us that the farther into space we peer, the farther back in time we see. So too, when we stand in an urban center and look toward the remote forest frontier, we see not only a changing spatial pattern of forests on today's landscape, but also a history of how that landscape evolved. Seen from the other direction, conditions near contemporary towns—old frontiers—provide hints about the future prospects of today's frontier regions. This section builds on our understanding of landholders' behavior, expanding from a single plot to an entire landscape, and from a snapshot to an evolving pattern.

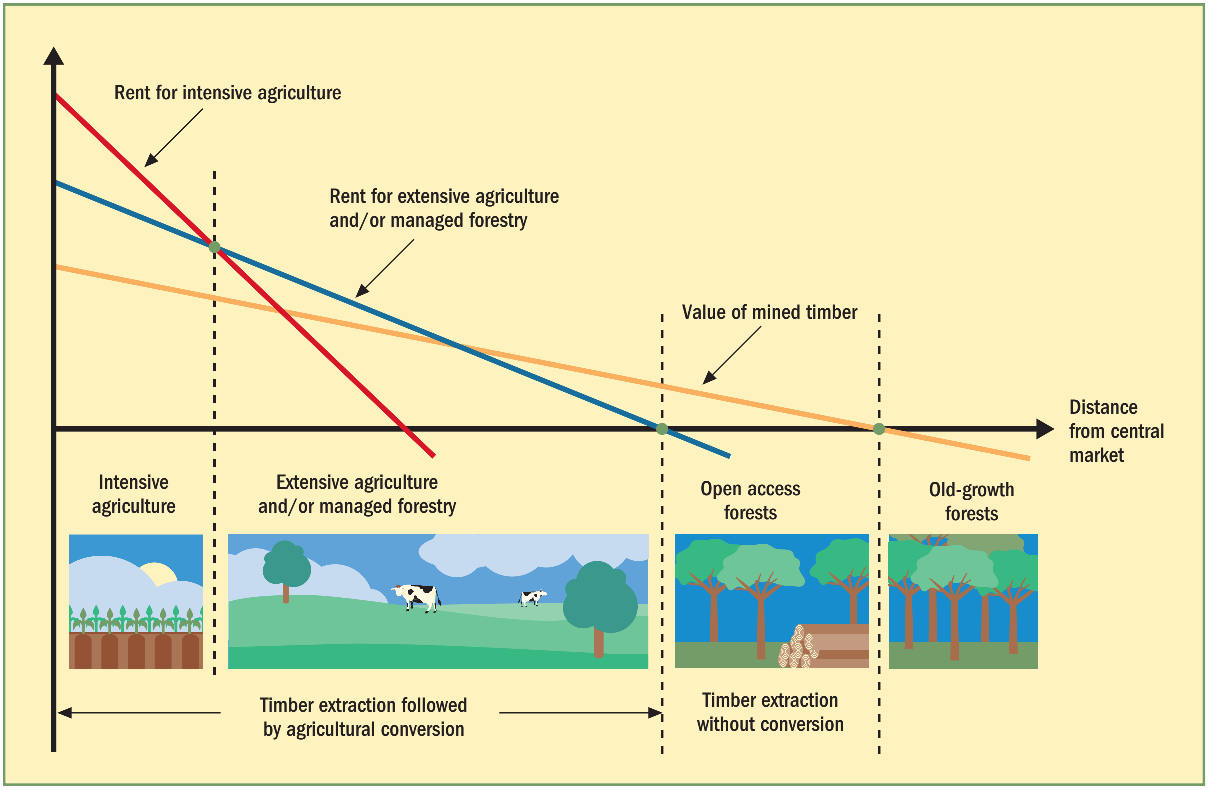
From Urban Center to Forest Frontier: A Stylized View of the Landscape

Let's first take a stylized journey from an urban center to a forest frontier, at a moment in time. Our guide is Johann Heinrich von Thünen, the 19th-century economist. Von Thünen's enduring insight was that farms and forests closer to towns are more valuable, other things (such as soils and topography) being equal. The reason is simple: if the price of rice or wood is determined in a town's market, then nearby farmers bear lower costs in getting their products to market. Because they make higher profits, their land is worth more—that is, its rent for agriculture is higher.

Rents fall with distance to town, rapidly for bulky or perishable commodities (vegetables, milk) and more slowly for others (beef, coffee, hardwood timber; see figure 2.2). As land values decrease, land uses become more extensive, with pastures displacing crops and rotating fallows replacing permanent fields. After a certain distance farmers can no longer profitably supply crops to market, and their land has no agricultural *rent*. This is the agricultural frontier; beyond it there are only subsistence farmers and standing forests. Thus this stylized model predicts concentric rings of land uses centered on urban areas. There is evidence that this model, inspired by German landscapes of the early 19th century, describes landscapes across the developing world (Chomitz and Thomas 2003; Barnes, Krutilla, and Hyde 2005).

How does forestry fit into this picture? There is an important distinction between one-time extraction of old-growth trees and sustainable management of planted or natural forests. Big, valuable, old trees tend to get extracted as soon as they are accessible. Smaller,

Figure 2.2 A Stylized Model of How Land Use Changes with Remoteness



Source: Authors, adapted from Angelsen 2006.

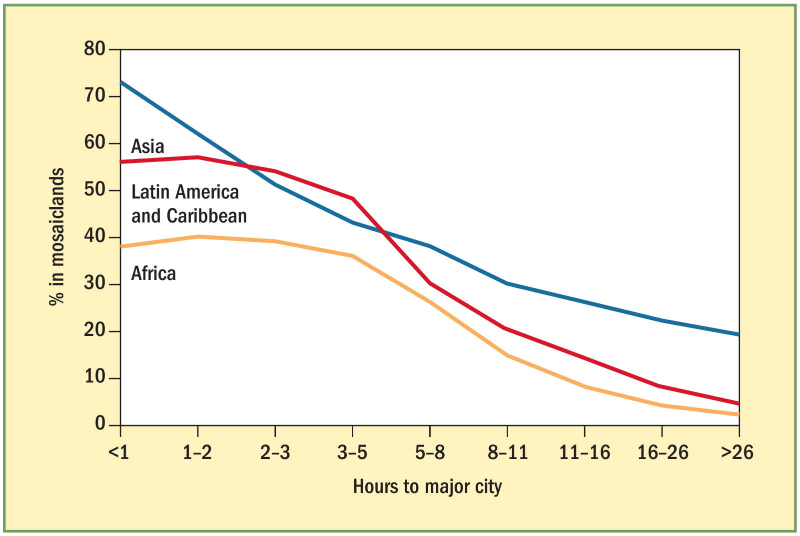
less valuable trees are often sold as a byproduct of clearing for agriculture in von Thünen's inner rings—especially if the central town has an appetite for fuelwood or charcoal. Only when natural forests are depleted does it become attractive to manage them, or plant new ones, for sustained harvest over time. When that happens, a forest ring can emerge at the edge of the agricultural ring.

Of course, real landscapes don't look like archery targets. Two elaborations are needed to make the model more realistic. First, as noted, the effects of distance are strongly modulated by soil, climate, and topographical features. Forests may remain on steep slopes near cities. Remote areas with excellent soils may attract early colonization. And different combinations of accessibility, soil characteristics, and topography may appeal to different land uses and users. Chomitz and Gray (1996), for instance, used extremely detailed land cover, topography, and soil data for Belize to elucidate the determinants of land use. They found that semisubsistence shifting cultivators—those who can't afford fertilizers and don't sell much in the market—favor hilly areas with nitrogen-rich soil and are only moderately sensitive to distance from town. In contrast, commercial cultivators—those who can afford fertilizers but rely on tractors—favor flat lands, regardless of soil fertility, and tend to be closer to markets.

Second, security of land tenure is a crucial part of the picture. Although the determinants of land tenure are complex and rooted in history and institutions, they follow an important geographic pattern. Typically, the more remote a plot of forest from settled areas, the more difficult it is to establish and defend property rights. So, elaborating von Thünen's model, the cost of defending property likely rises with distance from town. (Moreover, defending a managed forest is typically more costly than defending a pasture.) At some point—the frontier—the cost of defending property rights exceeds the profitability of land. Beyond that point it doesn't make economic sense to invest in establishing a farm or actively managing a forest plot.

In sum, von Thünen's theory tells us that agricultural lands give way to forests with increasing remoteness. Figure 2.3, based on pantropical data, shows that the theory does a good job of describing today's tropical world.

Figure 2.3 As Remoteness Increases, Mosaiclands Are Displaced by Forests, 2000



Source: Authors' calculations based on ECJRC 2003; see appendix B.
Note: Covers only nonsavanna areas.

From Forest Frontier to Urban Center: A Stylized View of Forest Dynamics

Let's now take a return journey, starting at the frontier. But this time we'll take the trip in a time machine, looking in a stylized way at the dynamics of change and the role of institutions, markets, and geography in shaping the trajectories of poverty, development, and environment. Some of these trajectories will end up at an urban center; others will not.

Arrival of the Frontier

The journey begins beyond the agricultural frontier. Population is sparse, and inhabitants are mostly long-residing indigenous peoples. An increase in forest rents triggers the arrival of the frontier. Gradually or suddenly it becomes worth mining forests for timber, or worth defending plots of land to establish farming or pasture. Areas that had been beyond the frontier are now under contention. A race for property rights—or a dispute—begins.

There are a number of triggers, some linked. Sometimes, as in Madagascar, the trigger is the growth of populations engaged in subsistence farming. This increases demand for land and lowers effective wages and can be visualized as a shift upward in the rent curve for agriculture.

But the most important trigger is the construction or substantial improvement of major roads, which make it possible to exploit new areas for timber and agricultural products. In the von Thünen diagram the impact of new roads can be visualized as a counterclockwise rotation of rent curves. The cost of transport falls and the reach of property rights is eventually extended, shrinking the rent penalty associated with remoteness.

There are several spurs for the construction of major new roads, which may coincide with other triggers. First, it may be worthwhile to finance roads precisely because they offer returns in exploitable timber and raise land value. Farmers do this on a small scale with local road construction. Mahogany loggers, seeking lucrative stands of timber, can finance forest roads hundreds of kilometers long. Miners can open new roads. And state or national governments may find it beneficial to open new areas to forest extraction and conversion.

At the national level, economic considerations blur with political ones. In Brazil and Indonesia between the 1960s and 1980s, roads were built in forested areas to promote colonization by landless farmers. Road expansion, though without organized colonization schemes, was important in the opening of the Bolivian and Peruvian

Amazon during the same period. Forest road construction is sometimes geopolitically motivated—aimed at increasing government or military presence in remote and border areas. Elite interests and corruption also play a role, if the rents created by road construction are funneled to politically connected interests (Ross 2001).

Finally, frontier expansion can be triggered by market and technological changes. These can include booming markets for forest-competing commodities such as cacao, oil palm, coffee, and beef. Agronomic technology can also change incentives for deforestation. As noted, the breeding of soybean varieties adapted to low latitudes facilitated conversion of Brazilian savanna areas to cultivation.

Trajectories Out of the Frontier: Disappearing or Rebounding Forests, Immiserization or Growth

When the frontier arrives, people jockey for rights to trees and land. Depending on who obtains possession of those resources, under what circumstances, and how they dispose of them, different trajectories of forest cover, income, and population evolve (table 2.3). Some of these trajectories correspond to the forest transition (box 2.1).

- *Intensification with deforestation.* In this trajectory, changes in markets or roads increase the value of both standing timber and agricultural land in areas with favorable soils and climate. The resulting rush to claim timber and land often leads to conflicts between large and small actors. Profits from timber sales are used to finance the costs of clear cutting and of establishing crops. Agricultural development and timber harvesting may stimulate the growth of market towns with sawmills, slaughterhouses, and other agriculturally oriented service and processing businesses. This in turn increases the local population and demand for land. Land values rise, benefiting landholders; the results may be good or bad for equity depending on whether large or small landholders appropriate the land. Labor demand rises, either on farms or in processing and servicing centers, with possible benefits for poverty alleviation. Forest cover stabilizes at a low level, with remaining forest occupying slopes or poor-quality land. Agriculturally favorable areas, especially near cities, would be expected to follow this trajectory. The soybean areas of the Brazilian savanna provide an example.

Table 2.3 Five Trajectories of Forest Cover, Income, and Population

Trajectory	Agricultural rent curve	Managed forest rent curve	Forest cover trend	Poverty and population trend	Location or identifying characteristics
Intensification with deforestation	Shifts up due to increasing urban or international demand and improved tenure	Is everywhere dominated by agricultural rent	Deforestation continues and stabilizes at low forest cover	Landowners prosper, labor demand probably increases, wages, and/or workforces increase, with labor growth possibly in towns	Periurban, good soils, high-input agriculture, and higher population density
Intensification with reforestation	Shifts up due to increasing urban demand, increasing returns, and improved tenure	Shifts up due to increased demand, exhaustion of mined sources, and demand for environmental services	Decreases, then rebounds	Landowners prosper, labor demand increases, and wages and/or workforces increase	Periurban, medium to good soils, medium- to high-input agriculture, and medium to high population density
Abandonment with regrowth	Shifts up due to increasing urban demand, then down due to rising wages	Shifts up due to improved tenure and increased demand for wood and environmental services	Decreases, then rebounds	Poverty decreases due to out-migration	Likely on marginal lands: hillsides and/or semiremote, forested, or low population density
Abandonment and irreversible degradation	Shifts up, then down due to land degradation	Never surfaces, either because of high costs of tenure or irreversibility of degradation	Decreases toward zero	Out-migration without poverty alleviation	Marginal lands, not near cities; nutrient-poor soils, slopes, or high incidence of fire; grasslands in forest biomes
Immiserizing deforestation	Shifts up due to falling wages and increasing food demand	Shifts down due to soil degradation, increases disputes over forest tenure	Decreases toward zero	Larger but poorer population	Probably not near cities; anomalously high population density given remoteness and agroclimate

Box 2.1 The Forest Transition

The concept of the forest transition, introduced by Mather (1992), describes a tendency for forest cover to decrease in response to colonization, development, and population growth, then rebound—a process that has occurred over the past two centuries in Western Europe, Japan, and the United States. Rudel and others (2005) describe the two forces behind such a turnaround. The forest transition can arise because higher wages, associated with the opening of more productive farmlands, induce the abandonment of marginal farmlands, leading to forest regrowth. The second route occurs when deforestation makes wood so scarce that it is worth replanting trees.

A number of developing economies appear to be experiencing this transition. According to Rudel and others (2005), rebounds in forest cover have been documented in Bangladesh, China, Costa Rica, Cuba, the Dominican Republic, The Gambia, the Republic of Korea, peninsular Malaysia, Morocco, Puerto Rico, and Rwanda. India and Vietnam may also be experiencing a forest transition. Note that it is possible for forest cover to show a net increase due to planting or secondary forest regrowth even while old-growth natural forest is being lost in another part of the country.

- *Intensification with reforestation.* The dynamics of intensification with reforestation are similar to those of the previous trajectory. But here, forest depletion leads to wood scarcity, and better tenure makes it possible for households and communities to manage forests. Under some conditions it becomes profitable to convert fields and pastures to woodlots or to tend and manage secondary forests. The result is a mosaic of croplands and managed forests. Examples include India (Foster and Rosenzweig 2003), Kenya (Tiffen and Mortimore 1994), and Tanzania (Monela and others 2004). This is one route to the forest transition described in box 2.1.
- *Abandonment with regrowth.* Here one possible trigger may have been population expansion onto marginal lands. After this trigger, rents are low and barely provide subsistence livelihoods for landholders. So if development elsewhere in the economy leads to higher wages, local populations migrate to better opportunities and these marginal areas are abandoned to natural forest regeneration. This is the most familiar manifestation of the forest transition, and it summarizes the forest

experiences of Western Europe, Japan, and the United States. For instance, the U.S. state of Vermont was largely cleared for agriculture in the early 19th century, despite its unfavorable terrain and climate. Vermont's fields were then abandoned as western frontier expansion and better transportation brought new more productive farmlands into the market. Among tropical areas, Puerto Rico is a striking and well-documented example, noted earlier. Other potential reasons for abandonment include a decline in the size of the youth cohort or in the price of agricultural commodities. Costa Rica's strong forest regrowth during the 1990s may be an example of the latter, if pastures were abandoned in response to declining beef markets.

- *Abandonment with irreversible degradation.* This trajectory is similar to the previous one, except that the land uses of in-migrants prove unsustainable. Soil fertility collapses due to nutrient exhaustion, compaction, or invasion by persistent weeds. The rent curve collapses, but natural regrowth doesn't occur. Examples include millions of hectares of *imperata* grasslands in Southeast Asia and large areas of apparently abandoned pastures near Belem, Brazil.
- *Deforestation and immiserization.* Here the trigger could be population expansion. A combination of stagnant technologies and immobile labor continues to push the rent curve out, but is combined with declining returns to labor and increased poverty. Poor agronomic conditions and inappropriate land use may further reduce incomes and increase pressure for nutrients from fresh deforestation. In environmental terms the outcome is similar to the abandonment with degradation trajectory. It differs in having a larger population and higher poverty rates. The humid forest of Madagascar exemplifies this scenario.

Summary

Soils, climates, markets, and governance shape pressures for deforestation across space and over time. Changes can be driven slowly, as when population and income growth boost demand for food; or abruptly, as when new roads, crop varieties, or markets create pressure to convert forests. Formerly valueless land becomes more valuable without forest cover than with. The resulting forest rents can range from barely more than zero to thousands of dollars a hectare. Landholders, especially newcomers, respond rationally to these incentives, deforesting their lands to capture the rents. Positive feedbacks kick in: for instance, burgeoning populations demanding food, fuel, and secure land rights. So do negative feedbacks, such as deteriorating soil quality. The balance of these forces determines the regional trajectory of environment, income, and population.

Different trajectories are possible and imply different associations between poverty and deforestation (Sunderlin and others 2005). A prominent win-lose trajectory has historically been associated with rural development: the conversion of forest to intensive agriculture. Here forests shrink but employment and incomes increase. Sometimes forest cover will rebound as wood becomes scarce, approximating a win-win outcome, but the recovered forest may not be equivalent in biodiversity or carbon storage to the previous forest. Alternatively, forest conversion can result in stagnant agriculture, providing subsistence income to a poor population that might be even worse off if denied access to this land. And in the worst, lose-lose case, forest conversion provides only an ephemeral income.

This chapter stresses that policies and conditions that make forestland valuable for agriculture will result in a negative association between deforestation and poverty. More valuable land tends to result in more rapid deforestation but also higher incomes.

Endnotes

1. It draws also on Chomitz and Gray (1996), Hyde and others (1997), and Hyde (forthcoming).

2. Land values in this report are net present values unless explicitly qualified as annual flows or as market prices or rentals.

3. See Boscolo and Vincent (2000) for a similar bioeconomic analysis from Malaysia, and Pearce, Putz, and Vanclay (2003) for a literature review.

4. The total value of timber was $324. But since the landholder may have the option to sell selectively extracted timber without clear cutting, the gross conversion cost is probably more relevant than the net cost in assessing the profitability of forest conversion.