Rethinking the Causes of Deforestation: Lessons from Economic Models

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This article, which synthesizes the results of more than 140 economic models analyzing the causes of tropical deforestation, raises significant doubts about many conventional hypotheses in the debate about deforestation. More roads, higher agricultural prices, lower wages, and a shortage of off-farm employment generally lead to more deforestation. How technical change, agricultural input prices, household income levels, and tenure security affect deforestation—if at all—is unknown. The role of macroeconomic factors such as population growth, poverty reduction, national income, economic growth, and foreign debt is also ambiguous. This review, however, finds that policy reforms included in current economic liberalization and adjustment efforts may increase the pressure on forests. Although the boom in deforestation modeling has yielded new insights, weak methodology and poor-quality data make the results of many models questionable.

Concern is rising about the adverse consequences of tropical deforestation. The loss of forest cover influences the climate and contributes to a loss of biodiversity. Reduced timber supplies, siltation, flooding, and soil degradation affect economic activity and threaten the livelihoods and cultural integrity of forest-dependent people. Tropical rain forests, which constitute about 41 percent of the total tropical forest cover, are considered the richest and most valuable ecosystem on the earth's land surface. During the 1980s about 15.4 million hectares of tropical forests were lost each year, according to estimates by the United Nations Food and Agriculture Organization (FAO 1992). From 1990 to 1995 the annual loss was estimated at 12.7 million hectares (FAO 1997), but it is unclear whether this reduction represents a slowdown in actual forest clearance or new definitions and better data.

This concern has led economists to expand their efforts to model why, where, and to what extent forests are being converted to other land uses. Kaimowitz and Angelsen

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(1998), in a comprehensive review of more than 140 models, describe why landholders behave the way they do and examine the links between the larger economy and decisions to clear—or to protect—the forest. The models vary with regard to the precise definition of forest, if indeed they provide any definition at all. In most instances in this paper, the term *deforestation* describes the complete long-term removal of tree cover. Like all social science models, those discussed here simplify complex multidimensional processes and highlight only a few of the many variables and causal relations involved in changing patterns of land use. These models, however, do allow one to think about deforestation more systematically and to explore the possible effects of policy or other exogenous changes on land use.

A Framework for Analyzing Deforestation

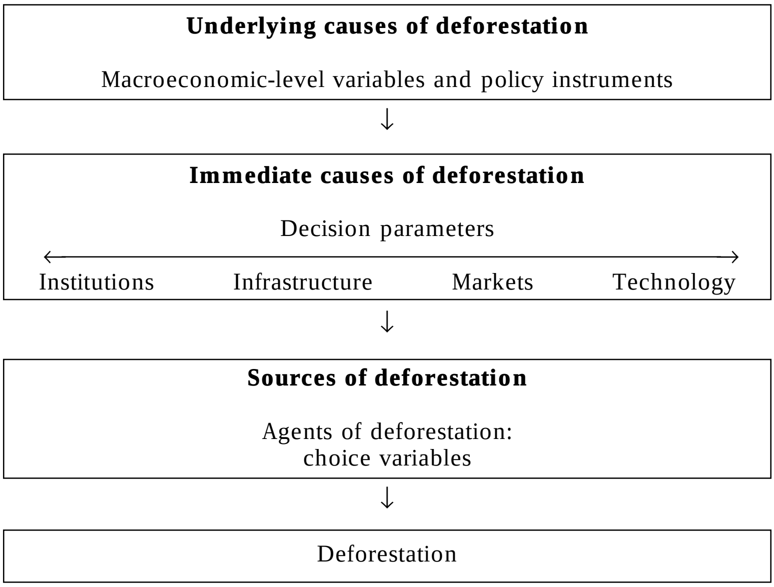
The conceptual framework used here is helpful both in understanding deforestation processes and in classifying modeling approaches. Five types of variables are used in models of deforestation:

- *The magnitude and location of deforestation*—the main dependent variable
- *The agents of deforestation*—those individuals, households, or companies involved in land use change and their characteristics
- *The choice variables*—those decisions about land allocation that determine the overall level of deforestation for the particular agent or group of agents
- *Agents' decision parameters*—those variables that directly influence agents' decisions but are external to them
- *The macroeconomic variables and policy instruments*—those variables that affect forest clearing indirectly through their influence on the decision parameters.

Figure 1 illustrates the relations among the main types of variables and provides a simple, logical approach to analyzing deforestation at three different levels: sources, immediate causes, and underlying causes. This schematic varies somewhat from the existing literature, which is rather inconsistent in its use of these terms. The starting point is to identify the agents of deforestation (small farmers, ranchers, loggers, plantation companies) and their relative importance. These agents' actions are the *sources* of deforestation. Theoretically at least, the magnitude of various sources can be directly measured—although it may be difficult to do so—and no economic analysis is required.

Next one might focus on agents' decisions, which are based on their own characteristics (background, preferences, and resources) and on decision parameters such as prices, technology, institutions, new information, and access to services and infrastructure. Together, these factors determine the set of available choices and the in-

Figure 1. *Variables Affecting Deforestation*



Source: Authors' construction.

centives for different choices. The decision parameters may be seen as the *immediate causes* of deforestation.

Finally, the agents' characteristics and decision parameters are themselves determined by broader forces. These *underlying causes* of deforestation influence agents' decisions through several channels—the market; the dissemination of new technologies and information; the development of infrastructure; and institutions, particularly the property regime.

For the sake of simplicity, figure 1 and the discussion so far imply that causal relations go in only one direction. But important effects also go in the opposite direction; for example, the decisions agents make will have important feedback effects on market prices (general equilibrium effects). Agents' collective actions, political pressures, and demographic behavior also affect underlying causes.

A clear distinction among the three levels is necessary for several reasons. First, it is useful to single out the parameters that directly affect decisionmakers. Second, the levels of variables are related to the type of model used: microeconomic models focus on immediate causes, whereas macroeconomic models tend to deal with underlying causes. Third, because the underlying causes determine the immediate causes, which in turn influence the agents who are the sources of deforestation, mixing these levels confuses the causal relations involved and leads to serious misspecifications in regression models. And fourth, the results regarding the sources and immediate causes are more conclusive than those for the underlying causes.

Although the article focuses on the immediate and underlying causes of deforestation, some comments on the sources are in order. There is a broad consensus that the expansion of cropped areas and pastures is a major source of deforestation and that the expansion of pastures is especially important in Latin America (Kant and Redantz 1997). No similar consensus has formed about logging, although it seems to be a direct source of deforestation in some contexts and an indirect source in others. Logging roads, for example, facilitate access to the forest by farmers (Burgess 1993). Southeast Asia is one region in which logging has contributed significantly to deforestation. Evidence regarding fuelwood collection and open-pit mining is weak, although it implicates them as the sources of some significant deforestation, particularly for fuelwood in Africa.

Surprisingly little is known about how the characteristics of agents affect their behavior. Researchers know that subsistence-type households are less responsive to market signals than families who are more market oriented, but existing models say little about the prevalence of such behavior. Nothing significant can be generalized from available information about the role of farm size, farmer background, or timber company characteristics. The conventional poverty-environment argument is that poorer families are more likely to clear the forest, either to grow crops or to cut wood, because they have shorter time horizons (higher discount rates); the counterargument says such families are less likely to do so because they lack the necessary capital to put additional land into production (see, for example, Rudel 1993). Existing models provide little evidence on this issue.

Analytical and empirical models suggest that time preferences and risk aversion are important to farmers and loggers. But their practical effect depends on what the relevant investment decisions are assumed to be. High discount rates and risk aversion are both likely to reduce investment, but that investment could be either to clear the forest or to conserve it (Southgate 1990; Mendelsohn 1994; von Amsberg 1994). These two types of investment are not symmetrical, however: whereas forest clearing requires action, forest conservation requires little more than leaving the forest alone. This suggests that forest clearing is more likely to be considered the relevant investment decision.

The Models Reviewed

We have reviewed more than 140 papers containing economic models that represent key processes associated with deforestation. The exclusive focus on formal models does not imply that these models are necessarily more useful or more accurate than informal studies based solely on descriptive statistics. Such “soft” analyses and studies complement formal models and offer important insights that are difficult to capture in formal models.

Quantitative models have many clear limitations. They focus on variables for which quantified data are available. They do not, typically, explicitly address issues related to market failure (users do not capture the full value of preserving tropical forests), which one could argue are the “real” underlying causes of deforestation (Pearce 1996). Further, institutional factors are rarely included. One could argue, however, that the variables related to market failure or institutional arrangements are fairly stable over time compared with prices, for example, and are therefore less relevant to changes in rates of deforestation.

Global reviews such as this one inevitably emphasize the similarities between countries and regions, rather than their differences. The factors affecting deforestation, the interactions between them, and the magnitude of their effects all vary significantly from one location to another. Models based on data from distinct locations can reach conflicting conclusions not only because they use distinct definitions, variables, or methodologies, but also because the processes themselves differ.

In this context, it should be noted that most of the empirical and simulation models that analyze a single country or region focus on a handful of countries: Brazil, Cameroon, Costa Rica, Indonesia, Mexico, Thailand, and, to a lesser extent, Ecuador, the Philippines, and Tanzania. Most of these countries are medium or large in size and population, are relatively politically stable, and have large areas of tropical rain forest, so the results presented here may be more applicable to countries with those characteristics.

Categories of Models Reviewed

Table 1 shows the distribution of the models analyzed here. We have classified the models based on two criteria: scale (household and firm, or microeconomic, level;

Table 1. *Models of Deforestation by Category*

Level	*Analytical*	*Simulation (including programming)*	*Regression*	*Total*
Household and firm	15	9	9	33
Regional	0	3	30	33
National	19[a]	23	38	80
Total	34	35	77	146

a. This figure includes an impressive 14 papers by Jones and O’Neill. Most have a similar methodological framework, but each has distinct features and addresses different issues.

Source: Authors’ calculations.

regional level; and national, or macroeconomic, level) and methodology—analytical, simulation, and empirical.[1]

Analytical models are abstract, theoretical constructs. They include no empirical data but rather clarify the implications of different assumptions about how agents behave and how the economy operates, which may not be obvious. Simulation models use parameters based on stylized facts drawn from various sources to assess scenarios. Most simulation models at the microeconomic level are whole-farm analyses using (linear) programming techniques, whereas the most common macroeconomic simulation models are computable general equilibrium (CGE) models. Empirical models quantify the relations between variables based on empirical data. Almost all empirical models use regression analysis, usually the standard ordinary least squares (OLS) method. Below we describe the three types of model.

Microeconomic Models

As the name suggests, these models seek to explain how individuals allocate their resources, using standard economic variables such as background and preferences, prices, institutions, access to infrastructure and services, and technological alternatives. A major distinction is between models that assume all prices are market determined and farmers are fully integrated into perfect markets (Southgate 1990; Mendelsohn 1994; Bluffstone 1995; Angelsen 1999) and those that do not (Dvorak 1992; Holden 1993; Angelsen 1999). Within the former category, production decisions are guided by market prices (including off-farm wages) and can be studied as a profit-maximizing problem. When farmers are not fully market integrated, decisions are based, in part, on farmers' subjective (and endogenously determined) shadow prices. Factors such as resource endowments (poverty) and household composition are important, and the consumption side must be included when making the production decision. This distinction turns out to be critical for how model makers predict land use will change in response to changes in population, agricultural prices, and income. Analytical models have been very useful in highlighting the role played by the underlying market and behavioral assumptions (Angelsen 1999).

The main strength of farm-level simulation (programming) and regression models reviewed here lies in their use of generally good-quality survey data regarding the magnitude of deforestation and description of farmers' behavior. Strictly speaking, however, these conclusions apply only to the area studied. Some of the conclusions of the simulation models depend heavily on the market assumptions discussed above, which the models normally do not test. Farm-level regression models often say little about farmers' response to price changes because the price variation within the area is normally too small to allow such analysis.

Regional Models

The coverage in such models is limited to a region or area with a distinct and characteristic ecology, agrarian structure, institutional and political history, set of trade networks, and pattern of settlement and land use (Lambin 1994:16). Analytical or simulation models rarely focus on a region, although there are a few exceptions.[2] Although deforestation is inherently a spatial phenomenon, most models lack an explicit spatial dimension; thus they cannot answer the *where* question.

Most regional models are thus regression models, which may be spatial or nonspatial. Spatial models measure the impact on land use of variables such as how far the forest is from markets and roads, topography, soil quality, precipitation, population density, and zoning categories. This type of analysis has become more popular since the advent of digitized land use data and geographic information systems that have made it easier to manipulate the data. Nonspatial models, however, are more common. These models use data obtained at a provincial or regional level in a manner similar to multicountry regression models, but the regional models generally have better data on forest cover: about half the models reviewed here used satellite data, either alone or in combination with land surveys.

Decisions affecting the rate of deforestation are taken at the household level, but the most interesting consequences affecting biodiversity and watersheds often occur at the district or regional level. Accounting for behavioral changes of farmers and other agents is difficult in spatial models. It should soon be possible in some cases to use panel data for spatial regression models, which will facilitate the inclusion of price variables (Foster, Rosenzweig, and Behrman 1997). It should also be possible to incorporate agricultural census and survey data into a geographic information systems framework, which would allow modelers to take into account many additional variables.

Macroeconomic Models

National and multicountry models emphasize the relations among underlying variables, decision parameters, and deforestation. Analytical, simulation, and regression models are all well represented at this level.

To model complex macroeconomic processes in a strictly analytical framework and still reach interesting conclusions, model makers have generally had to place strict limits on the number of variables and make some strong assumptions. Both analytical and computable general equilibrium (simulation) models at the national level add two important dimensions to the analysis that are absent in household- and firm-level models. First, they make some prices endogenous. Thus they move beyond simply asking how decision parameters influence agents and look at how the underlying variables determine one particular set of decision parameters (prices).

This provides an important link to macroeconomic variables and policy instruments. Second, most models include the interactions among different sectors, for example, (subsectors of) agriculture, forestry, and manufacturing, which makes them useful in analyzing the underlying causes of deforestation.

Some computable general equilibrium (CGE) models take a conventional approach and assume that land is a factor of production and that forest is cleared up to the point where the current land rent is zero (Coxhead and Jayasuriya 1994; Aune and others 1997). Others pay particular attention to the property regime (Persson and Munasinghe 1995; Unemo 1995). A third group applies a forest rotation (Faustmann) approach (Thiele and Wiebelt 1994; Thiele 1995). CGE models can be criticized for the poor quality of their data and the parameters commonly used, their questionable assumptions about perfect markets, and (particularly in the case of the forest rotation approach) their descriptions of farmers' or loggers' behavior. In such models the conclusions depend heavily on the responsiveness of the variables to changes in prices and income, and these elasticities are often chosen rather arbitrarily.

Multicountry (global) regression models comprise the single largest category of deforestation models. They rely on national data to make global generalizations on the major processes affecting tropical deforestation. But problems with the method and the data make their usefulness and validity questionable. First, most researchers use deforestation data from the Food and Agriculture Organization Forest Resource Assessments (1981, 1992) or from the FAO production yearbooks. We agree with Rudel and Roper (1997: 54) that neither is "acceptable for empirical analysis of the causes of deforestation" because they are based largely on dubious data sources or are mere extrapolations based on forest cover data from a single point in time. For example, in the 1990 assessment (FAO 1992), only 21 of the estimates for the 90 countries were based on two or more national forestry inventories. For the remaining countries, deforestation rates were extrapolated from a single data point using a model with population density and ecological classes as its only explanatory variables. Three countries had no forest inventory at all; of the 66 countries with one inventory, 39 inventories were taken before 1981. The data for African countries are particularly poor.

Because of the difficulty of obtaining reliable data, many multicountry regression models use the percentage of forest land as a proxy for deforestation. Kummer and Sham (1994) argue persuasively, however, that forest cover depends on the percentage of land originally in forests and the total amount of forest cleared throughout human history and is not related in any simple way to recent deforestation. Moreover, many models mix sources, immediate causes, and underlying causes in their independent variables. (The work of Kant and Redantz 1997 is an exception to this general picture.) Besides potential statistical problems of multicollinearity and biased estimates, this mixing will also distort the interpretation of cause and effect.

And finally, to produce meaningful cross-country results, it is important that the variables included affect deforestation in roughly the same manner across countries. This is obviously a strong assumption because studies indicate that the effect of and interaction among economic growth, foreign debt, population, and other variables may differ greatly from one country to the next. In principle, this problem could be overcome by adding interaction terms among the independent variables, but in practice, the degrees of freedom are too small to do that.[3]

In sum, most of the existing multicountry regression models do not accurately estimate the direction and size of the effects that different variables have on deforestation. Because of these weaknesses, we have given less weight to these models in the discussion.

The Immediate Causes of Deforestation

The main source of deforestation is clearing by households or companies for agriculture or timber. The question is: what factors make farmers and loggers decide to clear more forests? Table 2 gives an overview of the main results of the models.

Agricultural Prices

Substantial evidence supports the assertion that higher prices for agricultural products stimulate forest clearing. As frontier agriculture becomes more profitable, both the existing population and migrants from other areas begin to shift resources into forest clearing. Higher prices also provide capital to put additional land into agricultural production.

On the theoretical level, there is only one reason why higher agricultural prices might not increase deforestation: when farmers exhibit a preference for subsistence-type farming, they will opt for leisure once they have reached some minimal consumption level. In this case they will produce less when prices are higher because they can meet their basic consumption needs without clearing more land. Microeconomic simulation models that assume subsistence behavior, such as Ruben, Kruseman, and Hengsdijk (1994) and Angelsen (1999) find less deforestation when agricultural prices are higher, while models that assume farmers are profit maximizers show the opposite (Monela 1995).

Although it is possible that some households might respond to higher agricultural prices by reducing the amount of land farmed, there is no evidence for this at more aggregated levels. Regional regression models on Mexico by Barbier and Burgess (1996) and Deininger and Minten (forthcoming), on Sudan by Elnagheeb and Bromley (1994), on Tanzania by Angelsen, Shitindi, and Aarrestad (1998), and on

Table 2. *Major Results on Immediate Causes of Deforestation*

Variable	Effect of increase in variable, by model type: Analytical	Simulation and empirical	Comments
Agricultural output prices	Increase	Increase	Farm-level analytical models predict increase, unless there are strong income effects (subsistence models).
Agricultural input prices	Indeterminate	Mixed	Fertilizer price increases may induce shift to more land-extensive systems.
Off-farm wages and employment	Reduce	Reduce	Among the most significant findings.
Credit availability	Indeterminate	Increase[a]	Depends on whether the relevant investment is forest clearing or forest management and agricultural intensification; most studies find that credit finances deforestation.
Technological progress on frontier farms (direct effects)	Indeterminate	Little evidence	Similar to price increase; new labor-intensive technologies may reduce deforestation if labor supply is inelastic.
Accessibility (roads)	Increase	Increase	Among the most significant findings, although roads are partly endogenous.
Homesteading property regime	Increase	Little evidence	Claims to future land rents give farmers an additional incentive to clear land.
Land tenure security	Indeterminate	Increase[a]	Empirical evidence is relatively weak.
Timber prices	Indeterminate	Increase[a]	Empirical findings are weak but tend to find a positive link.

a. Data may not be reliable.
Source: Authors' analysis.

Thailand by Panayotou and Sungsuwan (1994) all find a positive correlation between higher agricultural prices and deforestation. Binswanger and others (1987) found a positive correlation between total cropped area and agricultural prices in a cross-country analysis of 58 countries. All the analytical macroeconomic and computable general equilibrium models also show that increased agricultural prices boost deforestation, although this result is as much a product of their initial assumption that farmers are profit maximizers as it is of the empirical evidence.

It should be emphasized that this discussion refers only to changes in the aggregate terms of trade for agriculture with respect to other sectors. Changes that affect the relative prices of different crops and livestock products may have quite different effects. Thus it is impossible to predict how specific policies will affect forest clearing without looking at their impact on prices for specific products and the pressure each product puts on forests. For example, Gockowski (1997) shows that deforestation increased in Cameroon after relative prices shifted in favor of plantains, the production of which requires substantial forest clearing, from cocoa, which requires less land.

Although the prices of agricultural products and other decision parameters can be taken as given by the individual farmer, they are not truly exogenous in the models (as is also the case for many of the other variables in table 2). Output prices are a function of total supply. The regression models reviewed do not attempt to separate out predetermined (exogenous) changes (taxes, exchange rates, and so on) from the response to these changes. The response to an exogenous price increase will dampen the initial increase, but this effect is likely to be small because output from recently cleared land often has a small market share.

Prices of Agricultural Inputs and Credit

The theory of how changes in agricultural input prices affect forest clearing leads to indeterminate conclusions, and the empirical evidence is mixed, particularly for fertilizers. Analytical models point to two conflicting effects. On the one hand, higher fertilizer prices lead farmers to adopt more extensive production systems that use more land and less fertilizer. On the other hand, the higher costs associated with increased fertilizers make agriculture in general less profitable and can lead to a reduction in the amount of land devoted to crops.

Attempts to resolve the issue empirically have been only partially successful. Linear programming and regression models suggest that fertilizer price increases in southern Africa provoke greater deforestation or have little impact (Monela 1995; Aune and others 1997; Holden 1997; Mwanawina and Sankhayan 1996), whereas in some Latin American contexts such price increases may reduce deforestation (Barbier and Burgess 1996). Higher fertilizer prices seem most likely to induce greater forest clearing when farmers are wavering between intensive sedentary agriculture and more extensive shifting cultivation systems. This finding adds a cautionary note about the possible negative impact of current policies aimed at reducing fertilizer subsidies in Sub-Saharan Africa (Holden 1997).

The evidence regarding the prices of other agricultural inputs, such as seeds, pesticides, and hand tools, suggests that higher prices reduce forest clearing (Ruben, Kruseman, and Hengsdijk 1994; Ozório de Almeida and Campari 1995; Monela 1995). In these cases the reduced profitability of agriculture appears to outweigh any shift toward more extensive production.

In theory, credit expansion could reduce the pressure on forests if it were used for more intensive agriculture or for forest management investments. It will, however, increase the pressure if used to finance activities associated with forest clearing, such as extensive cattle ranching. Most empirical evidence on credit comes from farm- and regional-level regression analysis in tropical Latin America and concludes that credit availability is positively correlated with deforestation (Ozorio de Almeida and Campari 1995; Barbier and Burgess 1996; Andersen 1997; Pfaff 1997). The only significant exceptions are two studies of indigenous farmers in Bolivia and Honduras, which found that farmers who used credit deforested less (Godoy and others 1996, 1997). In these cases, families with credit may be less dependent on forest-based activities or may choose to engage in off-farm work to repay their loans. Modeling work in Africa and Asia has largely ignored the issue of credit availability (with the exception of Monela 1995, who finds a positive relationship between credit availability and forest clearing in Tanzania), perhaps because it is less important there.

Wages and Off-Farm Employment

All types of microeconomic models strongly suggest that higher rural wages reduce deforestation by making agricultural and forestry activities more costly. They also suggest that, at the individual household level, greater off-farm employment opportunities produce a similar effect by competing with such activities for labor (Holden 1993; Ruben, Kruseman, and Hengsdijk 1994; Bluffstone 1995; Godoy and others 1996, 1997; Pichón 1997).

Regional and national analytical and simulation models also support these conclusions, although the hypotheses have yet to be successfully validated in macroeconomic empirical models because of limited data on wages and off-farm labor. One has, therefore, strong reasons to believe that policies that favor rural wage increases and generate off-farm employment opportunities for rural people should reduce deforestation. Such policies should simultaneously conserve forests and diminish poverty.

Technological Progress in Agriculture

Technology has both a direct effect on farmers' behavior and an indirect effect resulting from its impact on product and factor prices (including wages). We focus here on the first set of effects, leaving the second for a later section.

Technological changes that increase yields without significantly altering labor or capital requirements can be expected to increase deforestation. The extent of forest clearance is likely to be even greater if technological changes are labor- or capital-saving, or both, since this will free up resources for farming additional land (Southgate 1990). Conversely, if the new technology is more labor- or capital-intensive *and* if farmers find it difficult, expensive, or inconvenient to hire wage labor or obtain credit, then such changes can lead farmers to devote more labor and capital to their existing farms, leaving them with fewer resources for expansion. Under these circumstances the net effect is indeterminate (Larson 1991). More generally, technologies that make more intensive production systems more profitable reduce the need for clearing additional forest land for agriculture, according to linear programming models by Nghiep (1986) and Holden (1993).

These findings imply that agricultural research and extension policies designed to limit deforestation should focus on promoting profitable technologies that are labor- and capital-intensive and more easily applicable to land already under cultivation. The empirical evidence, however, is still limited, and this is clearly an important area for future research.

Accessibility and Roads

Analytical and empirical models and studies find that greater access to forests and markets accelerates deforestation. Roads, rivers, and railroads all facilitate access. Forest fragments are more accessible than large compact forests, and forests in coastal countries and islands are more accessible than those in continental countries (Krutilla, Hyde, and Barnes 1995; Rudel and Roper 1996).

Spatial regression models are well suited for studying the effects of access. Models of this type for Belize (Chomitz and Gray 1996), Cameroon (Mertens and Lambin 1997), Costa Rica (Sader and Joyce 1988; Rosero-Bixby and Palloni 1996), Honduras (Ludeke, Maggio, and Reid 1990), Mexico (Nelson and Hellerstein 1997), and the Philippines (Liu, Iverson, and Brown 1993) all show a strong relation between roads and deforestation. Several find a similar result between proximity to markets and forest edges. Most studies show that forest clearing declines rapidly beyond distances of 2 or 3 kilometers from a road, although Liu, Iverson, and Brown (1993) report significant forest clearing up to around 15 kilometers from the nearest road. These results are also supported by nonspatial regression models from Brazil (Andersen 1997; Pfaff 1997), Ecuador (Southgate, Sierra, and Brown 1991), the Philippines (Kummer and Sham 1994), and Thailand (Panayotou and Sungsuwan 1994; Cropper, Griffiths, and Mani 1997).

The simple correlation between distance to roads and deforestation found in regression models tends to overstate the causality, since some roads are built precisely because an area has been cleared and settled, rather than vice versa. And both the land and the roads can be simultaneously influenced by a third set of factors, such as soil quality or population density. Model makers have attempted to account for this alternative by including some of those factors as separate independent variables, using road density, say, and analyzing only forest clearings that occur *after* roads are built. These attempts have been only partially successful, but no policy intended to influence deforestation can be considered comprehensive unless it provides clear guidelines on investments in transportation infrastructure.

Property Regime and Tenure Security

In the absence of well-defined and secure property rights, forest clearing often becomes a way to claim property rights to land (homesteading). Such strategic behavior has been reported by Anderson and Hill (1990), Mendelsohn (1994), and Angelsen (1999). Under these circumstances, there are at least three reasons why forests may be cleared *beyond* the point where the current net benefits are zero. First, even though profits may be negative in the first few years, technological progress, new roads, and so on will make cultivation profitable in the future, and farmers need to act now so that others do not claim the land before they do. Second, in many cases land prices may reflect not agricultural potential but rather speculation that the purchaser will profit from selling the land at some future date (Clark, Fulton, and Scott 1993). And finally, in situations where users compete for forest land, such as in conflicts between communities and government agencies, deforestation by one agent is costly to the other. Hence there may be incentives to clear the land oneself in order to squeeze out the competitor (Angelsen 1997).

Some empirical evidence suggests that where farmers can obtain property rights by clearing forests, land-titling projects can encourage them to clear larger areas (Kaimowitz 1996). Secure tenure encourages investment by making it less risky, and if the investment involves clearing land in the forest, deforestation should increase as a result. Nevertheless, household- and regional-level regression models from Latin America show that deforestation is lower in areas with secure land tenure (Southgate, Sierra, and Brown 1991; Godoy and others 1996; Pichón 1997). Thus a conclusion is premature at this time.

Timber Prices

The literature on the effect of logging on deforestation is smaller, and the results are less conclusive. The effect of higher timber prices remains particularly controversial. Higher prices for timber are likely to promote deforestation by making logging more profitable (Capistrano 1990; Gullison and Losos 1993; von Amsberg 1994; Barbier and others 1995; Deacon 1995; Mæstad 1995). Higher timber values also increase the net benefits of clearing land (assuming the timber is sold) and encourage deforestation (Southgate 1990; Deininger and Minten forthcoming).

Using a traditional supply-demand framework, trade restrictions, such as log export taxes and import bans, would reduce total demand for timber by lowering prices and production even if lower prices increased domestic demand. Other authors suggest, however, that in the medium term, low timber prices discourage efficient harvesting and processing techniques, leading in turn to more logging (Barbier and others 1995). Low timber prices may also discourage efforts to prevent farmers from clearing logged areas (van Soest 1996).

The Underlying Causes of Deforestation

It is harder to establish clear links between underlying causes and deforestation. Macroeconomic variables influence decisions through complex paths, and many of the causal relations are indirect. Further, such studies typically require data that often do not exist or are of poor quality. Table 3 summarizes the major findings on the underlying causes of deforestation, with these reservations in mind.

Population Pressures

Deforestation rates may increase because the population is growing and needs more land for food, fuelwood, timber, or other forest products. Growing populations also affect labor markets, as an abundant supply of labor pushes down wage rates. But

Table 3. *Major Results on Underlying Causes of Deforestation*

Variable (effect of an increase in the variable)	*Effect of increase in variable, by model type*		*Comments*
	Analytical	*Simulation and empirical*	
Population	Increase	Increase	The empirical results suggest that population density is positively correlated with deforestation, but the evidence is weaker than often believed; regional population should be considered endogenous.
Income level	Indeterminate	Increase	Higher income increases demand for agricultural and tropical products and access to markets but also increases off-farm employment.
Economic growth	Indeterminate	Mixed	Same as above.
Technological progress (general equilibrium effects)	Reduce	Limited evidence	Should induce downward pressure on agricultural prices and upward pressure on wages and interest rates (unless the changes reduce labor and/or capital intensity).
Foreign debt	Indeterminate	Mixed	Theory weak; empirical evidence weak and contradictory.
Trade liberalization and devaluation	Indeterminate	Increase[a]	Higher agricultural and timber prices increase clearing, but income declines may offset this in the short run; relative prices also matter.

a. Data may not be reliable.
Source: Authors' analysis.

population growth may also induce technological progress and institutional changes that contribute to reduced pressures on forests.

Analytical models that consider the labor supply to be exogenous give quite different results from those that assume it to be highly elastic with respect to wages. In the former, deforestation rates tend to be much more sensitive to agricultural price changes, and agricultural intensification is more likely to diminish forest clearing (Angelsen 1999).

Several multicountry regression models show a positive correlation between population density and deforestation (such as Palo 1994; Rock 1996). Many of their results are spurious, however, because they rely on the FAO Forest Resource Assessments, which are themselves based on population data. As Rudel and Roper (1997: 54) note, "a variable which FAO used to construct the dependent variable is now being used to predict the value of that variable!" At the regional level, studies from Brazil (Andersen 1996; Pfaff 1997), Ecuador (Southgate, Sierra, and Brown 1991), Mexico (Barbier and Burgess 1996), the Philippines (Kummer and Sham 1994), and Thailand (Katila 1995; Cropper, Griffiths, and Mani 1997) also find a positive correlation between population density and deforestation. In the multicountry and regional studies, this correlation disappears when additional independent variables are added, implying that population may be acting as a proxy for some other factors in these models (Capistrano 1990; Deacon 1994; Harrison 1991).

The evidence on the relation between population growth and forest clearing is even weaker. Kimsey (1991) and Rock (1996) report that population growth increases deforestation. Burgess (1991) and Inman (1993) find that it reduces deforestation or has mixed effects, and Cropper and Griffiths (1994) and Palo (1994) say it has no effect.

Few models focus specifically on the relation between population and the demand for agricultural and forest products. Economic liberalization and globalization are likely to make this aspect less important at the national and regional levels because global demand is increasingly likely to determine prices and demand. New prospects for agricultural and forestry exports may lead to rapid deforestation in countries where small domestic markets previously limited deforestation.

At the local and regional levels, population is endogenous and is determined by infrastructure availability, soil quality, distance to markets, off-farm employment opportunities, and other factors. Several studies show that population growth in previously forested, low-population areas occurs in response to road construction, available high-quality soils, and growing demand for agricultural products (Harrison 1991; Southgate, Sierra, and Brown 1991; van Soest 1995; Andersen 1997). Government policies that affect migration (and hence population) at this level include road construction, colonization policies, agricultural subsidies and tax incentives, and gasoline prices. This implies that the latter factors, rather than population growth per se, are the causes of deforestation in these areas. People migrate to forested areas because clearing forest for agriculture is economically attractive, and so the size of the population in those areas cannot be considered an independent variable in models of deforestation.

Income Level and Economic Growth

Higher national income and economic growth can be expected to reduce the pressure on forests by improving off-farm employment opportunities, but to increase it by stimulating demand for agricultural and forest products and improving access to virgin forests and markets. Countries with higher incomes may also demand that forests be protected rather than depleted. Forest depletion may contribute to economic growth, implying a causal relation in the opposite direction.

Many studies of developing countries associate higher national per capita income with greater deforestation (Capistrano 1990; Burgess 1993; Krutilla, Hyde, and Barnes 1995; Barbier and Burgess 1996; Mainardi 1996). Again, these models have significant data and methodological weaknesses and should be regarded with caution. Evidence on the impact of income growth rates is even weaker. Because there is no strong short- or medium-term relation between economic growth rates and average per capita national income, the fact that higher incomes are associated with more deforestation does not necessarily imply that higher growth rates will be.

The models are also not very clear about whether deforestation declines or is even reversed beyond certain income levels as countries become richer, a possibility noted by the "forest transition" hypotheses (Mather 1992; Grainger 1995) and by the environmental Kuznetz curve literature (for example, Stern, Common, and Barbier 1996). Based on the dubious FAO data, several authors claim to have found an environmental Kuznetz curve for deforestation; that is, at low levels of income, an increase in income will accelerate the rate of deforestation, but higher income beyond a certain level reduces deforestation. But the levels of per capita income they estimate must be reached before deforestation declines vary considerably (Panayotou 1993; Cropper and Griffiths 1994; Rock 1996). In addition, the driving forces behind such a possible transition are still unclear. They could be economic forces (the attraction of off-farm employment, a higher value placed on pristine forest by the public and the government, or expanded state capacity to enforce forest protection). Even if such a relationship does exist, income levels in most tropical countries are well below the level at which deforestation begins to decline.

External Debt, Trade, and Structural Adjustment

Some studies find a positive correlation between external indebtedness and deforestation (Burgess 1991; Kahn and McDonald 1994; Mainardi 1996; Kant and Redantz 1997), while others find no clear connection (Capistrano 1990; Kimsey 1991; Inman

1993). The empirical studies are based on poor-quality data; the analytical models make very simplistic assumptions about government objectives and policy formation that limit their empirical relevance.

According to analytical models, policies to improve the terms of trade for agriculture tend to raise the prices received by farmers and hence increase deforestation (Jones and O'Neill 1994, 1995). Thus structural adjustment policies of this type may potentially increase pressure on forests, and policies such as overvalued exchange rates, industrial protectionism, and urban-biased spending may actually be good for forest conservation—although obviously not necessarily for other parts of the economy.

Market characteristics and general equilibrium effects can either strengthen or dampen these policy effects. Increases in agricultural and timber prices will generate more deforestation when labor supply is relatively elastic. If it is not, the initial effect of price increases will be dampened as rural wages rise in response to greater demand for labor.[4] Conversely, higher rural wages could potentially generate more demand for agricultural and forest products.

Structural adjustment and trade liberalization policies designed to increase the terms of trade in favor of agriculture may have short- or medium-term recessionary consequences that reduce urban food demand, which could lead to lower, rather than higher, agricultural prices and thus to less deforestation. But a recession might also lower urban employment, putting downward pressure on rural wages and consequently stimulating deforestation (Jones and O'Neill 1995).

Policies designed to increase agricultural and forest product exports are likely to affect deforestation more than policies that promote production for the domestic market (since the latter are more likely to exert downward pressure on prices). Similarly, pro-agricultural policies can be expected to have stronger deforestation effects in the contexts of globalized agricultural markets and trade liberalization.

The previous findings are supported by several analytical macroeconomic and computable general equilibrium models, which show that currency devaluation, trade liberalization, and agricultural subsidies increase deforestation (Cruz and Repetto 1992; Jones and O'Neill 1994, 1995; Wiebelt 1994; Barbier and Burgess 1996; Mwanawina and Sankhayan 1996). It should be remembered, however, that these models depend heavily on more or less arbitrary assumptions about price elasticities and use generally poor data. Moreover, all of them tend to look at the agricultural and forestry sectors at a very aggregated level. Changes in relative prices within these sectors may have a greater impact on deforestation than the overall sectoral terms of trade, and to date these models have shed little light on this subject.

These findings suggest the difficulties of evaluating the effects of macroeconomic policies; important effects are not included. For example, will increased public revenues give officials the leverage they need for better regulatory intervention? Or will affluence mean additional investments that increase forest clearance? One lesson is that any general claims about the relations among economic liberalization, structural adjustment, and deforestation are misleading. In particular, claims that structural adjustment programs will "generally contribute to both economic and environmental gains" (Munasinghe and Cruz 1995) seem unjustified based on the evidence. If anything, the findings support the opposite claim because higher agricultural output and timber prices lead to increased pressure on forests.

The Indirect Effects of Technological Change

Technological inputs also have indirect (general equilibrium) effects on product, labor, and factor markets. Technologies that increase aggregate supply and lower prices should reduce pressures to clear additional forest land. In some cases this may even offset the initial effects of technology on deforestation, as is possible in the case of maize production in the Philippines reported by Coxhead and Shively (1995). Technological changes that affect products with inelastic demands are more likely to reduce deforestation. Labor-intensive technologies will raise rural wages and should dampen—and even reverse—the deforestation associated with the increased profitability of agriculture. In fact, the more labor-intensive the technology, the more rigid the labor supply, and the more prices of agricultural products respond to changes in labor costs, the greater will be the effect. Similarly capital-intensive technologies might have the same effect if farmers have limited access to capital.

Technologies such as irrigation that require substantial infrastructure and that benefit farmers with access to markets are particularly likely to reduce pressure on forests; they will tend to push down agricultural prices and bid up wages without increasing the profitability of frontier farming. At the empirical level, some studies conclude that technological progress leads to more deforestation (Katila 1995), while others find the opposite (Panayotou and Sungsuwan 1994; Southgate 1994; Deininger and Minten forthcoming).

Rethinking the Causes of Deforestation

This review raises serious questions concerning the conventional wisdom about the causes of deforestation, either by providing contrary evidence or by showing the weakness of the supporting evidence. In particular, the models raise significant doubts about the following hypotheses:

- *The population thesis.* The models offer only weak support for the explanation that population growth is a driving force of deforestation. The correlations are largely based on flawed data or incorrectly specified models. At the local and regional levels, population should be considered endogenous, particularly in the medium to long term.

- *The poverty thesis.* There is little empirical evidence on the link between deforestation and poverty. If forest clearing requires investment, rich people may in fact be in a better position to clear new forest land. Moreover, off-farm employment opportunities simultaneously affect both poverty and deforestation, and any apparent relation between poverty and deforestation may actually be reflecting the off-farm employment-deforestation connection. Poverty (and discount rates) should therefore be considered endogenous variables.
- *The win-win thesis.* The thesis advocated by the World Bank and others, that economic growth and the removal of market distortions are good for people and forests, finds limited support in this review. Economic liberalization and currency devaluations tend to yield higher agricultural and timber prices that, in general, will promote deforestation. Moreover, higher incomes, within the relevant range of income found in developing countries, is likely to increase the pressure on forest resources
- *The making-the-forest-valuable thesis.*Those who oppose boycotts of tropical timber and other timber market restrictions often claim that lower timber prices will discourage sound forest management. This review of the literature suggests that lower timber prices should both reduce logging activities and restrain agricultural encroachment stimulated by logging.
- *The tenure security thesis.* Land titles and more secure tenure have contradictory effects. Where forest clearing gives farmers a claim to the land, increasing the security of such claims may lead to greater forest clearing. This finding contradicts the conventional thesis of resource and environmental economics that more secure property rights are good for the environment.
- *The intensification thesis.* How improvements in agricultural technology affect forest clearing cannot be determined a priori, without information regarding the type of technology and the output and factor market elasticities. On the one hand, intensification programs targeted at farmers living near the forest frontier make farming more profitable and may shift resources to forest clearing and attract new migrants, although this effect may be at least partially outweighed by the resulting downward pressure on agricultural prices and upward push on wages. On the other hand, new technologies for nonfrontier agriculture should reduce pressure on the agricultural frontier. Labor-intensive technological changes are more likely to reduce pressure on forests than general yield-augmenting productivity increases and labor-saving technologies.

Although the evidence is not sufficient to reject all of these hypotheses, it does at least raise significant doubts. It is time to rethink the causes of deforestation and redirect research to focus more on issues such as the impact of credit markets, technological change, poverty reduction, and land tenure.

Notes

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1. Models also vary with regard to their temporal nature (static-dynamic), type of data used (cross-section, time series, panel), spatial-nonspatial, and specific methods used.

2. The exceptions include Wiebelt's (1994) regional CGE model for the Brazilian Amazon and the dynamic ecological–land tenure analysis (DELTA) model built for Rondônia in Brazil by scientists from Oak Ridge National Laboratory (that is, Dale and others 1994).

3. Many studies include regional dummies, but this approach allows only point intercepts to vary across regions, rather than the slopes (coefficients). This problem can be solved by multiplying regional dummy variables by the global variables to create separate explanatory variables, but only at the expense of considerable degrees of freedom (Mainardi 1996; Kant and Redantz 1997). Another potentially useful approach in the case of panel data, suggested by one of the reviewers and yet to be explored in analysis of deforestation, is to run regressions separately for each country. Then the estimates are averaged over countries, and these averages are much more precise than the individual country estimates. It should be noted that OLS on the pooled data may not converge to the country average effects.

4. Local labor supply is likely to be much more elastic in the long run because of the possibility of migration.

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