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The Causes of Tropical Deforestation in Ecuador: A Statistical Analysis

DOUGLAS SOUTHGATE
RODRIGO SIERRA
LAWRENCE BROWN

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The Authors

Douglas Southgate is an Associate Professor of the Department of Agricultural Economics at Ohio State University and an Associate Fellow of the London Environmental Economics Centre.

Rodrigo Sierra is a Graduate Student of the Department at Ohio State University.

Lawrence Brown is Professor at the Department of Geography at Ohio State University.

Contact Addresses

The authors may be contacted at:

Department of Agricultural Economics
Ohio State University
2120 Fyffe Road
Colombus
Ohio 43210 1099
USA

or via:

IIED/UCL London Environmental Economics Centre
3, Endsleigh Street.
London WC1H ODD, UK

Tel: 01-388-2117
Telefax: 01-388-2826

THE CAUSES OF TROPICAL DEFORESTATION IN ECUADOR: A STATISTICAL ANALYSIS

by

Douglas Southgate, Associate Professor
Department of Agricultural Economics
Ohio State University

Rodrigo Sierra, Graduate Student
Department of Geography
Ohio State University

and

Lawrence Brown, Professor
Department of Geography
Ohio State University

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ABSTRACT

Reported in this paper is a statistical analysis of the causes of agricultural colonization and land clearing in eastern Ecuador. The results of the analysis bolster many of the arguments that have been made about the social forces driving tropical deforestation. In general, the prospect of capturing agricultural rents stimulates settlement of tree-covered hinterlands. Accordingly, the presence of roads and urban centers attracts rural settlement. Colonists also prefer to go where soils are suitable for crop or livestock production, all else remaining the same. In addition to being a function of population pressure, the extent of land clearing is shown to be a consequence of tenure insecurity.

THE CAUSES OF TROPICAL DEFORESTATION IN ECUADOR

INTRODUCTION

Widespread concern over the impacts of tropical deforestation has stimulated examination of the factors inducing people to settle in and to clear tree-covered hinterlands in the third world. Binswanger (1989) and Mahar (1989) have found, for example, that subsidies and tax breaks encourage land clearing in the Brazilian Amazon. Similarly, Gillis (1988) has demonstrated that governmental interference with market forces results in forest depletion in Asia. Complementing this general analysis are several case studies of frontier communities' response to a variety of governmental policies and market forces (Macdonald, 1981; Moran, 1983; Rudel, 1983; Lisansky, 1989).

Although it yields valuable insights, the existing literature does not constitute a satisfactory basis for assessing the causes of frontier settlement and land clearing in developing countries. In particular, one cannot draw general lessons about the relative strength of different causes from a series of case studies, each one having a narrow geographic focus.

Reported in this paper are the results of a study of tropical deforestation in a much larger area: eastern Ecuador's Amazonian lowlands. A wider geographic scope has allowed for statistical analysis, rather than a case study approach, to be used. That analysis clarifies relationships among land clearing, rural population pressure, local demand for agricultural commodities, infrastructure development, and tenure insecurity.

The model explaining tropical deforestation is presented at the beginning of the paper. Next, data used to elaborate the model are described and the results of regression analysis are presented. Discussed at the end of the paper are needs for additional research as well as the implications of this study for policy governing development of the Amazon Basin.

THE MODEL

Although population growth in tree-covered hinterlands and deforestation are closely related, land clearing is not an exclusively demographic phenomenon. As Bromley and Cernea (1989) point out, tangible environmental problems in the developing world, including tropical deforestation, are often a manifestation of underlying institutional crisis.

Institutional crisis is obvious where public sector claims on forests far outstrip the government's capacity to manage "its" properties. In Ecuador, for example, public sector claims are extensive. Practically all the country's tree-coverd land is designated as "forest patrimony" or national parks. By contrast, the government's effective control of that land is negligible. No rangers work in the 2,000,000 HA of forest patrimony delimited in the northwestern and northeastern parts of the country (MAG, 1987) and, as of 1987, a mere 2 administrators, 25 technicians, and 119 permanent and seasonal rangers had been assigned to the 2,100,000 HA of parks in continental Ecuador (DINAF, 1989).

Alone, the wide discrepancy between public sector claims on forests and limited governmental capacity to control access to those same resources would bring about what Hardin (1968) calls a "tragedy of the commons." That is, individuals encroaching on the forest patrimony or national parks (e.g., to collect fuelwood) would neglect the costs society as a whole associates with forest degradation. Tacitly recognizing this, Ecuador's government allows individuals and firms to make claims on tree-covered land. Private parties cannot acquire forests, however, timber concessions having been banned in

1982. Instead, formal property law, as executed by the Ecuadorian Institute for Agrarian Reform and Colonization (IERAC), establishes that deforestation is a prerequisite for tenure for those settling in tree-covered hinterlands.

Alone, this tenurial regime induces a cycle of excessive land clearing and inadequate soil conservation in the vicinity of agricultural frontiers (Southgate, 1990). Aggravating the institutional crisis that underlies deforestation in countries like Ecuador, however, is bureaucratically induced tenure insecurity. Like other land reform agencies established during the era of the U.S.-sponsored Alliance for Progress, IERAC requires a long time, often years, to adjudicate claims for formal property rights. Delays are explained in part by administrative constraints. IERAC's record-keeping system is extremely cumbersome and the agency did not acquire its first computer until the late 1980s. In addition, the complexity of formal property law draws out the adjudication process, IERAC being obliged to execute ten separate procedures during the course of settling a tenure claim (Seligson, 1984).

In the face of tenure insecurity, which is an especially severe problem for those who lack the funds or influence needed to "move the system along," agricultural colonists in the Amazon Basin tend to safeguard claims on land by using their parcels continuously for crop or livestock production (Rudel, 1983). Indigenous groups respond identically to the same institutional incentives. Macdonald (1981) reports, for example, that the periodic fallowing scheme long practiced by the Amerindian community of Pasu Urcu, in eastern Ecuador, was abandoned during the 1970s after IERAC agents informed the community that fallow lands could be claimed by agricultural colonists, who were 50 KM away at the time. For colonists as well as indigenous inhabitants, then, continuous agricultural production is a way to assert and to protect property rights.

Given that deforestation is caused by demographic as well as institutional forces, the model described in this paper treats settlement in tree-covered hinterlands and land clearing as two separate activities. In the rest of this section, the determinates of both activities are explained.

Agricultural Colonization. Since frontier tenure regimes prevent individuals and firms from capturing forestry and other non-agricultural rents, settlement in tree-covered hinterlands is stimulated by the prospect of capturing agricultural rents. That is, there is a direct and positive relationship between demographic pressure at any particular site and agricultural (as opposed to non-agricultural) rents at the same site.

Agricultural rents and, hence, settlement are an increasing function of three factors: the scale of nearby urban development, soil productivity, and accessibility to outside markets. The presence of cities and towns enhances rents by strengthening local demand for agricultural commodities. By contrast, soils underlying tropical forests are usually infertile and often erodible (Nicholaides et al., 1983), which tends to impede agricultural colonization. Finally, improved accessibility is critical for agricultural development in developing country hinterlands. For example, Bromley (1981) points out that primary forests covered practically all of northwestern and northeastern Ecuador before all-weather highways were constructed in those two regions.

These influences on agricultural rents are expressed by the three right-hand side terms of the first regression in our model, which explains the extent of extent of agricultural colonization in eastern Ecuador's twenty cantons (the average size of which is comparable to the area of a county in the midwestern United States):

$$AGPOP = b_{10} + b_{11} URBPOP + b_{12} SOILS + b_{13} ROADS , \quad (1)$$

where:

AGPOP = the canton's agricultural labor force,

URBPOP = the canton's urban population,

SOILS = hectares in the canton covered with soils that do not have major limitations for crop production, and

ROADS = kilometers of all-weather roads in the canton.

AGPOP is an indicator of rural population pressure. As indicated above, the size of the canton's urban population, URBPOP, is a satisfactory proxy for local demand for agricultural products. Discussed in the next section are the criteria used to measure the variable, SOILS. The extent of all-weather roads in a canton, ROADS, indicates the canton's accessibility. Regression coefficients b_{11} through b_{13} are all expected to be positive.

Some explanation of the exogeneity of the three factors influencing agricultural rents is in order. Urban activity in the Amazon Basin is often very weakly linked to agricultural production in the surrounding countryside. The growth of northeastern Ecuador's towns, for example, has been closely linked to petroleum industry development. At an extreme, the large size of Manaus, Brazil is explained by its being declared a duty-free zone, which has greatly stimulated industrial development. Given this characteristic of urban development in the region, it is appropriate to treat URBPOP as exogenous in equation (1).

The second right-hand side variable in the same equation is clearly independent, the natural capacity of land to support crop or livestock production being outside of human control.

The history of the Amazon Basin, generally, and eastern Ecuador, specifically, demonstrates that the penetration of highways into forested hinterlands usually leads to agricultural colonization, not vice versa. The governments of Brazil and other countries have constructed roads more to establish "human frontiers," which safeguard territorial claims, than because they have been strongly convinced that the Amazon Basin's agricultural potential is great (Landau, 1980). Also, settlement of northeastern Ecuador began in earnest only after infrastructure had improved. That improvement followed the discovery of petroleum in the region (Bromley, 1981). Brazilian and Ecuadorian experience confirms, then, that the variable, ROADS, can be treated as exogenous in this analysis.

Land Clearing. The second equation of the regression model reflects the institutional crisis underlying deforestation in the Amazon Basin. That is, it relates the extent of land clearing in a canton, DEFOR, to demographic pressure (specifically, the first equation's dependent variable) as well as to a non-negative index of relative tenure security, TENSEC:

$$\text{DEFOR} = b_{20} + b_{21}\,\text{AGPOP} + b_{22}\,\text{TENSEC}\ . \qquad (2)$$

AGPOP's coefficient, b_{21}, is expected to be positive. TENSEC is constructed so as to indicate differences in formal tenure security among cantons:

$$\text{TENSEC} = \frac{\text{adjudicated \% of a canton's agricultural land}}{\text{adjudicated \% of agricultural land in eastern Ecuador}} \qquad (3)$$

If the value of TENSEC for any particular canton were greater than 1.00, then that canton's farmers would be more likely than others in eastern Ecuador to hold formal tenure in their land. Conversely, a value less than 1.00 indicates that a canton's farmers are less likely to hold formal tenure.

TENSEC's coefficient, b_{22}, is expected to be negative because increased formal tenure security is assumed to reduce the need for continuous exercise of informal agricultural use rights. The pace of land adjudication in different parts of the country being the prerogative of the national government, TENSEC is an exogenous variable.

Arguably, tenure security could influence farmers' locational decisions. However, because the correlation between AGPOP and TENSEC is only 0.133, it is reasonable to conclude that, in eastern Ecuador at least, formal tenure security influences colonists' resource development decisions (i.e., choices about land clearing) once they which have settled in a particular area. Colonization, itself, is driven by forces expressed in equation (1).

DATA

The first equation's dependent variable, AGPOP, and one of its independent variables, URBPOP, were obtained from a 100 percent sample of individual returns collected in eastern Ecuador during the country's most recent census, conducted by the Institute of Statistics and Censuses (INEC) in 1982. Agricultural labor force was found to be highly correlated with other measures of settlement in the countryside (e.g., rural population or rural employment). Similarly, urban population is highly colinear with other proxies for local demand for agricultural commodities (e.g., non-agricultural work force).

The variable, SOILS, which equals the area in each canton with "good" agricultural potential, was assessed through interpretation of soil maps prepared by the National Program for Agrarian Regionalization (PRONAREG).

Recognizing the principal environmental constraints on crop and livestock production in eastern Ecuador, we classified the region's soils according to drainage and fertility. Our procedure yielded results very similar to those obtained by the country's National Development Council (CONADE) and the United Nations Environmental Program (UNEP), which also relied on PRONAREG maps. Whereas CONADE-UNEP (1986) found that 5.69 percent of eastern Ecuador is a suitable site for agriculture, we found that 5.64 percent of the same region was free of serious drainage or fertility problems.

Road maps prepared by INEC as well as an inventory completed by the Ministry of Public Works (MOP, 1987) were used to determine how many kilometers of all-weather roads existed in each canton (i.e., variable ROADS) in 1982.

The National Institute for the Colonization of the Ecuadorian Amazon (INCRAE) and the Center for Integrated Inventory of Natural Resources (CLIRSEN) have used aerial photographs and satellite images to assess land use change in different parts of eastern Ecuador between 1977 and 1985 (INCRAE-CLIRSEN, 1987). The results of that study allowed for calculation of the extent of tropical deforestation in the early 1980s (i.e., the second equation's dependent variable) in eleven of eastern Ecuador's twenty cantons. No such estimates are available for the other nine cantons.

Finally, records showing cumulative land adjudication in eastern Ecuador were collected from IERAC. Those records, along with INCRAE land use data, were used to determine the index, TENSEC, for each canton.

Correlations among each regression equation's right-hand side variables are, in general, quite low. The major exception is the 0.636 coefficient for URBPOP and ROADS, which is understandable since urban settlement is generally rare where all-weather roads have not yet penetrated. Colinearity between the two variables impedes reliable estimation of their respective standard errors (see next section). As indicated above, the two right-hand side variables in the second equation, which explains land clearing, are not colinear.

REGRESSION RESULTS

Equations (1) and (2) comprise a recursive system of regressions. Koutsoyiannis (1977, pp. 340-342) points out that ordinary least squares (OLS) estimates of such a system's coefficients are efficient.

OLS estimation of equation (1), which explains agricultural settlement, yields the following results (standard deviations are shown in parentheses):

$$\underset{}{AGPOP} = \underset{(251.334)}{469.144} + \underset{(0.061)}{0.263}\ URBPOP + \underset{(0.002)}{0.008}\ SOILS + \underset{(2.527)}{3.350}\ ROADS$$

$$F = 26.856 \quad adj\ R^2 = 0.803 \quad n = 20\ .$$

In spite of limited degrees of freedom, applying the F-test with a 99 percent confidence interval leads to rejection of the hypothesis that all regression coefficients equal zero. This test result is consistent with the maintained hypothesis underpinning this equation, which is that the prospect of capturing agricultural rents stimulates colonization of forested hinterlands. At the same time, application of a t-test with a 99 percent confidence interval leads to rejection of the null hypothesis for the coefficients of the first two right-hand side variables. The somewhat lower t-statistic for the coefficient of ROADS is possibly explained by multicollinearity between that variable and URBPOP. The signs of the right-hand side coefficients are all positive, as had been expected.

OLS regression of the second equation, which explains land clearing, yields the following results:

$$\text{DEFOR} = \underset{(23{,}977.621)}{16{,}111.728} + \underset{(6.241)}{51.073}\ \text{AGPOP} - \underset{(12{,}321.915)}{26{,}989.394}\ \text{TENSEC}$$

$$F = 36.097 \quad \text{adj } R^2 = 0.875 \quad n = 11 .$$

Applying the F-test with a 99 percent confidence interval leads to rejection of the hypothesis that the second equation's right-hand side coefficients all equal zero. AGPOP's and TENSEC's coefficients are positive and negative, respectively, as had been expected. AGPOP's coefficient is significantly different from zero when a 99 percent confidence interval is used. If a confidence interval of 94 percent or less is used, then TENSEC's coefficient is also significantly different from zero.

Preceding estimates of regression coefficients are efficient. Had a larger sample been available, then confidence intervals around true coefficient values would have been smaller. In particular, more conclusive testing of the significance of TENSEC's coefficient would have been possible. In addition, the problem of multicollinearity is frequently addressed by using a larger sample. Consequently, high covariance between URBPOP and ROADS, which might explain acceptance of the null hypothesis for the latter's coefficient, might be symptomatic of the small sample used in this research.

In spite of the small data set available to us, the preceding results of regression analysis provide clear evidence about the causes of tropical deforestation.

DISCUSSION

To date, case studies have constituted the principal point of empirical reference for discussions of the causes of tropical deforestation. That literature provides useful insights into the market forces and public policies inducing people to clear tree-covered land near the equator. However, a series of case studies does not constitute a satisfactory basis for making general statements about linkages among land clearing, tenure security, rural population pressure, and the factors influencing rents along agriculture's extensive margin.

The research reported in this paper constitutes a methodological departure from previous analysis of the causes of tropical deforestation. Our results show that statistical analysis can indeed clarify the social context of land clearing across broad stretches of an agricultural frontier. In particular, regression analysis bolsters the argument that settlement of forested hinterlands is driven by the prospect of capturing agricultural rents. Perhaps the most interesting result of this study has to do with settlers' land clearing decisions. It should surprise no one that deforestation goes hand in hand with demographic pressure in rural areas. However, our analysis also suggests that colonists also clear natural vegetation in order to safeguard their tenuous legal hold on frontier lands.

These results, obtained with a small sample, should encourage similar research with the larger data sets that can be assembled in other countries. Also, as remote sensing technology advances, it will be possible to undertake analysis of the type reported in this paper with samples comprising smaller geographic units.

In and of itself, however, our statistical analysis yields useful insights for policy making. That there is a link between tenure insecurity and tropical deforestation suggests that governments, like Ecuador's, that now take years to process claims on frontier parcels could help arrest deforestation by streamlining their adjudication procedures. Also, developing country governments could promote forest conservation by creating property rights in primary forests and other tree-covered land. That is, deforestation should no longer be a prerequisite for formal tenure. As the latter type of reform is adopted, it will become possible to study whether migration to tree-covered hinterlands is stimulated or reduced by private parties' being able to capture forestry and other non-agricultural rents.

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David W Pearce, Edward B Barbier and Anil Markandya, Sustainable Development: Economics and Environment in the Third World, Edward Elgar Publishing Limited, London 1989 [in press].

The authors attempt to give some structure to the concept of sustainable development and to illustrate ways in which environmental economics can be applied to the developing world. Beginning with an overview of the sustainable development concept, the authors indicate its implications for discounting and economic appraisal. Core studies on natural resource management are drawn from Indonesia, Sudan, Botswana, Nepal and the Amazon.

David W Pearce, Anil Markandya and Edward B Barbier, Blueprint for a Green Economy, Earthscan, September 1989, £6.95

This book by the London Environmental Economics Centre was prepared as a report for the Department of Environment, as a follow up to the UK government's response to the Brundtland Report. Here it stated that: '...the UK fully intends to continue building on this approach (environmental improvement) and further to develop policies consistent with the concept of sustainable development.'
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