The Economics of Deforestation: Evidence from the Brazilian Amazon and New England

by

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Submitted to the Department of Economics
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy

at the

Massachusetts Institute of Technology

July, 1995

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ABSTRACT

This dissertation contains three economic analyses motivated by interest in deforestation. It starts with an analysis of a current episode of great interest, deforestation in the Brazilian Amazon. From there, it moves on to further investigations of particular effects suggested in the first analysis, specifically the implications of agglomerations of activity for land use within a region. First, an empirical analysis explores the concentration of population within historical New England, one simultaneous with reforestation of the region. Then a theoretical analysis investigates the implications of locational externalities for patterns of location of production.

The first essay analyzes the determinants of deforestation in the Brazilian Amazon. It derives and then estimates a deforestation equation using county level data for years between 1975 and 1988. The data include a new deforestation measure, from satellite images, which is a great advance in allowing within-country analysis. The level of population is significant when population is the sole explanatory variable for deforestation, but its effect disappears when other variables suggested in the model are included. A quadratic population specification is more robust to the inclusion of other variables. I propose that population is endogenous, and find qualified support for this claim using "migration push" instruments. Evidence exists that: being further from the rest of the country leads to less deforestation; better soil quality leads to more deforestation; and -- most important for policy -- increased road density leads to more deforestation. Finally, government development projects appear to increase deforestation, while the evidence on credit access policies is mixed.

In the second essay, after documenting a reversal of New England deforestation post-1850, I briefly discuss land use choice and a standard explanation for patterns of land use, comparative advantage. I then explore the potential for an explanation based on agglomeration in manufacturing. I review the theoretical features of manufacturing which predict low land use per unit of activity relative to agriculture, and then provide evidence suggesting the existence of agglomerative features. Within-region concentration measures based on county population

data for New England from 1790 to 1930 increase each decade from 1830 (the start of the transportation revolution). In addition, mapping this data reveals multiple but few centers of population, while limited town data show increasing within-county concentration as well. This evidence suggests locational processes, not just low land intensity or increasing returns, in manufacturing production. Then comparing the locations of population with those of bodies of water demonstrates the latter's locational importance. However, it also shows heterogeneity in population density within the set of comparatively advantageous locations, suggesting agglomeration in manufacturing.

The third essay modifies Krugman (1991)'s model of locational externalities in manufacturing. The principal change is to allow mobility of agriculture (to match manufacturing), which creates a model of location coordination involving both sectors. This allows exploration of whether a model with this approach to regional location, one independent of the more standard approach of comparative advantage, could be relevant to historical regional production patterns in the United States. A qualitative empirical test for the relevance of such a model is presented. Krugman's results remain as special cases, and the parametric conditions which allow for historically relevant equilibria are determined.

ACKNOWLEDGEMENTS

I feel extremely fortunate to have interacted with the people I have met while in graduate school. I have never been in a place with so many people in which any given conversation is likely to pique my interest and the conversants to teach me something. Although from many backgrounds, they have in common great ability and the pursuit of excellence. All have been inspiring, and I am lucky to count a few as good friends. I have been equally fortunate to have received the support of a great number of people during my time here. I think that I have put forth sufficient effort and output to merit this degree, but am keenly aware both that I could never have done so without the support of others and that my effort easily could have gone unchanneled and been wasted without the guidance of many.

Given the academic state in which I arrived at MIT, I feel that my completion of this degree reflects well on all those mentioned below, as well as on the structure of and individuals involved in the MIT Economics Department graduate program. Even should I never produce further research, I would count myself fortunate for having been here, for having seen from up close the research process at its best. It is not everyone who is lucky enough, having wondered about a subject, to spend time first listening to and then talking with its best practitioners.

Throughout my time here, particular professors have given significantly of their time and effort in nudging me towards various ends. In some form of chronological order:

Jim Poterba has helped me all through this process. He deserves thanks: for giving me the impetus and energy to start down the MIT road; for maintaining a research sub-community in which I could have a small identity, even early on. This group also exposed me to both ongoing and polished research, and to what it takes to move from one to the other; for holding helpful opinions strongly enough to guide me, while listening enough to help me pursue the topics I chose; and for being willing to offer (good) advice when consulted on any topic.

Rob Stavins has also furthered my development as an interested and functioning economist in many ways. I am grateful to him for taking me on and giving me independence as a research assistant, and for always leaving the door open for me to take a break and observe the fascinating world of applied economics and policy. I am also thankful that, when asked, he has always been forthcoming with his opinions as an advisor, colleague and friend. At the same time, he painstakingly respects the paths of different people, and supports considered individual choices whether or not they dovetail with "accepted wisdom". Finally, in addition to providing an advisor's economic feedback on my ideas and speculations, he has rightly tried hard to impress upon me the importance of clear communication tailored to one's audience.

Robert Solow deserves my greatest thanks for three reasons in particular. First, as a student advisor, he listened patiently to my attempts to refine interests and half-formed thoughts into more concrete questions and research topics. Such acceptance, and willingness to steer a novice economist's energy gently and helpfully toward more economic thoughts, was a great gift to one who had not yet developed confidence in this field. Second, as a thesis advisor, he brought his justifiably honored wisdom to bear on all my speculations, helping me to form the set of ideas which became my thesis. Most impressively, he regularly demonstrated immense class, creating for me the image of the "regular-guy intellectual". Never flaunting his capacity for great achievement, he was unfaltering in his respect for and enjoyment of others.

Finally, Dick Schmalensee has been a true advisor from the moment he agreed to take me on as an advisee quite late in my tenure. Displaying great dedication to this role, he employed a simple, mutually exacting standard: real effort deserves feedback. If I worked, he would put his mind to my problem as well, however numerous the understandable demands on his time. Never has there been better incentive. In what I feel is the greatest tradition of mentoring, he would push me on all fronts, but support me if I wavered, as well as supporting me with respect to the "outside world".

While I have had less interaction with Jon Gruber, I do owe him my thanks. He was always enthusiastic and willing to lend a helping hand whenever it was needed. This was the case even though my work was quite different from his own.

On another front, I would be remiss if I did not give the credit that is due to others who made possible the first essay, the cornerstone of the thesis. After much searching I discovered that David Skole at the University of New Hampshire had collected state of the art satellite vegetative land cover data, and that Eustaquio Reis at the Institute for Applied Economic Research in Rio de Janeiro (IPEA/Rio) had collected a fantastic databank for the Amazon. Both during my extended visit at IPEA/Rio and during my work at MIT, their efforts and those of their colleagues helped me greatly in using these datasets. Among their colleagues, I want to thank in particular Walter Chomentowski at UNH, and Maria Jose Silveira Pessoa and the computational staff at IPEA/Rio. In making their data available to me and in their ongoing contributions, these two groups were absolutely crucial in making this first essay possible.

Further, I might never nave finished this degree if not for the financial assistance of a number of organizations. I gratefully acknowledge funding from: a National Science Foundation graduate fellowship, the Schultz Fund (in MIT Economics), the University of Florida and FLAS, the Social Science Research Council's International Predissertation Fellowship Program, the MIT World Economy Lab, and the MIT Joint Program on the Science and Policy of Global Change.

I feel fortunate that a number of my fellow students have become friends as much as colleagues. A few students have had particularly large roles in my graduate school experience. Donald Marron in particular deserves special mention for being: a good friend; a great fellow economics novice in our first years, as we lived on the phone; a great colleague in general, talking for hours about any given topic that had caught his or my eye, or had been forced upon him through my insistence. Kaivan Munshi has also been a special colleague and friend. He has shared knowledge and opinions, and never loses his deeply felt attachment to real life.

Other colleagues and friends who have significantly shaped my experience here for the better are Bill Miracky and Matt Slaughter, who hung with me as we went in all directions; Gordon Hanson and Andrew Bernard, who helped me to envision a good way to go about this kind of life; and all of my officemates, especially David Laibson, Jeromin Zettelmeyer, Andres Almazan, and Ilan Goldfajn, who lived this student life with me.

My greatest thanks are also due my family, who through words and example have both supported me and pushed me when necessary. They have always encouraged me to pursue what I felt was interesting, regardless of my ability to master the topics, or the likely short-term professional consequences. Their unwavering support of me as an individual has been invaluable throughout my life, no doubt more than I know, including during this thesis.

Finally, special thanks are due Kimberly Ann Pfaff Putalik. Coming into my graduate school experience mid-way, she immediately saw both the potential and the peril in this professional life, and has helped me to keep both in sight. While willingly accompanying me on long trips (literal and figurative) in pursuit of this degree, she has helped me incalculably to start to make such pursuits a part of a life we can truly live.

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ESSAY ONE

WHAT DRIVES DEFORESTATION IN THE BRAZILIAN AMAZON ?

1. INTRODUCTION

Protest over the depletion of rainforests demanded the attention of policymakers during the 1980's. An initial source of major concern was potential species extinction. Then scientists alarmed the world with talk of future global warming caused by atmospheric accumulation of "greenhouse gases" such as carbon dioxide (CO_2). Since forests store carbon, deforestation can potentially contribute to such climate change. It is important to note that despite the attention depletion of the Brazilian Amazon has received, this rainforest remains almost ninety percent intact. Thus examination of deforestation is not merely an historical exercise; decisions taken now and in the future will significantly affect rainforest survival.

Policymakers must understand what drives deforestation if they are to respond appropriately to such concerns. Much has been learned in the past two decades about topics ranging from nutrient cycling to the sustainability of extractive production. However, important questions remain about why rainforests are being cut down and whether public policies can affect the rate at which deforestation takes place. It is these questions that this paper seeks to address.

Much has been written about these questions, but economic understanding remains rudimentary at best. What empirical research there is has focused almost exclusively on population. This paper suggests an economic framework encompassing not only population but also other factors such as roads, credit, and soil quality. Starting from an individual clearing decision, I derive a county level cleared land equation. My empirical analyses then take the existing literature as a starting point and move forward in three steps. These advances are possible because of the data set I have assembled. This data set merges new deforestation data, from satellite images, with Brazilian county level data in a way which permits Amazon-wide, within-region analysis.

Confirming the standard result in the literature, population as a sole explanatory variable appears to have a significant positive effect on deforestation. However, including other variables suggested in the model makes population insignificant, and, in addition, these other factors have significant effects. Interestingly, a quadratic population specification, which allows population's level to affect its marginal impact, is more robust to the inclusion of other variables. The implications of such a nonlinear relationship differ from those of the linear relationship often presented in the literature. I propose that population is endogenous, i.e. that population and deforestation are jointly determined by other factors, and thus that their correlation may be spurious. Instrumenting for population using "migration push" variables provides qualified support for this claim, although additional instruments would help greatly. This procedure also provides additional evidence on other effects, although, again, the effectiveness of the instruments must qualify any such conclusions.

Across these steps, a number of consistently significant effects are found: greater distance from the center of the country is associated with lower deforestation; higher soil quality leads to more forest clearing; and, most important for policy, increased road density leads to more deforestation. Also of policy interest is evidence that development projects lead to greater deforestation. However, the evidence on credit access policies is mixed.

The paper is organized as follows: Section 2 reviews the existing literature. Section 3 describes the data which allow this paper to move beyond previous empirical analyses. Section 4 provides geographic and historical background on the Brazilian Amazon, as well as summary statistics showing the changes which took place in the Amazon in the period studied here. Section 5 derives a equation for cleared land, working from a model of an individual clearing decision. Section 6 presents results of two types: first, those which follow the literature and include the level of population as the sole explanatory factor for deforestation; and second, those which follow my derived cleared-land equation. This second group includes many factors suggested in the model but maintains the assumption common in the literature that population is exogenous to deforestation. Section 7 then presents this paper's contention that population is jointly determined with deforestation, suggests causal factors which might capture an exogenous component of population, and presents the results of re-estimation of the deforestation equation in this light. Finally, Section 8 concludes and presents potential extensions of this work.

2. REVIEW OF EXISTING LITERATURE

For over a decade researchers have considered the relationships between government actions, private reactions, and deforestation in a variety of settings. I review the existing literature within three broad categories -- policy analyses, field work, cross-country -- and conclude with discussions of a handful of more closely related works. Research in the first category tends to contain little formal analysis of the determinants of deforestation. Research in the second and third categories often contains such analysis. Those categories differ from each other, and from this paper, in scale of analysis: field works tend to address one or a few localities within a region of a country, cross-country analyses take whole countries as units of observation, and this paper takes counties as units of observation within the Brazilian Amazon.

2.1 Policy Analyses

A number of analyses have sought to illuminate the effects of Brazilian government policies on forests in the Amazon. This body of work mushroomed in the 1980's, and ranges from research on the effects of subsidies and roads on the proliferation of cattle ranching in the Amazon (e.g. Hecht 1985) to works on various countries' policies and their consequences for forests which attracted a fair amount of attention and helped to spur reactions in the developed country policy world (e.g., Repetto & Gillis 1988, Binswanger 1989, and Mahar 1989).

2.2 Field Work

Many analyses focus in great detail on particular subregions of the Brazilian Amazon. For example, Hecht (1982) evaluates policy effects on cattle ranching in the eastern Amazon; Fearnside (1986) analyzes the "carrying capacity" of a particular colonization area; Fearnside (1990) discusses myriad factors affecting land use; Smith (1982) describes Trans-Amazon Highway settlement; Uhl *et al* (1991) studies selective logging in a town in the eastern Amazon; and Bunker (1985) analyzes the development around a huge state mining project in the eastern Amazon. Moran (1981,1990) describes and analyzes the Amazonian colonization experience both in a particular study area and in general. He points to the potential for errors in assuming homogeneous colonists and in analyses performed at a scale large enough to induce error from assumptions of homogeneity. Examples of a different sort are Branford and Glock (1985) and

Schmink and Wood (1992) on land conflict in the eastern Amazon. More recently, Alston *et al.* (1994) investigate at a local level the importance of property rights in land use decisions in the Amazon. These works provide a information on producers in the Amazon region that is relevant for the microeconomic modeling in this paper.

2.3 Cross-Country Work

These works attempt to correlate factors of interest with measures of deforestation among nations. Their most common result is that population (or its density) is the most significant factor in explaining deforestation. Two notes: as cross-country studies, they may feature population levels more exogenous than those within a country or a region; second, population is considered principally in light of its demand-side effects on deforestation. Both Allen and Barnes (1985) and Palo *et al.*(1987) include a population term in deforestation regressions alongside land use and output measures and find population to be important. Lugo *et al.* (1981) regress deforestation on population, energy use, and terrain variables, finding population to be important. Rudel (1989) finds population to be the key variable in explaining deforestation. Cropper(1994) and Deacon(1994) also examine the relationship between population and deforestation across countries, again finding population to be important. Cropper provides evidence of the significance of income levels, or stage in development, while Deacon provides evidence of the significance of weak or unstable government and by implication weak property rights. While cross-country results should be applied to any particular country only with great caution, these results make up a large part of the existing empirical literature and thus provide a starting point for the analyses in this paper.

2.4 Most Closely Related Works

Almeida (1992) provides a great deal of information at the level of the entire Amazon region. However, the book mainly tries to answer the question "Was agricultural colonization of the Amazon worth its cost, and the best option?", and thus it provides more measurement than testing of the importance of given factors in deforestation. Sungsuwan (1985) and Panoyotou and Sungsuwan (1989), on Thailand, take an approach similar to that taken here. They find that deforestation is driven by population density, wood price, income, and distance to Bangkok. Kummer (1991) analyzes deforestation in the Philippines. He emphasizes national (versus cross-country) study, as well as the use of deforestation (versus percentage forest cover) measures.[1] He finds agricultural area to be an important determinant of deforestation. Also, unlike almost all others, he finds only a small role for population growth in deforestation, and suggests that this link merits further consideration. Harrison (1991) studies Costa Rican deforestation and also raises the issue of whether population is a cause or a "shared symptom" of other issues. She also allows for different population effects in different regions and relates these in part to land use differences. Southgate *et al.* (1991) focus in part on population in analyzing deforestation in Ecuador's Amazon region: they first explain population with variables expected to affect "the prospect of capturing agricultural rents", and then explain deforestation with population and other factors. Reis and Margulis (1990) and Reis and Guzman (1992) present econometric analyses of deforestation in the Brazilian Amazon. They find population density, road density, and crop area to be important determinants of their deforestation measure. Their work leads into this paper, including the use here of some of Reis' data. The principal differences between their works and this are: three years of Amazon-wide satellite deforestation data; new policies data; and further theoretical and empirical attention to particular roles for population and other factors. Finally, Stavins and Jaffe (1990) suggest a method for moving from an individual model of land use decision-making to implications for county level data which seems appropriate here. They find that US government engineering projects foster depletion of forested wetlands by changing the economic environment of private landowners.

In summing up these more closely related works, the major points appear to be: one, population is cited as an important variable; and two, while various authors describe a variety of situations within which there exists a variety of potential deforestation dynamics, there is little attempt to formalize these dynamics and their implications for causal linkages. Thus the empirical work, although it may be interpreted in various ways, is often not formally linked to

[1] He argues that land that is currently not covered with forest may never have been, and thus may never have been deforested. Alternatively, it may not have been forested recently, and thus its deforestation should not be attributed to recent movements in explanatory variables. Either way, it may be incorrect to claim that recent deforestation equals one minus the recent forest cover measure.

particular hypotheses shedding greater light on the deforestation processes in question. In what follows I improve on this work by formalizing the deforestation dynamics and by considering the role of many variables in addition to population.

3. DATA

The data come from three main sources: scientists at the University of New Hampshire who specialize in state-of-the-art satellite measures of vegetative land cover; the Brazilian census; and other Brazilian agencies. The analyses here will be conducted at the county level, the most disaggregated level for which these census data are available. The county structure in the Amazon changed over the period studied here. Specifically, the number of counties increased, as old counties were split into multiple new counties. Since a uniform set of counties is required for analysis of more than one year of data, the more recent observations have been aggregated backwards using the county-structure transformations. Thus the analyses take place in 1970 counties. There were 316 counties in 1970, 336 in 1980, 399 in 1985, and 506 in 1991.

3.1 Deforestation Data

The dependent variable is the satellite deforestation measure, which exist for 1975, 1978, and 1988. The original units of observation by the satellite are much smaller than counties, and are aggregated to county level.[2] These data indicate what fractions of a county are standing forest area, cleared forest area, and "never-forested area", or *cerrado*, at a given point in time (all area is classified as one of these three). *Cerrado* is the main vegetation other than forest in the Brazilian Amazon. It is a scrubby vegetative land cover, whose important characteristic for this paper is that it has lower clearing costs than dense forest.

In the satellite data, the *cerrado* areas are seen as constant: their boundaries are fixed, and the deforestation measure misses any clearing which takes place in *cerrado*. Because of this, the "fraction cleared of a county" variable calculated with the satellite data is re-normalized, with only the "ever-forested" areas in the denominator, as only those areas can be

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[2] The references to consult concerning this data are Skole and Tucker (1993) and Skole *et al* (1994).

observed to be cleared. Finally, from the same source, although unrelated, come the "soil quality" measures, which are measures of the soil density of nitrogen and carbon.

3.2 Population Data

Rural and urban population come from the Brazilian Demographic Census for 1970, 1980, and 1991.[3] The regressions use population densities. In deforestation equations, the 1970 population is paired with 1978 deforestation, and the 1980 population is paired with 1988 deforestation. This means that population is lagged sufficiently to eliminate some concerns about endogeneity of population.[4] Also from this source comes information on migration. In particular, the distribution of a county's migrants according to state of origin is provided. This information is used in creating "conditions in the weighted average state of origin" variables which are used as independent variables in population equations.

3.3 Price, Quantity, and Area Data

Prices, such as output prices and wages, are also from the Brazilian census, in this case from the Agricultural Census, for 1975, 1980, and 1985. Because of concern about endogeneity, the wage used in the regression is an average industrial wage from the Industrial Census. One way to address such concerns for prices would be to calculate "effective county output prices", i.e. weighted averages of national level prices, using as weights the fractions of county output made up by crops, cattle, and timber outputs. As suggested in this procedure, quantities are also available for the crops for which there are prices. These include cattle stocks and flows, as well as wood output quantities. The areas in various crops, and in crops and ranching overall, are also available.

3.5 Transport Data

Road (paved and unpaved) lengths, river lengths, and distance measures come from maps

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[3] The definition of "urban" is not precisely laid out in Census books. They refer one to "municipal law".

[4] Another implication of the need to use observations for explanatory variables for years earlier than those of the observations for the dependent variables is that population, a main variable, has only two useful observations, because the 1991 observation occurs after all the observations of deforestation.

provided by Brazilian government agencies. Road observations exist for 1976 and 1986. It may be possible to further separate both paved and unpaved roads into federal and state subcategories, which could be helpful in distinguishing degrees of exogeneity in road construction. Also, note that the rivers which are included must satisfy a "navigability criterion" of the form that they exceed a minimum depth for a minimum period of time during the year.[5]

3.6 Data On Government Actions

Credit extension data come from the Banco do Brasil (BdB). The original data indicate how many BdB agencies were present in the county in 1985 and what year the first BdB agency appeared. From that information one "false, number panel" and one "true, existence panel" were created: the former assumes that all the agencies present in 1985 appeared when the first agency in the county appeared; the latter panel indicates whether there was at least one agency in the county. Development projects information comes from Sudam (Superintendency for the Development of Amazonia). This information is also only for 1985 but with certain dates (first funding, first implementation, etc) allowing another "false, number panel" to be created, exactly as just described. Hydropower dam information come from Brazilian agency publication.[6] It includes the name of the county in which the powerhouse is located, plus total inundated area, but not flooded areas in "non-powerhouse" counties.

4. BACKGROUND

4.1 Geography

The Brazilian Amazon lies in the northwest corner of the country, surrounded by a number of other countries (Figure 1). It contains 5 million of Brazil's total area of 8.5 million square kilometers; the latter area is larger than the continental United States. The Amazon region is traversed by the Amazon River, the confluence of runoff from higher areas to the north, south, and west of the river basin. Rivers permeate the region (Figure 1).

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[5] This criterion could be binding in, for instance, the upper highlands where the rivers start as streams. Exactly what qualifies should affect one's prior about the effect of the river variable in the regressions.

[6] See IBGE(1992).