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Abstract:

Brazil has long ago removed most of the perverse government incentives that stimulated massive deforestation in the Amazon in the 70s and 80s, but one highly controversial policy remains: Road building. While data is now abundantly available due to the constant satellite surveillance of the Amazon, the analytical methods typically used to analyze the impact of roads on natural vegetation cover are methodologically weak and not very helpful to guide public policy. This paper discusses the respective weaknesses of typical GIS analysis and typical municipality level regression analysis, and shows what would be needed to construct an ideal model of deforestation processes. It also presents an alternative approach that is much less demanding in terms of modeling and estimation and more useful for policy makers as well.

Keywords: Deforestation, Amazon, Brazil, econometric modeling
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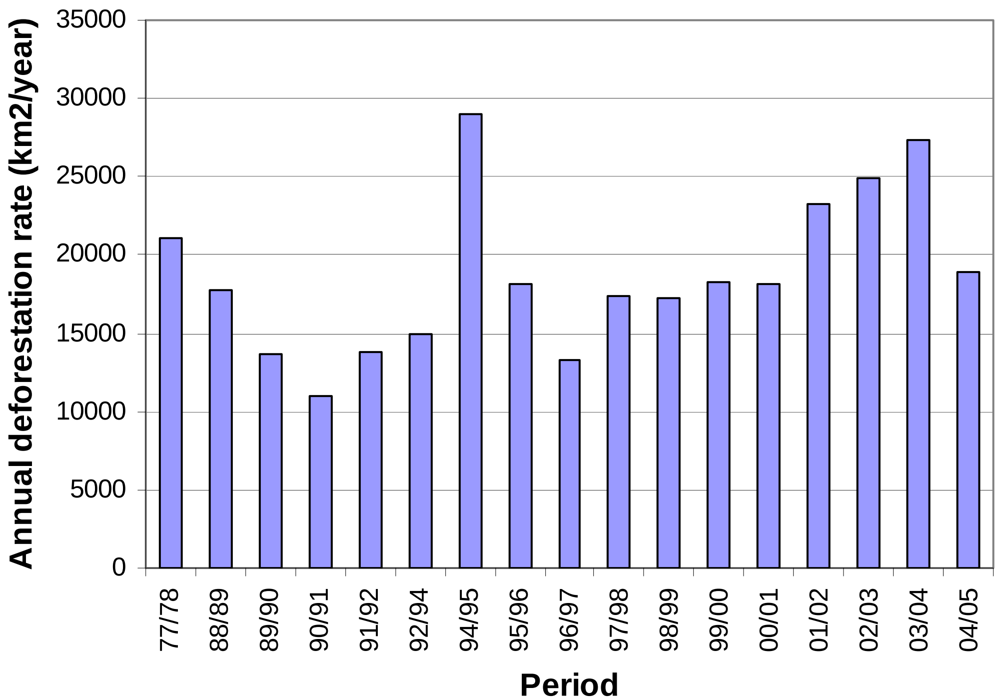
1. Introduction

Despite a significant increase in environmental consciousness in developing countries, tropical deforestation continues at a worrying pace. According to estimates based on satellite photos, deforestation rates in the Brazilian Legal Amazonia fluctuate around 20,000 km^2/year depending on economic conditions (see Figure 1). By 2005 almost 1 million km^2, or close to 20% of Legal Amazonia, had been deforested.

If deforestation continues at the rate of almost 200.000 km^2 every decade, the entire Legal Amazonia would be gone in about 200 years.

Figure 1: Annual deforestation in Legal Amazonia, Brazil.



Source: Official National Institute of Space Research (INPE) figures.

While part of the deforested areas has turned into highly productive agricultural land, a lot has been wasted with very little social benefit. It is in everybody's interest to assure that wasteful deforestation is minimized and that future deforestation is limited to areas where it brings substantial social benefits.

It is now widely agreed that a lot of wasteful deforestation in the past has been induced by special government incentives, such as land concessions based on deforested area, highly subsidized credit, and tax breaks. These perverse policies brought large private gains irrespective of land productivity, which implied socially wasteful deforestation (e.g. Binswanger 1994).

Most of these incentives have been long dropped, both because they were expensive for the government, and because the occupation of the Amazon has gained so much momentum, that artificial incentives are no longer necessary.

One highly controversial policy remains, though, and that is *road building*. Many authors are very critical of the construction of roads through the Amazon, as roads invariably attract farmers who deforest along the road. The alarming article in *Science* by Laurance *et al* (2001), for example, predicts that 28-42% of Legal Amazonia would be deforested by 2020, if the road building projects outlined in the plan *Avança Brasil* were implemented. The same year, an article by Nepstad *et al* (2001) concluded that as much as 462,000 km^2 of forest could be damaged as a result of *Avança Brasil* road building.

Other authors suggest that not all kinds of road building are necessarily bad. If existing unpaved roads are paved, for example, this may encourage farmers to settle down close to the road and intensify their agricultural activities on a relatively small plot, instead of deforesting and practicing extensive agriculture further into the forest. Thus, while roads may cause an increase in deforestation close to the road, they may cause a decrease in deforestation farther away from the road (e.g Andersen *et al*, 2002).

Whether this substitution effect actually occurs, and to what extent, is an empirical question which we so far have not been very good at analyzing. While we now have excellent data due to the constant satellite surveillance of the Amazon, the econometric methods applied so far have been inadequate. The purpose of this paper is to explain why the usually applied methods give misleading results, and point out some alternatives.

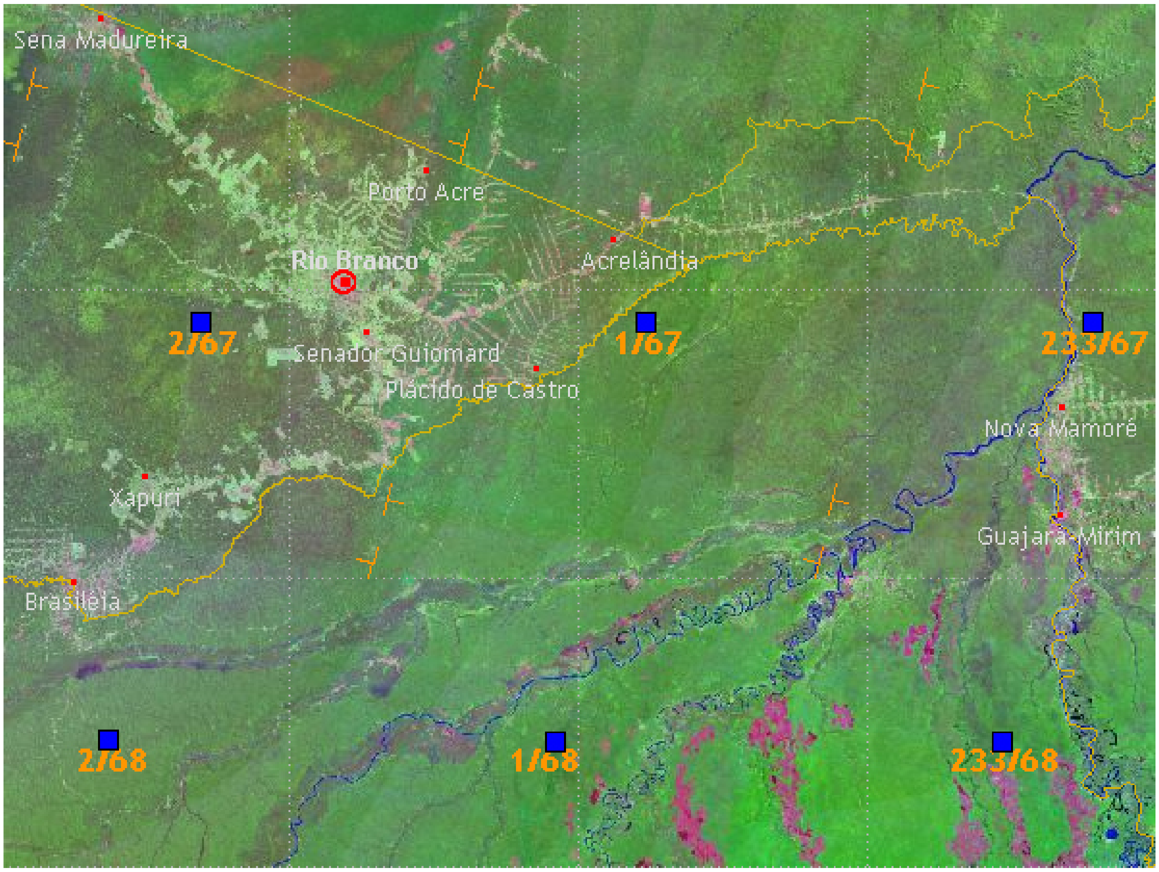
The remainder of the paper is organized as follows. Section 2 discusses the widely used method based on the GIS analysis of satellite pictures, and explains why this method is not suitable for the analysis of the net effect of roads on deforestation. Section 3 discusses another widely used method based on municipality level regressions, which also has serious limitations. Some methods of alleviating the problems are discussed, but the problems cannot be entirely corrected in this framework. Section 4 discusses how an ideal model could be constructed, but it also presents an alternative approach which is much less demanding and more directly useful for policy makers as well. Section 5 concludes.

2. GIS analysis of roads and deforestation

The raw material used to analyze deforestation consists of satellite pictures of the forest. When looking at those pictures, it is quite evident that deforestation is concentrated around major roads as well as secondary roads constructed perpendicularly to the main roads, frequently creating the easily recognizable fish-bone pattern of deforestation (see Figure 2).

People who have analyzed these pictures thoroughly have shown that almost all deforestation so far has taken place within 50 kilometers of a main road. Considering this, it is possible to calculate the percentage of vegetation that has been cleared within a 100 kilometer wide buffer zone around all main roads that are at least, say, 20 years old. Let us call this percentage X.

Figure 2: Processed satellite photo of the area around Rio Branco, Acre.



Source: INPE.

It would then seem logical to expect that if you construct 1 kilometer of new road, this would cause X% x 1 km x 100 km = X square kilometers of additional deforestation within 20 years.

This kind of reasoning can of course be made more sophisticated and flexible by including additional variables, such as soil quality, forest density, rainfall, distance to important markets, etc. For example, X might be smaller in areas with poor soil located far away from any markets.

Problems with the static spatial analysis

While simple and intuitive, this kind of GIS analysis has one major problem: It does not take into account spatial correlation between deforestation in different pixels.

Spatial correlation can be either positive or negative. It is probably positive for plots close together, as the clearing of one plot makes it much easer to clear an adjacent plot, both because of easier access and because fragmented forest burns more easily.

But correlation may be negative for plots farther between. This would for example be the case if labor is a scarce factor. If a person spends all his time clearing and cultivating one plot, he cannot at the same time clear another plot. This means that if deforestation goes up in one place, it would have to go down in another, if the number of people dedicated to agriculture is constant.

In reality the rural population in Legal Amazonia is growing over time (by 1.7 percent per year between 1970 and 1995 according to census information), but several farm-level studies suggest that labor is a very scarce factor in the Amazon (e.g. Ozorio de Almeida and Campari, 1996; Campari, 2005). This means that there is likely a negative spatial correlation, but it is difficult to say how strong it is.

In order to test the impact of a road on overall deforestation, it would be very important to take into account this possible negative correlation. The following simple example explains why.

Imagine that a previously unpaved and seasonally impassable road through the eastern part of the Amazon gets paved, and it suddenly becomes much easier and cheaper to get agricultural products to the market any time of the year. Land along the road would become more valuable, which means that farmers are likely to intensify their use of the land. Farmers would concentrate their available capital and labor investments in a smaller area and sell off the rest to reap a capital gain. With this capital gain they could invest in perennial crops which yield a much higher output value per hectare, but which require more initial investment, more labor inputs, better market access and more stability than annual crops (Campari, 2005). If the buyer of the sold-off fractional plot is a typical Amazonian colonist, who prefers a small plot close to a road and desirable public services instead of a larger plot further into the forest, then the paving of the road has indeed caused more deforestation close to the road, but it has prevented even more deforestation farther away from the road. The net impact of the road would thus be less deforestation.

The simple GIS model cannot capture this effect. Indeed, the stronger the effect is, the more it will seem as if roads are causing deforestation, because the roads attract farmers like flypaper attracts flies. The spatial model captures all the additional deforestation along the road well, but it does not and cannot capture the avoided deforestation further into the forest. The model thus cannot say anything about the net amount of deforestation caused by the road.

The negative correlation also holds at an even larger scale. If Brazil wasn't clearing an enormous amount of *cerrado* (scrub forest) to grow soy beans, then some other countries would have to clear their natural areas, because world wide demand for soy beans is increasing tremendously. If Bolivia, for example, were to supply the soy beans instead of Brazil, a much larger area would have to be deforested, as Bolivian soy bean farming is not nearly as efficient as it is in Brazil (Andersen, 2006).

3. Municipal level regressions

Another widespread technique used to analyze deforestation in the Amazon is municipal level regressions with some measure of deforestation as the dependent variable and policy variables, including roads, among the explanatory variables.

Since municipality level regressions use much larger spatial units than GIS analysis, the problem is not as severe as in the GIS analysis. This is because at least part of the avoided deforestation will be in the same municipality, but farther away from the road, so some of the avoided deforestation is indeed included in the municipal level data.

Some municipal level regression analyses do attempt to include spatial correlation explicitly, but due to the coarseness of the spatial information, it is necessarily in a rather crude manner. Andersen *et al* (2002), for example, include neighbor variables which measure the average of key variables in neighboring municipalities. Among many other things, they find that high land prices in neighboring municipalities discourage new clearing, all other things being equal. This may be an indication of the intensification effect discussed above. When farmers have a choice, they prefer a smaller plot with good access to markets and basic services, rather than a large plot in the middle of nowhere.

Problems with the municipal level regression analysis

The main problem with municipal level regression analyses is that they are very fragile. Deforestation processes have changed dramatically over the last few decades, and a regression made on data from the 1970s is likely to yield completely different results from one made on data from the 1990s. These differences are very likely real, which implies that data from different time periods cannot be pooled to create one large sample. Regressions have to be made individually for each time period, which means that the number of observations is limited by the number of municipalities (257 to 628 in Legal Amazonia, depending on the time periods included).

Since there are hundreds of possible explanatory variables available at the municipal level for Legal Amazonia, and since the dependent variable itself can be expressed in many different ways (levels, logs, shares, changes, changes in shares, based on either satellite information or on agricultural census information), it is possible to get virtually any result you might be looking for, if you try hard enough. This means that the reader should be highly skeptical when presented with one particular regression result. It may easily be the result of conscious or unconscious data mining.

One possible solution to this problem is *thick modeling* (see Granger & Jeon, 2004). This idea suggests that applied econometricians should not just present the one regression model that they like best, but rather a whole set of alternative models which hopefully encompass “the truth”.

An application of this idea is found in Andersen *et al* (2002). The authors applied the usual Hendry model reduction procedure in which a general model with many explaining variables is initially estimated and variables found not to be statistically significant are sequentially deleted until a final, parsimonious model is obtained. However, the authors applied this procedure one hundred times using a random elimination process, resulting in 100 different final models for each time period. They then counted how many times each of the 60 possible explaining variables entered the final model, and, in addition, they registered the lowest and highest coefficient estimate for each variable in order to judge the stability of the coefficient.

The results illustrate very well the main problem of municipality level regressions. Although almost all of the potential variables ended up significant in at least one of the 200 models estimated, very few ended up significant in all of the 200 final models. This demonstrates how fragile these regressions typically are and how much room there is for researchers to “design” their final model.

The results also clearly show how the driving forces of clearing are changing over time: Many variables entered all the final models for one of the time periods, but not a single final model for the other time period.

The impact of roads in these regressions appear to change substantially over time. For the period 1980-85 the only two road variables that turned out significant were the logarithm of unpaved roads two periods earlier (1975) and the interaction of unpaved roads and cleared land two periods earlier. Both of them entered in all 100 final models. The negative coefficient on the first combined with the positive coefficient on the second, suggests that unpaved roads caused most forest damage in already highly cleared areas, and less in virgin areas. Paved roads were not found to have any systematic effect in this early period.

Between 1985 and 1995 the road impacts were quite different from the earlier period. Only two road variables entered in all the 100 final models: The logarithm of paved roads three periods earlier (old paved roads) and the interaction between old paved roads and cleared land. The coefficient of the first is positive and the second negative, indicating that paved roads do most forest damage in virgin areas, but little in highly cleared areas. Unpaved roads three periods earlier were also found to have a positive effect on clearing, at least in 97 of the models. This suggests that paving existing dirt roads in already highly cleared areas would do little, if any, damage to the forest, but that both paved and non-paved roads in virgin areas might do a lot of damage.

Another problem with many municipal level regressions is that they do not capture very well the interaction between logging and agricultural expansion. Logging in the Amazon is usually selective, removing a few of the most valuable species and leaving the rest (sometimes heavily damaged). Logging is rarely so intensive that logged areas can be called deforested, but logging activities may still contribute to deforestation indirectly. There are two important mechanisms at work. First, logging companies often construct dirt roads in pristine areas in order to get access to high value tree species. These roads then attract settlers who practice extensive agriculture and thus cause deforestation. Second, in more established areas, farmers often sell the rights to log over their lands which makes it easier for them to clear their land for agriculture later, and it also gives them some capital to work with.

Given that both GIS analyses and municipality level regression analyses have severe limitations, the following section proceeds to outline some alternative approaches.

4. Alternative approaches

Deforestation (or conversion of other types of natural areas) is simultaneously a spatial, a dynamic, and an economic process. Few researchers are able to handle the complexity that this implies. The GIS people are very good at handling the spatial dimension, but they pay little attention to dynamics and even less to the economic constraints behind the process. The typical municipality level analysis does not have small enough grid pattern to capture space well – or enough time periods to capture the subtle and changing dynamics. CGE models include both economic processes and dynamics explicitly, but usually ignore the spatial dimension. In addition, outcomes depend crucially on the specification and calibration of the model, and will often appear to the readers as a "black box", which does not inspire confidence.

It does not get any easier when you realize that limiting deforestation is not the only objective you have to deal with. The impact on the living standards of the local people is usually an additional objective that even environmentalists now a required to take into consideration.

This means that we have a highly complex dynamic, spatial system with many economic constraints and interactions, and two objective functions. If we ignore any part of this, our analysis may be seriously flawed.

Given enough time, a well-funded team of experts in CGE modeling, GIS analysis and deforestation might be able to develop a model that includes all these dimensions satisfactorily using available data. Whether the results of the model will be trusted, depends a lot on the composition of the research team. If it is dominated by environmentalists and funded by conservation institutions, people worried about local development may be worried that the analysis is biased towards conservation, and vice versa.

An attractive alternative, which is less demanding in terms of modeling and estimation, and which requires less cooperation and trust between environmentalists and developmentalists, is the following: Let environmentalists develop a map of conservation priorities (on a scale of 1 to 10, say) and let developmentalists create a map of development priorities, and then overlay the two maps to create a mosaic of land uses for development and conservation. There will probably be some areas of conflict between the two objectives, but in land abundant countries (all Amazonian countries) it should be possible to accommodate both development and conservation interests in a rational way.

The map of conservation priorities could be constructed based on sub-maps of species diversity, endemism, carbon sequestration capacity, erosion risk, water shed protection services, and other variables judged important by the conservation community. The map of development priorities is likely to take into account soil quality, existing infrastructure, current and expected future population concentrations, and the existence of other natural resources, such as oil and minerals.

The maps should ideally be made at the global level, but the results would be useless without the free movement of people across national borders. It is therefore more realistic to develop independent maps for each country. Each country would then obtain a map that indicates areas that should be conserved in its natural state, areas where development can be encouraged without too much environmental damage, and areas of conflict where care has to be taken as to which kind of development is encouraged.

Such maps should obviously not be used to confiscate properties and evict people who happen to live in a conservation priority area. Instead they should be used to plan the location of future public infrastructure projects so as to minimize environmental damage and maximize human development[1].

[1] An example of the application of this approach in Bolivia can be found in Andersen, Ledezma & Vargas (2006).

Advantages with the priority approach

The big advantage with the priority approach is that the two underlying maps can be done independently. The specialists in conservation sciences can concentrate on counting birds and beetles, estimating biodiversity, measuring carbon density and assessing environmental services. This is by no means an easy task, but at least they do not also have to worry about land prices, globalization and poverty. They do have to acknowledge, however, that there are geographical variations in conservation priorities. The approach won't work if they assign top priority to all remaining natural areas in the world.

The conservationists usually do not have to take into account the time dimension as natural areas change little even over several centuries, if left alone. In some specific cases, however, it might be useful to take into account the possible effects of global warming.

The specialists in development will clearly have to take into account population growth and the corresponding growth in demand for agricultural products. Their main tasks will be to make spatially explicit population projections and estimate aggregate demand for agricultural land. They have to analyze soil quality and other agricultural conditions as well as market conditions, in order to assess where agricultural activities ideally should be located. This is not an easy task, either, but at least they don't have to worry that a speckled, three-horned beetle might get squashed in the process.

Once the environmentalists and the developmentalists have made their priorities spatially explicit, an independent third party can overlay the maps and create a mosaic of "optimal" land uses that gives sufficient room for expected agricultural expansion and at the same time protects the areas that are most important for conservation purposes. This third party will undoubtedly encounter certain areas that both conservationists and developmentalists claim to be top priority. These are conflict areas, where specific interventions will be necessary in order to secure that the pressing development forces do not cause too much environmental damage. Such interventions could for example be to encourage eco-tourism, fish farming, high value perennial crops, or other relatively benign activities in stead of extensive agriculture. Further micro-level zoning can also be made within the areas of conflict, in order to reduce the environmental impact of the inevitable human presence in the area.

The other big advantage of this approach is that the results are immediately useful for policy makers, whereas typical municipal regression results may be difficult to decipher. It is not always politically feasible to implement the "optimal" land use mosaic, but at least policy makers receive important guidance, and thus have concrete arguments to back up their proposals and decisions.

5. Conclusions

Road building in the Amazon remains a highly controversial subject and Brazil's determination to develop the region is met with strong opposition from environmentalists, as is the less organized encroachment observed in the other Amazonian countries.

While data is now abundantly available, the analytical methods typically used to analyze the impact of roads on natural vegetation cover are methodologically weak and not very helpful to guide public policy. This paper has discussed the respective weaknesses of typical GIS analysis and typical municipality level regression analysis, and it has shown what would be needed to construct an ideal model of deforestation processes.

It has also presented an alternative approach that is much less demanding in terms of modeling and estimation, and which requires less cooperation and trust between environmentalists and developmentalists. The alternative approach consists of developing maps of conservation priorities and maps of development priorities and superimposing the two to create a land use mosaic which takes into account both conservation and development priorities at the same time, thus acknowledging that both conservation and local development are important objectives.

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