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DISCUSSION PAPER

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DEFORESTATION, DEVELOPMENT, AND GOVERNMENT POLICY IN THE BRAZILIAN AMAZON: AN ECONOMETRIC ANALYSIS[1]

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DISCUSSION PAPER

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SUMÁRIO

ABSTRACT

This paper develops a model of deforestation and economic development in the Amazon. It is based on the determinants of demand for agricultural land, i.e. on the interactions between population dynamics, urbanization and the growth of local markets, land prices, and government policies. The model is estimated using a panel data set covering 316 municipalities in the Brazilian Amazon during the period 1970/85.

The model is used to evaluate the effects of different policy instruments. The trade-off between economic growth and deforestation is shown to be quite good for subsidized credit but very bad for new road building.

1 - INTRODUCTION

The Amazon basin is by far the largest piece of contiguous tropical rainforest left in the World. Venezuela, Colombia, Ecuador, Peru and Bolivia claim part of it, but Brazil has the largest share. Brazil's Legal Amazonia comprises about 5 million square kilometers — more than half the national territory of the fifth largest nation in the World. Apart from the rubber boom around the turn of the century, this huge area has contributed very little to the formal Brazilian economy, however. The area was inhabited by various Indian tribes, but the Indians were not considered "real" Brazilians, they didn't contribute to the gross domestic product, and the government couldn't count on them to defend the national borders.

Early in the 1960s, the Brazilian government decided to initiate a huge development program that should integrate the Amazon region into the rest of the economy. Since then, around 60,000 kilometers of roads were constructed in the region, several hundred thousand people were helped to settle along these roads, and millions of others followed without official help. Billions of dollars of credit were extended at negative real rates of interest, and tax breaks and land concessions were offered to the entrepreneurs that were willing to start up agricultural establishments in the region. Billions of dollars were raised from international sources and put into the construction of hydroelectric facilities, ports, and railways.

The result of all this has been dramatic increases in both output, population and deforestation. The total population of Legal Amazonia increased from 7.3 million in 1970 to 13.2 million in 1985, real GDP increased from $2.2 billion to $13.5 billion during the same period, and 33 million hectares of more or less dense forest were converted into agricultural land. The questions are: Is that good or bad? Could it have been better? What can Brazil and the other Amazonian countries learn from this huge development experiment?

During the last decade, The Institute for Applied Economics Research (IPEA) in Rio de Janeiro has put together an Amazon panel data base that can be used to econometrically analyze the economic and environmental effects of various government policies. The data set currently covers 316 consistently defined regions during the periods 1970, 1975, 1980, and 1985 and measures a very large number of economic, ecological, and demographic variables.

The purpose of this paper is to use this Amazon data set to learn as much as possible from the Brazilian experiment about the trade-offs between economic growth and environmental degradation. These trade-offs are not the same for all policy instruments, and the current paper tries to identify which policies are good and which are bad in terms of the trade-off between economic growth and deforestation.

The paper is organised as follows. Section 2 describes how the model is set up and Section 3 describes the data. Section 4 explains the estimation procedure and reports the results. Section 5 uses the estimated model to analyze the trade-offs between economic growth and deforestation for different policy instruments. Section 6 concludes.

2 - THE MODEL

The conceptual model underlying the econometric model estimated in this paper is a two-sector model along the lines of Deacon (1995) and Reis (1995 and 1996). It consists of a rural sector, which uses cleared land and rural workers as its main inputs, and an urban sector which uses urban workers and agricultural output as its main inputs.

We assume that the urban sector does not cause deforestation directly because urban activities (government activities, transportation, services, mining, agroprocessing, etc.) requires only a negligible amount of land. However, there is an indirect effect on deforestation through the urban sector's demand for agricultural products, in the form of both raw materials and food for the urban population.

The model consists of six equations. The main equation predicts the demand for newly cleared land in region *i* at time *t* on the basis of past characteristics of region *i* and its closest neighbors. The remaining five equations explain the interaction between rural and urban populations, rural and urban output, and land prices. Each equation is discussed below.

2.1 - The Rural Sector's Demand for Agricultural Land

Before 1960 there was little economic incentive to create agricultural establishments in the Amazon. Most of the region was virtually inaccessible, there were no local markets for neither inputs nor outputs, and there was a total lack of social infrastructure. This changed, however, when the Brazilian government through ambitious road building and settlement programs decided to open up the region and "bring men without land to the land without people". During the subsequent decades several million people suddenly found it economically sensible to settle down in the Amazon.[1]

The settlement was not evenly distributed over the region, though. The eastern and southern regions received far more migrants than the western and northern regions, and clearing is visibly concentrated along the major highways, their feeder roads, and the big rivers, thus giving evidence to the critical importance of accessibility. In our empirical model, accessibility of a region is proxied by **a**) distance to the federal capital, Brasília; **b**) extension of the road network; **c**) length of main rivers in region; and **d**) the level of clearing in neighboring municipalities.

[1] The population in Legal Amazonia increased from 7.3 million in 1970 to 16.6 million in 1991 [IPEA/Desmat (1996)]. About 40% of the increase was caused by migration into the area, so the number of immigrants in the period is 3-4 million.

As population densities increase in early settled areas, land becomes more scarce and land prices are pushed up. The supply of land is expected to be very elastic for low levels of clearing, so that an increase in demand has only a small effect on the price of land. However, as clearing approaches 100% of total municipality area, the supply is becoming very inelastic, and an increase in demand will have a dramatic effect on land prices. To capture the effect of relative land availability in our empirical model, we use the following four variables: **a**) rural population density; **b**) land prices; **c**) lagged level of clearing; and **d**) lagged share of cleared land.

Besides the fundamental requirements of accessibility and availability of land, demand is affected by the economic prospects in a region. Because of the long distances and the high costs of transporting agricultural goods, farmers in the Amazon depend heavily on the availability of local markets. Local market conditions in the Amazon are improving. As evidence can be mentioned that the number of urban residents per rural resident in Legal Amazonia has increased steadily from 0.6 in 1970 to 1.2 in 1991. Furthermore, urban output grew at an impressive rate of 14% per year in the period 1970/85. The variables used to capture the local market conditions are the following: **a**) urban residents per rural resident; **b**) growth of urban output in the region; **c**) road length in region, and **d**) distance to the state capital.

Other factors directly related to the profitability of agricultural settlement are land prices and fiscal subsidies and incentives. Agriculture in the Amazon has been an attractive tax shelter because of the virtual exemption from income taxation [Binswanger (1989, p.20)]. This exemption naturally adds to demand for agricultural land, but it does so evenly over the whole region, and we are unable to measure the effect in our empirical model. However, some regions were officially designated as growth poles, and enjoyed extra favorable conditions.[2] We include a dummy for these regions to capture fiscal incentives. Credit incentives is proxied by the amount of Sudam credit[3] obtained in each region.

For a potential migrant the level of rural income per rural capita in the previous period is a good indicator for his expected future income. Relatively high expected income in a region will add to demand for converted land in the region so this variable is also included in our model.

[2] The Program of Agricultural, Livestock and Mining Poles in Amazonia (Poloamazonia) was designed to create a more favorable investment climate in Amazonia. The program concentrated of fifteen “growth poles” where infrastructure and investment were to be concentrated and entrepreneurial activities subsidized. One example of a growth poles in the Free-Zone of Manaus. For a full list and descriptions of the growth poles in Legal Amazonia, see Andersen **et alii** (1996).

[3] Credit granted by the Superintendency for Amazonian Development (Sudam) was heavily subsidized. Given the rates of inflation, the government was in effect offering enourmous amounts of money at negative real rates of interest [Hecht and Cockburn (1989)].

There is a good reason to believe that there are qualitative differences between newly cleared land and old cleared land in the Amazon. Because of the burning method typically applied, newly cleared land is highly productive and relatively pest-free compared to old agricultural land which requires very different farming methods based on different types of crops and the addition of fertilizers and pesticides.

The considerations above lead us to assume the following function for the demand for newly cleared land in region *i* during the period from time *t* - 1 to time *t*:

$\Delta CLR_{i,t'}$ = *f* (distance to federal capital$_i$, road length$_{i,t-1}$, river length$_i$, level of clearing in neighboring regions$_{i,t-1}$ rural population density$_{i,t-1}$, level of clearing$_{i,t-1}$, share of land cleared$_{i,t-1}$, change of urban output$_{i,t}$, distance to state capital$_i$, urban residents per rural resident$_{i,t-1}$, growth pole dummy$_i$, Sudam credit$_{i,t-1}$, land prices$_{i,t-1}$, rural income per rural capita$_{i,t-1}$, municipality area$_i$).

For estimation purposes, we assume that the function is log-linear. In the data set there are five calender years between each observation, which means that changes refer to the change in the natural logarithm of a stock variable during the five years period between time *t*-1 and time *t*.

2.2 - Population Dynamics

Total population in Legal Amazonia grew at an average annual rate of 4.0% during the period 1970/91. The urban part of the population expanded much faster than the rural, though, leading to a dramatic change in the composition of the population. Since rural and urban inhabitants have very different effects on deforestation, it is important to model these two groups separately. Urban inhabitants typically work in the service sector and are therefore assumed to have no direct impact on deforestation. There will, nevertheless, be an indirect effect through the demand for agricultural goods.

2.2.1 - Rural population

The size of the rural population is determined partly by the size of the inherent population and partly by new immigration. The number of immigrants depends both on push and pull factors. Push factors are population pressure in neighboring areas, while the main full factor is economic possibilities in the region. The economic attractiveness of a region depends on its accessibility, productivity, market conditions, and fiscal subsidies.

The increase in the rural population in region *i* from time *t* to time *t*-1 can then be predicted by estimating the following function:

$\Delta POP\text{–}RURAL_{i,t}$ = f (rural poupulation$_{i,t\text{-}1}$, rural population growth in neighboring regions$_{i,t}$, distance to federal capital$_i$, road length$_{i,t\text{-}1}$, river length$_i$, rural income per capita$_{i,t\text{-}1}$, level of urban output$_{i,t\text{-}1}$, growth of urban output$_{i,t}$, urban income per capita$_{i,t\text{-}1}$, distance to state capital$_i$, growth pole dummy$_i$, Sudam credit$_{i,t\text{-}1}$, municipality area$_i$).

2.2.2 - Urban population

The size of the urban population is also partly determined by the inherent urban population and partly by immigration. A relatively high urban income per urban capita is expected to attract people to the city, both when compared to rural incomes and when compared to urban incomes in other regions.

Other pull factors are fiscal incentives and a good urban infrastructure. As an indicator of urban infrastracture we use a composite variable computed as the sum of the share of households which have running water, the share of households which have electricity, and the share of households which have sanitary installations.

Thus, we expect to be able to estimate the size of the urban population in region i at time t from a function of the following form:

$\Delta POP\text{–}URBAN_{i,t}$ = f (urban population$_{i,t\text{-}1}$, rural population$_{i,t\text{-}1}$, urban income per capita$_{i,t\text{-}1}$, rural income per capita$_{i,t\text{-}1}$, road length$_{i,t\text{-}1}$, neighbors' road length$_{i,t}$, growth pole dummy$_i$, Sudam credit$_{i,t\text{-}1}$, urban infrastructure$_{i,t\text{-}1}$, municipality area$_i$).

2.3 - Rural and Urban Output

Agriculture's to share of total regional output has fallen steadily from 30% in 1970 to only 17% in 1985. This trend alone has a dampening effect on deforestation since we have assumed that only agropastoral activities have any significant effect on deforestation.

The growth rate of urban output is expected to depend on location and accessibility, fiscal subsidies, and the quality of the urban infrastructure. The square or urban population size is included to allow for increasing or decreasing returns to scale.

$\Delta GDP\text{–}URBAN_{i,t}$ = f (road length$_{i,t\text{-}1}$, river length$_i$, growth pole dummy$_i$, Sudam credit$_{i,t\text{-}1}$, urban infrastructure$_{i,t\text{-}1}$, urban population$_{i,t\text{-}1}$, urban population$^2_{i,t\text{-}1}$, urban income per capita$_{i,t\text{-}1}$, change in cattle herd$_{i,t}$, municipality area$_i$).

Similarly, the growth rate of rural output is expected to depend on accessibility and fiscal incentives plus vegetation and soil conditions. The quality of soil in the municipality is proxied by the estimated area of high yield soils.

The value of agricultural production in developing countries is in general very dependent of world prices for agricultural products. The development of these prices is largely external to the Amazonian rural sector, and we therefore include a trend term to allow for such external effects which are common to the whole region.

The equation for rural output then becomes:

$\Delta GDP{-}URBAN_{i,t}$ = f (road length$_{i,t\text{-}1}$, river length$_i$, neighbors' road length$_{i,t\text{-}1}$, Sudan credit$_{i,t\text{-}1}$, growth pole dummy$_i$, municipality area$_i$, natural forest area$_i$, high quality soil area$_i$, level of clearing$_{i,t\text{-}1}$, rural population$_{i,t\text{-}1}$, rural income per rural person$_{i,t\text{-}1}$, trend).

2.4 - Land Prices

The difference in land prices between the South and the North have been a powerful magnet driving migrants to the Amazon. In 1980, for example, a farmer could, on average, buy 14 hectares of land in the North for every hectare he sold in the South [Andersen **et alii** (1996, Table 8.1)].

There are also big variations in land prices within the Amazon region and these differences are expected to depend on soil quality, market conditions, and the distribution of government incentives. As proxies for market conditions we include: **a**) road length; **b**) change in road length; **c**) river length; **d**) distance to federal capital; **e**) distance to state capital; and **f**) urban income per urban capita. Soil conditions may be captured by: **g**) area with high yield soil; **h**) agricultural productivity; and **i**) growth of agricultural output. The third factor that may influence land prices in government subsidies, since particularly attractive tax and credit conditions would tend to be capitalized into land prices. To capture this effect we include: **j**) the growth pole dummy and; **l**) the amount of Sudam credit obtained.

As cleared land approaches 100% of a given area, little land is available for new clearing and land will develop scarcity value. To capture this effect, we include: **m**) the lagged share of cleared land.

To capture possible changes in relative land prices compared to other places in Brazil, we also include time dummies in our empirical model of land prices.

Thus, the function determining the growth of land prices in region i between time t-1 and time t becomes:

$\Delta LANDPRICE_{i,t}$ = f (length of roads$_{i,t\text{-}1}$, change in length of roads$_{i,t}$, river length$_i$, length of planned roads$_{i,t}$, distance to federal capital$_i$, distance to state capital$_i$, urban income per capita$_{i,t\text{-}1}$, area with high yeld soil$_i$, growth of agricultural output$_{i,t}$, cleared share$_{i,t\text{-}1}$, growth pole dummy$_i$, Sudam credit$_{i,t\text{-}1}$, T75-dummy, T80-dummy, land price$_{i,t\text{-}1}$, municipality area$_i$).

3 - THE DATA

All data used for this project is extracted from the panel data set[4] developed at IPEA in Rio de Janeiro. Data on economic, demographic, agricultural, and ecological variables have been collected for the years 1970, 1975, 1980, and 1985 for 316 consistently defined geographic areas in Legal Amazonia. For a more comprehensive description of the data set and the variables used for this project, see the Amazon report by Andersen **et alii** (1996).

3.1 - Cleared Land

Cleared area is estimated from comprehensive land surveys conducted by IBGE every five years.[5] Private land used for annual crops, perennial crops, planted forest, natural pasture, planted pasture, and fallow land is considered cleared, while all public land plus private land kept as natural forest is considered virgin.

Legal Amazonia comprises an area of approximately 5 million square kilometers. By 1985 about 23% of this area had been privatized, while only about 14% had been cleared.[6]

3.2 - Other Variables

Rural and urban populations are derived from the Brazilian Demographic Census for 1970, 1980, and 1991. The population values for 1975 and 1985 are calculated by geometric interpolation.

Data on urban and rural output and on land prices are obtained from the Agricultural Census, the Industrial Census, the Commercial Census, and the Service sector Census for 1970, 1975, 1980, and 1985.

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[4] Desmat (Dados Ecológicos e Sociais para Municípios da Amazônia Tropical), Feb. 1996.

[5] The data from 1991 is unfortunately very incomplete. Because of recession, the Brazilian Institute of Geography and Statistics were not allocated sufficient funds to complete the scheduled censuses. The latest period from which all the agricultural data is available is therefore 1985.

[6] The 14% clearing mentioned here is higher thant the usually quoted deforestation estimates derived from satellite imagery (about 7-8% in 1988 according to Fearnside 1996) because clearing includes land conversion not only in densely forested areas but also in the less densely forested cerrado and savanna areas of Legal Amazonia.

Infrastructure conditions are estimated from 1976 and 1986 road maps from the Department of Roads in the Ministry of Transportation. Several subcategories are available: state roads and federal roads, paved, non-paved and planned. Complementary information on accessibility is provided by the municipal network of rivers (with more than 2.1 meters of depth at least 90% of the time) estimated from maps available in the 1985 Statistical Yearbook.

The distances between the administrative center of each municipality and the state and federal capitals are used as proxies for access conditions to local and national markets.

Detailed data on soil quality was obtained from Embrapa maps. This paper uses the land area judged to have high yield soil as a proxy for soil quality in the municipality.

Data on credit from different sources (Banco do Brasil, Sudam, and other government entities) is available, but for 1985 only. To construct Sudam credit variables for earlier periods, we use information on the number of Sudam projects in each municipality in each period[7] and data on the aggregate level of Sudam credit as reported in Schneider (1995, Table 1.3).[8] In order to capture non-credit incentives, such as tax holidays, import and export duty exemptions, and various subsidies, a dummy was created for all municipalities located partly or wholly in a designated Poloamazonia growth pole.

The Demographic Censuses from 1970 and 1980 provide data on the urban infrastructure conditions. A proxy for the quality of urban infrastructure was created by adding together the share of households that have electricity, the share of households that have running water, and the share of households that have sanitary installations.

3.3 - Neighbor Variables

Distances between all municipality centers were calculated from the coordinates of the administrative center of each municipality. These distances are used to calculated 'neighbor variables', which are variables describing conditions in neighboring municipalities. The variable measuring the level of clearing in neighboring municipalities, for example, is constructed as a weighted average of the level of clearing in the closest five municipalities. The weights are inversely proportional to the distance between municipality centers and scaled to sum to

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[7] Constructed by Alexander Pfaff at MIT.

[8] Specifically, we first distribute credit across municipalities under the assumption that all projects in a given municipality receive the same annual amount of credit as in 1985 (in real prices). If the aggregated level of credit for the earlier years then doesn't sum to what Schneider (1995) reports, we multiply all numbers by a factor that makes them do so. This procedure secures that the aggregate level of credit is correct in each year, and that the calculated distribution of credit across municipalities corresponds to the actual distribution of Sudam projects.

one. When a neigbord variable is included as an explanatory variable, it corresponds to a spatially autoregressive model with five lags, SAR (5), where the coefficients are forced to decline as you get farther away from the municipality under consideration. This method of accounting for spatial correlation is inspired by Weinhold (1995).

The neighbor variables are used to explicitly model a pronounced spatial correlation in clearing and economic activity across the Amazon region. This spatial correlation arises because economic activity is not randomly distributed but rather follows a moving agricultural frontier. In front of the frontier there is little economic activity and thus little clearing. On the frontier, there is rapid clearing and a quickly emerging economy, while the area behind the frontier is characterized by a high level of clearing, a more mature economy, but less new clearing.

4 - ESTIMATION AND SPECIFICATION TESTING

The six equations were all assumed to be log linear. They were estimated[9] using a general-to-specific principle along with the set of specification tests described below. We started out by including all the theoretically relevant explaining variables, then deleted those that were statistically insignificant, one by one, until all remaining coefficients were statistically significant at the 1% level. The 1% level was chosen both because of the rather large sample size of almost a thousand observations and because experience had shown us that coefficients that were not significant at the 1% level were very sensitive to changes in the set of explanatory variables and to the removal of outliers.

Each equation was then subjected to the following series of specification tests, and depending on the results some adjustments may have been made:

Chow test for poolability over time — This test tests for the validity of pooling data from three different time periods. First we make a pooled regression and obtain the Restricted Residual Sum of Squares (*RRSS*). Then we make separated regressions for each time period and sum the Residual Sum of Squares (*RSS*) from each regression to obtain the total Unrestricted Residual Sum of Squares (*URSS*). Based on these sums of squares, we calculate the following *F*-statistic:

$$F_{timepool} = \frac{RRSS - URSS}{(T-1)K} - \frac{URSS}{T(N-K)}$$

[9] Both Gauss 386 and Eviews 1.1 were used in the estimations. Eviews were used for testing down, for standard test-statistics, and for systems estimation, while Gauss were used to create neighbor variables, to test for poolability and fixed effects, and for doing simulations.

which follows an $F((T - 1)K; T(N - K))$ distribution. Finally, we calculate the *P*-value, which is the probability of obtaining an *F*-statistic as large as the one we just calculated, given that the null hypothesis is true. Thus, low *P*-values are bad, given that we want our null hypothesis to hold. Fortunately the null was not rejected for any of the six equations at any reasonable level of significance. Table 3 to 8 report the specific *P*-values for each equation, both for this test and for the additional tests described below.

Chow test for excluding region specific fixed effects — In panel data models, it is customary to deal with the heterogeneity between regions by including region specific fixed effects in the form of a region specific intercept term. This is done under the assumption that all the coefficients of interest are identical across regions, but that there might be other unobserved, time invariant characteristics that differ among regions.

In this data set we have a lot of variables available which potentially could capture region specific fixed effects **explicitly**. In that case we would not only know that there are differences, but we would know **why** there are differences. These differences may be explained by soil quality, location, river access, distance to major cities, original vegetation, and many other things which we have variables to proxy for.

In this paper, we have a strong preference for explicitly modelling these effects, rather than just including a region-specific intercept in our model. Not only because it gives us more information, but because some of the coefficients of interest cannot be estimated in the fixed effect model because the variables are time-invariant.

To test whether it is reasonable to disregard possible fixed effects, we have developed the following Chow test: first we make a pooled regression without fixed effects and obtain the *RRSS* from this regression. Then we estimate a fixed effect model with **N** individual intercepts and obtain the *URSS* from that. Based on these two Sum of Squares, we calculate the following *F*-statistic:

$$F_{no\,fix} = \frac{RRSS - URSS}{(T-1)K} \div \frac{URSS}{TN - N - K}$$

which follows an $F((T - 1)K; TN - N - K)$ distribution. Finally we calculate the *P*-value for the null hypothesis of no fixed effect. In the cases where the null was strongly rejected we tried to include state-dummies to reduce the problem. Even though the null was still rejected for some equations, we can maintain the specification without fixed effects with the argument that the potential reduction in bias does not outweigh the increase in variance and the loss of parameters of interest.

Normality test — Normality was strongh rejected by the Jarque-Bera test for all equations. The rejections were generally due to excess kurtosis rather than skewness. This is a warning sign that there may be some highly influential outliers. Therefore we removed the worst outliers, and did indeed find that in some cases it changed a coefficient from significant at the 1% level to insignificant. Both the variable of that coefficient and the outliers were then removed, and all tests were performed again on the adjusted equation. Normality is still rejected for all equations, but not as strongly as before. See Tables 1-6 for the final *P*-values.

Test for spatial correlation — All our estimations are made under the assumption that the observations are independent both over time and across space. While we cannot make an autocorrelation test with only three time observations, it is possible to make an equivalent test for correlation in the spatial dimension.

In order to apply the principles of the standard autocorrelation tests we have to reduce the two-dimensional space in which the regions are located to a one dimensional space like the time dimension. This is done by lining up all the regions according to their location so that we start from one corner of the Amazon and then take the nearest municipality, and the next-nearest, etc. There is room for ambiguity here, of course, but fortunately we didn't have to actually do this ordering, because the municipalities were originally numbered according to location, so we just had to sort all data according to municipality number.

When that is done, we can use the large sample Breusch-Godfrey Serial Correlation LM test statistic[10] as a proxy for a test of spatial correlation. We make the test with five neighbors, which is also the limit we have chosen for the construction of spatial variables.

When the null of no spatial correlation were rejected, we tried to include additional spatial variables to reduce the correlation problem. This usually helped and the remaining spatial correlation problems are small.

Tests for heteroskedasticity — Heteroskedasticity in the error terms makes conventionally calculated standard error unreliable. With panel data sets as the current one, based on data from big and small, forested and deforested, untouched and economically developed regions, it is almost impossible to avoid heteroskedasticity in the error terms. Therefore we should bear in mind that the reported standard errors and *t*-values may be misleading. Typically the coefficients are not as significant as they look.

We report two different tests for heteroskedasticity. The first is the ARCH test proposed by Engle (1982) where we regress the squared residuals on the squared residuals of five neighbors. The second is White's heteroskedasticity test [White

[10] Reported by Eviews 1.1. See Johnston (1984, p.319-321) for details about the test.

(1980)] where we regress the squared errors on the original regressors plus the squares of the original regressors. The last test is the toughest, since the null hypothesis underlying the test assumes that the errors are both homoskedastic and independent of the regressors and that the linear specification of the model is correct. Failure of any one or more of these conditions could lead to a significant test statistic. And indeed it does for all our equations. The fact that the ARCH test do not reject the null nearly as strongly as the White's test (compare *P*-values in Tables 1-6), suggests two things: first, that we may be ignoring important non-linearities in our data, and second, that the coefficients of interest may not be stable across regions. These two problems deserve further scrutiny, but the present paper will have to live with them.

4.1 - Estimation Results

After having gone through a series of specification tests and model adjustments the model was deemed "as good as possible".[11] The results are reported in Tables 1 to 6.

The amount of newly cleared land is almost exclusively determined by the demand for new agricultural land, which in turn depends on the expected profitability of that land. The profitability depends on factors such as accessibility, availability, market conditions, and fiscal incentives.

Accessibility of land in a particular municipality was captured by its distance to the federal capital, road length in that municipality, and by the clearing situation in neighboring municipalities. Access is easier the higher the level of clearing in the neighboring municipalities. All three variables have the expected signs and are highly significant.

The coefficient of the lagged level of clearing is negative and highly significant. This is evidence of the saturation effect. As the level of clearing gets high, less forest is available for new clearing. The supply restrictions are further captured by

[11] It was considered to estimate the six equations as a system using the Seemingly Unrelated Regression (SUR) method to take advantage of any cross-equation correlation in the error terms. However, this would result in the loss of a substantial number of observations (224), since all equations would be estimated with the smallest common number of observations (826). It also meant that a handful of variables became insignificant and that further testing would become more difficult.
To judge which method was best, OLS or SURE, we made an in-sample test of each model in the following way. We made a multi-period forecast from 1970 to 1985 using the estimated parameters of each model along with actual values of all exogenous variables and the actual values of the endogenous variables in 1970. This resulted in a set of forecasts for the years 1975, 1980, and 1985, for each model. These forecasts were compared to the actual values, and a sum of squared errors were obtained for each endogenous variable over all regions over all three forecasting periods. A comparison of the two models showed that the OLS model outperformed the SURE model for all equations by having a lower sum of squared erros for all endogenous variables. Consequently, we chose the OLS results.

rural population density. The more densely populated the municipality, the less new clearing can take place.

Economic prospects in a region are captured by urban output growth which indicates favorable local market conditions and by the lagged level of agricultural output.

Table 1
Demand for newly cleared land

Dependent variable: ΔCLR_t		
Explaining variables:	Coefficient	*T*-value
Constant	2.879	6.9
Distance to federal capital	-0.237	-5.3
Road length$_{t-1}$	0.047	5.0
Neighbors' change in clearing$_t$	0.281	6.4
Rural population density$_{t-1}$	-0.002	-2.7
Level of clearing$_{t-1}$	-0.325	-15.9
Growth of urban output$_t$	0.095	2.8
Land prices$_{t-1}$	-0.097	-4.5
Cattle herd$_{t-1}$	0.149	10.6
Change in cattle herd$_t$	0.267	11.2
Change in agricultural output$_t$	0.164	4.4
Change in land prices$_t$	-0.280	-11.6
Dummy for Mato Grosso	0.168	2.7
Number of observations	831	
Adjusted R^2	0.486	
Specification tests		*P*-value
Normality test		0.0000
Spatial correlation test		0.1748
ARCH test		0.0373
White's test		0.0000
Test for poolability over time		0.9999
Test for fixed effects		0.0002

The negative coefficients on land prices indicate that clearing mostly takes place in frontier areas where land prices are still low. As the frontier becomes more developed and land prices increase, permanent agriculture becomes relatively more attractive compared to the slash-and-burn methods practiced in land abundant areas.

Finally there are highly significant and positive coefficients on the size of the cattle herd in the previous period and on the change in the cattled herd. This supports the widespread accusations of cattle farming as an important cause of land clearing.

The growth rate of the rural population is mainly determined by population pressure from neighboring municipalities, as shown by the highly significant coefficient to neighbors' change in rural population. Market conditions in the municipality are captured by four variables: **a**) urban income per urban capita; **b**) the growth rate of urban output; **c**) road length; and **d**) a city dummy indicating whether there is a major city located in the municipality.

Table 2
Rural population equation

Dependent variables: $\Delta POP\text{–}RURAL_t$		
Explaining variables:	Coeficient	*T*-value
Constant	-0.345	-7.0
Neighbors' change rural population$_t$	0.657	13.4
Road length$_{t\text{-}1}$	0.011	3.5
Growth of urban output$_t$	0.105	9.9
Urban income per urban capita$_{t\text{-}1}$	0.037	4.8
Change in cattle herd$_t$	0.026	3.3
City dummy	0.087	2.8
Dummy for Rondônia	0.390	4.1
Dummy for Pará	0.074	4.8
Dummy for Maranhão	0.065	4.9
Number of observations	831	
Adjusted R^2	0.410	
Specification tests		*P*-value
Normality test		0.0000
Spatial correlation test		0.9156
ARCH test		0.0075
White's test		0.0000
Test for poolability over time		1.0000
Test for fixed effects		0.9948

There is a significantly positive coefficient on the change in the cattle herd, indicating the use of rural labor to clear forest to establish new pastures.

The increase in the urban population is mainly determined by the pull effect of relatively high urban income per urban capita compared to rural income per rural capita. This shows from the highly significant positive coefficient on the first variable and the negative coefficient on the second. Accessibility is also important as indicated by positive coefficients on lagged road length and the increase in roads in neighboring municipalities. Finally, subsidized credit from Sudam appear to be a factor, even though this credit was specifically intended for agricultural establishments. The high significance of this coefficients supports the allegation that much of the highly subsidized credit granted to especially cattle ranches, were channeled to more profitable investments in the cities (where the ranch owners usually resided and conducted other business).

The highest agricultural growth rates are clearly experienced at the agricultural frontier, rather than in more developed areas. This shows on the negative coefficients on rural per capita incomes, on lagged level of agricultural output, and on neighbors' road length.

Table 3
Urban population equation

Dependent variable: $\Delta POP\text{–}URBAN_t$		
Explaining variables:	Coefficient	*T*-value
Constant	-0.152	-2.0
Urban population$_{t\text{-}1}$	-0.032	-6.9
Rural income per rural capita$_{t\text{-}1}$	-0.039	-3.9
Urban income per urban capita$_{t\text{-}1}$	0.080	9.4
Road length $_{t\text{-}1}$	0.023	6.5
Neighbors' change in road length$_{t\text{-}1}$	0.050	5.2
Sudam credit$_{t\text{-}1}$	0.006	5.2
Neighbors' change in urban pop$_{t\text{-}1}$	0.291	5.3
Municipality area	0.027	5.8
Dummy for Amapá	-0.129	2.8
Number of observations	872	
Adjusted R^2	0.321	
Specification tests		*P*-value
Normality test		0.000
Spatial correlation test		0.4360
ARCH test		0.4475
White's test		0.0000
Test for poolability over time		1.0000
Test for fixed effects		0.7561

Subsidized credit gets a significantly positive coefficient in this regression. In contrast to popular perception, this indicates that subsidized credit did have positive effects on agricultural output. That is, not all credit was absorbed by non-performing large-scale cattle ranchers focusing on land speculation. Road building also contributes to the growth of agricultural output and the highly significant coefficient on neighbors' change in agricultural output indicates a strong frontier effect.

Subsidized credit again appear to be an important factor for urban development, even though subsidized credit was intended for the rural sector. The highly significant coefficient supports the allegation that many of the funds intended for agropastoral activities were channelled away from the rural sector to the urban sector where returns tended to be higher. The positive coefficient on the cattle herd also supports this, because the credit often was attached to the cattle.

While the growth rate of urban output in neighboring municipalities was not significant, the growth rate of rural output was. This is probably because there is much more economic interaction between a city and its surrounding rural areas than between two cities.

The significantly negative coefficient on the lagged level of land prices shows that land prices tend to rise rapidly in the beginning but stabilize as land prices reach a level reflecting the true productivity of the land. The positive coefficient on neighbors, change in landprices is again a sign of a pronounced spatial correlation caused by the frontier effect.

Table 4
Rural output equation

Dependent variable: $\Delta GDP\text{–}RURAL_t$		
Explaining variables:	Coefficient	*T*-value
Constant	2.088	9.7
Road length$_{t\text{-}1}$	0.036	4.1
Change in road length$_t$	0.049	3.6
Sudam credit$_{t\text{-}1}$	0.012	4.4
Municipality area	0.065	6.8
Rural income per rural pop$_{t\text{-}1}$	-0.256	-10.1
Neighbors' road length$_{t\text{-}1}$	-0.033	-2.7
Agricultural income$_{t\text{-}1}$	-0.088	-5.9
Neighbors' change in agricultural income$_t$	0.403	9.8
Dummy for Pará	0.143	4.3
Number of observations	947	
Adjusted R^2	0.409	
Specification tests		*P*-value
Normality test		0.0000
Spatial correlation test		0.1132
ARCH test		0.0002
White's test		0.0000
Test for poolability over time		0.9483
Test for fixed effects		0.0000

Table 5
Urban output equation

Dependent variable: $\Delta GDP\text{-}URBAN_t$		
Explaining variables:	Coefficient	*T*-value
Constant	0.4894	3.4
Sudam credit$_{t\text{-}1}$	0.012	4.5
Urban output per urban capita$_{t\text{-}1}$	-0.102	-4.8
Municipality area	0.049	4.8
Change in cattle herd$_t$	0.089	4.1
Neighbors' change in agricultural output$_t$	0.502	11.7
Dummy for Mato Grosso	0.14	2.9
Number of observations	826	
Adjusted R^2	0.275	
Specification tests		*P*-value
Normality test		0.0000
Spatial correlation test		0.0000
ARCH test		0.0003
White's test		0.0000
Test for poolability over time		0.7361
Test for fixed effects		n.a.[a]

[a]Too many missing observations caused the estimation procedure to fail when the fixed effect matrix were included.

The negative coefficient on the distance to the state capitals shows that land prices tend to grow more rapidly the closer the land is located to major markets. The importance of good markets are further captured by the positive coefficient to the level of urban income per urban capita.

Table 6
Land price equation

Dependent variable: $\Delta LANDPRICE_t$		
Explaining variables:	Coefficient	*T*-value
Constant	2.908	10.5
Distance to state capital	-0.062	-3.4
Urban income per urban capita$_{t-1}$	0.164	5.0
Landprices$_{t-1}$	-0.562	-21.8
Municipality area	-0.111	-6.3
Neighbors' change in landprices$_t$	0.253	6.2
Dummy for Acre	-0.682	-4.3
Dummy for Pará	-0.229	-3.6
Dummy for Amapá	-0.542	-3.1
Dummy for Maranhão	-0.229	-3.6
Dummy for Mato Grosso	0.425	4.9
Number of observations	873	
Adjusted R^2	0.527	
Specification tests		*P*-value
Normality test		0.0000
Spatial correlation test		0.0014
ARCH test		0.0000
White's test		0.0000
Test for poolability over time		1.0000
Test for fixed effects		0.0000

4.2 - Model Evaluation

To evaluate the estimated model, we simulate the behavior of the six endogenous variables during the sample period using actual values in 1970 as starting values, and actual values of all exogenous variables during the whole period. Table 7 compares the simulated values in 1985 with the actual values in 1985. It also reports the correlation between the simulated and actual values at municipality level. The last column reports the logarithm of the sum of squared deviations between the actual and simulated values of the endogenous variables across all regions and over all three forecasting periods. It is thus an aggregate measure of how well the model captures the dynamics and thereby is able to make multi-step ahead forecasts.

Table 7 shows that there is little relationship between the R^2s of the estimated equations and their forecasting performance. The equation explaining land prices had the highest R^2 of all equations, but it clearly performs very badly. It consistently underestimates the real prices during all time periods, and the correlation between simulated and actual values is only 0.13. The rest of the equations are performing much better, having correlations of 0.79-0.95. However, the two output equations also consistently underestimate the true values.

Table 7
Model evaluation

Variable	Actual 1985 values	Simulated 1985 value	Correlation[a]	log (SSE)[b]
Urban population (millions)	6.5	6.3	0.98	11.08
Rural population (millions)	6.7	6.5	0.82	11.22
Urban GDP (billion 1985-US$)	11.2	7.5	0.95	18.58
Rural GDP (billion 1985-US$)	2.3	1.9	0.79	16.62
Cleared area (million hectares)	68.7	57.1	0.96	9.42
Average land price (1985-US$)	131	83	0.13	4.09

[a]The correlation at municipality level between the actual and simulated values in 1985.

[b]The sum of squared errors calculated across all municipalities over all three forecsting periods for each variable. This amounts to some very large numbers, so the logarithm is reported rather than the actual sums.

To avoid persistent biases in our model we tried to vary the constant terms of each equation to see how that affected the sum of squared errors for our six equations. Some small changes (within the 95% confidence intervals) did indeed improve model performance in terms of reducing the sum of squared errors over all three forecasting periods.[12]

4.3 - The Causes of Deforestation

To find out how much deforestation was caused by the aggressive development policies pursued during the 1970-1985 period, we compare the results from a factual simulation (using actual values of all exogenous values) with the results from a counter-factual simulation, where we set new road building, subsidized credit, and growth pole-incentives to zero during the 1970/85 period, while maintaining all other exogenous values at their actual levels. Any difference between the two simulations must therefore be attributed to the development policy package. The results, using the fine tuned model, are shown in Table 8.

The simulations show that extra deforestation of 9.6 million hectares can be attributed to the aggressive development policies. 72% of this is explained by road building and 28% by subsidized credit. Growth poles were not found to have any significant effect on clearing.

[12]After advice from professor Tore Schweder at University of Oslo, we also tried to vary the other coefficients to see if the dynamics of the model could be improved by that. Of particular concern was the coefficients to neighbor variables (spatially lagged dependent variables), since simultaneity problems may have caused them to be wrongly estimated by OLS. However, no other coefficients than the constant terms could be adjusted to improve the overall performance of the model.

The simulations also show that the development policies caused an extra GDP increase of $4.5 billion, of which 85% took place in the urban sector. This amounts to extra GDP in 1985 of $466 per hectare of extra cleared land.

Table 8
In-sample simulations

	Simulated values in 1985	
	Active scenario	Passive scenario
Urban population (millions)	6.3	4.8
Rural population (millions)	6.5	5.7
Urban GDP (billion 1985-US$)	11.4	7.6
Rural GDP (billion 1985-US$)	2.4	1.7
Cleared area (million hectares)	78.7	69.0
Average land price (1985-US$)	131	128

5 - COST-BENEFIT ANALYSIS OF DEFORESTATION

The differences in output between the active and the passive scenario measures the trade-off between economic growth and forest clearing.

With the past mix of development policies, each extra hectare of land cleared yielded a GDP increase of $466. This value should be compared to the costs incurred by the development policies. That is, the costs of road building, the costs of providing subsidized credit, as well as the costs of deforestation.

According to Diniz (1985), from 1974 to 1986, the two programs PIN and Proterra together invested approximately 13 billion dollars in roads and settlement programs along the roads. This amounts to about $50/year per hectare of land cleared. The value includes both the direct infrastructure costs and the costs of the settlement programs that should encourage people settle along the roads.

During the period 1970/85 rural credit worth $276.4 billion was granted in Brazil at real interest rates varying between -1.4% to -37.7% p.a. (Young 1996, Table 5.7, quoting Goldin and Rezende 1993). If the government could have invested this money with a real return equal to the social discount rate (for example, 2%), then the cost of subsidizing credit amounted to $54 billion (assuming that the credit was granted for 12 months periods on average). According to Mahar (1989), the Amazon region received less than 2% of the credit subsidy. Thus, dividing a credit subsidy to the Amazon of about $1 billion[13] with the 27 million hectares cleared during the 1970/85 period, we get a fiscal cost of subsidizing credit of about $3/year per hectare of cleared land.

Allowing for infrastructure costs, settlement costs, and the cost of subsidizing credit, we get a net GDP increase in the order of $400 per year per hectare of

[13]This number is supported by Binswanger (1989, p. 15) who state that the fiscal costs of subsidizing livestock ranches exceeded US$ 1 billion in 1975/86.

cleared land. At a 2% discount rate this amounts to a net present value of $20,000/ha.

According to Andersen (1997), the costs of deforestation (lost sustainable logging, lost ecological services, bio-diversity loss, carbon release to the atmosphere, etc.) is in the order of $18,000/hectare when applying a social discount rate of 2% (not including the funds transferred from the federal government to stimulate deforestation). This estimate comes with a large degree of uncertainty, however. Thus, the overall costs of deforestation appear to be approximately equivalent to the benefits when seen from the viewpoint of a global planner.

It is worth investigating the different components of the development policy separately. Road building causes substantial deforestation but is predicted to have only a small effect on output. This is because federal road building suppresses land prices and promotes wasteful use of land. The trade-off between output due to road building and clearing due to road building is estimated by our model to be $113/year/hectare. Deducting the direct costs of road building from the benefits, we get net benefits in the order of $63/year/hectare which amounts to a net present value of only $3,150. This is clearly not sufficient to cover the global costs of deforestation.

Subsidized credit yields quite large returns in the form of higher rural and urban output. If the development policy consisted only of subsidized credit, the trade-off between deforestation and GDP would increase to about $1,336/year per hectare of land cleared. This amounts to a net present value of $66,800/hectare, which is substantially higher than the estimated costs of deforestation. Credit has a positive effect on rural GDP because credit allows investment in perennial crops which give higher yields per hectare than the cheaper annual crops [see Andersen (1997)]. Subsidized credit, which was intended for agropastoral activities, is also estimated to have a substantial effect on urban output. This is partly because of the stimulation of the urban agro-processing industries. An additional explanation may be that the people who were most successful in obtaining subsidized rural credit were urban based, and much of the credit granted for, for example, cattle ranching was never used for cattle raising, but rather for higher yielding urban investments. Credit, as opposed to road building and growth pole incentives, has the advantage of flowing naturally to the highest yielding projects. Subsidized credit is therefore the most efficient development instrument in terms the trade-off between GDP and deforestation.

Table 9 summarizes the empirical effects of the three categories of policies. The first row gives the total area that is estimated to have been cleared during the period 1970/85 as a consequence of each policy. The second row gives the estimated net present value of the additional economic growth that has been caused by the policies **minus** the global costs of deforestation (put at $18,000/ha no matter what the policy).

Table 9
Empirical effects of actual Brazilian policies

	Road building	Subsidized credit	Growth poles
Deforestation	+ 6.8 mio ha	+ 2.6 mio ha	0 ha
Global Welfare	- $ 14,850/ha	+ $ 48,800/ha	- $ 18,000/ha

6 - CONCLUSIONS AND POLICY IMPLICATIONS

During the last three decades, development of the Amazon region has been strongly encouraged by the Brazilian government since it was believed that the benefits of deforestation would exceed the costs. The present report has provided evidence that this indeed seems to be the case. However, some policy instruments have proven to be much more cost-effective than others. Subsidized credit implied a relatively good trade-off between economic growth and deforestation, while the big road building projects had a much less favourable trade-off. The policy implications in terms of efficiency are clear.

If the government can secure that credit is available on favorable terms, it will have a large, positive effect on economic growth in the Amazon. It will also cause deforestation, but the trade-off has been estimated to be so favorable that it can justify deforestation — even when taking all the local and global externalities into account. The favorable effect of subsidized credit works through several mechanisms. First, the advantage of subsidized credit capitalizes into land prices, and higher land prices promote more efficient use of land. Second, the availability of credit allows farmers to fulfil their desire of investing in the more expensive but more sustainable and more profitable perennial crops. Finally, if the private returns to agriculture is too low, the credit can be channelled to more profitable urban activities which cause little deforestation.

Road building, on the other hand, needs to be planned carefully in order to secure positive effects. Road building is harmful when it opens up new land and drives land prices down. It is good, however, if it improves infrastructure conditions in already cleared areas and thus pushes land prices upwards.

While subsidized credit is the most cost-effective way of stimulating economic growth, it is not the most equitable. Subsidized credit is generally only available to people who already own land and these constitute a small minority in Brazil. Road building, on the other hand, make cheap frontier land available for every-body. Poor people will tend to benefit relatively more from this policy, because their lower opportunity costs make them more likely to move to the frontier. Thus, on top of the growth-deforestation trade-off, there is a trade-off between efficiency and equity when choosing policy instruments. The present paper has focused only on the efficiency aspect.

One final insight were obtained from the above analysis. When performing a cost-benefit analysis of deforestation, it is not sufficient to include only rural benefits. This analysis has shown that there are very big spill-over effects to the urban sector. These effects can substantially increase the total benefits, and indeed tip the evidence in favor of deforestation. Further research on rural-urban interactions would be useful since it would be environmentally beneficial to stimulate an increase in the rural-urban spill-over factor.

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