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EXPLAINING AGRICULTURE EXPANSION AND DEFORESTATION: EVIDENCE FROM THE BRAZILIAN AMAZON — 1980/98*

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SUMÁRIO

RESUMO

O desflorestamento na Amazônia aumentou significativamente durante os últimos 20 anos. Aproximadamente 400.000 km^2 de florestas tropicais foram devastados entre 1978 e 1998, sendo a sua maioria convertida em pastagens e lavouras. Este trabalho usa dados de painel de oito estados da Amazônia, de 1980 a 1998, para estimar um modelo dos determinantes da expansão da área plantada e de cabeças de gado na região. Os resultados mostram que a expansão da área plantada está associada a variações de preços da terra, crédito agrícola e estradas, enquanto o aumento do número de cabeças de gado está determinado principalmente pela redução do preço do boi e pela expansão da malha rodoviária.

ABSTRACT

The extent of deforestation in the Brazilian Amazon grew significantly in the last 20 years. Approximately 400,000 km^2 of tropical forest were cleared from 1978 to 1998. Land conversion to pasture and crop areas were the main sources of deforestation, though the contribution of logging increased significantly in the nineties. This paper uses panel data for eight states of the Brazilian Amazon, from 1980 to 1998, to estimate a model of the determinants of crop area and cattle herd expansion within the region. Results show that the expansion of crop area is determined by changes in land prices, government agriculture credit and roads while the growth of cattle herd is mainly driven by the decrease in the price of cattle head and the expansion of the road network.

1 - INTRODUCTION

The Brazilian Amazon is regarded as one of the most important ecosystems in the world containing near 50% of the known biodiversity in the planet. It comprises an area of near 5 million squared kilometers of which approximately 70% are continuous forest domain. Due to its vast unclaimed territory, it has attracted migrants from other regions of the country searching for agricultural land. Nonetheless, it remains a frontier region. Because of its large distance from main centers and due to dense forest areas, almost 85% of its original forest cover is still intact.

Several attempts for development were undertaken by the Brazilian government since the beginning of the sixties. In order to integrate the northern region to the rest of the country a series of highways were constructed starting with the Belém-Brasília, followed by the Cuiabá-Santarém and the Tranzamazônica [Mahar (1988) and Moran (1996)]. Additionally numerous settlement projects were undertaken in regions near the new highways which were meant as a substitute for the lack of agrarian reform and massive demand for land in other regions of the country [Almeida and Campari (1995)]. Large amounts of subsidized credit were given for agriculture and cattle ranching activities and huge development projects such as the Carajás project were undertaken [Reis (1996)]. Nonetheless, these efforts were not successful in generating a sustainable growth process in the region. Although the regional GDP has grown substantially in the last 20 years, the Amazon is still characterized by poverty and unequal income and land distribution. Moreover, the pattern of growth is generating an unsustainable deforestation process that can jeopardize future economic potentials.

The extension of deforestation has grown significantly during the past 20 years. Approximately 400,000 km^2 of tropical forest were cleared between 1978 and 1998 according to satellite image estimates.[1] Moreover, the increasing forest fires and selective logging activities, which are not captured by satellite images, could imply that the extension of the deforested area is even larger.[2]

The causes of the increasing deforestation trend are closely related to government policies adopted in the past. Mahar (1988) and Binswanger (1991), describe government policies that have induced and aggravated the economic incentives for forest clearing. Among others, subsidized credit, tax breaks for agriculture and cattle ranching activities, land titling processes in open access areas and highway constructions are described as the main policies that created incentives for settlement, and at the same time, agriculture land clearing in the Amazon region.

The macroeconomic environment generated additional incentives for deforestation through high interest rates and uncertainty derived from high inflation rates. The

[1] This estimates are based on INPE (2000) subtracting the estimated cleared area in 1998 from the estimated cleared area in 1978.
[2] See Fearnside (1996) for a comparison of deforestation estimates.

prevailing high price of land decreased the incentive for smaller farmers to buy land and increased the incentives for migrating to the frontier generating a race for property rights. This movement was undertaken for acquiring land in order to develop an agriculture activity, and also as a way to speculate, expecting future rises in the land prices and capital gains.[3]

Since the mid-eighties, several government policies have changed. Agriculture credit subsidies have decreased considerably, tax exceptions have been reduced drastically, direct colonization settlements have terminated and large infrastructure projects have been phased out. Nevertheless, deforestation has not slowed down.
The building of new paved and the pavement of existing roads are regarded as one of the main factors driving the persistence of the deforestation process. In some cases, roads create fresh access to new settlements in frontier regions. More often, however, they drastically reduce transportation costs in earlier settled areas thus relieving one of the main restrictions to the profitability of agro pastoral activities in the Amazon context. Alves (1999) estimates that between 1991 and 1996, more than 75% of the total cleared area near the three major road networks occurred with a 50 km distance from the roads.[4] The clearing and appropriation of open access areas adjacent to paved roads also contribute for a substantial portion of deforestation, especially when initial non-paved roads were opened by logging purposes. Additional incentives for deforestation were created by the contradictory policies of government agencies such as the Brazilian Renewable Resource Institute (Ibama) and the Agrarian Reform Institute (Incra). While the Ibama obliges all properties in the Amazon to retain 80% of their forest area, the Incra will often consider a property that follows this rule as unproductive and thus susceptible to expropriation [Alston, Libecap and Mueller (2000)].

The macroeconomic policies adopted during the nineties may have exacerbated the prevailing institutional failures. Stabilization macro policies may have increased incentives for deforestation through high interest rates and low credit availability that could have had a significant impact on the choice for land clearing. Theoretically speaking, the impact of interest rate on deforestation is ambiguous, increases in interest rate make a large owner postpone investment in agriculture and cattle ranching and tends to decrease new land clearing. On the other hand, for small owners and agents living in the frontier an increase in interest rates increases the cost of capital generating a negative income effect that could have effects of increasing frontier settlement. This could help explain why deforestation by small holders increased in the Amazon during the nineties.

The objective of this paper is to analyze the causes of frontier expansion and deforestation in the Brazilian Amazon in the eighties and nineties. The analysis

[3] For a description and analysis of this process see Alston, Libecap and Schneider (1995) and Schneider (1995).

[4] Moreover, Alves (1999) also seem to indicate that major deforestation processes are taking place near pioneer deforestation areas that were opened up in the eighties.

uses annual data, from 1980 to 1998, for eight states of the region[5] to explain the expansion of crop areas and cattle herds. The paper undertakes panel data estimation of the causes of deforestation using as explanatory variables output and input prices, government credit, road extension, distance and soil quality.

Previous econometric studies of tropical deforestation in the Amazon used cross-section [Reis and Guzmán (1993)] or panel data models, based upon municipal data from the Brazilian Agricultural Census published every five years except for 1990 when the census survey was not undertaken [Reis (1996)]; Andersen, Granger and Reis (1997); Young (1996)]. Another approach was undertaken by Reis and Margulis (1991) and Pfaff (1999), combining agricultural census data with satellite image data. None of the previously mentioned empirical analysis, however, went beyond the mid-eighties. Moreover, to incorporate the 1995/96 Agricultural Census data is not an easy task because of methodological changes that created problems of comparison with the previous 1985 Agricultural Census.[6]

This paper uses a new database which combines state level data from two annual agricultural surveys undertaken by IBGE — Pesquisa Agrícola Municipal (PAM), and Pesquisa Pecuária Municipal (PPM) and data on agricultural credit and roads from other government sources with FGV (Fundação Getúlio Vargas) data on crop and factor prices in agriculture and cattle activities. This data enable us to update the analysis of deforestation process in the Amazon up to the late-nineties. An additional contribution of the paper is the improved specification of the estimation procedure using fixed-effect and panel corrected standard error models, allowed by the use of time series cross-section data, notwithstanding the fact that the time span of the sample — 19 years — is still short.

A disadvantage of using the PAM and PPM is that the data on cropped areas from and cattle herds are less precise estimators of deforestation compared to the consistent land use categories of the Agricultural Census. Cropped areas do not necessarily lead to clearing and deforestation, since fallow lands could be available for use. The same is true for pasture areas. However, for cattle rising, even pasture areas will have to be inferred from the size of herds, the only information available. Therefore, we have to assume a stable relation between herds and pasture areas or intensity of grazing.

The theoretical background model used is based upon Reis and Guzmán (1993), Deacon (1995), Angelsen (1997), Cropper, Griffiths and Mani (1999) and Barbier (1999). The land clearing process is simply modeled as an interaction of demand and supply of cleared land for agriculture and a reduced form for the demand of cleared agriculture land is obtained. Although this model does not take into account important dynamic issues such as land speculation, we believe it is

[5] The region defined as the Legal Amazon comprises of the states of Acre, Amapá, Amazonas, Maranhão (west of the 44^{o} W), Mato Grosso, Pará, Rondônia, Roraima and Tocantins. Nevertheless, data on the state of Amapá was not available for the whole analyzed period.

[6] See Helfand (1999) for a comparison of the 1995 census results with the PAM.

realistic and simple enough to motivate the economic determinants of deforestation in the Amazon.

This study has several contributions. First, it explores the time-series cross-section structure of our data estimating OLS, fixed and random effects and panel corrected standard error models. Second, it generates elasticities for changes in percentage of crop area and density of cattle with respect to prices, credit and roads (variables that are influenced directly by the government).

2 - DEFORESTATION, LAND USE CHANGE AND ECONOMIC GROWTH

The extension of deforestation has grown significantly during the past 20 years. Approximately 400,000 km^2 of tropical forest were cleared between 1978 and 1998 according to satellite image estimates.[7]

In Table 1 we present the extension of deforestation in km^2 for selected years showing that from 1978 to 1988, approximately 225,000 km^2 of forest were cleared. For some states like the Amazonas and Roraima, the growth in the cleared areas was above 1,000%.

The growth in deforestation decreased for the whole Amazon region during the 1988/98. Nonetheless, still approximately 174,000 km^2 of forests was cleared in this period. In the states of Amapá, Mato Grosso and Roraima, the extension of deforestation actually increased during the nineties and for Acre and Rondônia, it remained relatively stable.

Table 1

The Extension of Deforestation in the Brazilian Amazon: 1978, 1988 and 1998

(Km^2)

States	1978	1988	1998	% Growth in Deforested Area 1978/88	% Growth in Deforested Area 1988/98
Acre	2,500	8,900	14,714	256.0	65.3
Amapá	200	800	1,962	300.0	145.3
Amazonas	1,700	19,700	28,866	1,058.8	46.5
Maranhão	63,900	90,800	100,590	42.1	10.8
Mato Grosso	20,000	71,500	131,808	257.5	84.3
Pará	56,400	131,500	188,372	133.2	43.2
Rondônia	4,200	30,000	53,275	614.3	77.6
Roraima	100	2,700	5791	2,600.0	114.5
Tocantins	3,200	21,600	26,404	575.0	22.2
Total	154,178	379,488	553,780	146.1	45.9

Source: INPE (2000).

[7] These estimates are based on INPE (2000) subtracting the estimated cleared area in 1998 from the estimated cleared area in 1978.

Table 2 presents data from the 1985 and 1996 Agriculture Censuses. Decomposing the major land uses and comparing their evolution, it is found that approximately 145,837 km^2 of land clearing occurred between 1985 and 1995/96 (this is close to the value of 174,292 obtained by satellite estimates if we subtract the extension of deforestation in 1998 from the value in 1988).[8] The area of planted pasture increased from 298,423 km^2 in 1985 to 477,273 km^2 in 1996, representing an increase of approximately 60% in 10 years.

Table 2

Land Use in the Brazilian Amazon: 1985 and 1996 (Area in km^2)

Land Use	1985	1996
Perennial Crops	10,183.27	10,788.24
Annual Crops	79,735.44	70,604.42
Planted Forest	3,031.78	5,800.30
Planted Pasture	298,423.46	477,273.20
Fallow Land	43,517.64	29,030.27
Productive Land not Used	114,754.61	74,275.44
Total Cleared Area	1,378,194.56	1,524,032.00

Source*: IBGE agriculture census 1985 and 1995. The Brazilian Amazon considered here includes the state of Maranhão and the state of Goiás.*

In this study, we use annual data for crop area and the number of cattle heads as indicators of deforestation. A disadvantage of using the PAM and PPM is that the data on cropped areas from and cattle herds are less precise estimators of deforestation compared to the consistent land use categories of the Agricultural Census. Cropped areas do not necessarily lead to clearing and deforestation, since fallow lands could be available for use. The same is true for pasture areas. For cattle rising, even pasture areas will have to be inferred from the size of herds, the only information available. Nonetheless, there is a close correlation between the evolution of crop area and cattle heads and the extension of deforestation [Andersen *et alii* (1996)].

In Figure 1 we present the evolution of the total crop area and the total number of cattle heads in the region as obtained by the PAM and PPM. We observe a dramatic increase in both proxies for deforestation during the 20-year period; although the trend of cattle head is more stable.

Logging is currently considered an important source of deforestation in the Amazon. Although it is hard to measure the exact amount of extracted timber due to illegal and unreported logging, Table 3 presents the volume of timber extracted in the Brazilian Amazon for the years 1980, 1985, 1990, 1995 and 1999 as estimated by the Brazilian Statistical Office (IBGE). The volume of timber

[8] Although there are some problems of comparability between both census. A general trend can be inferred by comparing their results. For a description of the change of methodology that was undertaken by IBGE for the 1995/96 census and its possible consequences see Helfand (1999).

extraction increased by 345% between 1980 and 1995, but after 1995, the IBGE figures suggest that the amount of timber extracted decreased considerably.[9]

Figure 1
Evolution of Crop Area and Cattle Head in the Brazilian Amazon: 1979-1999

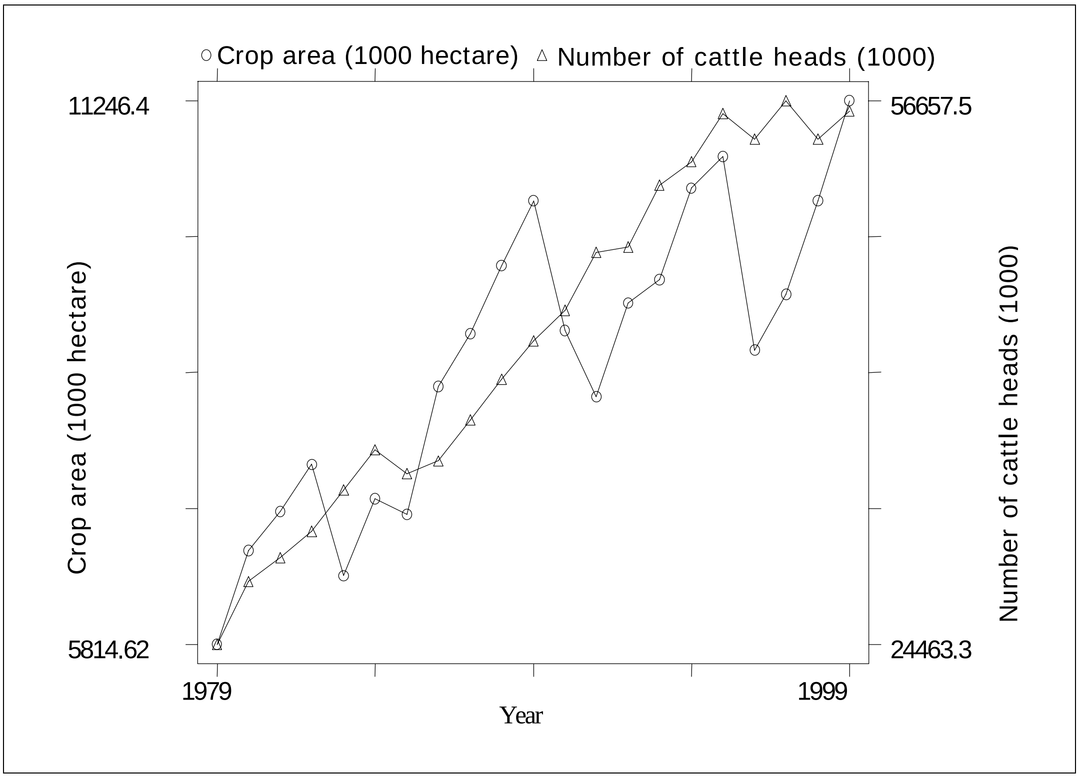


Table 3
Timber Extraction in the Brazilian Amazon

(In 1,000 m^3)

Year	Volume of Timber Logs Extracted
1980	11,720.7
1985	23,960.0
1990	46,310.3
1995	52,285.6
1999	16,535.6

Source: IBGE Extraction Survey.

[9] Although the estimations undertaken from the IBGE are highly controversial, they are very close to the result obtained by Veríssimo, Arima and Lima (2000) from a field survey undertaken in a sample of sawmills throughout the Amazon. They estimate an extraction of 27,8 millions of m^3 for the period 1997/96. In contrast, the IBGE estimates that for 1996 approximately 43,980,000 m^3 were extracted from the Amazon region while in 1997 this value decreased to 20,694,000 m^3. An average between these two values would be quite close to the Veríssimo, Arima and Lima (2000) estimates.

2.1 - The Evolution of the Causes of Deforestation

The economic literature on deforestation, summarized by Kaimowitz and Angelsen (1998), separates the variables affecting the land clearing process into three different levels: underlying causes, immediate causes and sources of deforestation. Underlying causes are related to macro level variables and are generally thought as income, population and macroeconomic policies. In this level, increasing rural population density and GDP per capita are usually blamed as the most important factors driving the deforestation dynamics [Cropper and Griffiths (1994) and Cropper, Griffiths and Mani (1999)]. Nevertheless, the evidence is somewhat mixed once other important variables are included in the econometric analysis [Angelsen and Kaimowitz (1999)].

Existent evidence for the Brazilian Amazon seems to support the hypothesis of rural population migrations having a large effect only in opening new frontier areas. Pfaff (1999) find that once the area is occupied, increasing population density, controlling for other variables, have a negligent effect on land clearing expansion. It is important to note that population is actually an endogenous variable and migrations occur as a response to economic incentives. An alternative model is used by Andersen, Granger and Reis (1997) who explains migrations based on a set of economic variables. Nonetheless, after controlling for other characteristics including neighbor change in clearing, rural population density is not found to be statistically significant.

The Amazon region GDP grew by an average of 15% per year from 1970 to 1980 and income per capita more than doubled. Economic growth was obtained in the Amazon through the establishment of colonization projects in the region and the massive infrastructure investment and credit concessions. The leading sector in this boom was the industry with an average growth rate of 26% per year motivated by the creation of the Manaus Free Export Processing Zone. The share of industry in local production increased from 15% in 1970 to an impressive 40% in 1980 [Reis and Blanco (1996)].

During the eighties and nineties, the growth was maintained, but there was a substantial difference among states. Industrial growth was not widespread and in some states, agriculture activities were the main factor motivating growth. In Table 4 we show the average and the cumulative GDP growth for each state of the Legal Amazon from 1985 to 1997. We also include the agriculture GDP growth as a mean of comparison. The first important observation is that the most industrialized state, Amazonas, had a low average growth rate while other states such as Acre and Rondônia that depend mostly on agriculture, cattle and extraction had average growth rates over 4%. We also observe that the states with the highest growth rates, Roraima and Amapá, also had a highest agriculture GDP growth (based on agriculture and cattle ranching, both activities which induce deforestation). This pattern seems to be confirmed when we compare Table 4 with

Table 1. The states that presented the highest agriculture GDP growth also had the highest deforestation growth rate between 1988 and 1998.

Table 4
GDP Growth Rates in the Amazon Region States between 1985 and 1997

State	GDP Average Growth Rate	Cumulated GDP Growth Rate	Agriculture GDP Average Growth Rate	Cumulated Agriculture GDP Growth Rate
Acre	4,86	58,31	0,31	3,71
Amapá	6,72	80,65	11,02	132,20
Amazonas	0,56	6,77	0,50	6,06
Maranhão	1,05	12,56	0,94	11,24
Mato Grosso	2,91	34,96	2,68	32,13
Pará	2,68	32,17	5,14	61,65
Rondônia	4,01	48,11	4,57	54,85
Roraima	7,20	86,34	16,98	203,82
Tocantins	2,53	30,41	0,22	2,65
Amazon region	3,61		4,71	

Source: Silva and Medina (1999).

Despite the significant growth in GDP, high inequality in income and land is still present in the region. The Gini coefficient for land in the northern region of Brazil decreased from 0.86 in 1975 to 0.79 in 1985 [Schneider (1995)], but it is still one of the largest in the world. Additionally, land and environmental degradation and the lack of rural development have generated a massive migration to urban areas creating additional problems.

The urban population in the Amazon region increased considerably during the nineties. In 1991, 44% of the population in the Amazon was rural. In 2000, the preliminary results from the IBGE census indicate that this proportion decreased to 32%. Moreover, the urban population in the Amazon region increased in an average of 5.9% per year while for Brazil as a whole the urban population increased by an average of 2.7% per year. An important point is that the largest growth in urban population occurred in Amapá and Roraima, states which are both agriculture related activities. This could be an indication of a rural-urban migration process that may be occurring due to unsustainable pattern of agriculture production and poor living conditions in remote rural areas.

Macro variables affect immediate causes, which can be described as parameters that shape economic agents´ decisions. These parameters are related to institutions (property rights), markets, governments and technology. Both levels are important for the Brazilian case and are closely related. Government policies have had an impact on both the deforestation process and the microeconomic relations through an institutional context of land inequality, insecure tenure rights and market imperfections that have contributed to intensify regional policy failures.

Migration processes and property right allocations are closely linked to deforestation. Weak defined property right structures are known to be one of the main determinants of land clearing processes in tropical forests. The colonization projects introduced in the Amazon during the seventies attracted a huge amount of farmers to the frontier motivated by property right claims. Almeida and Campari (1995), Schneider (1995) and Alston, Libecap and Schneider (1996) have found a strong relationship between incentives for land clearing and insecure property right regimes.

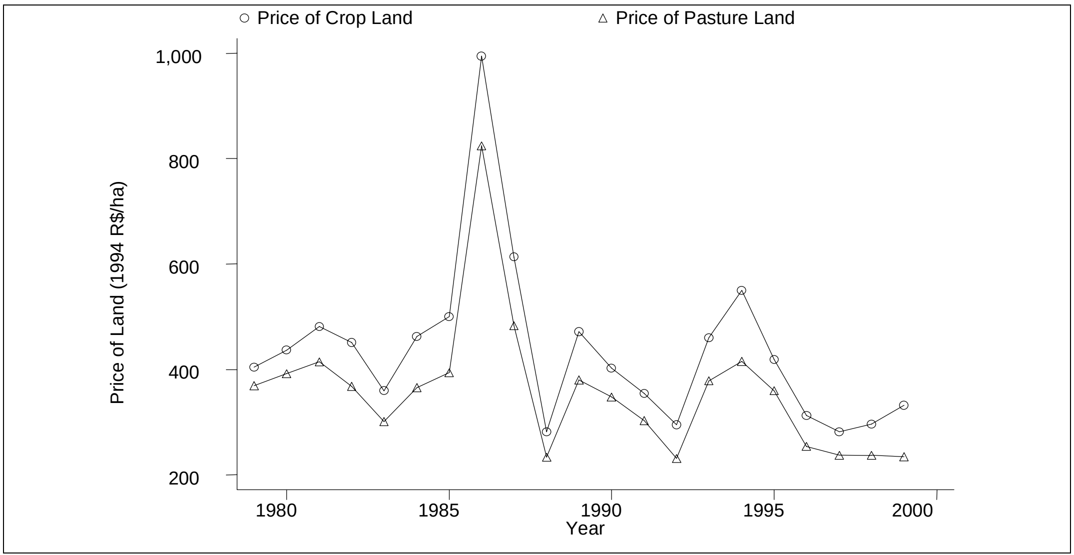
Immediate causes of deforestation are closely linked to economic incentives. Imperfect markets for crops, labor and land have induced land-clearing processes. Among these factors, land speculation has been one of the driving aspects inducing deforestation processes in the region, especially in the eighties. The open access characteristic of the Amazon forest induced a race for property rights, both as direct government strategy and as a market response to the possibility of obtaining land titles. Subsidized rural credit for pasture conversion and cattle ranching created an additional pressure on land prices through the demand for large amounts of land.[10] Additionally, the great uncertainty generated by high inflationary processes contributed for the use of land as a secure asset.

Therefore, the relationship between changes in the price of land and the demand for cleared land is quite complex. An increase in the price of land raises the cost of acquiring or renting land and tends to decrease the demand for cleared land as an input. Nevertheless, in dynamic terms, an increase in the price of land generates expected future gains and could increase the demand for land for speculative motives. Additionally, cattle and land serve as secure assets in periods of high inflation.

In Figure 2 we present the evolution of the price of land in the Amazon region. From the early eighties until the Real plan in 1994 the price of land was greatly determined by macroeconomic variables, specially inflation and interest rate [Reydon (1999)]. The increase in the real price of land that occurred in the seventies until the mid-eighties created an additional incentive for deforestation through smaller farmers. Since high land prices limited the possibility of smaller farmers to buy land, it created incentives for migration and frontier settlements generating further forest conversion [Schneider (1995)]. After a peak in 1986 the price of land has decreased considerably and since 1994, reduced inflation rates associated with restrictive macroeconomic policies on credit and consumption, brought down definitively the price of land for both crop areas and pasture land as we observe in Figure 2. Another observation is that the price of cropland is, on average, higher than the price of pastureland, although over time their behavior is almost identical.

[10] See Brandão (1988) for an analysis of the determinants of the price of land in Brazil.

Figure 2
Average Price of Land in the Brazilian Amazon: 1979/99



The deforestation process in the Amazon is closely linked to the rural labor market as well. The opportunity cost of migrating in the frontier is given, in part, by the rural wage that could be obtained by working on a farm. Low rural wages imply low opportunity cost of migration inducing a higher land clearing. Moreover, the demand for additional land is also related to the cost of inputs, inclusively rural labor. In Figure 3 we present the evolution of the average rural wage rate for temporary workers in the Brazilian Amazon. Except for peaks in 1986 and 1989, and the 1992/96 periods, the rural wage has been on a declining trend since 1979. This decline creates incentives for hiring labor intensively for clearing activities and, at the same time, decreases the opportunity cost of migration, creating incentives for movements along the frontier in search of open access land.

Land price dynamics and wage rate movements in the Amazon are closely related to infrastructure building, especially road constructions [Binswanger (1991)]. Since the seventies, a massive colonization effort through road building was undertaken by the Brazilian government. The availability of roads decreased transport costs enabling large pastures and agriculture areas to become financially viable.

Extensive networks of paved and unpaved roads were built in the Amazon during the 1979/99 period as illustrated by Figures 4 and 5. The extension of paved roads increased by more than 100% during the 1979/99 period and unpaved roads increased by approximately 460%. On average 16,000 km of additional non-paved roads were built between 1980 and 1995. Although paved roads are generally related to new frontier areas, small-unpaved roads opened by logging companies also generate further occupation.

Figure 3
Average Rural Wage in the Brazilian Amazon

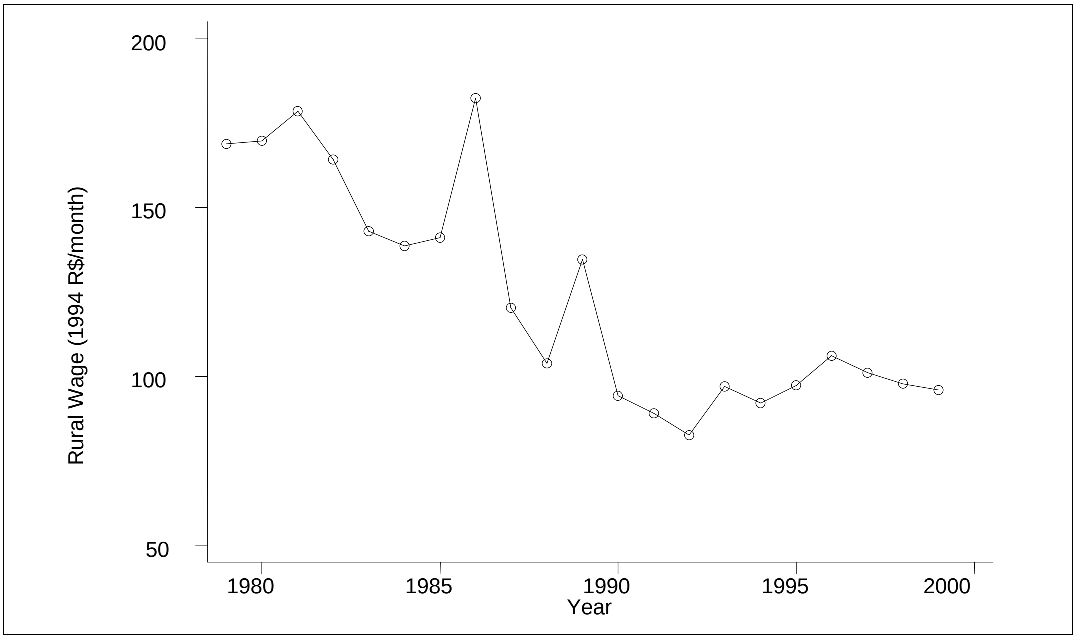


Figure 4
Extension of Paved Roads in the Brazilian Amazon: 1979/99

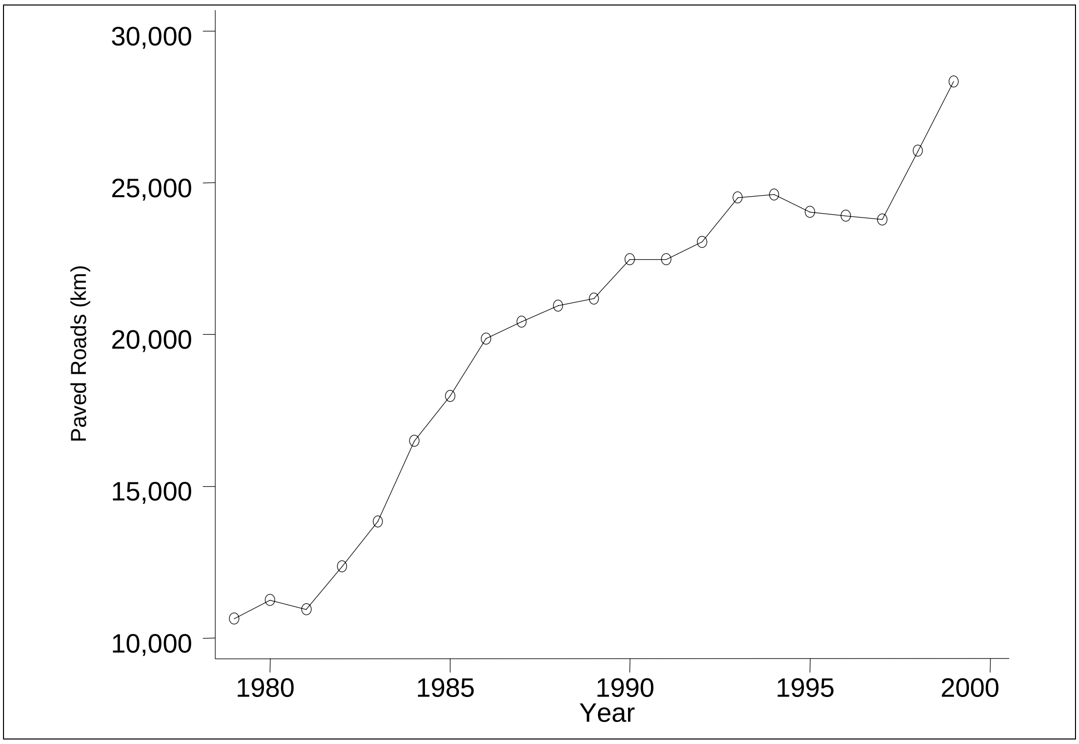
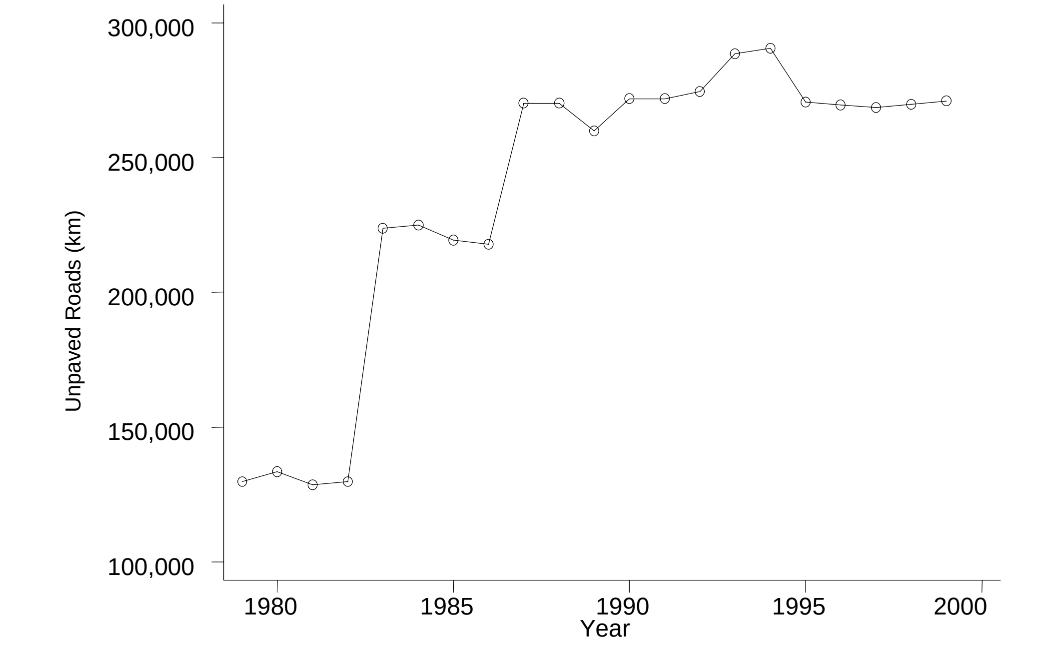


Figure 5
Extension of Unpaved Roads in the Brazilian Amazon: 1979/99

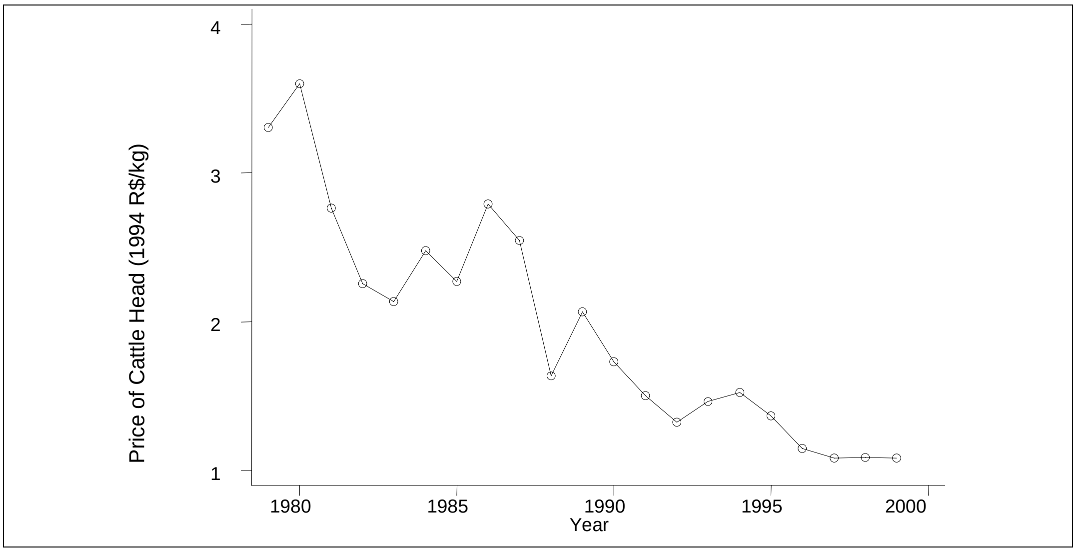


A fraction of the deforestation process is undertaken by smallholders who clear land for subsistence consumption. Another substantial portion is carried out by commercial crop and cattle-ranching activities. Since cattle-ranching activities are in general oriented towards the market, we would expect the price of output to determine the expansion of commercial agriculture and cattle ranching in the Amazon region.

In Figure 6 we present the evolution in the average price of commercialized cattle in the Amazon from 1979 to 1999. Despite of some short-term fluctuations, we observe a declining trend. Although the price of beef has been declining in real terms as well, it is very likely that the decrease in the real price of cattle has induced a capital accumulation effect.

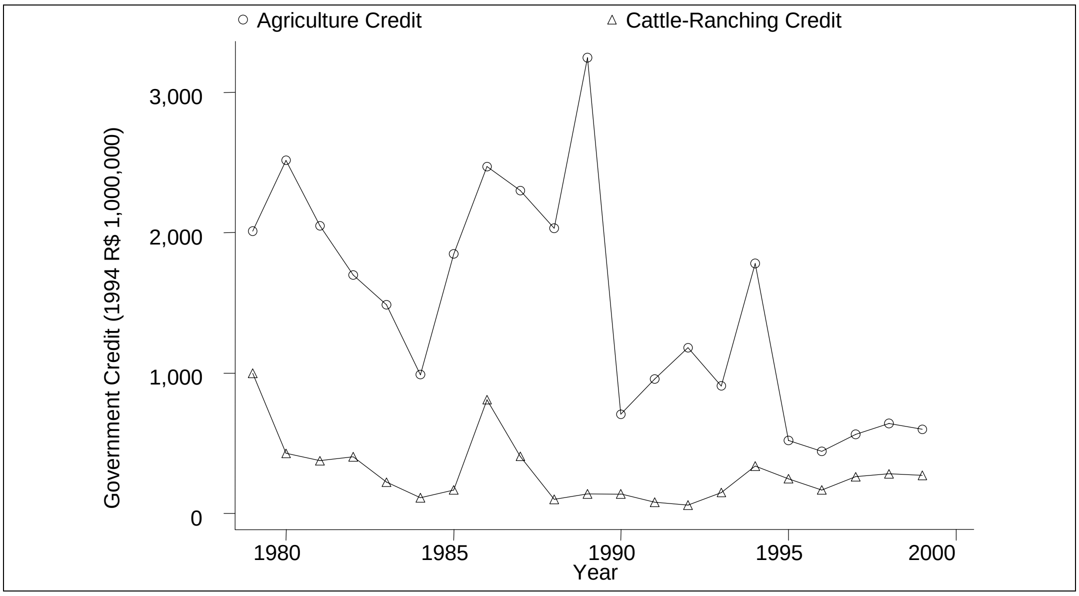
Schneider *et al.* (2000) estimate a low internal rate of return for the cattle activity in the Amazon suggesting that additional explanations are needed in order to elucidate on the massive growth of cattle in the region. Walker, Moran and Anselin (2000) suggest that even tough beef prices felt in real terms, the relative price of beef with respect to crops such as rice, beans and black pepper have increased making cattle-ranching profitable even for small farmers. Additionally it is important to take into account that there are additional returns to the cattle activity such as the establishment of property rights and protection against high inflation. Another possible explanation for the increasing cattle-herd is history dependence and important cultural and institutional aspects, especially due to past government incentives.

Figure 6
Average Price of Cattle in the Brazilian Amazon: 1979/99



It is widely agreed that government credit, through subsidies and tax break incentives, was one of the most important factors that drove the agriculture frontier expansion in the Amazon [Biswanger (1991), Schneider (1995), Andersen, Granger and Reis (1997)]. In Figure 7 we present agriculture and cattle-ranching credit distributed by the government. We observe that the availability of rural credit decreased considerably during the economic crisis of the early eighties. Nonetheless, from 1984 to 1989 there was a substantial growth in government credit particularly for agriculture activities. In the nineties, rural credit increased again until 1994 and since 1995 it has been relatively stable.

Figure 7
Government Credit for Agriculture and Cattle-Head Activities: 1979/99



2.2 - The Social Costs of Deforestation

Deforestation and environmental degradation in the Amazon introduces social costs to local economic agents as well as affects citizens outside its borders. The current unsustainable deforestation process can have important effects on future growth possibilities in the region. The conversion of forest into pastureland and crop area is almost irreversible since the soil nutrients are exhausted leaving the soil in extremely poor conditions. Seroa da Motta and Ferraz (2000) estimated the user cost associated with timber extraction in the Amazon. They show that logging, following the process of land conversion to agriculture, do not reflect scarcity and depletion costs.

The deforestation process harms other activities as well. The possibilities of future income with sustainable forestry, use of biodiversity, eco-tourism, carbon sequestration and other environmental services decrease considerably with the current deforestation rate.

One of the main consequences of deforestation is the loss of biodiversity. In 1997 there were 228 fauna species in danger of extinction in Brazil [(Ibama (1997)] from which approximately 90 species were from the Amazon [BDT (2001*a*)]. Although it is hard to calculate the value of biodiversity in the region, it is widely agreed that the Amazon presents several unique ecosystems and species, some of which could have pharmaceutical use value and others may have a large existence value for non-residents.

Predatory logging also causes extinction of valuable commercial tree species such as Mahogany. Martini *et al*. (1994) discriminated 305 species of trees into three groups according commercial interests and ecological parameters. They found that 45 species are strongly susceptible to timber extraction in terms of population reduction.

The deforestation process in the Amazon also creates environmental social costs through CO_2 emissions. Andersen and Reis (2000) estimate average carbon emissions from the Legal Amazon of 168 million tons per year during the 1970/85 period. This corresponds to approximately 95 ton of Carbon per hectare cleared, which contributes to aggravate the world concentrations of CO_2, the main cause of climate change.

Deforestation and logging are also related to the increasing risk of fires in the region. With its humid microclimate, the tropical forest contributes to fire control. Both the selective logging and the land clearing processes increase the probability of fire dispersion in a significant manner. This occurs because of the damages wreaked by logging, particularly because logging opens up the forest canopy — up to 50% — allowing the sun's heat to reach the earth, drying out leaf litter and other materials that may become combustible. Therefore, deforestation induces potential for massive ecological and economic losses through accidental fires [Nepstad *et al.* (1999)].

3 - THE EMPIRICAL MODEL AND ECONOMETRIC SPECIFICATION

Constructing a simple model to describe the pattern of deforestation in the Brazilian Amazon is not an easy task. The difficulty comes from the fact that the Amazon is a heterogeneous region where several institutional settings coexist. In some parts of the region, particularly in the first frontier areas such as parts of Mato Grosso, Tocantins and Pará, there are developed land and labor markets. Conversely, in areas beyond the frontier, markets are weakly developed and open access areas prevail. Further differences arise from economic agents clearing the forest that range from small subsistence agrarian peasants to large cattle landholders.

In order to simplify our analysis and study the specific variables that are likely to influence the evolution of cleared land, we will assume that we can represent the process of deforestation by a simple demand and supply model. We follow Reis and Guzmán (1993) and Cropper, Griffiths and Mani (1999) in breaking up the deforestation process in two steps: at each price level, economic agents chose the amount of land that is cleared. Separately, at prevailing prices, farmers chose the amount of land that would be used for cropping. Although farmers may clear their own land and farm it, this two-step framework allows us to model separately the effects of agriculture decisions on the deforestation process.

The demand for cleared land is derived from farmers undertaking a crop based or cattle activity. A representative farmer uses traditional inputs labor, capital and cleared land in order to produce an agriculture output. Additionally its production is affected by geographical and agro-ecological factors such as distance to markets and soil quality.

The supply of cleared land and the demand of cleared land by farmers from equation determine the equilibrium amount of cleared land and its rental price. It would be possible to take this model to the data, except for the fact that we do not observe separate supply and demand for cleared land. Instead, what we observe is the equilibrium extension of cleared land used for agriculture and cattle ranching at each period. In order to take this model to an estimable equation, we follow Reis and Guzmán (1993) and Cropper, Griffiths and Mani (1999) and we suggest a reduced form equation of cleared land.

The reduced form equation of cleared land obtained depends on the factors affecting the demand for cleared land, but also on factors affecting the supply of deforested land. In the present model, the amount of cleared land increases with the output price, the road availability, the soil quality and the amount of credit and should decrease with the distance to the market, the forest density, the rural wage and the price of land.

Our objective is to estimate the main determinants of the evolution of agriculture land and cattle head in the Brazilian Amazon. The approach undertaken consists in estimating two separate independent regressions — one for cattle and one for agriculture — using a panel data approach.[11] According to our model, the area of cleared land for agriculture and the number of cattle heads, in state *i* at period *t*, are determined by three types of factors: market incentives, geographical factors and agro-ecological characteristics.

Since the extension of cleared land for agriculture and the number of cattle head per state are likely to vary with the size, omitting size from the estimated equation causes a spurious correlation between cleared agriculture area and size varying variables such as roads and credit.[12] This is not a problem in the fixed-effect estimation since size will disappear once we take first-differences, but it will be a problem in the random effect estimation. In order to keep comparability between estimates, we control for different state sizes in all estimations by dividing the dependent variable and size varying factors, such as roads and credit, by the size of the state area.[13]

The estimations were undertaken in linear and log form. The logarithmic specification resulted in a better-fit, expected signs of coefficients and significance. Therefore, we only present the estimated equations in logarithmic form with the coefficients generating direct elasticity estimates.

The reduced form estimated equation for the evolution of the cattle head density in the Amazon is:

$$\begin{aligned} \ln \mathrm{chd}_{it} &= \alpha_0 + \alpha_1 \ln \mathrm{pch}_{it-1} + \alpha_2 \ln \mathrm{ppl}_{it-1} + \alpha_3 \ln \mathrm{w}_{it-1} + \alpha_4 \ln \mathrm{ccrd}_{it-1} + \\ &+ \alpha_5 \ln \mathrm{prd}_{it-1} + \alpha_6 \ln \mathrm{nprd}_{it-1} + \alpha_7 \ln \mathrm{dist}_i + \alpha_8 \ln \mathrm{sd}_i + \mathrm{f}_i + \varepsilon_{it} \end{aligned} \tag{1}$$

where *chd* is the density of cattle head; *pch* is the price of cattle head; *ppl* is the price of pasture land; w_{it} is the rural wage rate; c*crd* is the rural credit density for cattle ranching activities; *prd* is the density of paved roads (paved roads/state area); *nprd* is the density of non-paved roads (non-paved roads/state area); *dist* is the distance from the state capital to the federal capital; *sd* is the proportion of medium to high quality soil; f_i is a specific effect for each state and ε_{it} is the contemporaneous error term.

For the crop area, we estimate a similar reduced form equation, except that the dependent variable is *cad*, the crop area density, and for the covariates, the price of

[11] Although it would be desirable to estimate a structural model linking both sources, we do not undertake such a task due to data restrictions: the area for agriculture cannot be directly linked with the data for cattle head. Only the use of census data would permit such a task. See Andersen, Granger and Reis (1997) for a transition model of land use.
[12] See Granger and Hyung (1997) for possible problems of spurious correlation that occur when omitting size variables.
[13] Of course it would be more precise to divide it by the size of the potential agricultural area. Nevertheless such figures are not available.

land *pcl*, refers to crop land and credit density *acrd* refers to agriculture credit density. The estimated equation can be expressed as:

$$\ln cad_{it} = \beta_0 + \beta_1 \ln pcl_{it-1} + \beta_2 \ln w_{it-1} + \beta_3 \ln acrd_{it-1} + \beta_4 \ln prd_{it-1} + \beta_5 \ln nprd_{it-1} + \beta_6 \ln dist_i + \beta_7 \ln sd_i + \mu_i + \eta_{it} \quad (1)$$

Although equations (1) and (2) represent simple models, their estimation raises several important econometric issues. Both equations are estimated using panel-data for small number of states and large time series (8 states and 19 years), which makes our data similar to data sets used in estimations of growth country studies and political science statistic applications.

We assume the existence of significant fixed effects even when we take into account state specific variables such as soil quality and distance from main markets. Several other factors such as state inherent population ability, rain fall, climate, vegetation cover, slopes, public infrastructure, and other factors could explain different crop area and cattle head density. Since these omitted factors are likely to be correlated with included variables such as rural credit, roads and land prices, the omission of any of these variables would generate biased coefficients under OLS estimation.

The advantage of working with panel-data is that such fixed-effects can be wiped-out using a least square dummy variable (LSDV) model. We believe that controlling for non-observed fixed characteristics for each state will generate more precise estimates of the causes of land clearing expansion. Of course, there is a disadvantage of using a fixed-effect model; we cannot estimate directly the effect of soil quality and distance to main markets on the planted area and cattle density.[14]

Another important issue is the existence of non-spherical error covariance matrices. The type of data used — time series cross section (TSCS) — is generally characterized by groupwise heterocedasticity, panel correlation and autocorrelation. These issues are generally not emphasized in econometric applications with large *N* and small *T*. Nonetheless, models with small *N* and large *T*, common in political science studies, usually require appropriate variance-covariance matrix in order to make correct inference and hypothesis testing.

The traditional correction for auto-regressive processes and correlation between panels, generally known as the Parks method, uses a FGLS estimator to compute adequate standard errors. Asymptotically, this solution will generate unbiased and consistent estimates of parameters and standard errors. Nonetheless, in finite samples, especially those usually used by political scientist, where *T* varies from 15 to 40, Beck and Katz (1995*a*) find that this method would seriously under-estimate standard errors generating wrong inference. Usually this method would tend to over-reject the null hypothesis that specific parameters are equal to zero.

[14] There are indirect methods of retrieving such estimates.

An alternative method, the panel corrected standard error (PCSE) is proposed by Beck and Katz (1995*a*) suggesting that it is a more accurate estimator of standard errors. In a different article, Beck and Katz (1995*b*) compare their estimator with Kmenta (1986) cross-sectionally heterocedastic and timewise autocorrelated (CHTA) model. They conclude that the weighting procedure for eliminating heterocedasticity is only worth if it is a real problem and that for modeling dynamics, the use of a lagged-dependent variable is highly preferred than the FGLS model. Beck and Katz (1995*b*) argue strongly in favor of using an OLS estimator with a lagged dependent variable and PCSE. They emphasize that the IV estimator for removing the correlation between the lagged dependent variable and the error term should only be used if there is really the presence of strong serial correlation.[15]

Another significant point in the estimation procedure is related to the price of land. It is hard to assume that perfect functioning land markets exist in the whole Amazon. Some regions have weak markets and even no markets (open access). This is exactly one of the causes of deforestation. Therefore introducing the market land price seems like a strong assumption based on our model. Nonetheless, in regions where land markets are developed, an increase in the price of land would induce a reduction in the demand for land as a factor of production and consequently a decrease in land clearing. If land is just used as a production factor in a static context, then a negative relationship between the land price and the amount of cleared land is expected. Nevertheless, our model indicates that a higher expected value of land will generate further land clearing.[16] The first effect occurs through the demand for cleared land while the latter occurs through the supply of deforested land. That is, by privatizing the land, prices will increase from zero (open access) to some positive value. Hence, an increase in the price of land can be a signal for increasing clearing and supplying additional deforested land. Therefore, we cannot assume *a priori* a specific sign for the relationship between cleared land and land price.

An extra difficulty in the estimation procedure is related to simultaneity. Since we are estimating an assumed reduced form of a demand and supply system of agriculture cleared land, the price of land could be correlated with the error term.[17] In order to identify our reduced form demand equation, we would need a cost-shifting variable that can serve as an instrument for land price. As it is well known, this variable has to be correlated with land price and not correlated with the error term. Nevertheless, in practice finding a suitable instrument is not an

[15] See Arellano and Bond (1991) for the IV estimator in the presence of lagged dependent variable and FE.

[16] Moreover, an increase in the price of land diminishes the possibility of poorer farmers to buy land creating incentives for penetration into open access areas.

[17] One exception for this problem would be if the demand and supply are undertaken by the same economic agent, as occurs in some regions of the Amazon.

easy task.[18] To diminish this problem, we use the lagged value of the land price as an explanatory variable for the cleared land and cattle head. Thus, in our model, farmers are assumed to decide how much cropland would be used in the beginning of the period and if they decide to use more land, they would take the purchase decision in the beginning of the period depending on previous period prices.

Using current rural wages could also cause simultaneity problems. An increase in the planted area is likely to generate an additional demand for rural labor that would increase the rural wage rate. A solution for this problem would be to find a valid instrumental variable for rural wage as well, but similarly to the case of the land price, such instrumental variable is not available. We choose for the same strategy using the rural wage from last period as an explanatory variable for current planted area.

The problem of simultaneity is also important for the other variables such as credit and roads. It is hard to define the right causality between credit and crop area since more rural-credit creates incentives for increasing the crop area, but usually land is used as collateral and a higher proportion of crop area would induce a larger amount of rural credit. The same is true for roads since the demand for new roads could be generated in places where the crop area is large and there is a necessity of distribution network. In order to avoid reversal causality effects and simultaneity we prefer to include both credit and road variables using one period lag.

4 - THE DATA

In order to analyze the causes of land clearing expansion in the Brazilian Amazon we use state level data from 1980 to 1998 for eight states considered part of the Amazon ecosystem: Acre, Amazonas, Goiás, Maranhão, Mato Grosso, Pará, Rondônia and Roraima. The state of Amapá, although part of the Amazon, is not included in our analysis due to the lack of complete data on land prices, cattle prices and wages. Oppositely, the states of Maranhão and Goiás are completely included, although only parts of them are considered to be on the Amazon ecosystem. Moreover, the state of Goiás, which was separated into the states of Goiás and Tocantins in 1988, is also included entirely since it was not possible to obtain data for some variables for Tocantins alone prior to 1988. For the years after 1988, we combined the data for Goiás and Tocantins.

Our aim is to estimate the causes of the expansion of the deforestation. Since the data on the extension of deforestation measured by satellite, for all states of the Amazon, is only available after 1988, we approximate the agro-pastoral frontier

[18] For the Amazonian context, a variable which reflects the property right structure could be used as an instrument. We would expect property right structure to affect the behavior of land clearing, but not the demand for agriculture land. In a reduced form estimation, the property right structure would only affect the equilibrium amount of cleared land through its effect on the price of land. Although such a variable is available from the agriculture census, it is not available for all the years we are using.

evolution by analyzing the change in the proportion of crop area and the density of cattle head through time. It is important to note the difference from the methodology undertaken by Reis and Guzmán (1993), Reis (1996) and Andersen *et al.* (1996) that used census data at the municipality level and estimated the cleared area as cropland plus pasture land and planted forest. Since the agriculture census is not available yearly, we opted for using annual data, but losing information on the extension of pastureland. Our study also differs from Andersen, Granger and Reis (1997) who estimated the probability of forestland being converted into crop area or pastureland.

Each indirect deforestation source is analyzed in a separate regression. Data for crop area was obtained from the *Pesquisa Agrícola Municipal* (PAM) and the data for cattle head was taken from the *Pesquisa Pecuária Municipal* (PPM), both surveys are undertaken yearly by the IBGE at the municipal level. Nevertheless, since economic variables such as prices, wages, credit and roads are only available annually, we aggregated the municipal information. There are substantial differences between the results reported by the PAM and PPM when compared to the agriculture census. Since the census is a more detailed survey, we will expect it to be more precise with respect to estimated crop area. Nevertheless, the PAM and the PPM are the only annual agriculture surveys available, and although we observe its limitations and interpret the results obtained here with caution, they are the best source we can work with.

The price of agriculture products was calculated using a moving base Laspeyres index. Two types of indices were constructed: one using all products and another using only the five most important products for each state.[19] The price of each product was obtained implicitly from the PAM by dividing the reported value of production by the quantity produced of each crop. The indexes were then deflated by the general price index (IGP-OG) with a 1994 = 100 base.

Land prices were obtained from the Fundação Getulio Vargas (FGV) for crop area and pastureland. Prices are available by semester and an average was calculated in order to obtain annual figures. The price of land given in Real per hectare were then deflated and expressed in 1994 currency. Rural wages for permanent workers were also obtained from the FGV database.[20] Monthly wages were averaged to get annual figures and then deflated in order to obtain real wages in terms of 1994 currency.

For both land prices and rural wages, we have missing variables for five observations. Two alternatives were used to complete the series. First, a linear interpolation was used between the years for which data was available. Second, we analyzed the evolution of the missing variables in neighbor states and assumed

[19] The most important products were ranked according to crop area and production. Both categorizations yielded approximately the same results.

[20] Similar calculations were undertaken for temporary workers, but did not introduce any significant changes in our results.

that the variables behaved as an average of the change in neighbor states. We undertook a simple comparison of both strategies for years where data was available and find that the first methodology was preferred yielding more accurate estimations.

The extension of paved and non-paved roads was obtained from the Geipot statistical yearbook. The yearbook provides data on the extension of paved and unpaved roads in Km for all Brazilian states. For 1994 and 1996, the data was not available for some states and we undertook a linear interpolation between the available years. It is important to note that due to depreciation and lack of investment the extension of roads decrease in some periods.

Data on soil quality was obtained from soil maps available from the IBGE tabulated in the Desmat dataset.[21] The soil quality variable was calculated as the percentage area of each state that have soils considered of regular to high quality. This variable is imperfectly measured due to the aggregation of soil types that made impossible to separate some type of medium quality soils from high quality soils.

Another important variable is the distance from the main market that is used as a proxy for transportation costs. It was calculated as the distance of each state capital to the national capital Brasilia.

Finally, government agriculture and livestock credit was obtained from the Central Bank Rural Credit Annual Yearbook. It includes total rural credit that was granted by government institutions for rural activities. Two adjustments were undertaken on total rural credit figures. For agriculture credit, we subtracted credit given for extractive activities that we think do not influence the crop choice. For livestock credit, we subtracted all credit granted for other activities other than cattle ranching. Both credit variables were then converted to 1994 currency and deflated by the IGP-OG.

5 - ESTIMATION RESULTS

We estimate equations (1) and (2) separately. Although it is widely agreed that deforestation agents first use the land for temporary crops and then introduce cattle, it was not possible to introduce a structural approach due to the difference in the type our data (we do not have the area devoted for cattle, only the number of cattle heads).

Both equations are estimated as a function of four types of variables: output and input prices, government credit, road availability, geographical variables (distance to the market and the proportion of high quality soil). Of course, variables that do

[21] We thank Eustáquio Reis for making this data available. For a description of the Desmat dataset see Andersen, Granger and Reis (1997).

not vary over time (distance and high quality soil) drop out when we estimate the fixed-effect model. For each equation, we estimate alternative specifications with all the available explanatory variables and excluding non-significant variables.

As mentioned before, some deforestation econometric models use the rural population density as an explanatory variable. We expect its effects on land use decisions to be captured in wages and land prices. As expected, after including other variables, rural population density was not found to be significant and was not included in final estimations.

We estimate both equations by OLS, fixed-effects (FE), random-effects (RE) and panel corrected standard error (PCSE) methods taking into account group heterocedasticity, panel correlation and autocorrelation.

5.1 - Estimation Results for the Cattle Head Density

The results for the regression on the behavior of cattle head density are reported in Table 5. It is important to note that for cattle ranching, we do not have data on land use and we employ instead, the cattle head density as a proxy for pastureland expansion.[22]

The dependent variable is the log of the density of cattle head (number of cattle heads divided by the state area) and the independent variables used are the price of pasture land, the price of cattle head, density of government credit for cattle, density of paved roads, density of non-paved roads, distance to federal capital and the proportion of high quality soil. All variables are used in logarithmic terms and all covariates are lagged one period in order to decrease the chances of endogeneity, as mentioned in Section 4. Distance to federal capital and the proportion of quality soil are fixed variables that disappear in the fixed effect estimations.

The price of beef is likely to be an important variable to explain the evolution of cattle head, but state level data is not available for the Amazon. We included this variable varying only through time, but due to its high correlation with the price of cattle head, it was not found to be significant. Another variable that was tested was the rural wage. Since cattle's ranching is a land intensive activity (relative to labor), we would not expect changes in the rural wage rate to determine the number of cattle heads. We estimated the model including wage rate in our specification and as expected, it was not found to be significant in any estimation as well. Another specification that was used was a two-way fixed effect model. None of the time dummies was found to be statistically significant and was excluded from the presented model.

[22] Although we know this is a far from perfect proxy due to the intensification of the cattle-ranching activity in some states of the Amazon, we hope to obtain an approximate answer for the pattern of deforestation dynamics driven by the cattle ranching activity. Similar analysis was undertaken by Barbier and Burgess (1996).

On the first two columns of Table 5 we present estimates of the OLS model. All the variables are statistically significant, although the price of pastureland has an unexpected positive sign. The OLS model explains a large portion of the variance in the density of cattle head (R^2 = 0.91). The simple OLS estimation does not take into account fixed geographical characteristics. Once we control for geographical variables such as distance and soil quality, the price of land turns out to be non-significant with all the other variables being significant. The introduction of these two variables improves only slightly the fit of the regression increasing the R^2 by 0.03. The OLS results suggest that cattle head density increases with lower cattle head prices; larger amount of credit, more paved and unpaved roads, smaller distance from the federal capital and higher quality soil.

Table 5
Determinants of Cattle Head Density in the Brazilian Amazon: OLS and FE Results

	OLS		FE	
	(1)	(2)	(3)	(4)
Ln (Price of Cattle-Head) $_{t-1}$	-0.498	-0.375	-0.516	-0.468
	(0.126)**	(0.100)**	(0.085)**	(0.074)**
Ln (Price of Pasture Land) $_{t-1}$	0.223	0.012	0.032	
	(0.073)**	(0.073)	(0.064)	
Ln (Cattle Credit Density) $_{t-1}$	0.166	0.070	0.027	
	(0.047)**	(0.034)*	(0.023)	
Ln (Paved Road Density) $_{t-1}$	0.117	0.216	0.156	0.163
	(0.050)*	(0.048)**	(0.050)**	(0.050)**
Ln (Unpaved Road Density) $_{t-1}$	0.638	0.403	0.214	0.213
	(0.052)**	(0.043)**	(0.049)**	(0.049)**
Ln (Distance)		-0.644		
		(0.088)**		
Ln (Prop. of High Quality Soil)		0.233		
		(0.024)**		
Constant	3.084	9.734	3.286	3.560
	(0.549)**	(0.971)**	(0.449)**	(0.249)**
Observations	152	152	152	152
R^2	0.91	0.94	0.63	0.63

*Note: The dependent variable is the log of cattle head density. Robust standard errors in parentheses for OLS, Standard errors are in parentheses. * Indicates variables significant at 5% level and ** indicates variables significant at the 1% level. The R^2 for the FE is the within R^2. The period used is 1980/98 and the eight states included in the regression are AC, AM, MA, MT, PA, RO, RR .*

Nonetheless, if we believe the existence of important regional effects apart from distance and soil quality, the previous pooled OLS estimators would be biased and inconsistent. Alternatively, we estimate the model using a fixed-effect (FE) model which controls for these other fixed state characteristics.

Once we include dummies for states, the density of government credit is not found to be statistically significant. Even after we take out the price of pastureland, credit density is still non-significant. We also tried specifications with the price of land taking out the price of cattle head, but the price of land and credit were not significant in all combination of specifications. Therefore, in column (4) we present the results for the FE including only the significant variables.

The three significant variables that explain the evolution of the density of cattle head in the Amazon are the price of cattle head, the density of unpaved roads and the density of paved roads. All three variables are statistically significant at the 1% level and have the expected sign. We also note that the coefficient value on the price of cattle increases and the coefficients of the two road variables decrease once we use fixed effects instead of the two geographical variables. This suggests that unobserved fixed effects are negatively correlated with the price of cattle head and positively correlated with the two road variables.

A decrease in the price of cattle head of 1% increases the density of cattle head by 0.47%. Both increases in the density of paved and unpaved roads are associated with an increase in density of cattle head. The elasticity of paved roads is 0.16 while the elasticity of unpaved roads is 0.21. These results seem to indicate that unpaved roads have a larger effect on the adoption of a larger stock of cattle than paved roads. However, this difference decreases once we account for fixed effects. The importance of using fixed effects instead of a simple OLS is inspected with an *F*-test. For the complete specification, we reject the null hypothesis that all fixed effects are zero with an $F(7,139) = 31.95$ while for the second specification we reject the null hypothesis with an $F(7,140) = 36.37$.

An additional model is estimated assuming that specific state level effects are random instead of fixed. The advantage of the random effect model is based on efficiency criteria. The random effects transformation removes less of the variation due to differences in means among units than the fixed effect transformation does, preserving more of the information in the data. Therefore, it can be shown that the random effect transformation is more efficient, at least when the assumptions of the random effects model are satisfied (unit-specific errors f_i are uncorrelated with other regressors in the model). However, if they are correlated, the estimates are inconsistent. The fixed effects model does not require such assumption as they are viewed as the coefficients of regular dummy variables that are allowed to covary with other regressors. The well-known Hausman test is used to decide which estimator is more appropriate for fitting our model. For the complete cattle-head model the test-statistic for the Hausman test is equal to 87.4 rejecting the null hypothesis of zero correlation and endorsing the use of the fixed-effect model.

Additional test were used for checking the robustness of the FE model. A modified Wald test for groupwise heteroskedasticity is used in both fixed effect models rejecting the null hypothesis of homocedasticity for both estimations ($X^2(8) = 405.27$ for the first specification and $X^2(8) = 345.17$ for the second). A Breusch-Pagan LM test was used to inspect the possibility of cross-section independence. Based on the results, we cannot reject the null hypothesis of independence (values for the test are $X^2(28) = 25.92$ and $X^2(28) = 34.22$).

An additional issue that comes out, specially with a long time series is the possibility of serial-correlation. Since we use annual data and all variables are lagged, there is a high chance that a shock in one period propagates into the next period causing serial-correlation. We tested for serial-correlation in our fixed-effect specifications and found evidence of autocorrelation. For the model presented in column (3), the LM test rejects the null hypothesis of no autocorrelation, that is, that either rho = 0 if residuals are AR(1) (LM = 37.72) or that lambda = 0 if residuals are MA(1) (LM5 = 6.14).

Following the proposed estimation method discussed in Beck and Katz (1995), we present additional estimations correcting the standard errors obtained in our regressions for heterocedasticity, panel correlation and autocorrelation. This panel corrected standard errors (PCSE) methodology is found to generate correct standard errors allowing for accurate inference. Three type of PCSE models are presented: a simple OLS estimation with correct standard errors, an OLS with correct standard errors controlling for distance and soil-quality and PCSE model with state fixed-effects. All models assume a unique AR(1) autocorrelation coefficient which is estimated in a first stage OLS regression. After that, a Prais-Wisten method is used to account for the assumed AR(1) process.[23] The results are presented in Table 6.

Table 6

Determinants of Cattle Head Density in the Brazilian Amazon: PCSE Estimations

Independent Variable	OLS/PCSE		FE/PCSE	
Ln (Price of cattle-head) $_{t-1}$	-0.296	-0.204	-0.203	-0.311
	(0.102)**	(0.063)**	(0.061)**	(0.064)**
Ln (Price of pasture land) $_{t-1}$	0.065	-0.020		0.004
	(0.053)	(0.034)		(0.036)
Ln (Cattle credit density) $_{t-1}$	0.067	0.018		0.012
	(0.023)**	(0.014)		(0.015)
Ln (Paved road density) $_{t-1}$	0.250	0.219	0.221	0.175
	(0.056)**	(0.054)**	(0.054)**	(0.060)**
Ln (Unpaved road density) $_{t-1}$	0.525	0.188	0.198	0.167
	(0.059)**	(0.049)**	(0.050)**	(0.050)**
Ln (Distance)		-1.070	-1.071	
		(0.111)**	(0.102)**	
Ln (Prop. of High Quality Soil)		0.358	0.361	
		(0.035)**	(0.033)**	
Constant	4.568	12.725	12.735	3.481
	(0.450)**	(0.773)**	(0.588)**	(0.423)**
State Dummies	No	No	No	Yes
R^2	0.73	0.78	0.79	0.91
ρ	0.70	0.80	0.79	0.63
Observations	152	152	152	152

*Note: The dependent variable is the log of cattle head density. Robust standard errors in parentheses for OLS, Standard errors are in parentheses. * Indicates variables significant at 5% level and ** indicates variables significant at the 1% level. The R^2 for the FE is the within R^2. The period used is 1980/98 and the eight states included in the regression are AC, AM, MA, MT, PA, RO, RR .*

[23] For more details on the PCSE see [Beck and Katz (1995*a* and *b*)].

The first two columns present OLS results. In column (1) we estimate the simple OLS while in column (2) we control for geographical characteristics. We observe that once we control for distance and soil quality and use the corrected standard errors, credit is not significant for explaining differences in cattle head density. This result is robust and is found if we control for unobserved fixed characteristics with dummy variables. The other significant variables (price of cattle and roads) continue to be significant with a slight change in the estimated coefficient due to the Prais-Winsten transformation.

The presence of serial correlation is confirmed from the estimations of the correlation coefficient between 0.70 and 0.80. The fit of the equations with the Prais-Winsten transformation decreases, but remain acceptable with an R^2 of 0.80 for the OLS/PCSE and 0.63 for the FE/PCSE.

In sum, the differences and evolution of cattle head density among states in the Amazon are driven by the price of cattle head and paved and unpaved roads. A decrease in 1% in the price of cattle head increases the density of cattle head in 0.31% while the elasticity for paved and unpaved roads is found to be equal with an estimated value of 0.17.

5.2 - Estimation Results for the Agriculture Cleared Area

For the agriculture cleared land density, we introduce two additional variables: the price of agriculture products (a Laspeyres index) and the rural wage. We would expect an increase in output prices and a decrease in real rural wages to increase the proportion of crop area. Similar to what was done for the cattle head estimation, we first present the OLS and fixed-effects estimations in Table 7.

For the OLS estimation, three specifications are presented in columns (1), (2) and (3). The price of agriculture output is not found to be statistically significant in both specifications (1) and (2) and therefore it is excluded from specification (3). All the other variables included in the first model are significant, most of them at the 1% level. Nonetheless, the sign of rural wage is puzzling since we would expect a higher cost of labor to decrease the extension of crop area. One possible explanation for this result is the correlation of rural wage with omitted variables such as distance and soil quality. In column (2) we take into account these two factors and the rural wage variable turns out to be non-significant, together with the price of land and the distance. This result is unchanged if we take out the price of agriculture output as presented in column (3).

In the OLS model, the elasticity of agriculture credit is estimated in 0.30 while the elasticities for paved and unpaved roads are estimated at 0.67 and 0.28 respectively. Surprisingly, neither the price of cropland nor rural wage is significant. Greater distance, included in the third OLS specification, is likely to increase transport costs and decrease profitability, but it is not found to be significant as well. Even tough the OLS model explains a large part of the variance in the proportion of crop area with agriculture credit, paved roads, unpaved roads and soil quality ($R^2 = 0.9$).

Table 7

Determinants of Crop Area in the Brazilian Amazon: OLS and FE Estimations

	OLS			FE	
	(1)	(2)	(3)	(4)	(5)
Ln (Price of Agriculture Products) $_{t-1}$	0.004	0.148		-0.040	
	(0.101)	(0.080)		(0.054)	
Ln (Price of Crop Land) $_{t-1}$	-0.276	-0.055	-0.071	-0.090	-0.092
	(0.073)**	(0.101)	(0.102)	(0.060)	(0.060)
Ln (Rural Wage) $_{t-1}$	0.532	0.001	0.060	-0.190	-0.207
	(0.205)*	(0.216)	(0.209)	(0.120)	(0.117)
Ln (Agriculture Credit Density) $_{t-1}$	0.237	0.292	0.300	0.075	0.076
	(0.044)**	(0.046)**	(0.048)**	(0.028)**	(0.028)**
Ln (Paved Road Density) $_{t-1}$	0.550	0.656	0.671	0.190	0.204
	(0.074)**	(0.071)**	(0.068)**	(0.054)**	(0.050)**
Ln (Unpaved Road Density) $_{t-1}$	0.478	0.311	0.284	0.085	0.082
	(0.065)**	(0.067)**	(0.065)**	(0.051)	(0.051)
Ln (Distance)		0.319	0.331		
		(0.171)	(0.176)		
Ln (Prop. High Quality Soil)		0.232	0.214		
		(0.037)**	(0.038)**		
Constant	3.006	1.936	2.184	2.628	2.623
	(0.782)**	-1.516	-1.566	(0.439)**	(0.438)**
Observations	152	152	152	152	152
R-squared	0.87	0.90	0.90	0.30	0.30

*Note: The dependent variable is the log of cattle head density. Standard errors are in parentheses. * Indicates variables significant at 5% level and ** indicates variables significant at the 1% level. The period used is 1980/98 and the eight states included in the regression are AC, AM, MA, MT, PA, RO, RR .*

Although we controlled for some geographical and ecological characteristics in our OLS results, we are likely to have two types of problems with the pooled OLS estimation. First, other type of fixed-effects between states such as climate conditions, which are likely to be correlated with included variables, may exist. Thus, the OLS estimation would generate biased and inconsistent coefficients. Second, standard errors generated by the OLS do not take into account typical anomalies of TSCS data such as panel heterocedasticity, panel correlation and autocorrelation. Thus, standard errors used for inference could be biased.

We try to correct for these problems sequentially. First, we control for omitted fixed state characteristics using the least square dummy variable (LSDV) estimator. This FE model control for the missing characteristics by introducing a dummy variable for each state included in the regression. The results for this second model are presented in columns (4) and (5).

The importance of the FE are confirmed with an *F*-test ($F(7,138) = 78.97$) rejecting the hypothesis that the fixed-effects are jointly zero. For the other specifications, the value of the *F*-test is similar, confirming the existence of significant fixed-effects that should be taken into account.

We would expect fixed effects to include agro-ecological and geographical characteristics that are fixed through time and are not restricted to type of soil and distance. The comparison between the OLS specification including distance and soil quality in column (3) and the second specification of the FE in column (5) differ substantially in the estimated coefficients for credit and roads. Once we take into account other important fixed characteristics of states, the estimated coefficients for agriculture credit and paved roads decrease substantially suggesting that unobserved fixed effects might be positively correlated with these variables. Additionally, unpaved roads turns out to be significant only at the 10% level.

The results from the FE model suggest that agriculture credit and paved road density are the main factors that explain the proportion of crop areas (unpaved road density is only significant only at 10% level). An increase in 1% in the density of agriculture credit is associated with an increase in of 0.075% of the proportion of crop area while the coefficient for paved road density states that an increase in 1% the paved road density is associated with an increase of 0.19% of the proportion of crop area. The specification presented in column (5) leaves out the price of agriculture product and the results obtained are quite similar: credit and paved roads determine the proportion of crop area.

An alternative model was used to estimate the previous relationship by assuming random effects. If the correlation between the error term and the included variables were zero, the RE would generate estimates that are more efficient. We test this using the Hausman test. The test rejects the null hypothesis of zero correlation between the random effects and the regressors (H = 47.38 for the complete model). This test value indicates that the FE model presented would produce consistent estimates of our desired parameters.

The OLS and FE models presented above were estimated without taking into account some particular characteristics of the TSCS dataset. Usually this type of data is characterized by correlation between panels, panel heterocedasticity and autocorrelation, especially if dynamics are not modeled correctly. All these properties would cause residuals to be biased and wrong standard errors would be used for inference. We tested the residuals obtained from the FE estimations for these three problems.

For all models, the modified Wald test for groupwise heteroskedasticity rejected the null hypothesis of constant variance across panels (chi2 (8) = 283.8 for the first FE model and chi2 (8) = 337.2 for the second). For testing for correlation between panels we use a Breusch-Pagan LM test of independence. The test values cannot reject the hypothesis that panels have independent residuals (chi2(28) = 38.4 Breusch-Pagan LM test of independence: chi2(28) = 33.5). The last test we undertake is for autocorrelation. Since we are not modeling the dynamics that are likely to exist in cropping activity, the residuals are likely to be dependent through time. The null hypothesis that either rho = 0 if residuals are AR(1) or that lambda = 0 if residuals are MA(1) are rejected based on the LM = 54.4 (asymptotically distributed as chisq(1)) and LM5 = 7.4 (asymptotically distributed as N(0,1)) respectively.

Following the PCSE estimation method employed previously, we present additional estimations correcting the standard errors for heterocedasticity, panel correlation and autocorrelation. Three type of PCSE models are presented: a simple OLS estimation with correct standard errors, an OLS with correct standard errors controlling for distance and soil-quality and PCSE model with state fixed-effects. All models assume a unique AR(1) autocorrelation coefficient which is estimated in a first stage OLS regression. After that, a Prais-Wisten method is used to account for the assumed AR(1) process.

The first interesting comparison to make from the results presented in Table 8 is between the previous OLS estimation (Table 7, column 1) and the OLS estimation with PCSE (Table 8, column 1). Once the model corrects standard errors for grouwise heterocedasticity and serial-correlation, the wage variable is not found to be significant anymore.

Table 8

Determinants of Crop Area in the Brazilian Amazon: Panel Corrected Standard Errors

Independent Variables	OLS/PCSE				FE/PCSE	
	(1)	(2)	(3)	(4)	(5)	(6)
Ln (Price of Agriculture Products) $_{t-1}$	0.009		0.056		0.013	
	(0.061)		(0.061)		(0.048)	
Ln (Price of Crop Land) $_{t-1}$	-0.132	-0.132	-0.175	-0.170	-0.122	-0.121
	(0.060)*	(0.060)*	(0.062)**	(0.062)**	(0.050)*	(0.050)*
Ln (Rural Wage) $_{t-1}$	0.104	0.104	0.117	0.115	0.050	0.051
	(0.115)	(0.115)	(0.119)	(0.117)	(0.094)	(0.094)
Ln (Agriculture Credit Density) $_{t-1}$	0.152	0.153	0.132	0.129	0.046	0.047
	(0.031)**	(0.031)**	(0.033)**	(0.032)**	(0.026)	(0.026)
Ln (Paved Road Density) $_{t-1}$	0.355	0.353	0.442	0.410	0.161	0.157
	(0.094)**	(0.093)**	(0.090)**	(0.091)**	(0.073)*	(0.070)*
Ln (Unpaved Road Density) $_{t-1}$	0.349	0.350	0.223	0.219	0.119	0.121
	(0.074)**	(0.074)**	(0.077)**	(0.077)**	(0.055)*	(0.054)*
Ln (Distance)			-0.626	-0.667		
			(0.184)**	(0.184)**		
Ln (Prop. High Quality Soil)			0.297	0.291		
			(0.062)**	(0.062)**		
Constant	2.925	2.948	8.626	8.931	2.326	2.349
	(0.674)**	(0.658)**	(1.302)**	(1.294)**	(0.549)**	(0.547)**
State Fixed-Effects	No	No	No	No	Yes	Yes
R^2	0.50	0.50	0.72	0.70	0.90	0.90
ρ	0.83	0.83	0.74	0.76	0.65	0.65
Observations	152	152	152	152	152	152

*Standard errors in parentheses. * Significant at 5% and ** significant at 1%.*

Nonetheless, as described previously, these results are likely to be biased due to the existence of important state level fixed effects. These FE are corrected first by introducing distance and soil quality and alternatively by introducing state dummy variables.

Differently from the previous OLS results, with the corrected standard errors both distance and soil quality are found to be significant to explain the proportion of crop area (columns 3 and 4). The elasticity of distance is found to be large with an increase in 1% in the km distance from the federal capital, the proportion of crop area decreases by 0.66% (once we leave out the price of agriculture products). The elasticity found for soil implies that an increase in 1% in the proportion of medium to high quality soil increases the proportion of crop area by 0.29%.

The price of cropland, that was not found to be significant once distance and soil were introduced in Table 7, is now significant with an elasticity of -0.17. The other three important variables — credit, paved roads and unpaved roads — are still significant, but their estimated elasticities are lower than previously estimated.

Instead of including distance and soil quality to control for geographical characteristics, we include a state fixed effect. The main effect of using FE is to lower the estimated coefficient of agriculture credit (which is only significant at the 10% level), paved roads and unpaved roads. This effect was shown to occur in the results presented in Table 7 as well and is probably due to the positive correlation between the unobserved fixed effects and these three variables.

What are then the main differences between FE estimations with and without PCSE? The first main issue is related to the importance of the price of land. Once we correct the standard errors, the price of cropland is found to be significant in explaining the proportion of crop area. A 1% increase in the price of cropland is found to decrease the proportion of cropland in 0.12%. Unpaved roads, which were also not found to be significant, are now significantly different from zero once we use the corrected standard errors. Agriculture credit is only significant at the 10% level and the estimated elasticity is lower than the previously found 0.067.

6 - CONCLUDING REMARKS

Deforestation in the Brazilian Amazon is a complex phenomenon. The forest conversion process is undertaken by several economic agents such as family farmers, large cattle-ranchers, frontier settlers, land speculators and logging companies. Moreover, the process is influenced by markets as well as institutions and government policies. Therefore modeling its dynamics is not an easy task.

We use a simple model of the cleared land market in order to motivate our econometric estimation. We advanced beyond previous studies in two issues.

First, we use an annual panel-data at the state level in order to measure the causes of agriculture land clearing in the Brazilian Amazon. Moreover, previous econometric studies of the causes of deforestation had only used data until 1985. Instead, we analyze the evolution of cattle head density and proportion of crop area for the 1980/98 period. Second, we use different estimation methods including the PCSE methodology in order to obtain standard errors that are robust to Time Series-Cross-Section characteristics such as group heterocedasticity and autocorrelation.

The conversion of forest into pastureland is still the main source of deforestation in the region. This is found both by analyzing the land use pattern comparing the agriculture census of 1985 and 1996 and by observing the evolution of the cattle-herd in the Amazon. Nevertheless, such an observation does not explain why cattle formation has been increasing.

With an average of 0.3 animals per hectare in the whole region [Chomitz and Thomas (2000)] and an internal rate of return for the activity that varies between 4% to 14% [Schneider *et al*. (2000)], it is not easy to understand its dynamics only in terms of economic returns. Additional incentives must exist in order to generate such a massive investment in cattle ranching. Of course, part of this process is explained by large government subsidies and the need to use the land for acquiring property rights. Other explanations such as insurance and risk diversification are also possible and should be examined in future research using household level data.

Based on our estimations, we find that decreasing prices of cattle had allowed farmers to increase their stock. Government policies, especially road construction, are directly related to cattle head expansion in the region. The construction of a paved road network has created the access to potential markets and decreased transport costs. Nevertheless, our estimations present evidence that unpaved roads are also responsible for a substantial portion of cattle-head expansion, probably more associated with smaller farmers' activities.

Walker, Moran and Anselin (2000) have found evidence that smaller farmers are responsible for a substantial portion of deforestation in the Amazon adopting pasture and cattle ranching activities. Surprisingly, the decrease in the price of pastureland does not appear to have helped small and large owners to obtain land through markets and develop cattle related activity.

The expansion of crop area density, although a smaller source of deforestation in the Amazon, is also important since part of the land conversion process is undertaken through nutrient mining. Farmers first convert forest into crop area, use the soil as much as they can and then, when productivity has been sufficiently reduced by nutrient mining, convert the area to pasture.

Changes in the demand for agriculture-cleared area seem to be more affected by economic variables. Although output prices and rural wages are not found to be significant in explaining differences of crop areas, land prices are found to be significant in explaining agriculture land clearing, once we take into account the existence of groupwise heterocedasticity and serial-correlation.

The price of land is expected to play a dual-role in deforestation incentives. A higher price of land decreases the demand for land as an input and therefore decreases the incentives for agriculture land clearing. In contrast, a higher price of land creates a wealth for deforestation agents by increasing expected prices generating sustained speculative processes. This effect can only be picked up in models that include time-series variables since price change dynamics are not incorporated in cross-section spatial models such as Chomitz and Gray (1996) and Pfaff (1999). The price of land is only found to be significant in explaining the proportion of crop area once we take into account serial-correlation. Then it has a negative sign that means that a higher price of land would reduce the demand for additional crop areas.

The lack of response of agriculture clearing to output prices was also found by Cropper, Griffiths and Mani (1999) in Thailand. They test the effect of the prices of rice and other crops such as Cassava and Maize on land clearing expansion and do not find any evidence of incentives for deforestation created by agriculture output prices variation. In our case, one possible explanation for this result is the existence of subsistence agriculture shifting cultivation, which do not have access to major markets, and do not respond to output prices. Nonetheless, with such aggregate data we can only hypothesize about this issue.

Government credit for agriculture, differently from credit for cattle, is found to be marginally significant in explaining variation of crop areas. Although rural government credit disbursements have been reduced for the Amazon region during the last decade, our results suggest that it still constitutes an important incentive for cropping in many areas. This result is related to similar findings from the work of Andersen, Granger and Reis (1997) and Pfaff (1999) that found a significant effect of credit in deforestation incentives.

Paved roads, as expected, are also found to generate agriculture land clearing. Road construction decrease the transportation costs of inputs and outputs and create networks for production distribution. Roads also facilitate migration process and integrate rural labor markets. All this effects increase incentives for land clearing. Additionally, non-paved roads are also significant in explaining the evolution of crop area. This result is important due to the growing timber logging activities in the Amazon which open small non-paved roads to extract timber creating the possibility for new peasants' movements in the frontier.

Our results that introduce geographical variables show that the distance to the federal capital and soil quality are important to explain both the density of cattle head and the proportion of agriculture area. The expected negative sign is found for distance, implying that states that are far away in the frontier, controlling for other variables, have a lower cattle- head density. This effect can be capturing precipitation level which is quite important for a profitable agriculture and cattle activity and it is not included in our model. States localized more far away in the north have on average higher precipitation rates and a lower probability of succeeding with cattle-activities [Chomitz and Thomas (2000)].

Although the current study generates important insights on the deforestation process of the Brazilian Amazon, there are several data and methodological limitations. A better comprehension of the deforestation process would be obtained with more desegregated data, such at the municipal level, or even household units. Such data would enable the application of spatial econometric techniques which are crucial in understanding deforestation spatial distribution. Nevertheless, another important component of the deforestation process is dynamics. A dynamic model is needed in order to fully understand the effects of land prices, speculation and history dependence of previous settlements.

Another point is related to the proxies used for deforestation. It would be important to combine in a way undertaken by Pfaff (1999) local census data with satellite images in order to analyze both the spatial and dynamic distribution of deforestation. Nevertheless this type of data is not available yet under a large time-series with sufficient spatial distribution.

The contribution of logging to deforestation is another important issue which is not taken into account. A reliable database is needed in order to access the contribution of logging to deforestation and create environmental policies which are related to the sources of deforestation in the region. Institutional factors are also important, and the incorporation of property rights in econometric models should be undertaken in the future. The dynamics of the frontier can only be fully understood once such institutional effects are introduced in the model. Technology adoption and technical change are another important feature to be studied. An increase in technological change could either increase or decrease deforestation depending on the factors used and the type of technological change introduced. Therefore, understanding the effect of agriculture R&D on deforestation is crucial for sustainable policy formulations.

Even with such methodological and data limitations, the results found here are useful for policy recommendations. The results emphasize the importance of paved and unpaved roads in driving both the cattle ranching activity and the crop area expansion. The Brazilian government is proposing under the *Avança Brasil* program,[24] the construction of a network of paved roads in order to foster growth and development in the Amazon region. According to our results, the increase in 1% in the extension of paved roads per km^2 increases by 0.18% the density of cattle and 0.15% the proportion of crop area in the region. The elasticities of unpaved roads are lower, but quite significant with 0.17% for cattle density and 0.12% for crop area. This result is different from the Pfaff (1999) that obtain a negative coefficient for non-paved roads.

[24] See Nepstad *et al*. (2000) for an overview of the Avança Brasil project.

Moreover, we note that the impact of roads on cattle and crop area is overestimated if we do not take into account geographical effects such as distance to federal capital, soil quality and in the last estimation, fixed-effect.

Although we do not simulate the possible effects of the *Avança Brasil* program, this type of infrastructure policies, given the prevailing incentives and institutional background, are likely to generate a boom in the deforestation process while imposing serious doubts on the sustainable and equitable economic growth in the region.

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