Deforestation, Growth and Agglomeration Effects: Evidence from Agriculture in the Brazilian Amazon

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Abstract

The role of population growth and migration has been emphasized as a key variable to explain deforestation and land conversion in developing countries. The spatial distribution of human population and economic activities is remarkably uneven. At any geographical scale we find that different forms of agglomerations are pervasive. On the one hand, in central countries or regions, agglomeration is reflected in ‘large varieties of cities. On the other, less developed regions faces a dynamic process where new agglomerations form and develop as a result of frontier expansion. The recent literature on spatial economics has emphasized the role of agglomeration and clustering of economic activities as fundamental causes of an enhanced level of local economic performance, creating externalities that cause firms to grow faster and larger than they otherwise would do. However, very little has been done to examine the presence of agglomeration economies on economic performance of agricultural activities. In this paper we empirically examine whether an initial level of agglomeration impacts the subsequent economic growth and deforestation rates in the Brazilian Amazon. The regression estimates indicate that there is a significant non-linear association between the initial intensity of agglomeration with both growth and land conversion in subsequent periods.

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I. INTRODUCTION

The role of population growth and migration has been emphasized as a key variable to explain deforestation and land conversion in developing countries. In early studies a 'Malthusian' process is put forward to associate the growing demand for resources caused by larger populations in frontier areas (Myers 1980, Walker 2004). Recent empirical research has also focused on the role of population primarily as a measure for local demand and pressure over natural resources (Lugo et al 1981 , Allen and Barnes 1985 , Palo et al 1987, Rudel 1989, Cropper and Griffiths 1994, and Deacon 1994). The Brazilian Amazon is not an exception and population levels been part of all the empirical specifications in the same fashion (Reis and Guzman 1992, Reis and Margulis 1991, Pfaff 1999, Andersen and Reis 1997, Ferraz 2001, Andersen et al 2002). However, in none of these studies population size is put into a more analytical context connecting the theory of land use with the modern developments of spatial economics.

The spatial distribution of human population and economic activities is remarkably uneven. At any geographical scale we find that different forms of agglomerations are pervasive. At global level it is easy to see that income and output is concentrated in a small number of industrialised countries. However, spatial concentration within countries is equally important. On the one hand, in central countries or regions agglomeration is reflected in 'large varieties of cities as shown by the stability of urban hierarchy within most countries' (Fujita and Thisse 2002, p.2). On the other, less developed regions faces a dynamic process where new agglomerations form and develop as a result of frontier expansion.

The recent literature on spatial economics has emphasized the role of agglomeration and clustering of economic activities as fundamental causes of an enhanced level of local economic performance, creating externalities that cause firms to grow faster and larger than they otherwise would do[1]. So far the theoretical and empirical work on these subjects have focused on urban contexts looking at the existent relationships between firms and their capacity to generate positive externalities when in close proximity[2]. However, very little has been done to examine the presence of agglomeration economies on economic performance of agricultural activities. Nevertheless, provided that agglomeration of economic activity exist, in principle there is no reason to exclude less urbanised environments and more traditional activities from the impacts suggested by the arguments put forward by modern spatial economics and a number of cases are starting to become evident (Nadvi and Schmitz 1997, Schmitz 1999).

One important consideration in spatial economics is that the positive externalities generated by agglomerations could be offset to some degree by negative externalities due to congestion effects. Congestion is most likely in the densest agglomerations, so that it is an interesting empirical question to examine whether the balance of positive and negative externalities swings in favour of congestion effects at the higher levels of agglomeration. Again, congestion effects are typically associated with large urban areas but in principle, when broadly defined, smaller towns and even rural areas could face some sort of congestion effects negatively impacting growth and economic performance. A second fundamental idea lies on the relevance of transport costs for generating unequal patterns of distribution of economic activity. Here proximity to markets for both inputs and outputs are central to explain growth and development of local areas.

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[1] The richness of agglomeration diversity is often encountered within an urban hierarchy. On the one hand we find large metropolises, like New York, Tokyo, London or Paris, which are highly diversified. On the other, there are specialised towns and cities such as the so-called Italian districts and the Silicon Valley, or even factory towns like the Toyota City or the IBM's Armonk in New York. Agglomeration is also manifested in a very small spatial scale conforming the set up of inner cities. Agglomeration at this level take forms of commercial districts, like Soho in London, or of small agglomerations of theatres, restaurants and shops in the same neighbourhood or even in the same street. Agglomerationing must also be embodied in a shopping mall (Fujita and Thisse 2002, p.2)

[2] See Fujita et al 1999, Fujita and Thisse 2002, Baldwin et al 2004 for surveys of the theoretical literature. See Thisse and Henderson 2003 for an account of the empirical research.

When looking to rural areas in developing countries, the counterparts of economic growth and development are land use change and processes of deforestation. Absence of markets for biodiversity, ecosystem and climate stability, carbon repositories and environmental amenities have been listed as main causes for generating conversion rates higher than the socially optimum. In addition, elements responsible for boosting agricultural profitability are usually claimed as sources of deforestation. However, some level of deforestation would be expected anyway as a joint outcome of agricultural activities dependent on land as the main input. Accordingly, spatially specific characteristics such as access to markets, climate conditions and property rights structure represent the usual candidates for explaining the variation of deforestation rates throughout the regions (Barbier and Burgess, 2001). Therefore the positive economic effects generated by agglomerations might also result in negative outcomes in terms of environmental degradation. Thus, in order to understand whether agglomeration economies matter for rural areas in developing countries it is important to bring into the analysis the trade-off conservation-development.

The Brazilian Amazon is perhaps one of the most interesting regions for analysing eventual relationships between agglomeration economies, economic growth and deforestation. Firstly, the region encompasses 5 million square kilometres of land of which roughly 85% is still forested areas (see Andersen et al, 2002 for a brief description of the region). Secondly, agriculture, cattle ranching and other economic activities are unevenly distributed and rapidly expanding in many areas in the Amazon increasing the pressure over forests. Thirdly, low levels of development and poverty are serious problem in the region, suggesting that the spatial distribution of economic activity matters in both efficiency and equity grounds.

In this paper we empirically examine whether an initial level of agglomeration impacts the subsequent economic growth and deforestation rates in the Brazilian Amazon. We also test whether congestion effects at the higher levels of agglomeration limit these impacts by a non-linear relationship. Apart from these externality effects, there are a number of other factors that should necessarily be incorporated into models of growth and deforestation. We therefore introduce some ancillary variables in an attempt to capture the spatial specific characteristics of local areas and provide a more comprehensive explanation of our data. To summarize the structure of the paper, after an initial synopsis of theoretical issues, we then present the data used in the study and discuss the selection of variables. In the main section, spatial econometric models are estimated conditioning on the level of agglomeration and a set of other initial conditions, thus capturing spillover effects across area boundaries. The regression estimates indicate that there is a significant non-linear association between the initial intensity of agglomeration with both growth and land conversion in subsequent periods. We also find evidence of other factors associated with growth and land conversion.

II. DRIVERS OF DEFORESTATION

Different models, estimation methods, data sources, and periods of analysis have been used to try to identify the main factors driving deforestation in tropical areas (see Barbier and Burguess 2001, and Kaimowitz and Angelsen 1998, and Brown and Pearce 1994 for extensive reviews). Among them there are spatial regression models, which try to measure correlation between land use and other geo-referenced variables. These variables include distance from markets and transportation infrastructure, topography, soil quality, precipitation, population density, forest fragmentation and zoning categories. In addition socio-economic variables from census data have been incorporated to the models. Population is normally included in the models generating a direct demand for land through subsistence activities or making deforestation more profitable by pushing down the wage rates. The typical results generated by regional models suggest that landholders are most likely to convert forest to agricultural use where agriculture is more profitable which normally is associated to good access to markets and favourable environmental conditions for farming (Kaimowitz and Angelsen 1998).

The Brazilian Amazon is the focus of several of these studies (Pfaff 1999, Margulis, 2003, and Andersen et al 2002 are some of recent applications). We the remaining of this section we provide an account of their main findings and approaches. Early empirical studies for the Brazilian Amazon (Reis and Margulis 1991 and Reis and Guzman 1992) find that population density, road density, and crop area to be important determinants of their deforestation measure. Deforestation patterns in the Amazon are therefore primarily outcomes of economic decisions regarding alternative land uses.

The role of policy is discussed in many studies where road-building is alleged to be the most important contribution to deforestation. Secondly, subsidised credits and other fiscal incentives had been combined to increase the profitability of agricultural settlements. However, Andersen and Reis (1997) present evidence showing that only about a third of the deforestation occurred between 1970 and 1985 was due to "aggressive" development policies. According to their results 9.6 million out of 33 million hectares of deforestation can be attributed to road building or subsidised credit. Also, they suggest that 72% of the policy-induced deforestation in this period was due to roads and 28% related to credits or subsidies, indicating a much better trade-off in the second policy measure.

The dominant land use in the cleared land is pasture, accounting for more than three-quarters of the agricultural land. Chomitz and Thomas (2001) show that in average this land use presents very low productivity and labour absorption, indicating that may not be a socially optimal use. An interesting finding presented by these authors relates to the relationship between agricultural activities and levels of rain precipitation. Their multivariate analysis shows that the probability that the land is currently claimed, used for agriculture or for cattle declines substantially with the precipitation level, holding other factors constant.

Inspired by an economic theoretical framework and merging satellite with census data, Pfaff (1999) has empirically estimated a model aiming to assess the drivers of deforestation in the region. He finds that a number of variables suggested by his land-use model are significant and helps to explain land conversion. Among them are some environmental characteristics such as soil quality and vegetation, and variables impacting transport costs such as density of paved roads (in the county and in neighbouring counties). Moreover, he finds that population density does not have a significant effect on deforestation. This is a surprising result and goes against most of the studies mentioned above. Nevertheless population quadratic is significant and negative which he interprets as evidence that the first migrants have greater impacts than the later ones.

\Adopting a data driven approach Andersen et al (2002) have estimated models for different dependent variables including land clearing, rural and urban GDP, growth, rural and urban population growth, and cattle herd growth. With a set up encompassing spatial and temporal factors the authors come to the general conclusion that in addition to the spatial process of frontier maturation ‘many processes in the Amazon are now endogenously determined with growing centers of urban demand acting as a driving force behind many agricultural activities’(p. 149). Moreover, their regression analsysis also provide evidence about the role of cattle ranching and transport network on deforestation dynamics.

An important result from their model relates to the relationship between roads and land clearing. They find that both paved and unpaved roads are associated with more clearing. However, their models suggest that the connections between roads and deforestation are more complex than usually assumed. As the impact of paved roads is stronger in areas that have been already cleared the authors argue that the direction of causality is not clear but the models provide evidence that paved roads are associated with land intensive activities, typically part of the urban GDP, and unpaved roads associated to land extensive activities such as most of the agriculture carried out in the region.

It is clear from the studies mentioned above that in order to understand patterns of deforestation it is crucial to take into account local economic, social, demographic and environmental factors. This is particularly acute in the case of the Brazilian Amazon because of its characteristics with respect to the agrarian structure. On the one hand, it is well known that land is extremely concentrated in the region with 1% of properties concentrating around 50% of the agricultural land. It is not clear whether small establishments with less than 20 hectares have similar production systems, choose same location or pursue equal economic objectives of large farms with over 10,000 hectares. On the other, producers have different conditions regarding land ownership. Owners, renters, sharecroppers and squatters carry out agricultural activities in the region. They have different property rights and pay different prices for land use (See Andersen et al 2002 for a description of land use rights in the region).

Another issue that has been part of the political discussions regarding land use in the Amazon has to do with farm size and deforestation. Fearnside (1993) argues that it is not clear that small landholders are responsible for a large proportion of deforestation. However, since the policies providing the incentives for cattle ranchers to engage in large-scale land clearing have been scaled back or eliminated, the government claims that additional deforestation is primarily the work of small landholders. Fearnside (1993) concedes that small establishments do deforest land more intensively than large ones, however he criticizes the government's position as being politically motivated as a way to characterize environmentalists as being against the rights of poor people to improve their circumstances. He points out that some ranches still receive subsidies and many large establishments that continue to deforest land never received government incentives to begin with.

In addition to theoretical considerations, Fearnside (1993) offers data to support his position that in fact large landholders are still responsible for the lion's share of deforestation in the Amazon. He divides agricultural establishments into three categories: small (less than 100 ha), medium (between 100 and 1000 ha) and large establishments (over 1000 ha). Using data from the 1985 agricultural census and the 1990 and 1991 estimates of deforested land from LANDSAT satellite data from INPE, he shows that small farmers account for only 30% of the deforestation. His argument is largely descriptive: large establishments deforest more land in absolute terms than do small establishments because large establishments still occupy a much larger share of total land area than small establishments (62% versus 11%). Because small landholders deforest land more intensively, if the proportion of small establishments were to increase then the rate of deforestation would be expected to increase accordingly.

Finally, cattle ranching has been singled out as the main source of deforestation and also rural growth in the region. Margulis (2003) has shown that ranching activities are profitable in many parts of the Amazon especially in the southern part. Andersen et al (2002) has been also evidenced the role of herd size. Using data from four specific sites in the Brazilian Amazon, Walker et al (2000) have estimated models decomposing the pastureland in large and small ranching. They argue that large and small farms do not represent the same production systems as large farmers are attached to external capital and small farmers operates based on standard household choices. Their results support Fearnside's arguments and suggest that large properties are accountable for a considerable share of deforestation in the region. However, they also argue that the contribution of small plots with cattle cannot be neglected. Moreover given the extremely high land concentration in the studied region the authors recognise that large farms relative contribution should be qualified. In addition, as the study relies on cross-sectional data any attempt to establish causal relations is problematic.

Although most of the studies reviewed above adopt a regional approach focusing on spatially specific characteristics as the main drivers of deforestation they do not attempt to link their findings to the recent developments in spatial economics, which focus on agglomeration effects. In addition with the exception of Walker et al (2000) the methods used do not take into account spatial econometric methods to control for eventual spatial autocorrelation in their empirical estimations. Pfaff (1999) and Andersen et al make firs steps in that direction by including spatial lags of explanatory variables in their regressions but do not look at the potential effects of spatial autocorrelation in the dependent variables and more generally in the disturbances. In the next section we provide the conceptual motivation for interpreting some of the above results in the light of the literature on growth and agglomeration. Then after the presentation of the data we pursue our empirical exercise estimating spatial econometric models.

III. GROWTH AND AGGLOMERATION

The observed spatial configuration of economic activities is the result of processes involving two opposite types of forces: agglomeration (centripetal) and dispersion (centrifugal). These forces are associated with increasing returns to scale, externalities, and imperfectly competitive markets. A fundamental idea of the literature on agglomeration is a shift in focus from the firm to productive systems and an understanding of the phenomenon of competitiveness as a collective result rather than the outcome of individual processes. Increasing returns to scale are necessary to explain agglomerations primarily on economic grounds, without appealing to the attributes of physical geography. However, in case of agricultural activities and rural environments the local physical geography also plays a crucial role.

The role of externalities is also fundamental to describe and understand the spatial concentration of economic activities and population[3]. The idea is that cities, productive systems or agglomerations of different kinds are abundant in externalities (Fujita and Thisse 2002, Anas et al 1998, Fujita et al 1999, Baldwin et al 2004, Duranton and Puga 2003, Porter 1998; Thisse and van Ypersele 1999). Of particular interest is the role of communication externalities and face-to-face interaction in enhancing learning processes and innovation.

An early recognition of this phenomenon is of course to be found in the work of Alfred Marshall (1920). For Marshall it was clear that specialisation as a result of an internal division of labour is one of the main drivers for an improvement in the efficiency and quality of the productive processes, and for the firm's growth (internal economies). However, these improvements could also be secured by geographical

[3] Following Scitovsky (1954) the concept of externalities is split in "technological externalities (also called spillovers) and "pecuniary externalities". The former deals with the effects of non-market interactions that are realised through processes directly affecting the utility of an individual or the production function of a firm. In contrast, pecuniary externalities are by-products of market interactions: they affect firms or consumers and workers only insofar as they are involved in exchanges mediated by the price mechanism. Pecuniary externalities are relevant when markets are imperfectly competitive, for when and agent's decision affects prices, it also affects well-being of others.

concentration of firms and external economies derived from integration among agents. Marshall identified three main factors related to the external economies, which could stimulate industrial concentration: the existence of thick markets for specialized labour, the occurrence of technological spillovers, and the emergence of subsidiary trades. The industrial concentrations would be sustained while these external economies are strong enough to promote competitiveness.

Marshall was primarily concerned with externalities generated by firms within a particular industry. However, Jacobs (1969, 1984) has suggested that the same arguments could be applied to diversified agglomerations where positives externalities would flow across sectors and contribute to their productivity levels. The existence of such externalities could then explain why people are willing to pay higher rents to live in cities (see Glaeser et al 1992 for a detailed discussion).

More recently there have been several attempts to explain the existence of economic agglomerations through formal models, in which increasing returns in the firm's production function lead to pecuniary and technological external economies (Krugman 1991a, 1991b, 1995; Fujita and Thisse 1996, 2002; Fujita et al (1999); and Baldwin et al 2004). This new literature has been labelled as the New Economic Geography. The workhorse of the so-called New Economic Geography is the Core-Periphery Model, which was first proposed by Krugman (1991a). Although recognising the value of the three sources of externalities originally proposed by Marshall, in the Core-Periphery Model Krugman adopts a highly parsimonious set up focused on increasing returns, pecuniary externalities and transport costs[4].

The mechanics of the model is driven by three effects: market access, cost of living, and market crowding. As summarised by Baldwin et al (2004), the ‘market access effect’ describes the tendency of monopolistic firms to locate their production in the big market and export to small markets (an exogenous change in the location of demand leads to a *more than proportional* relocation of industry to the enlarged region); the ‘cost of living effect’ concerns the impact of firms’ location on the local cost of living (goods tend to be cheaper in the region with more industrial firms since consumers in this region will import a narrower range of products and thus avoid more of the trade costs); the 'market crowding effect' reflects the fact that imperfectly competitive firms have a tendency to locate in regions with relatively few competitors.

The first two effects encourage spatial concentration while the third discourages it. Combining the market-access effect and the cost-of-living effect with interregional migration creates the potential for 'circular causality' – also known as 'cumulative causality', or 'backward and forward linkages.' (Baldwin et al 2004, p.10 and 11). The basic result is that at some level of trade costs ('break point') the agglomeration forces overpower the dispersion force and self-reinforcing migration ends up shifting all industry to one region (catastrophic agglomeration). On the other hand, when trade costs are very low and the economy features catastrophic agglomeration, increases in trade costs will not change the geography up to a threshold level where trade costs are high enough (sustain point) to generate dispersion forces stronger than agglomeration forces, which motivate migration from the core to the periphery and generate a symmetric distribution of industry.

The typical New Economic Geography behavioural assumptions have been recently expanded to incorporate some alternative micro-foundations for agglomeration economies. Duranton and Puga (2003) distinguish three types of micro-foundations: sharing, matching and learning mechanisms[5].

Micro-foundations of urban agglomeration economies based on sharing mechanisms might involve sharing indivisible public facilities, sharing the gains from the wider variety of input suppliers that can be sustained by a larger final-goods industry, sharing the gains from the narrower specialization that can be sustained with larger

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[4] For full presentation and several extensions of the Core-Periphery Model see Fujita et al 1999, Fujita and Thisse 2002 and Baldwin et al 2004.

[5] The authors conclude that different microeconomic mechanisms may be used to justify the existence of cities. Moreover, these mechanisms generate final outcomes that are observationally equivalent in many respects. This point has an important policy implication as it suggests that it might not be easy to identify which microeconomic mechanisms has been responsible for growth or decline of a particular city and therefore create problems for targeting policy initiatives.

production, and sharing risks. As for matching Duranton a Puga (2003) identify two sources of agglomeration economies: ‘an increase in the number of agents trying to match improves the quality of each match, and stronger competition helps to save in fixed costs by making the number of firms increase less than proportionately with the labour force’ (p.19). The latter force originates from the assumption that, as the workforce grows, the number of firms increases less than proportionately due to greater labour market competition. As a result, each firm ends up hiring more workers, which in the presence of fixed production costs means higher output per worker. Also, in order to examine the potential impacts of matching on income per worker it is possible to examine the issue looking at mismatch costs.

Finally, when looking at learning Duranton and Puga (2003) discuss mechanisms based on the generation, the diffusion, and the accumulation of knowledge. In any of these mechanisms, learning it is not a solitary activity. Instead it involves interactions with others and many of these interactions have a ’face-to-face’ nature (p.30). Since the original work by Jacobs (1969), numerous authors have been studying how cities contribute with the creation of new ideas. More importantly these authors have emphasized that the advantages of cities for learning involve not only cutting edge technologies, but also the acquisition of skills and ’everyday’ incremental knowledge.

Knowledge accumulation has become the main aspect of learning processes due to its connections with economic growth. As mentioned by Duranton and Puga (2003) there are two main approaches dealing with knowledge accumulation. The first one looks at the dynamic effects of static externalities and the second one focuses on dynamic externalities. In the former growth is driven only by the externality in the city production function. In the latter approach, growth is driven by an externality in the accumulation of human capital in the city. In both cases the externality plays a dual role as engine of growth and agglomeration force.

The standard models in the New Economic Geography are only concerned with spatial distribution of economic activity and don’t take growth into consideration. However, those models have been extended merging growth with geography through the combination of technological externalities with innovation and investment (for a discussion see Baldwin and Martin 2003 and Baldwin et al 2004). As stated by Baldwin and Martin (2003) growth and agglomeration are difficult to separate and the positive correlation between them has been documented by economists working in different fields (Lucas 1988, Williamson 1988, Fujita and Thisse 1996 and Quah 2002). For some 'agglomeration can be thought as the territorial counterpart of economic growth' (Fujita and Thisse 2002).

Geography and growth models points to the existence of a possible spatial equity-efficiency trade-off. However, the matter is more subtle and perhaps more ambiguous than the standard win-lose situation resulting from the agglomeration process in static geography models. This kind of dynamic models of growth and geography suggest that the emergence of regional imbalances, due to continual lowering of trade costs, is accompanied by faster growth in all regions and therefore generates a tension between static losses (relocation of economic activity) and dynamic gains (faster growth) in the periphery. Second, in some models, growth affects geography by creating a growth-linked circular causality; forces that foster the location of industry in a region also foster investment. Moreover, agglomeration process in these models operates creating growth poles and growth sinks – 'firms want to be in the growing region, people want to invest in that region since it is growing and this investment in turn makes the region grow faster' (Baldwin and Martin 2003).

With respect to knowledge spillovers Baldwin et al (2004) propose two different models: one with global spillovers and another with local spillovers. In the global spillovers model growth can impact geography as discussed above but geography is not relevant for growth because the transmission of knowledge in innovation is unaffected by distance. Each region learns equally from an innovation made in any other region. This eliminates the importance of proximity and face-to-face interactions for the transmission of knowledge. This model is interesting but of limited usage for our purposes here. Therefore we concentrate in the local spillovers model that assumes that some frictional barrier reduces the diffusion of public knowledge to distant innovators and therefore re-establish the role of proximity in knowledge diffusion.

In the local spillovers model endogenous growth and knowledge accumulation is an agglomeration force (the region that head start in innovating finds that it accumulates innovation experience faster than the other region. This lowers the replacement cost of capital faster which in turn attracts more resources to innovation in the fast-accumulating region). However, knowledge spillovers is a dispersion force (as spillovers become less localised the growth-linked agglomeration force becomes weaker). The combination of these two forces generate a new tension related to the integration of poor and rich regions. In other words in the local spillovers model integration can be stabilizing or destabilizing whereas in the core-periphery model integration is always destabilizing (economic integration eventually ends up creating extreme divergence between initially symmetric regions, i.e. that integration always fosters agglomeration). As Baldwin et al summarise 'a purely tradecost reducing integration policy encourages agglomeration and eventually results in extreme agglomeration. By contrast, a policy that lowers the cost of transporting both goods and public knowledge may avoid extreme agglomeration'.

Another important feature of the local spillovers model is that that economic geography can affect the growth rate. Assuming a constant intensity of learning spillovers, the cost of innovation decreases substantially (innovation costs decreases with the size of the local economy) when the economy move from a symmetric to a core-periphery pattern. Therefore, by triggering agglomeration, trade integration raises the economy to a higher growth path ("growth take-off"). As mentioned, the higher growth path applies to the whole economy not only to the core region due to the low cost innovation that spills over the periphery. This crystallize the trade-off between static losses and dynamic gains where the net outcome for the periphery is ambiguous.

IV. DATA AND VARIABLES

The empirical exercise covers the Brazilian Legal Amazon (AML), which is an administrative area in the northern part of Brazil including 10 states and around 5million of km^2 (about 60% of the Brazilian national territory). The data used is part of a database (Desmat) managed by IPEA/DIMAC (The Directorate of Macroeconomic Studies of the Institute of Applied Economic Research, Brazil). IPEA/DIMAC assembled a data panel for all the municipalities of Brazilian Legal Amazon (AML) including thousands of variables on major economic, demographic and geo-ecological aspects**.** The unit of observation is the municipality (*município*)**,** which compromises between the spatially detailed geo-ecological information available in GIS and the systematic and relatively long time-consistent series available in socio-economic sources, in particular Demographic and Economic Census data observed in 5-year periods from 1970 to 2000.

To illustrate the relevance of this database for statistical analysis, it suffices to say that Legal Amazonia had 763 municipalities in 1997 (which were 508 in 1991). Another important aspect of the database is to take account of changes in the number and areas of municipalities between Census years, thus providing information for a panel of comparable geographic areas from 1970 to 1997. For the period 1970-1997 as a whole, the size of the panel is 257 comparable areas. In our analysis we use this 257 comparable areas as geographical units using the Censuses of 1996 as the main source of information (for a detailed presentation of this database see Andersen et al 2002).

The dependent variables are growth rates of cleared land and output. Following Andersen et al (2002) we choose growth rates rather than levels to avoid spurious correlations. The levels are highly trending in several of the used variables. Moreover, by taking rates we eliminate some of the municipality-specific fixed effects, which help to control for omitted variables. We use population size as our measure of agglomeration. As the municipalities vary considerably in terms of area size we include it as an additional exploratory variable. By doing that we are effectively measuring all the other variables in terms of density. As mentioned above population size has been used in most studies as the key variable to explain land use change. However, they have interpreted the impact of population purely in terms of demand effects. Here we extend the analysis and argue that population density can also capture the impacts of positive and negative externalities generated by close proximity of agents. These effects include the size of demand for agricultural outputs but also include thicker markets for labour and knowledge spillovers.

The remaining explanatory variables included in the models follow the literature and aim to describe the local characteristics of municipalities. First, we include a number of spatial variables such as distances to the state capital and Sao Paulo, and the length of roads. The latter is also meant to capture the impact of public policies towards the provision of infrastructure. We also include a set of dummy variables for states. Second, environmental characteristics are added including soil quality, rain precipitation, average temperature, altitude, and length of rivers. Third, two cost variables are included namely wages and land prices. As usual, wages are interpreted as a measure of labour productivity. Land prices serve as an indication of proximity to the frontier. Fourth, we aim to capture the effect of human capital by including a measure of local educational level. Fifth, in order to characterize the agrarian structure we introduce a proxy for property rights (proportion of farms owned by the farmer) and the proportion of small properties (less than 50 hectares). Finally we also include the levels of both output and cleared land to capture dynamic elements of growth and land use change. The measure of output only includes agricultural products and the measure of cleared land is the total area of the municipality less the sum of different land uses (agricultural, pasture, fallow, planted forests, abandoned land). Table 3 present the descriptive statistics for all variables included in the models.

In order to test the impact of neighbourhood effects and to better characterize the spatial dynamics in the region we also include spatially lagged variables for output, cleared land and population. The spatial lags measure the averages values of those variables in surrounding areas. To spatially associate the municipalities we construct a so-called Spatial Weight Matrix (W matrix henceforth), which is a square matrix of dimension 257. The values in W reflect an *ad-hoc* hypothesis of spatial interaction between the municipalities. The diagonal contains zeros, and the off-diagonal elements reflect the spatial proximity between the municipalities. We follow fairly standard practice in assuming that interaction is a diminishing function of distance. For each municipality we set the distance decay for the 5 nearest neighbours and zero for the remaining ones. A further step in the construction of the W matrix is to standardise it so that each row sums to 1. Hence

$$W_{ij}^{*} = \frac{1}{d_{ij}}$$

$$W_{ij} = \frac{W_{ij}^{*}}{\sum_{j} W_{ij}^{*}}$$

Standardising helps with interpretation, since the value for area *j* of the spatial lag, defined as the *j*'th cell of *Wx*, is then the weighted average of the values of the variable *x* in the areas that are 'neighbours' to J, and so its estimated coefficient can be compared directly to the coefficient for *x*. Also, using the standardised *W* matrix usefully identifies a parameter value below 1 as being consistent with a 'non-exploding' process while 1 and above leads to complex and little understood consequences for inference and estimation (the mathematical background to this and implications of spatial unit roots consistent with a parameter equal to 1 are discussed in Fingleton, 1999).

V. THE EMPIRICAL MODEL

In this section we set out a model that seeks to explain the change in local growth and deforestation over the period 1985-1995. The model is a modified version of a growth model proposed by Henderson (2000). We envisage a non-linear relationship between agglomeration intensity and growth and deforestation, and this non-linearity reflects the presence not only of positive externalities but also negative externalities, with negative externalities becoming increasingly relevant as the agglomeration intensifies, due to the effects of congestion[6]. Hence, in the initial stages of increasing agglomeration intensity, it is likely that employment growth will increase as the externalities associated with agglomeration become more powerful. However, it is likely that some point negative externalities associated with congestion will also start having an effect that will increasingly counteract the positive externalities as agglomeration intensity increases, to the point that employment growth will fall to zero and then become negative. In order to test this hypothesis, we assume that change G (both in growth and deforestation) is a quadratic function of agglomeration intensity and linear in a set of initial conditions, *X*, that also are assumed to determine the change of cleared land and output, hence our basic empirical equation is

$$G_{85-96} = aP_{85}^2 + bP_{85} + X_{85}c + d + u \qquad [1]$$

The model should have significant regression coefficients for both agglomeration intensity and the square of agglomeration intensity, with a positive coefficient on the former and a negative coefficient on the latter. The hypothesis of increasing congestion effects is rejected if the coefficient on P^2 is either insignificantly different from zero or is positive.

In order to check for spatial autocorrelation and test the robustness of coefficients we extend equation 1 and estimate the following standard spatial econometric models (Anselin 1988, 2003). A general homoskedastic spatial autoregressive model can be written as

$$y = \rho Wy + X\beta + e \text{, where } e = \lambda We + u \qquad [2]$$

In this paper we consider the two usual particular cases. First the spatial lag model with $\lambda = 0$ and second the spatial error model with $\rho = 0$. These two models control for global spatial autocorrelation where neighbours at closer proximity carry more weight (Anselin 2003). Simple manipulation of spatial lag and spatial error models yields the respective following reduced forms

[6] For a similar empirical application in an urban context see Fingleton et al (2005).

$$y = (I - \rho W)^{-1} X\beta + (I - \rho W)^{-1} u \qquad [3]$$

$$y = X\beta + (I - \lambda W)^{-1} u \qquad [4]$$

In equation 3 we see that both explanatory variables and the disturbance are impacted by the same spatial multiplier $(I - \rho W)^{-1}$ in the spatial lag model. However, equation 4 shows that in the spatial error model the spatial multiplier $(I - \lambda W)^{-1}$ only operates in the autocorrelated disturbances. We extend these two standard models to incorporate local spatial autocorrelation in three of the explanatory variables which the theory suggests that are likely to generate spatial spillovers (Anselin 2003, Florax and Folmer 1992), namely output, population and cleared land. Thus the our complete versions for the spatial lag and spatial error models become

$$y = \rho Wy + X\beta + ZW\gamma + u \qquad [5]$$

$$y = X\beta + ZW\gamma + \lambda We + u \qquad [6]$$

Where Z is a matrix including only output, population and cleared land variables.

Models depicted by equations 5 and 6 are initially estimated using the method of maximun likelihood proposed by Anselin (1988). This method requires that *u* follow a normal distribution. In order to test whether the assumption about normality of residuals is significantly impacting the results we also estimate the spatial error model using the Generalised Method of Moment estimator developed by Kelejian and Prucha (1998), which does not requires the normality assumption[7].

[7] All models are estimated using Matlab codes adapted from James Le Sage spatial econometrics toolbox (see www.spatial-econometrics.com).

VI. RESULTS

The four estimated models provide evidence of the determinants of both growth of agricultural output and growth of cleared land. The estimated coefficients in the four models for each of our dependent variables are robust as they are generally similar in value and significance. Tables 1 present the estimates for the 4 models of cleared land and Tables 2 present the estimates for the 4 models of output.

As suggested by the literature on spatial economics the estimates for population, controlled for area size, are significant for both the linear and quadratic terms, with positive coefficient for the linear variable and negative for the quadratic one in the models for cleared land and output. These results provide evidence that agglomeration intensity is relevant for the joint process of development and land cover change. Moreover the effects of agglomeration work in a similar way. For low levels of agglomeration the increase in population size contributes to both economic growth and land conversion. However, at higher levels of agglomeration congestion effects start to 'quick in' producing negative externalities that reduce growth and result in less land conversion as well. The results do not allow us to identify what kinds of agglomerations effects are working in the case of the Brazilian Amazon and distinguish the potential impacts of market size, public facilities sharing, better matching between firms and workers or knowledge spillovers. Possibly we would find most of these factors in a greater or lesser extent depending on the local conditions.

The results for levels of output and cleared land in 1985 allow us to extract some information about the dynamic process of development and frontier expansion. In the cleared land regression, level of cleared land has negative and significant coefficients and level of output have positive and significant coefficients. These results suggest that the pace of deforestation tends to slow down as the areas become more cleared but at the same time additional output puts more pressure on deforestation regardless the level of land already cleared. However, in the output regression, output level is negative and significant but the level of cleared land is positive but only marginally significant. This indicates an interesting relationship between economic activity and land use. First we see that there have been some sort of convergence on growth and areas that have grown faster in the past are now slowing down. This has an impact over deforestation, as the growth of land clearing is associated with previous level of output. Second, as previous cleared land is contributing poorly to future growth and there are weak feed backs from deforestation to economic growth and therefore we could envisage that there are forces in place constraining the expansion of both economic activity and deforestation in the region.

Another robust result across all models for both dependent variables relates to transport costs. Transport costs to Sao Paulo, which is a proxy for access to national markets, have negative and significant results in all models. This is in line with the theory showing that closer proximity to large markets is likely to contribute to economic activity and consequently in this case with deforestation as well. However, we have the opposite result for transport costs to the nearest state capital. This is a surprising result and suggests that agriculture activities are developing faster in areas further away from the local urban centres, which raises the question about the role of regional markets. Local roads have been the focus of much debate in the related literature. In our regressions once we control for other spatial variables we do not find correlation between road length and deforestation. However, the variables are marginally significant and positive in the output regression, indicating that they might be more important for economic growth than for the extensive use of land resources.

The cost variables also provide insights on the process of growth and deforestation. Both wages and land prices are positive and significant in the output regression. As mentioned above wages serve as a proxy for productivity it is significance is the in line with the basic microeconomic theory. Land prices in turn measures the stage of frontier development and higher growth where land is more expensive would add to the arguments related o spatial economics and agglomeration effects, in particular in line with the ‘von Thunen’ basic proposition regarding the local of more productive farmers.

Looking at the spatial lags completes the characterization of the spatial dynamics. In the cleared land regression we find that output levels in neighbouring areas are negatively correlated and cleared land levels in neighbouring areas are positively correlated with future expansion of land clearing. This tells us that the expansion of the frontier is a complex process as we can see that deforestation is a spatial local process and is likely to evolve from previous deforested areas but at the same time neighbours with large economic activity contribute to prevent deforestation in their neighbours. Curiously spatial lags for population are not significant in any model. In addition we see that the variables capturing global spatial autocorrelation are more important to explain output growth than the expansion of cleared land. In the output regression the spatial lags in the disturbances are highly significant and the spatial lag for the dependent variable is marginally significant. On the other hand, in the regression for cleared land only the spatial lag for the disturbance in the maximum likelihood model is significant, indicating that in this case perhaps local spatial process dominate.

A very interesting result comes from the human capital variable. Educational level is not significant for output growth but is highly significant and negative for the expansion of cleared land. We can then speculate that formal educational does not contribute so much to how to work in agriculture in general but somehow impacts how farmers are using land resources. Here further research is clear necessary to unravel the relevant underlining mechanisms.

Our results do not support the literature on property rights as the proportion of farmers who owns the property where agricultural activities take place turned out to be insignificant in all models. Another result on the agrarian structure relates to the relationship between farm size and economic performance. Here we find that the proportion of small properties has no correlation with subsequent output growth but at the same time higher proportion of small farms are positively correlated with larger land conversion contrasting the arguments put forward by Fearnside (1993) and Walker et al (2000).

Finally we find that environmental conditions are relevant for land conversion but not so much for output growth. As expected soil quality is significant and has negative coefficient in the regression for cleared land. On the other hand the presence of the two types of forests ('high forests' and forests along river banks) are positively correlated with deforestation, which relates to the more stringent natural constraints to extensive expansion of agriculture. The surprising result relates to the insignificance of the levels of rain precipitation, which is counterintuitive and contrast with previous studies for the region (Chomitz and Thomaz 2001). We don't have good interpretation for this result but it is possible that our level of spatial aggregation is not appropriate to capture the local variation of rain levels. Interestingly only forests along river banks result to be significant in the regression for output. Again we don't have the technical information to interpret the result.

VII. CONCLUSIONS

In this paper we have estimated four different models for growth of output and cleared land in the Brazilian Amazon. We extend the previous empirical literature in two ways. Firstly we motivate the study by connecting the spatial processes of economic growth and deforestation with the modern literature on spatial economics and agglomeration. Secondly, we adopt spatial econometric methods that take into account a wider range of spatial effects and control better for spatial autocorrelation.

The empirical results allow us to confront the factors impacting growth and deforestation and also to compare them with previous studies in the field. The main results provide evidence of the relevance of spatial economics for understanding the reality in the Amazon region. Firstly, we find that agglomeration intensity has a non-linear relationship with both economic growth and deforestation, suggesting that at initial levels of agglomeration positive externalities dominate and positively impact subsequent growth. However, negative externalities start to mount at higher levels of agglomeration imposing constraints to growth of output and land clearing due to congestion effects. Moreover, spatial theory is supported by our results with respect to transport costs to national markets as proximity to Sao Paulo seems to be an important factor for growth. However, the role of local roads is not duly evidenced by our estimations and we join the authors who claim that the issue deserve much more careful analysis as the causal relationships seem to be complex. The spatial autocorrelation in the cleared land regressions result to be mainly local than global, suggesting that the models in previous studies are not subject to significant misspecification problems. However, in the output regressions global spatial autocorrelation is strong indicating that equations on economic growth must be extended accordingly.

Finally, we also provide evidence on the impact of other local characteristics such as environmental conditions, human capital and the agrarian structure. Here, some of the results are in line with previous studies and others are not. We believe that the differences found indicate the complexity of the reality in the ground. Therefore, despite the rich existent literature in this field, more efforts enhancing the theoretical developments and applying more advanced empirical methods would certainly contribute to enhance the understanding of underlining spatial processes of economic growth and deforestation in the Brazilian Amazon.

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APPENDIX

Table 1a. Estimates for Change of Cleared Land

Variable	OLS	Spatial Lag	Spatial Error	GMM
Constant	-7.783027 ***	-7.765370 ***	-7.826414 ***	-7.814971***
	(-3.113901)	(-3.354698)	(-3.426170)	(-3.399360)
Product	0.231110 ***	0.227151***	0.243624 ***	0.239927 ***
	(2.941851)	(3.099027)	(3.280600)	(3.250163)
Population	1.787846 ***	1.797278 ***	1.822853 ***	1.812589 ***
	(3.499616)	(3.799263)	(3.882784)	(3.841859)
Population Sq	-0.084978 ***	-0.085300 ***	-0.086492 ***	-0.086071 ***
	(-3.498842)	(-3.792791)	(-3.887154)	(-3.845061)
Education	-0.251633 **	-0.260124 ***	-0.254919 ***	-0.253734 ***
	(-2.385488)	(-2.652770)	(-2.707682)	(-2.656228)
Area	0.000003 **	0.000004 **	0.000004 **	0.000004 **
	(1.990535)	(2.188212)	(2.350194)	(2.273938)
Clear	-0.529640 ***	-0.528282 ***	-0.537877 ***	-0.535090 ***
	(-8.471051)	(-9.098798)	(-9.217546)	(-9.182606)
Small Farms	0.958042 ***	0.932464 ***	0.896537 ***	0.917436 ***
	(3.091515)	(3.244969)	(3.188464)	(3.234666)
Owners	0.352695	0.345866	0.330699	0.338922
	(1.188089)	(1.258127)	(1.226227)	(1.245791)
Land Prices	-0.000516	-0.000534	-0.000534	-0.000530
	(-0.244821)	(-0.273619)	(-0.294263)	(-0.284639)
Wages	0.000041	0.000044	0.000051	0.000047
	(0.989404)	(1.133143)	(1.322853)	(1.232385)
Herd Size	0.123786 ***	0.122591 ***	0.105967 ***	0.111527 ***
	(3.700916)	(3.943987)	(3.568154)	(3.697749)
R2	0.4979	0.4961	0.5067	0.5024

*** significant at 99% confidence level

** significant at 95% confidence level

* significant at 90% confidence level

t statistics in brackets

Additional control variables not reported: state dummies

Table 1b. Estimates for Change of Cleared Land (Spatial Variables)

Variable	OLS	Spatial Lag	Spatial Error	GMM
Transport Costs to	0.000334 ***	0.000333 ***	0.000331 ***	0.000332 ***
State Capital	(2.803578)	(3.025534)	(3.168911)	(3.117126)
Transport Costs to	-0.000264 ***	-0.000270 ***	-0.000281 ***	-0.000276 ***
Sao Paulo	(-3.041796)	(-3.348220)	(-3.676980)	(-3.547166)
Roads	0.000265	0.000265	0.000251	0.000257
	(1.352004)	(1.462510)	(1.387928)	(1.417400)
Spatial Product	-0.578938 ***	-0.562826 ***	-0.557981***	-0.564503 ***
	(-3.662931)	(-3.824330)	(-3.897923)	(-3.913469)
Spatial Population	-0.097340	-0.115129	-0.121690	-0.114173
	(-0.827402)	(-1.045660)	(-1.168173)	(-1.080043)
Spatial Clearing	0.656950 ***	0.655607 ***	0.662139 ***	0.660343 ***
	(7.276918)	(7.836074)	(7.965929)	(7.921477)
Spatial Growth		-0.065964		
		(-0.800723)		
Spatial Error			-0.203932 **	-0.137061
			(-2.178038)	(-1.409423)

Table 1c. Estimates for Change of Cleared Land (Environmental Variables)

Variable	OLS	Spatial Lag	Spatial Error	GMM
Rivers	0.000387	0.000373	0.000418	0.000409
	(1.132157)	(1.175098)	(1.341049)	(1.304209)
Soil Quality	-0.003875 **	-0.004024 **	-0.003976 ***	-0.003948 **
	(-2.059660)	(-2.300385)	(-2.568506)	(-2.451574)
Rain	0.000092	0.000026	-0.000123	-0.000055
	(0.195775)	(0.058937)	(-0.298787)	(-0.130373)
Temperature	0.002144	0.004296	0.009403	0.007060
	(0.148577)	(0.320146)	(0.738981)	(0.545032)
Altitude	-0.000061	-0.000049	-0.000076	-0.000070
	(-0.173087)	(-0.149777)	(-0.251878)	(-0.226788)
Forests 1	0.006720 ***	0.006888 ***	0.006839 ***	0.006811 ***
	(3.365466)	(3.704694)	(3.919555)	(3.822568)
Forests 2	0.015334 ***	0.015514 ***	0.014837 ***	0.015021 ***
	(3.925459)	(4.275915)	(4.177826)	(4.197080)

Table 2a. Estimates for Change in Output

Variables	OLS	Spatial Lag	Spatial Error	GMM
Constant	-9.671001 ***	-9.863348 ***	-10.456095 ***	-10.150756 ***
	(-3.531708)	(-3.912396)	(-4.166140)	(-4.016716)
Product	-0.508285 ***	-0.525902 ***	-0.542531 ***	-0.528994 ***
	(-5.905632)	(-6.633600)	(-7.046461)	(-6.779691)
Population	2.232378 ***	2.287328 ***	2.448331 ***	2.363680 ***
	(3.988551)	(4.438959)	(4.840603)	(4.610341)
Population Sq	-0.100965 ***	-0.103337 ***	-0.110321 ***	-0.106681 ***
	(-3.794393)	(-4.218222)	(-4.573883)	(-4.367849)
Education	-0.048360	-0.046173	-0.063369	-0.059143
	(-0.418462)	(-0.433106)	(-0.584700)	(-0.545965)
Area	0.000003	0.000003	0.000002	0.000002
	(1.499950)	(1.453897)	(1.333567)	(1.423744)
Clear	0.092726	0.099755	0.090899	0.092395 *
	(1.353672)	(1.580428)	(1.469864)	(1.477524)
Small Farms	0.041788	0.094818	0.087243	0.071246
	(0.123081)	(0.302944)	(0.277661)	(0.225993)
Owners	-0.118339	-0.135917	-0.214233	-0.176520
	(-0.363862)	(-0.453924)	(-0.718060)	(-0.587105)
Land Prices	0.008265 ***	0.007731 ***	0.006877 ***	0.007447 ***
	(3.582761)	(3.630501)	(3.017117)	(3.337400)
Wages	0.000102 **	0.000103 **	0.000102 **	0.000102 **
	(2.241791)	(2.449727)	(2.485971)	(2.455834)
Herd Size	0.088753 ***	0.092272 ***	0.101726 ***	0.096510 ***
	(2.422022)	(2.734862)	(2.906998)	(2.782937)
R2 Adjusted	0.2208	0.2144	0.2496	0.2347

*** significant at 99% confidence level

** significant at 95% confidence level

* significant at 90% confidence level

t statistics in brackets

Additional control variables not reported: state dummies

Table 2b. Estimates for Change in Output (Spatial Variables)

Variables	OLS	Spatial Lag	Spatial Error	GMM
Transport Costs to	0.000380 ***	0.000386 ***	0.000443 ***	0.000420 * **
State Capital	(2.917518)	(3.210486)	(3.536359)	(3.384414)
Transport Costs to	-0.000241 ***	-0.000244 ***	-0.000273 ***	-0.000262 ***
Sao Paulo	(-2.531374)	(-2.784695)	(-2.968466)	(-2.883815)
Roads	0.000290	0.000339 *	0.000385 **	0.000353 *
	(1.350154)	(1.716096)	(1.981034)	(1.794765)
Spatial Product	-0.117498	-0.079695	-0.135484	-0.125933
	(-0.678551)	(-0.494677)	(-0.821415)	(-0.772706)
Spatial Population	-0.026677	-0.025672	0.017550	-0.000575
	(-0.206979)	(-0.216120)	(0.138244)	(-0.004647)
Spatial Clearing	0.146885	0.115676	0.111467	0.124331
	(1.485084)	(1.260884)	(1.217002)	(1.358296)
Spatial Growth		0.143026 *		
		(1.755780)		
Spatial Error			0.265015 ***	0.163166 **
			(3.500442)	(1.968089)

Table 2c. Estimates for Change in Output (Environmental Variables)

Variables	OLS	Spatial Lag	Spatial Error	GMM
Rivers	0.000255	0.000291	0.000281	0.000277
	(0.680113)	(0.843726)	(0.816179)	(0.798117)
Soil Quality	-0.003383	-0.003019	-0.002680	-0.002982
	(-1.641255)	(-1.588251)	(-1.220671)	(-1.430985)
Rain	0.000218	0.000242	0.000138	0.000165
	(0.424156)	(0.512046)	(0.279715)	(0.338249)
Temperature	-0.000343	-0.001762	-0.000081	-0.000319
	(-0.021706)	(-0.120794)	(-0.005318)	(-0.021244)
Altitude	0.000146	0.000096	0.000068	0.000107
	(0.377839)	(0.268938)	(0.174006)	(0.282498)
Forests 1	0.001514	0.001606	0.002232	0.001947
	(0.692149)	(0.797080)	(1.051559)	(0.930889)
Forests 2	0.016137 ***	0.015610 ***	0.015279 ***	0.015615 ***
	(3.770760)	(3.957400)	(3.849405)	(3.927184)

Table 3. Descriptive Statistics

Variables	Mean	Median	Max	Min	St. Dev	Skewness
Educational Index 1996	2.37135	2.29787	5.18449	0.55428	0.81121	0.563305
Employment 1995	12729.7	6229	304523	216	26287.2	7.286956
Land Prices 1985	993.136	602.168	32038.1	34.6218	2221.86	11.3555
Wages 1995	165.611	54.8072	1976.43	0	267.746	2.985577
Permanent Agricultural Land (km2 1995)	3664.87	538.263	254334.	0	17801.0	11.60205
Seasonal Agricultural Land (km2 1995)	18155.4	3636.55	147553	0	102495.	12.3752
Natural Pasture (km2 1995)	70543.1	10440.2	237479	0	211037.	7.380614
Planted Pasture (km2 1995)	130655	15722.5	507364	0	500393.	7.975517
Natural Forests (km2 1995)	193313.	24335.7	770377	1.716	792465	7.014679
Planted Forests (km2 1995)	1345.81	4.08	75937	0	7473.87	7.680762
Herd Size 1995	140252	25714	4857335	0	493703	7.335426
Paved Roads 1991	52.0155	0	1412.88	0	153.583	5.978845
Non-Paved Roads 1991	117.055	0	4965.49	0	442.719	7.52083
Transport Costs to São Paulo 1995	3379.75	2951.62	10511.9	1270.5	1647.13	2.413455
Transport Costs to State Capital 1995	960.324	758.341	5949.00	0	960.914	3.285705
Farm Size <10 ha (share)	0.14003	0.05111	1	0	0.21733	2.22769
Farm Size >10 <100 ha (share)	0.24041	0.17798	0.96929	0	0.20587	0.982604
Farm Size >100 <1000 ha (share)	0.32121	0.32668	0.87158	0	0.17147	0.040784
Farm Size > 1000 <5000 ha (share)	0.18350	0.15567	0.73573	-2E-10	0.16884	0.648973
Farm Size 5000 and 10000 ha (share)	0.05384	0	0.97131	0	0.10596	4.464795
Farm Size 10000 and 100000 ha (share)	0.05246	0	0.78924	0	0.11404	2.935514
Farm Size >100000 ha (share)	0.00852	0	0.92726	0	0.07053	10.99526
Owners (share)	0.85571	0.94450	1	0.05591	0.20636	-2.22641
Renters (share)	0.01697	0.00272	0.36573	0	0.03774	4.933829
Sharecroppers (share)	0.00637	0.00065	0.13845	0	0.01764	4.971965
Squatters (share)	0.12094	0.03969	0.91727	0	0.19867	2.537895
Rivers (km)	54.9218	0	2282.74	0	181.197	8.163904
Rain	610.194	593.108	1016.57	0	181.054	-0.87523
Good Soil (share)	8.19131	0	100	0	21.1202	3.151817
Temperature in June	24.7090	25.7890	27.3602	0	4.70338	-4.60976
Temperature in September	26.4977	27.2798	29.3388	0	4.91168	-4.93647
Temperature in December	26.0486	26.9873	29.3833	0	4.84036	-4.89093
High Forests (%)	21.4401	0	97.7340	0	32.2902	1.085811
River Forests (%)	7.25843	0	97.221	0	15.0501	3.021361
Semidecidual Forests (%)	1.52949	0	60.2253	0	7.06142	5.788492
Short Forests (%)	31.3512	15.9987	100	0	34.5750	0.855985
Shrubs (%)	25.8387	6.43768	100	0	33.2936	1.031956
Natural Fields (%)	7.06753	0.1478	91.8460	0	14.8838	2.906489
MCA Area 1997	19748.8	3542.4	361329	104.8	49952.0	4.622097
Altitude	129.691	60	1186	0	153.943	2.448508
Agricultural Output 1995	22.2085	7.245671	932.04	0.207216	73.15438	9.331964