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Multidimensional characteristics and deforestation: an analysis for the Brazilian Legal Amazon

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Multidimensional characteristics and deforestation: an analysis for the Brazilian Legal Amazon[1]

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Resumo
O recente debate sobre a Amazônia Legal no Brasil sugere que o desmatamento é um fenômeno multidimensional. Muitos estudos analisaram o desmatamento nesta região nas esferas econômica e institucional, tratando-o em conjunto ou separadamente. No entanto, além de incluir estrutura familiar e aspectos sociais, este trabalho busca identificar as múltiplas configurações que potencialmente levam ao desmatamento. Para isso, aplicamos técnicas estatísticas exploratórias para analisar os 762 municípios localizados na Amazônia Legal e extrair quatro dimensões características: desenvolvimento típico, ambiente familiar, abertura ao comércio e propriedade e escala rural. Essas dimensões formam possíveis combinações em uma análise configurável que são mais consistentes com os fenômenos de desmatamento. Os resultados conclusivos sugerem que a configuração lógica entre alto "desenvolvimento típico" e alta "propriedade e escala rural" cobre 55% dos municípios analisados e é altamente consistente com o alto desmatamento na Amazônia Legal.

Palavras-chave: Desmatamento, Amazônia Legal, Análise Multivariada, Análise Comparativa Qualitativa (QCA)

Abstract
The current debate concerning the Legal Amazon in Brazil suggests that deforestation is a multidimensional phenomenon. Many studies have analysed deforestation in this region in the economic and institutional spheres, treating them jointly or separately. However, in addition to including family structure and social aspects, this work seeks to identify the multiple configurations that potentially lead to deforestation. For this purpose, we applied exploratory statistical techniques to analyse the 762 municipalities located in the Legal Amazon and to extract four characteristic dimensions: typical development, family environment, openness to trade and property and rural scale. These dimensions form possible combinations in a configurational analysis that are more consistent with deforestation phenomena. The conclusive results suggest that the logical configuration between high "typical development" and high "property and rural scale" covers 55% of the municipalities analysed and it is highly consistent with the high deforestation in the Legal Amazon.

Keywords: Deforestation, Legal Amazon, Multivariate Analysis, Qualitative Comparative Analysis (QCA)

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1 Introduction

The Brazilian Amazon region is well known and mentioned nationally and internationally for hosting large areas of forests and areas of environmental conservation. The presence of these areas makes the region quite distinct and raises a number of issues. One is that the region is of outstanding importance for possessing a large portion of the world's biodiversity and it functions as a regulator of the global climate (Barbier, 2001). In general, the Brazilian Amazon encompasses nine states[4] and for the purposes of planning and management, the region was established as the Legal Amazon. The region represents around 60% of the country's territory, but contains only 12% of the population according to the Instituto Brasileiro de Geografia e Estatística (IBGE, 2016).

Other issues related to the region will be the subject of study of this work. The purpose of it is to provide, first, a characterization of the municipalities that compose the Amazon considering three broad aspects: social, economic and property rights. Second, it aims to carry out an analysis of the relationship between the dimensions of the characteristics found and deforestation to include environmental issues in the discussion as these are among the most important aspects in understanding the processes governing the region. Finding ways to reduce the destruction of forest cover has become a priority for the environmental development agenda of the region. Thus, a better understanding of the characteristics of the region and the factors that may be closely associated with deforestation deserves further investigation.

The Amazon region is marked by the strong exploitation of forest resources, driven largely by economic and commercial interests. Several drivers of deforestation in developing countries were discussed widely in Allen and Barnes (1985) and Angelsen and Kaimowitz (1999). The main empirical results suggest that deforestation occurs most generally when forest areas are more affordable, commodity and wood prices are high, wages in the agricultural sector are low and there is a trading opportunity in the international market. Barbier (2000) shows through a basic model how changes in input and product prices influence the conversion of forest land into agricultural use. The underlying assumption is that political reforms towards economic liberalization affect domestic prices and thus encourage the expansion of the agricultural frontier. Agricultural activities in less developed regions, such as the Amazon, are characterized by more intensive land use. If the returns for these sectors increase, the result is more land demand and increased pressure on natural resources.

Even within the economic context of the relationship between international trade and deforestation, according to Ferreira (2004), the usual indicator of openness to trade (X + M)/GDP)[5] is a significant predictor of deforestation if institutional expropriation and corruption factors are present. For Brazil, López and Galinato (2005) conclude that the degree of openness to trade between 1980 and 1999 had a positive impact on forest cover. Faria and Almeida (2016), considering the period 2000–2010, found that an increase in the degree of openness to trade encouraged more deforestation in the Amazon. Hargrave and Kis-Katos (2013) point out that the subsidized credit to agricultural producers, measured in terms of credit density, contributes to increased deforestation in the Amazon.

Other aspects evaluated as associated with deforestation are property rights and government programmes and projects for the Amazon region. In the 1970s especially, the Brazilian government encouraged and provided subsidies for mining, farming and livestock in the region, as well as funding major highway projects that contributed to the establishment

[4] Rondônia (RO), Acre (AC), Amazonas (AM), Roraima (RR), Pará (PA), Amapá (AP), Tocantins (TO), Maranhão (MA) and Mato Grosso (MT).

[5] Where *X* is the exports and *M* the imports.

of new settlers from other parts of the country (Mahar, 1989). One of the major problems associated with new settlements in the region was the lack of regulation by federal and state governments, which resulted in confusion over land ownership. Over the years, this generated land conflicts between farmers, miners, settlers and indigenous groups, mainly in border regions (Brandão *et al.*, 2006). Thus, in the Legal Amazon an important issue is weak enforcement with respect to property rights, particularly with respect to public lands. Public lands, when not incorporated in legally protected areas, may suffer from illegal occupation. Conflicts commonly occur in the so-called arc of deforestation (Fearnside, 2001). It is worth noting that even on private land, normally concentrated in medium and large farms (> 100 ha) (McAlpine *et al.*, 2009), there is an incentive to deforest most of the virgin forests as the owners could lose them to expropriation and invasion.

As there is no official indicator of the enforcement of property rights, different measures have been used to relate this issue to deforestation. Araujo *et al.* (2009) used the number of homicides related to land conflicts and number of expropriations performed by INCRA as proxies for the lack of enforcement of property rights. The main results indicated that most of the occupants of land had no legal title of ownership and that the insecurity of property rights contributed to increased deforestation. Faria and Almeida (2016) used the proportion of establishments for which the status of land ownership was squatters as an indicator of insecurity of property rights. The results of this study showed a positive relationship between this indicator and deforestation.

The association between social context and deforestation in the Brazilian Amazon cannot be considered completely separately from the economic context. The Amazon region offers economic opportunities arising from its forest resources and this has an impact on the level of regional development. Diegues (1996) suggests that among the causes of the deforestation in the Amazon are factors related to population dynamics and social programmes that have encouraged the rural settlement of families. Painter and Durham (1995) suggest that the social causes of deforestation are related to human subsistence needs, which again are associated with the economic issue as forest resources are used as a source of obtaining the means of subsistence. Fujisaka *et al.* (1996) pointed out that deforestation from the conversion of forest land to pasture in the Amazon occurs, in many cases, because the settlers believe that this practice can increase the value of land by adding ponds, corrals and fencing to their pasture lands. For Pffaf (1999), the main social causes of deforestation in the Amazon are related to the distribution of the population, not the population density. Thus, the first migrants to a location have a greater impact on deforestation than the next settlers.

The inherent issues most influential in terms of social development, such as the Municipal Human Development Index (HDI-M), infant mortality and basic housing infrastructure, have not been used by other studies as variables associated with deforestation. Moreover, it is not possible to find any characterization of the region considering different dimensions, in this case, economic, social and property rights. Thus, this study aims to make a twofold contribution, first through the characterization of the municipalities of the Legal Amazon and second by determining the association between the dimensions found in the characterization of the municipalities and deforestation.

It is worth noting that the paper uses the level of municipalities as a spatial reference unit. Microeconomic models that are based on the use of micro data tend to focus on the specific behaviour of landowners and families in relation to deforestation (Bluffstone, 1995; Chomitz and Thomas, 2003). Such an approach ignores the broader influences of deforestation (e.g. the indirect effects of international trade). Empirical macroeconomic models use aggregated data that can more easily be found in relative terms, but such data often result in an average that is representative of a large number of regions, which may lead to inaccuracies in the analysis. Regional models provide appropriate solutions because they

are based on data at the local level, simultaneously making it possible to avoid erroneous inferences from the use of highly aggregated data and to incorporate local features in the analysis.

To achieve the study objectives, two approaches were used. The characterization of the municipalities of the Legal Amazon was performed using factor analysis and exploratory spatial data analysis (ESDA). Factor analysis allowed us to create synthetic indicators that summarize the complete set of information based on the common variations thereof. Thus, we can see how the variables are associated in the formation of the characteristics and how these underlie a typology of municipalities. ESDA allowed us to verify the existence of spatial patterns with respect to each of the factors or characteristics (dimensions). Finally, we employed a fuzzy set qualitative comparative analysis (fsQCA) to verify if possible logical combinations of the dimensions exhibit sufficient links with deforestation. In short, this is a strategy to associate directly the intrinsic characteristics of the municipalities with environmental issues. The main hypothesis in this paper is that the forest resources of the region are strongly associated with different characteristics of the municipalities, whether economic or social.

In addition to this introduction, this paper comprises four sections. Section 2 briefly describes the articulation between statistical and configurational techniques. Section 3 shows the base data and indicators. The fourth section presents and discusses the results. Section 5 provides concluding remarks.

2 Empirical strategy

Our empirical strategy consists of three successive steps. For the first step, we used exploratory factor analysis based on Spearman (1904) to summarize the economic, social and institutional characteristics of the municipalities of the Legal Amazon in latent dimensions. This technique also helps us to identify a typology for the municipalities under analysis. The factor analysis model postulates that the vector *p* of standardized variables, $\mathbf{Z}' = [Z_1, Z_2, \ldots, Z_p]$, is linearly dependent on *m* common and unknown factors, $\mathbf{F}' = [F_1, F_2, \ldots, F_p]$, as well as *p* specific factors, $\boldsymbol{\varepsilon}' = [\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_p]$, according to the matrix form:

$$\underset{(px1)}{\mathbf{Z}} = \underset{(pxm)}{\mathbf{L}} \underset{(mx1)}{\mathbf{F}} + \underset{(px1)}{\boldsymbol{\varepsilon}} \tag{1}$$

where $\underset{(pxm)}{\mathbf{L}} = \{\ell_{ij}\}$ is a matrix with coefficients ℓ_{ij} of the i-th standard variable (Z_i) in the j-th factor (F_j).

Common factors exhibit null means, unit variances, are not correlated and are independent of specific factors. These exhibit almost the same statistical properties as common factors, excepting variance, which are not necessarily unitary but equal. Faced with such assumptions, the structure of the correlation matrix is defined as $\underset{\mathbf{pxp}}{\mathbf{P}} = \mathbf{LL}' + \Psi$, where $\underset{(pxp)}{\Psi} = diag[\psi_1 \quad \psi_2 \quad \ldots \quad \psi_p]$ is the matrix of specific variance; $Var(Z_i) = h_i^2 + \psi_i$, where $h_i^2 = \sum_{j=1}^{m} \ell_{ij}^2$ is the variability of Z_i expressed by *m* factors, known as commonality (Johnson and Wichern, 2007). For the estimation of ℓ_{ij} and ψ_i, this study used principal components

analysis as most of the variables do not present univariate or multivariate normal distribution.[6]

Thus, when applying the spectral decomposition to the factorization of the correlation matrix, with pairs of eigenvalues and eigenvectors, $(\lambda_i, \mathbf{e}_i)$, $\mathbf{e}_i'\mathbf{e}_i = 1, \mathbf{e}_i'\mathbf{e}_k = 0$. If $m < p$, the factor loadings matrix in this method become $\mathbf{L} = \left[\sqrt{\lambda_1}\mathbf{e}_1, \sqrt{\lambda_2}\mathbf{e}_2, \ldots, \sqrt{\lambda_m}\mathbf{e}_m\right]$ and therefore $\mathbf{LL}' \cong \sum_{i=1}^{m} \lambda_i \mathbf{e}_i \mathbf{e}_i'$ and $\mathbf{P} \cong \mathbf{LL}' + \Psi$.

Commonly, the choice of m is made taking into account the Kaiser criterion, the eigenvalues of which are at least equal to unity, and the Pearson criterion, in which the selected number of factors reaches at least 80% of the proportion of variance. To facilitate interpretation and preserve the statistical properties of common factors, Kaiser's (1958) varimax orthogonal rotation tends to be applied. After applying these criteria, the factor scores are estimated. As the data were not normally distributed, we used Bartlett's (1937) weighted least squares method (Johnson and Wichern, 2007; Mingoti, 2007).

For the second step, we used the scores of the common factors (dimensions) selected to verify the presence of significant spatial patterns in the Legal Amazon region. Two ESDA techniques were applied. From Moran's I, it is possible to indicate whether or not there is global spatial autocorrelation in the municipalities of the region. The local indicator of spatial association (LISA) has the capacity to capture local and statistically significant patterns. This represents four types of cluster association: high-high, low-low, high-low and low-high. To apply the ESDA, it is necessary to define a spatial weights matrix that represents the spatial structure of the data (neighbourhood or contiguity criterion), or rather to condense a certain spatial arrangement of the resulting interactions of the phenomenon to be studied. Each municipality is related to a set of neighbours by means of purely spatial tendencies, introduced exogenously in the spatial weights matrix (Anselin, 1995, 1996).

Finally, for the third step, we used Ragin's (1987, 2000) fsQCA to identify patterns of associations between the latent dimensions and deforestation in the Legal Amazon. This analysis is based on set-theoretic notions and applies Boolean logic to evaluate the most possible combinations of factors that are present or absent when a phenomenon of interest occurs or not. FsQCA is capable of dealing with equifinality (Ragin, 2000), the idea that there may be various combinations of conceptual factors that, among other things, promote deforestation. In other words, the ability of fsQCA to account for equifinality and complex interactions reflects deforestation in the Brazilian Legal Amazon.

Nevertheless, the results obtained do not strictly "prove" causal relations, but rather reveal patterns of associations between the sets, thus providing support for the existence of such causal relationships (Riheux and Ragin, 2009; Schneider and Wagemann, 2010; Legewie, 2013). For example, a solution such as "AB → Y" points to the logical combination between conditions A and B potentially causing result Y. However, this solution may also simply represent particular empirical concordances between conditions and the outcome that are not truly causal (Schneider and Grofman, 2006).

In fsQCA the membership cases of sets can be partial or complete, allowing values of conditions from 0 to 1 by means of conditional probabilities (Ragin, 2006). The advantage of this fuzzy set variant of QCA lies in the possibility of staggering different scores of association (Schneider and Wagenemann, 2010). Generally, three qualitative anchors define a

[6] If the variables have normal multivariate distribution, the maximum likelihood method can be applied.

fuzzy set: full membership (indicated by a membership score equal to 1), no adhesion (score equal to 0) and a cutoff point (score equal to 0.5) (Ganter and Hecker, 2014).[7]

If there are k = 4 dimensions (e.g. extracted by factor analysis), there will be 2^k or 16 possible logical combinations, some of which are associated with high or low deforestation, while others are not observed empirically. These combinations are organized in a truth table, but this can be reduced considering the consistency and coverage of each configuration. These traditional measures show us how well the cases in a data set fit in terms of necessity or sufficiency (Ragin, 2006). The coverage indicates the number of empirically observed cases for each configuration, while the consistency shows the proportion of municipalities consistent with the outcome, namely the deforestation of the Legal Amazon. The closer to 1 the value, the greater the consistency of a configuration in relation to the outcome; a value below 0.5 denotes low consistency. Ragin (2000, 2006) considers that for this measure to be adequate, it must be at least equal to 0.80 for all configurations.

Configurations consistent with or sufficient in relation to the outcome are presented in so-called "primitive expressions". However, these primitive expressions are often complex because they include a large number of configurations (greater than three). Thus, fsQCA uses "Boolean minimization" to reduce primitive expressions and to identify the most general combinations of sufficient conditions for the outcome to remain logically true. This is done using the Quine–McCluskey algorithm (Schneider and Wagemann, 2010).

Compared to traditional quantitative techniques (e.g. econometrics), fsQCA makes it possible to find distinct combinations of causal variables, which in turn suggest different theoretical paths according to certain results. Econometric models, for example, seek to establish the analysis of the variables and relationships between causal and dependent variables, these being additive relations and linear causal effects. As fsQCA focuses on the analysis of different configurations that produce different results, the relations are non-additive. Thus, fsQCA has a limitation in relation to quantitative models, which is the inability to establish cause-and-effect relationships. Thus, fsQCA is not able to quantify the impact of an exogenous policy or to determine marginal effects in the associations between variables (Rihoux and Ragin, 2009).

3 Base data

The data used in this study for the characterization of the municipalities of the Legal Amazon correspond to four data sources: the Human Development Atlas in Brazil (from the United Nations Development Programme, Institute for Applied Economic Research – IPEA and the João Pinheiro Foundation), the Brazilian Institute of Geography and Statistics (IBGE), the Ministry of Development, Industry and Foreign Trade (MDIC) and the National Institute for Space Research (INPE). The latter source was used to obtain the deforested area data. All information corresponds to the year 2010 for 762 municipalities of the Legal Amazon.

In this study, we attempted to cover five major aspects of characteristics of the municipalities to associate them with the pattern of deforestation using the fsQCA technique, thus illustrating possible causal links between them. Table 1 presents the variables selected for the factor analysis. The factor analysis determines the most important dimensions for different groups of municipalities. In other words, it determines a typology of municipalities according to different dimensions. The factor analysis also provide scores for each dimension

[7] Operationally, the original variables are transformed into fuzzy sets. Software such as Stata, fsQCA, Tosmana, and R are used to compute such set operations.

based on the variability of the data, which are transformed into fuzzy sets or causal conditions that – when combined – should relate sufficiently to the deforestation of the Legal Amazon.

Together, these variables seek to replicate the five aspects, namely: (a) human capital; (b) urban infrastructure; (c) family and health structure; (d) economic environment and inequality; (e) property rights and the rural scale of the municipalities. For the indicators (a) to (c), the latest information from the Human Development Atlas was used with reference to the year 2010 (Human Development Atlas in Brazil, 2013). Considering factors that have an influence on the social development of the Amazon region contributes to better understanding of the characterization of its municipalities (Fearnside, 1990; Ebeling and Yasué, 2008). It is worth mentioning that we included the variable *dependency ratio* to treat the family structure.

Table 1 – Selected indicators of the municipalities of the Legal Amazon – 2010

Indicators	Acronym	Description	Mean	SD	Min.	Max.
Deforestation	Def	Deforested area (in km^2)	1077.8	1372.7	0.0	16989.9
Human capital	HDI-M	Municipal Human Development Index (HDI-M)	0.6	0.1	0.4	0.8
	Dformal	Degree of formalization of the employment – 18 years and over	31.6	14.8	3.0	80.4
	Illrate	Illiteracy rate – 18 years and over	19.9	8.6	3.5	43.5
Urban infrastructure	Elec	Percentage (%) of the population in domiciles with electricity	91.4	9.9	27.4	100.0
	Bath	Percentage (%) of the population in households with bathrooms and running water	58.1	24.9	4.9	99.4
	Sew	Participation (%) of people in households with inadequate water supply and sewerage	23.6	18.0	0.1	85.4
Family and health structure	Infmort	Infant mortality	23.0	6.8	12.4	45.3
	Fec	Total fecundity rate	2.8	0.6	1.7	4.9
	Dep	Dependency ratio	61.0	11.8	35.8	118.0
Economic environment and inequality	PCI	Per capita income (in R$)	363.0	175.6	96.3	1162.4
	Poor	Percentage (%) of poor	36.6	17.6	1.8	78.6
	Opt	Openness to trade total: (Exports + imports) / GDP	0.1	0.5	0.0	9.3
	Opp	Openness to trade primary	0.1	0.4	0.0	9.2
Property and rural scale	Own	Owners: number of establishments	696.4	934.2	0.0	9278.3
	Rural	Rural population	8781.3	10144.9	140.0	125336.0

Source: Human Development Atlas in Brazil, 2013, INPE (2016) and IBGE (2016).
Note: The variable Dep represents the proportion of people in families with a dependency ratio higher than 75%.

In the dimension "(d) Economic environment and inequality" there are variables such as *per capita income*, *proportion (%) of poor* and two indicators of the degree of economic openness to international trade. One of these indicators is the degree of openness of each municipality to international trade considering all products traded (*openness to trade total*). The other indicator also denotes the degree of openness to international trade, but considers only primary goods traded with foreign countries (*openness to trade primary*).[8] As primary products represent relatively high participation in the production of the municipalities of the Legal Amazon, it is expected that there will be different effects from the two openness-to-

[8] The primary products include products of animal, vegetable and mineral origin.

trade measures. The data on per capita income and proportion of poor people were also taken from the Human Development Atlas. The variables of openness to trade were elaborated based on data from the AliceWeb System data of MDIC[9] for exports and imports and IBGE for gross domestic product (GDP). Economic aspects may have strong connection with specific characteristics of the region (e.g. deforestation), which can contribute to a more comprehensive characterization of municipalities (Angelsen, 1999; Hargrave and Kis-Katos, 2013; Faria and Almeida, 2016).

Finally, the indicator "(e) Property rights and rural scale of the Amazon municipalities" includes two variables, namely the number of establishments, for which the status of the land is the owner (*owners: number of establishments*), and the *rural population*. The property rights issue in the Amazon region is a topic that is widely discussed. One of the main points involves the debate on whether property rights are well defined or not in the region (Fearnside, 2001; Araujo *et al.*, 2009; McAlpine *et al.*, 2009; Brito and Barreto, 2010). In addition, there is discussion concerning how the degree of weakness in the definition of property rights affects deforestation (Ferreira, 2004; Araujo *et al.*, 2009; Araujo *et al.*, 2010). Conflicts over land tenure, the illegal occupation of land and squatters are facts in the region, so considering a status indicator of tenure makes the characterization of the municipalities of the Amazon region more appropriate. Data on land ownership were obtained from the most recent Brazilian Agricultural Census of 2006 (IBGE, 2012). The information on this year was extrapolated by progression up to 2010. For this, information from the previous census was also used. Data on the rural population were collected from the Human Development Atlas.

Two facts with respect to the data are worth mentioning. The first is that the Legal Amazon region has 782 municipalities that are part of the Program for the Estimation of Deforestation in the Brazilian Amazon (PRODES).[10] However, of this total number of municipalities, 762 have data included in the Human Development Atlas. Therefore, this paper considers the sample of 762 municipalities in the Legal Amazon region. The second is that some variables presented missing observations in relation to some municipalities. To circumvent this problem, geographically weighted estimates were used to generate observations. The procedure implies estimation by ordinary least squares (OLS), using the following specification:

$$m = \alpha + \beta_1 x + \beta_2 y + \beta_3 x^2 + \beta_4 y^2 + \beta_5 x^3 + \beta_6 y^3 + \varepsilon \qquad (2)$$

where x and y represent the latitude and longitude of the centroid of each spatial unit; m refers to the vector of variables used that presented missing observations; β^i is the vector of coefficients for each i, where i indicates the relevant variable with missing observation and ε is the error term. The adjusted values of the specific regression for each variable were predicted and used in place of the missing information.

4 Results

We present the results of our three analytical steps and then we describe and explain the characteristics of the municipalities located in the Legal Amazon and how they are associated with deforestation in the region. We can identify a typology as well as a spatial pattern in the latent dimensions obtained. Preliminarily, it can be seen that the municipalities of the Legal Amazon have an average Municipal Human Development Index (HDI-M) of

[9] www.aliceweb.gov.br

[10] The data on deforestation correspond to the deforested area (km^2). The methodology for estimating the rates of deforestation is based on geo-referenced satellite images; more information on this can be found at http://www.obt.inpe.br/prodes (INPE, 2016).

0.62, a level below the national average of 0.66 for 2010, but above the average HDI-M of the North and Northeast regions, equal to 0.61 and 0.59 respectively. The municipalities of the Legal Amazon had a mean per capita income (PCI) of R$362.95, an amount that was more than twice as low as the national average for the same year (R$793.87) (Human Development Atlas in Brazil, 2013).

The efficiency of the factor model depends on the coefficients of the correlation matrix as this technique describes the interdependencies or commonalities between the variables. High correlations between certain variables should reproduce factor loadings and high commonalities in certain latent factors; otherwise, the variables will not be well explained by these respective factors. For this reason, a prior analysis of the correlation matrix is recommended. The correlation matrix is presented in Table 2. Examining this, we notice that from a total of 105 coefficients, 51% present values above 0.30 (Hair *et al*., 1998), which allows us to infer that the data structure used can be considered adequate for the factor analysis. There is a pattern associated with the degree of regional development in the municipalities, or rather that indicators such as human capital are positively correlated with urban infrastructure, PCI, family structure and favourable health conditions, as well as being negatively correlated with the level of poverty and illiteracy.

Table 2 – Correlation matrix of the variables

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	HDI-M	1														
2	Dformal	0.82***	1													
3	Elec	0.57***	0.41***	1												
4	Bath	0.85***	0.79***	0.51***	1											
5	Sew	-0.68*	-0.64*	-0.36*	-0.86*	1										
6	Infmort	-0.65*	-0.60*	-0.06*	-0.62*	0.46***	1									
7	Fec	-0.63*	-0.56*	-0.50*	-0.67*	0.57***	0.36***	1								
8	Dep	-0.76*	-0.68*	-0.61*	-0.79*	0.64***	0.47***	0.82***	1							
9	Illrate	-0.75*	-0.63*	-0.30*	-0.66*	0.41***	0.7***	0.43***	0.59***	1						
10	PCI	0.87***	0.83***	0.41***	0.79***	-0.63*	-0.64*	-0.58*	-0.74*	-0.70*	1					
11	Poor	-0.90*	-0.85*	-0.55*	-0.90*	0.7***	0.63***	0.67***	0.84***	0.71***	-0.89*	1				
12	Rural	-0.21*	-0.21*	-0.14*	-0.33*	0.39***	0.13***	0.04	0.16***	0.02	-0.16*	0.23***	1			
13	Opt	0.2***	0.24***	0.06*	0.12***	-0.07*	-0.14*	-0.08*	-0.13*	-0.18*	0.24***	-0.17*	0.06	1		
14	Opp	0.18***	0.22***	0.05	0.11***	-0.08*	-0.13*	-0.05	-0.11*	-0.15*	0.22***	-0.15*	0.01	0.93***	1	
15	Own	-0.01	-0.02	-0.09*	-0.05	0.13***	-0.08*	-0.09*	-0.06*	-0.16*	0.06*	-0.01	0.51***	-0.01	-0.01	1

*** p<0.01; **p<0.05; * p<0.10.

The high ratio between poverty and most other variables is significant, especially with HDI-M (r = 0.90, p-value < 0.01) and dependency ratio (r = 0.84, p-value < 0.01). PCI is highly correlated with the degree of formalization of employment (r = 0.83, p-value < 0.01) and HDI-M (r = 0.81, p-value < 0.01). The relationship between the establishments of owners and rural population is also significant (r = 0.51, p-value < 0.01), which is consistent with the literature signalling the rural scale in the Legal Amazon. The correlations provide empirical evidence that the set of characteristic variables for local development has a low relationship with rural scale in the 762 municipalities, an observation that must be reflected in factor loadings. Therefore, several of these correlations may represent a latent dimension, constructed by factor analysis.

Table 3 reports the main results of the factor analysis derived from principal components analysis.[11] The statistical tests for these results are satisfactory. Bartlett's

[11] We carried out an analysis of the distribution of the original variables using graphical tools and statistical tests, such as histograms, Kernel graphs, the Q-Q graph, the Shapiro-Wilk test (1965) and symmetry and

sphericity test for the correlation matrix indicates that there are coefficients statistically different from zero. The value of the Kaiser-Meyer-Olkin (KMO) criterion is 0.86, which indicates that the factorial model is adequate (considering a minimum reference value of 0.8) (Johnson and Wichern, 2007).

The number of factors selected satisfies both traditional criteria, Kaiser (1958) and Pearson, because the eigenvalues exceed unity, so that each retained factor represents at least the information of an original variable; the four factors obtained, when accumulated, reach approximately 82.5% of the total variance in the data. To facilitate the interpretation, the factor loadings were rotated using the Kaiser (1958) varimax method.[12] Finally, it should be mentioned that the commonalities are higher than 0.69, indicating that the interdependencies of the variables are well described by the four factors, the result of which is a reflection of an adequate correlation matrix. Despite this, we still have to be careful when evaluating the reliability of our multi-item measures (Flynn *et al*., 1990). The literature uses Cronbach's alpha to evaluate the reliability between items. The results for all measurements indicate acceptable reliability (close to 0.90).

Table 3 – Results of factor analysis

Acronym	Description	Factors				Commonalities
		1	2	3	4	
HDI-M	Municipal Human Development Index (HDI-M)	0.845				0.892
Dformal	Degree of formalization of the employment – 18 years and over	0.810				0.779
Illrate	Illiteracy rate – 18 years and over	−0.836				0.742
Bath	Percentage (%) of the population in households with bathrooms and running water	0.830				0.901
Sew	Participation (%) of people in households with inadequate water supply and sewerage	−0.663				0.691
Infmort	Infant mortality	−0.883				0.825
PCI	Per capita income (in R$)	0.855				0.839
Poor	Percentage (%) of poor	−0.846				0.919
Elec	Percentage (%) of the population in domiciles with electricity		−0.849			0.768
Fec	Total fecundity rate		0.677			0.724
Dep	Dependency ratio		0.658			0.861
Opt	Openness to trade total: (Exports + imports) / GDP			−0.974		0.961
Opp	Openness to trade primary			−0.974		0.956
Rural	Rural population				−0.854	0.775
Own	Owners: number of establishments				−0.850	0.738
Eigenvalues		6.216	2.483	1.988	1.684	
Proportion of variance		0.414	0.166	0.133	0.112	
Cronbach's scale test: 0.902						
Kaiser-Meyer-Olkin (KMO): 0.863						
Bartlett's sphericity test: 12.026 (p-value = 0.000)						

Source: Research results elaborated based on Stata software.
The hidden values are below of 0.650.

kurtosis testing. Even transforming the original variables using the Box and Cox method and adding a constant and taking the logarithm, the asymmetric distribution remained for some variables. Thus, the conditions of normal univariate distribution and in particular multivariate distribution were not satisfied, making it impossible to apply the maximum likelihood method. This attempt strictly followed the recommendations of Johnson and Wichern (2007).

[12] The PROMAX rotation was performed alternately and the results were robust to the VARIMAX rotation.

The factor loadings of the first factor synthesize the main locational aspects concerning the degree of development of the municipalities of the Legal Amazon. In regional economies in which poverty, inadequate water and sewerage supplies, illiteracy and infant mortality are relatively prominent, the scores will be positive. Municipalities with a higher HDI-M, a degree of formalization of employment, higher PCI and better basic infrastructure will present negative scores for this factor. In terms of regional policy, this result may contribute to highlighting the developmental disparities between municipalities, the configuration of which may be strongly associated with the deforestation of the Legal Amazon. In short, this first factor can be denominated "Typical Development", with a positive and greater score illustrating the predominance of local aspects of diseconomies in the municipalities.

The second factor describes the characteristics that are common to the family structure variable, the fecundity rate and the percentage of the population in households with electricity. From the signals of factor loadings, it can be observed that access to electric energy is positively associated with this factor. The presence of electricity gives households access to information through electronic devices (e.g. radios, televisions and computers), enabling them to take advantage of the opportunities (facilities, activities and services) needed for social and economic inclusion. In this regard, access to electricity can positively influence access to opportunities and social information for families and consequently reduce the dependence of family members and their own fecundity. In short, municipalities that exhibit a high proportion of people with access to electricity also have a family structure that is less dependent and a lower fecundity rate, almost certainly due to access to durable consumer goods. Therefore, this factor can be termed the "Typical Family Environment".

The third factor reports the interdependencies between the variables of openness to trade, both considering all products (variable Opt) and only primary products (variable Opp). Many municipalities in the Legal Amazon concentrate their productive structure in the production of primary goods rather than other types of product. Considering the possibility of foreign trade, such an association tends to be even greater. Thus, this third factor expresses "Openness to Trade", essentially capturing primary product activity, which is characteristically dependent on agricultural inputs for the expansion of production. Finally, the fourth factor describes a strong correlation between the rural population and number of agricultural establishments the land status of which is proprietary. The joint relationship between these two variables provides a more grounded dimension concerning the issues inherent to the property rights of the Legal Amazon region. Therefore, this factor is called "Property and Rural Scale". It is expected that this factor is positively associated with the deforestation of the Legal Amazon, or rather that it presents a sufficient relationship to lead to more deforestation.

In short, the order of importance of the factors, given the proportion of the explanation of variance, is relevant in the factor analysis. One result of the factor analysis is that the first factor has a greater capacity to represent the set of indicators analysed (Mingoti, 2007). Thus, the factor "Typical Development" represents the main characterization of the municipalities of the Legal Amazon. Factor scores were constructed and extracted in this step to proceed with the ESDA, which will allows us to verify the presence of spatial patterns in each factor at the global and local levels (Anselin, 1995, 1996). Thus, the ESDA will allow us to determine a typology of municipalities in the Amazon region based on their characteristics (dimensions). Table 4 provides the Moran's I value for each factor (characteristics or dimensions) according to the queen spatial weight matrix.[13] The Moran's I results indicate the positive presence of global spatial autocorrelation at the 1% level of significance for all

[13] Moran indices were calculated using other types of spatial weights matrices. The results remained robust.

factors. This means that there is a spatial pattern in the Legal Amazon along the municipalities considering each of the dimensions. The first factor, "Typical Development", is the one with the highest global spatial autocorrelation. Municipalities that exhibit locational aspects predominantly of diseconomies tend to be surrounded by municipalities also with low "Typical Development". The difference in the level of global spatial autocorrelation is related to the spatial features of each dimension.[14]

The same applies to the other factors, but the Moran's I value with regard to "Open to Trade" is lower than the others. Of the 762 municipalities considered, 226 carried out some type of foreign trade in 2010. The foreign trade of a certain municipality may occur due to some more specific characteristics of such a municipality, which may not be present systematically in the neighbouring municipalities.

Another way of identifying spatial autocorrelation is through the local indicator of spatial autocorrelation (LISA) statistic, which is a measure of local association. The LISA statistic provides, based on local spatial autocorrelation indices, cluster maps describing the significant spatial regimes of the four factors, as shown in the maps in Figure 1. For the "Typical Development" factor, two patterns can be observed (Figure 1a). The first shows a high–high cluster formed by municipalities that cover almost all the state of Mato Grosso and great part of the municipalities of Rondônia and Tocantins. This means that, in relative terms, municipalities with high "Typical Development" are neighbours of municipalities also with high "Typical Development". On the other hand, there are also two low–low clusters, one that is bigger covering the state of Maranhão and another that includes some municipalities of Acre and Amazonas.

Table 4 – Global spatial autocorrelation index of the factors

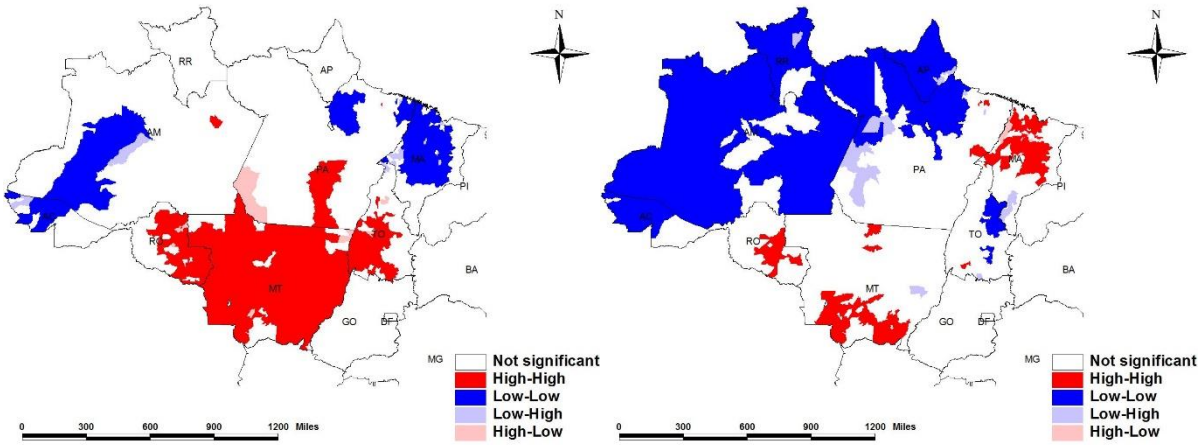
Factors	Moran's I	Mean	SD	p-value
Typical Development	0.758	0.000	0.022	0.001
Typical Family Environment	0.643	–0.002	0.021	0.001
Openness to Trade	0.076	–0.001	0.018	0.002
Property and Rural Scale	0.396	–0.002	0.022	0.001

Source: Research results elaborated based on Stata, GeoDa and ArcView GIS software.

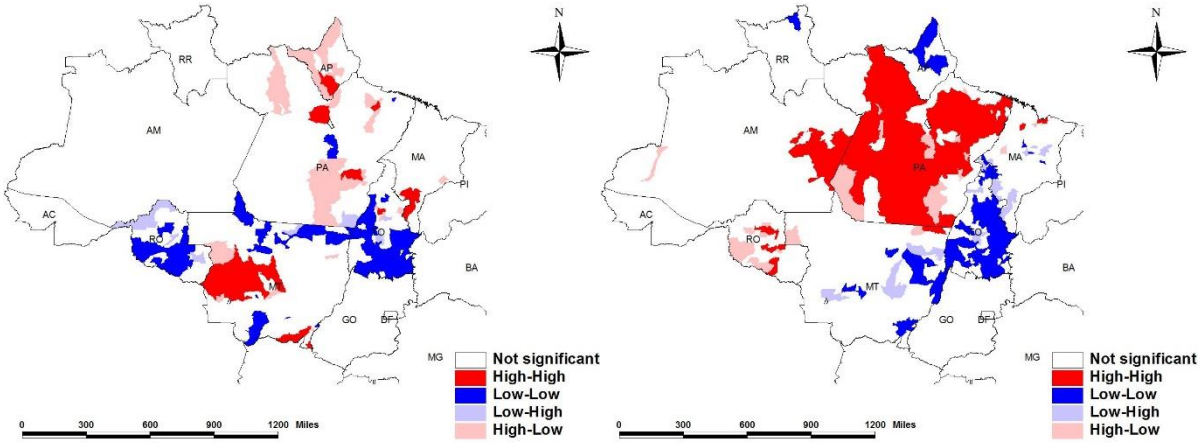
Figure 1 – Cluster maps of the factors

(a) Typical Development (b) Typical Family Environment

[14] For the ESDA, the reference in terms of positive and negative scores of this factor was reversed to provide a better interpretation of the results.



(c) Openness to Trade (d) Property and Rural Scale



Source: Research results elaborated based on Stata, GeoDa and ArcView GIS software.

For the factor "Typical Family Environment", as shown in Figure 1b the LISA result indicates that some municipalities in Maranhão and Mato Grosso form a high–high cluster. Given the relationship between the variables related to this factor, this result indicates that in such municipalities there is a significantly lower rate of fecundity and dependency ratio and a higher proportion of municipalities with access to electricity, in relative terms. Some municipalities in Amazonas and Pará show the opposite results, characterizing a low–low cluster. In turn, the LISA result for "Openness to Trade" indicates the existence of a high–high cluster involving some municipalities in Mato Grosso. The low–low pattern occurs mainly in Tocantins (Figure 1c).

Finally, the LISA result for the fourth factor, "Property and Rural Scale", indicates that most of the municipalities of Pará have a relatively high number of establishments the land status of which is proprietary and a high rural population spatially associated with similar municipalities (Figure 1d). This means that in this state there is a high-density rural pattern. This result does not indicate that this state has no problems related to the definition of property rights. On the contrary, the state of Pará has the largest number of agricultural establishments in the region, which increases the potential for insecurity in relation to the definition of property rights. Indeed, as Brito and Barreto (2010) have pointed out, Pará is one of the regions most affected by uncertainties regarding land tenure in the Amazon. According to these authors, in 2010, 36% of the territory of Pará did not have well-defined property rights and 70% of the total deforestation of the state was located in this part of the territory.

Having analysed the spatial associations of the four factors based on the interdependencies of the indicators in the municipalities of the Legal Amazon, it is opportune

to investigate if such factors, defined as conditions, show sufficiency relationships with the size of the deforested areas in these regions. Such relationships are potentially causal and should expose the particularities of empirical agreement between these four conditions and resulting deforestation. To examine this, we applied QCA, which initially transforms these five variables into fuzzy sets, providing the corresponding degrees of membership of the municipalities (or cases).[15] In this research, each set is represented by a letter, which if uppercase (lowercase) depicts a high (low) conditional probability of the cases in each set, as follows: (D) Deforestation; (M) Typical Development; (F) Typical Family Environment; (C) Openness to Trade; (P) Property and Rural Scale.

Table 5 – Matrix of sufficiency and necessity

	D	M	F	C	P
D	1.00	0.61	0.66	0.65	0.74
M	0.61	1.00	0.67	0.79	0.68
F	0.66	0.67	1.00	0.66	0.67
C	0.65	0.79	0.66	1.00	0.70
P	0.74	0.68	0.67	0.70	1.00

Source: Research results.

Independently, one can ascertain the proportion of the number of municipalities contained in each of the four conditions that coincides with deforestation, which should preliminarily provide the respective sufficiency and necessity relationships. Table 5 shows the proportion of the total overlap between pairs of sets, standardizing the coincidence scores by the respective set sizes. The Property and Rural Scale (P) set is the most sufficient in terms of leading to Deforestation (D) as the possible shared areas constitute 74%. Despite this significant overlap, Table 5 does not indicate the coverage rate and consistency, which would strictly indicate the relations of necessity and sufficiency. Or rather, it is not possible to indicate which of these two sets is contained in another and vice versa. The lowest registered coefficient is between M and D, signalling that characteristically poorer regions are not as closely associated with a profile of a high degree of deforestation in the Legal Amazon.

Nevertheless, in spite of this preliminary analysis, it is necessary to test the relationships of sufficiency, as well as to derive the logical combinations that cause or are associated with deforestation. Table 6 provides only those logical combinations that exhibit sufficient relationships with the strong and weak deforestation, statistically significant, whose respective consistencies are higher than 0.80, according to recommendations of Ragin (2000, 2006).[16]

Table 6 – Sufficient logical combinations

Classification	Logical Combinations	Consistency		F	p-value	Cases and Frequency		
		D	1–D			Number	Relative	Accumulated
High Deforestation	mfcP	0.87	0.79	9.46	0.00	48	6%	6%
	mfCP	0.88	0.79	16.33	0.00	22	3%	9%
	mFcP	0.90	0.75	34.52	0.00	57	7%	17%
	mFCP	0.88	0.76	19.38	0.00	47	6%	23%

[15] Parsimoniously, this transformation varies between 0 and 1 and does not change the calibration standard of the qualitative anchors.

[16] The number of municipalities describes those that present a score higher than 0.50 in each specific configuration. For more details, see Longest and Vaisey (2008).

	mfCp	0.83	0.88	4.51	0.03	12	2%	24%
Low Deforestation	Mfcp	0.81	0.92	31.11	0.00	27	4%	28%
	MfCp	0.76	0.92	54.14	0.00	54	7%	35%
	MFcp	0.83	0.93	24.96	0.00	24	3%	38%

Source: Research results.
Notes: "F" represents the distribution F used for the Wald test on the consistency scores. "Significant" p-value denotes that the consistency D and 1–D are statistically different. Column "D" evaluates the consistency of the combination with high D, while "1–D" evaluates the cases without high D.

There are logical configurations that lead to or are associated with high deforestation and those that exhibit sufficient relationships with the low deforestation score. Both settings are statistically significant at the 3% level. It can be noted that there are 54 municipalities, 7% of the total, that present a MfCp combination, i.e. relatively poorer regions (M), with families with low access to electricity, fecund and highly dependent (f), with a high level of openness to trade (C) and a low score in the property and rural scale factor (p), exhibiting a sufficient relation with low deforested areas (1–D). Altogether, there are four types of logical configurations that are related to low deforestation, reaching 15% of the total cases.

On the other hand, Table 6 provides the primitive expression with multiple paths (multi-causality) associated with high deforestation in the Legal Amazon (equifinality), or better:

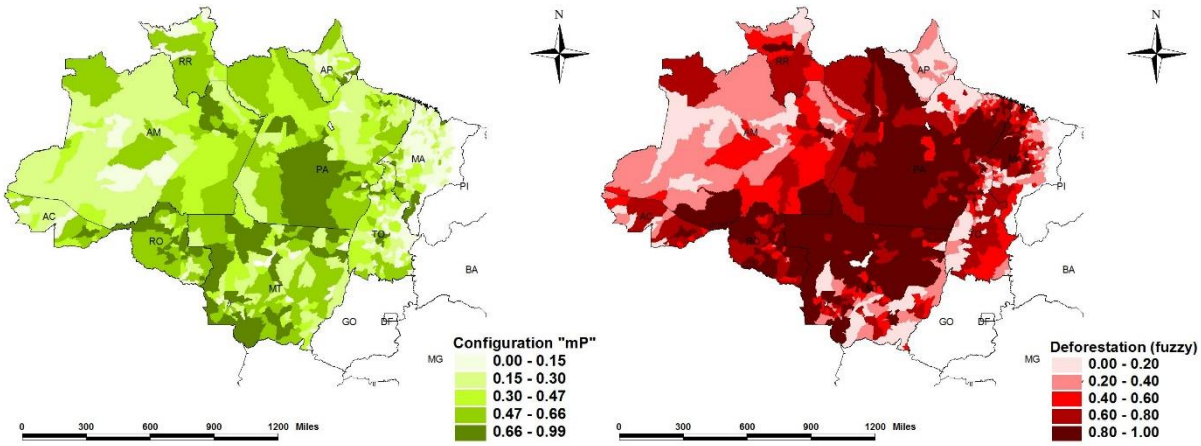
$$mfcP + mfCP + mFcP + mFCP \rightarrow D \tag{3}$$

However, when applying the Quine–McCluskey minimization algorithm, it can be noticed that the sets "Typical Family Environment" and "Openness to Trade" do not influence the occurrence of high deforestation. The condition of high "Property and Rural Scale" (P) is necessary, but not sufficient, as it only leads to the "D" result if combined with "m", that is, to a high degree of development. Thus, the condition "D" should not on its own produce the high deforestation in the Legal Amazon (D). In short, after the minimization process, the following sufficient relationship was obtained:

$$mP \rightarrow D \tag{4}$$

As this is a qualitative comparative analysis, it is important to present the adjustment measures of the model, i.e. the coverage and the consistency of the solution. The logical configuration "mP" presents consistency of 85% and coverage of 55% for the high deforestation in the Amazon. Municipalities with high development and high property and rural scale should generate or present high deforestation, but cover 55% of the cases observed for this configuration. In practice, this means that 45% of the deforestation in the Legal Amazon is independent of this configuration. It should be noted that generally in QCA, high consistency measures tend to be associated with low coverage, with consistency being the main criterion for validating the results generated. Therefore, expression (4) is satisfactory, with a moderate coverage rate. Figure 2 represents the spatial distribution of the "mP" configuration and the fuzzy set of deforestation. The maps in Figure 2 spatially illustrate the association of the reduced solution (4). It is observed that municipalities with high scores for the "mP" configuration, darker spots, are also those with higher values of deforestation on the map.

Figure 2 – Logical configuration "mP" and deforestation (fuzzy)



Source: Research results elaborated based on Stata, GeoDa and ArcView GIS software.

5 Final remarks

The objective of this paper has been to find dimensions of the characteristics of the municipalities of the Legal Amazon region and verify how these dimensions (factors) are associated with deforestation. For this purpose, variables with data for the year 2010 have been used to take into account economic aspects, social development and status in relation to land tenure. The methods used to perform the characterization of the municipalities were factor analysis and ESDA. To verify the relationship between the dimensions found and deforestation, QCA was used.

Aspects other than economic ones have also been considered with the objective of developing a broader characterization based on social conditions and basic housing infrastructure, which not only reflect the situation regarding the level of regional development, but also its association with deforestation. This approach is in contrast to that commonly adopted in the literature, which tends to focus on economic issues to explain the causes of deforestation in regions that have abundant forest resources, but which are notably less developed (Allen and Barnes, 1995; Angelsen and Kaimowitz, 1999). One of the results is that variables related to social issues (e.g. HDI-M, basic housing infrastructure, PCI and proportion of poor) are the main dimensions characterizing the municipalities of the Legal Amazon. In addition, the issue of the family environment, openness to trade and property and rural scale are also found to be dimensions that characterize the municipalities of the region.

The family environment dimension suggests that there is a negative relationship between the degree of access to electricity and fecundity rate and the dependence ratio in the region. Openness to trade, another dimension found, represents one of the main economic measures for defining the profile of the municipalities in the region. Not all municipalities carry out foreign trade, but those that do so tend to market primary goods, mainly goods from forest resources. The issue of insecurity with respect to property rights also represents another dimension found, but the result better represents a measure that synthesizes both the proprietary status of land and the rural population.

The results also indicate that deforestation tends to be higher in municipalities that have, at the same time, relatively greater development, a high number of agricultural establishments under ownership and a rural population. Put another way, deforestation tends to be larger when there is a greater rural density coupled with higher income per capita and HDI-M, for example. Therefore, deforestation in the region may be closely related to the intensity of agricultural practices. This argument reinforces the hypothesis that one of the major problems of forest conservation in the region is related to the expansion of the agricultural frontier. Increasing soybean production and pasture areas are the main

determinants of this expansion (Margulis *et al.*, 2004). Although there are already mechanisms in place to help discourage the private marketing of soy produced from deforestation (e.g. companies in the Amazon region that buy a fixed amount of product from each establishment), it is not possible to trace the origin of all production. Coordinated policies or actions between companies and public authorities could help increase the number and quality of inspections to reduce the incentives for deforestation in the region.

References

Allen, J.C. and D.F. Barnes (1985), 'The causes of deforestation in developing countries', *Annals of the Association of American Geographers* **75**(2): 163–184.

Angelsen, A. (1999), 'Agricultural expansion and deforestation: modelling the impact of population, market forces, and property rights', *Journal of Development Economics* **58**(1):185–218.

Angelsen, A. and D. Kaimowitz (1999), 'Rethinking the causes of deforestation: lessons from economic models', *The World Bank Research Observer* **14**(1): 73–98.

Anselin, L. (1995), 'Local indicators of spatial association – LISA', *Geographical Analysis* **27**(2): 93–115.

Anselin, L. (1996), 'The Moran scatterplot as an ESDA tool to assess local instability in spatial association', in H. J. Fischer and D. Unwin Scholten (eds.), *Spatial Analytical Perspectives on GIS*, London: Taylor & Francis, pp. 111–125.

Araujo, C., C.A. Bonjean, J.L. Combes, P.C. Motel, and J.E. Reis (2009), 'Property rights and deforestation in the Brazilian Amazon', *Ecological Economics* **68**: 2461–2468.

Araujo, C., C.A. Bonjean, J.L. Combes, P.C. Motel, and J.E. Reis (2010), 'Does land tenure insecurity drive deforestation in the Brazilian Amazon?', CerdI, Etudes et Documents, E 2010.13.

Barbier, E. (2000), 'Links between economic liberalization and rural resource degradation in the developing regions', *Agricultural Economics* **23**: 299–310.

Barbier, E. (2001), 'The economics of tropical deforestation and land use: an introduction to the special issue', *Land Economics* 77(2): 155–171.

Bartlett, M.S. (1937), 'The statistical conception of mental factors', *British Journal of Psychology. General Section* **28**(1): 97–104.

Bluffstone, R.A. (1995), 'The effect of labor market performance on deforestation in developing countries under open access: an example from rural Nepal', *Journal of Environmental Economics and Managemen*t **29**: 42–63.

Brandão, A.A.P., G.C. Rezende, and R.W.C. Marques (2006), 'Crescimento Agrícola no Período 1999/2004: A Explosão da Soja e da Pecuária Bovina e seu Impacto sobre o Meio Ambiente', *Economia Aplicada* **10**(1): 249–266.

Brito, B. and P. Barreto (2010), 'The impacts of the new land laws in defining property rights in Pará. Report Imazon', [Available at] www.imazon.org.br_.

Chomitz, K.M. and T.S. Thomas (2003), 'Determinants of land use in Amazonia: a fine-scale spatial analysis', *American Journal of Agricultural Economics* **85**(4): 1016–1028.

Diegues, A.C. (1996), 'The social dynamics of deforestation in the Brazilian Amazon: an overview', United Nations Research Institute for Social Development (UNRISD) Publications, [Available at] http://www.unrisd.org/80256B3C005BCCF9/(httpPublications)/4DF569C03BC4FE5480256B640055E523?OpenDocument&panel=relatedinformation .

Ebeling, J. and M. Yasué (2008), 'Generating carbon finance through avoided deforestation and its potential to create climatic, conservation and human development benefits', *Philosophical Transactions of Royal Society B*, **363**: 1917–1924.

Faria, W.R. and A.N. Almeida (2016), 'Relationship between openness to trade and deforestation: empirical evidence from the Brazilian Amazon', *Ecological Economics* **121**: 85–97.

Fearnside, P.M. (1990), 'Environmental destruction in the Brazilian Amazon', in D. Goodman and A. Hall (eds), *The Future of Amazonia Destruction or Sustainable Development?*, London: Palgrave Macmillan UK, pp. 179–225.

Fearnside, P.M. (2001), 'Land–tenure issues as factors in environmental destruction in Brazilian Amazonia: the case of Southern Pará', *World Development* **29**(8): 1361–1372.

Ferreira, S. (2004), 'Deforestation, property rights, and international trade', *Land Economics* **80**(2): 174–193.

Flynn, B.B., S. Sakakibara, R.G. Schroeder, K.A. Bates, and E.J. Flynn (1990), 'Empirical research methods in operations management', *Journal of Operations Management* **9**(2): 250–284.

Fujisaka, S., W. Bell, N. Thomas, L. Hurtado, and E. Crawford (1996), 'Slash-and-burn agriculture, conversion to pasture, and deforestation in two Brazilian Amazon colonies', *Agriculture, Ecosystems & Environment* **59**(1–2): 115–130.

Ganter, A. and A. Hecker (2014), 'Configurational paths to organizational innovation: aualitative comparative analyses of antecedents and contingencies', *Journal of Business Research* **67**(6): 1285–1292.

Hair, J.F., W.C. Black, B.J. Babin, and R.E. Anderson (1998), *Multivariate Data Analysis*, 5th ed., New York: Prentice Hall International.

Hargrave, J. and K. Kis–Katos (2013), 'Economic causes of deforestation in the Brazilian Amazon: a panel data analysis for the 2000s', *Environmental and Resource Economics* **54**: 471–494.

Human Development Atlas in Brazil (2013), 'Rio de Janeiro, PNUD, IPEA, Fundação João Pinheiro', [Available at] http://www.atlasbrasil.org.br/2013/pt/consulta/ .

IBGE – Instituto Brasileiro de Geografia e Estatística (2016), 'Cadastro de Municípios localizados na Amazônia Legal', Rio de Janeiro, [Available at] http://www.ibge.gov.br/home/geociencias/geografia/amazonialegal.shtm?c=2 .

IBGE – Instituto Brasileiro de Geografia e Estatística (2012), 'Censos Agropecuários 1995–1996 e 2006', Rio de Janeiro, [Available at] http://www.ibge.gov.br/home/estatistica/economia/agropecuaria/censoagro/default.shtm_.

INPE (2016), 'PRODES: Monitoramento da Floresta Amazônica por Satélite', [Available at] www.obt.inpe.br/prodes/.

Johnson, R.A. and D.W. Wichern (2007), *Applied Multivariate Statistical Analysis*, 6th ed., Englewood Cliffs: Prentice–Hall.

Kaiser, H.F. (1958), 'The varimax criterion for analytic rotation in factor analysis', *Psychometrika* **23**(3): 187–200.

Legewie, N. (2013), 'An introduction to applied data analysis with qualitative comparative analysis (QCA)', *Forum: Qualitative Social Research* **14**(3): 1–45.

Longest, K.C. and S. Vaisey (2008), 'Fuzzy: a program for performing qualitative comparative analyses (QCA) in Stata', *Stata Journal* **8**(1): 79–104.

López, R. and G.I. Galinato (2005), 'Trade policies, economic growth and the direct causes of deforestation', *Land Economics* **81**(2): 145–169.

Mahar, D.J. (1989), 'Government policies and deforestation in Brazilian Amazon region', Report 8910, International Bank for Reconstruction and Development and The World Bank, Washington: The World Bank, pp. 56.

Margulis, S. (2004), 'Causes of deforestation of the Brazilian Amazon', World Bank Working Paper N. 22, Washington: The World Bank, pp. 78.

McAlpine, C.A., A. Etter, P.M. Fearnside, L. Seabrook, and W.F. Laurance (2009), 'Increasing world consumption of beef as a driver of regional and global change: a call for policy action based on evidence from Queensland (Australia), Colombia and Brazil', *Global Environmental Change* **19**: 21–33.

Mingoti, S.A. (2007), *Análise de dados de métodos de estatística multivariada: uma abordagem aplicada*, Belo Horizonte: Editora UFMG.

Painter, M. and W.H. Durham (1995), *The Social Causes of Environmental Destruction in Latin America*, Ann Arbor: The University of Michigan Press.

Pfaff, A.S. (1999), 'What drives deforestation in the Brazilian Amazon?', *Journal of Environmental Economics and Management* **37**(1): 25–43.

Ragin, C.C. (1987), *The Comparative Method: Moving Beyond Qualitative and Quantitative Strategies*, Berkeley, CA: University of California Press.

Ragin, C.C. (2000), *Fuzzy–Set Social Science*, Chicago: University of Chicago Press.

Ragin, C.C. (2006), 'Set relations in social research: evaluating their consistency and coverage', *Political Analysis* **14**(3): 291–310.

Rihoux, B. and C.C. Ragin (2009), 'Configurational comparative methods: qualitative

comparative analysis (QCA) and related techniques', *Applied Social Research Methods Series*, 51, Los Angeles: SAGE Publications.

Schneider, C.Q. and B. Grofman (2006), 'It might look like a regression equation… but it's not! An intuitive approach to the presentation of fsQCA and FS/QCA results', Unpublished manuscript, [Available at] http://www.suz.uzh.ch/dam/jcr:d562d9c5–b9b6–47eb–add6–09d630ae4d2a/Text_26.pdf .

Schneider, C.Q. and C. Wagemann (2010), 'Standards of good practice in qualitative comparative analysis (QCA) and fuzzy-sets', *Comparative Sociology* **9**(3): 397–418.

Spearman, C. (1904), '"General intelligence," objectively determined and measured', *The American Journal of Psychology* **15**(2): 201–292.