ROAD DENSITY AND DEFORESTATION: EVIDENCE FROM BRAZIL

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ABSTRACT
This paper aims to estimate an Environmental Kuznets Curve (EKC) for Brazil, considering the impact of roads density on deforestation for 2017. The exploratory analysis pointed to spatial concentration for deforestation and road density in the *Centro-Sul* and Northeast regions. This configuration reflects the Brazilian colonization and occupation process that occurred more intensely in those regions. The best model are the SDM, which captured spatial spillovers from deforestation, road density and agricultural frontier expansion. For the EKC, we get an inverted "U" curve, indicating that deforestation increases until a certain threshold, as the region develops, from which it begins to fall. The road density and its spatial spillovers, which attracts migratory waves and agricultural activities due its cost reduction, are significant, leading to deforestation. Additional variables also induced deforestation: demographic density, crop, pasture, cattle productivity, altitude, temperature and protected area along with spatial spillovers from pasture, crop and deforestation.

RESUMO
Este trabalho busca estimar uma Curva Ambiental de Kuznets (CKA) para o Brasil, considerando o impacto da densidade rodoviária no desmatamento para 2017. A análise exploratória apontou uma concentração espacial para o desmatamento e densidade rodoviária nas regiões Centro-Sul e Nordeste. Essa configuração reflete a colonização e ocupação do Brasil que ocorreu de forma mais intensa nessas regiões. O melhor modelo é o SDM, o qual capta transbordamentos espaciais do desmatamento, densidade rodoviária e expansão da fronteira agrícola. Para a CKA, obteve-se uma curva em "U" invertido, indicando que o desmatamento aumenta até certo limite, conforme a região se desenvolve, a partir do qual começa a cair. A densidade rodoviária e seus transbordamentos espaciais, que atraem ondas migratórias e atividades agrícolas devido à redução de custos, são significantes, induzindo o desmatamento. Variáveis adicionais também induziram o desmatamento: densidade demográfica, plantação, pasto, produtividade bovina, altitude, temperatura e áreas protegidas conjuntamente com transbordamentos espaciais dos pastos, plantação e desmatamento.

1. INTRODUCTION
The Brazil holds a considerable part of the planet's natural resources, playing a key role in regulating the carbon cycle and global climate and the balance of the global ecosystem. The country has six biomes: Amazon, Atlantic Forest, Caatinga, Cerrado, Pampa and Pantanal. For example, the Amazon is the largest tropical forest in the world while the Cerrado is the richest savannah. Nevertheless, the country's deforestation has caused concern worldwide due to irreparable loss of its natural wealth and biodiversity, along with greenhouse gas emissions that leads to climate change (Myers et al., 2000).

Several factors can explain deforestation, especially agricultural activities and the advancement of the agricultural frontier in the biomes, which increase the pressure for opening new agricultural areas, inducing considerable land use changes and environmental degradation. For example, the Amazon is the most active agricultural frontier in the world in terms of forest loss and CO_2 emissions (Assunção et al., 2015; Bragança, 2018; Barros and Stege, 2019).

The construction of a basic infrastructure, especially roads, allowed the displacement of farmers to the interior of Brazil, intensifying its territory occupation. In fact, there is a close relationship between migration and the opening of roads, which enable the creation of access corridors to the regions. These, in turn, induce agricultural frontier expansion and possibly native areas deforestation because the road network expansion allows access to previously isolated areas, affecting its environmental degradation rhythm. Nevertheless, papers analyzing the roads impacts in the Brazilian deforestation are concentrated almost exclusively on the Legal Amazon (Nesptad et al., 2001; Soares-Filho et al., 2004; Pfaff et al., 2007; Fearnside et al., 2007; Freitas et al., 2010; Walker et al., 2013). In this sense, according to Alphan 2017, road development is an important factor that indicates trends of environmental change, since it causes many changes in land use, it facilitates and accelerates human access to natural resources, which eventually leads to fragmentation of ecosystems. (Vardei et al. 2014; Gill et al. 2014)

The literature has pointed to the impacts of agricultural practices on deforestation in the Brazilian biomes. In particular, we have activities related to cattle raising and crops that have recently gained market value, such as soybeans, maize and sugarcane. The increase in the national and international demand for beef, animal feed and biodiesel have been the main responsible for the high profitability that induces its production growth (Godar et al.; 2012; Andrade De Sá et al., 2013; Faria and Almeida, 2016).

Considering agricultural sector importance for the Brazilian economy, it would be natural to infer that a slowdown in the pace of expansion of the agricultural frontier in the regions can negatively affect their economic development. However, according to Assunção et al. (2015), Assunção and Bragança (2015), and Bragança (2018) there is no trade-off between economic development and environmental conservation on the biomes since the agricultural sector continued to perform well despite policies to inhibit deforestation in recent years. This fact is in accordance with the Grossman and Krueger (1995) theoretical preposition, known as the Environmental Kuznets Curve (EKC), which proposes an inverted U-relationship between economic development and environmental degradation. In this context, the main purpose of this paper are to investigate if the relationship between economic development and environmental degradation in Brazil fits the EKC theoretical approach.

In addition, according to Maddison (2006), Robalino, and Pfaff (2012), spatial interactions are a common effect when considering forest conversion and land use changes. In fact, several papers point out that spatial spillovers are relevant to understand deforestation in the Brazilian biomes, with a strong positive spatial interaction impacting negatively the environment (Igliori, 2006; Oliveira and Almeida, 2011; Andrade De Sá et al., 2015; Amin et al., 2019). Therefore, the biomes may also be connect through significant spatial spillovers from deforestation and agricultural activities.

Although there are several papers that sought to estimate an EKC for the Brazilian biomes or measure the roads impact on deforestation, none has covered all biomes at the same time, in a national perspective, or included road density in the EKC estimations. In this context, the present paper proposes to fill both gaps in the literature. Finally, the work is structured into four sections, including this introduction. In the second, we have theoretical framework on the EKC while in the third section, we sought to detail the methodology and the database used. The results and their analysis are in the fourth section, followed by the final considerations.

2. THEORETICAL FRAMEWORK

The Environmental Kuznets Curve concept are inspired by Kuznets (1955), which established an inverted "U" functional relationship between economic growth and income distribution. Grossman and Krueger (1991) adapted the Kuznets model (1955) to verify if there are an inverted U-relationship between economic growth and environmental. The authors decompose the effects behind the relationship, which resulted in three main effects identification: scale, composition, and technical. The scale effect occurs due to an increase in production, which causes a pressure on the environment, since greater natural resources use is needed along with pollutants derived from production. The composition effect is the change that occurs in the goods and services composition produced, such as, for example, the displacement of industrial goods (which are more polluting) for services (low pollutants). Finally, the technical effect is related to technological advances that increase productivity and/or can make production more "clean"', generating less waste. The composition and technical effects can be large enough to minimize the scale effect. In this context, the trajectory between growth and degradation may reverse, with economic development not leading to a rise in environmental degradation (Grossman and Krueger, 1991).

Several authors have attempted to broaden the understanding of the relationship between economic development and environmental degradation takes on an inverted U-shape. Among them, we can mention Shafik and Bandyopadhyay (1992), Selden and Song (1994), Arrow et al. (1995), Stern et al. (1996), Suri and Chapman (1998), De Bruyn et al. (1998), Culas (2007), which will be discussed in the next paragraphs. Selden and Song (1994), in turn, argue that the environmental pressure is due to increases in income and consumption, which lead to greater natural resources use. The reasons and processes that lead EKC to have an inverted "U" format, according to Selden and Song (1994), are mainly due positive income elasticity for environmental quality, changes in the production and consumption composition and technological innovations that increase productivity, induced by market competition and / or due to adjustments to imposed legislation. Arrow et al. (1995) argue that the EKC format is due to the natural process of how economic development occurs. That is, it induces a shift of productive activities from the primary (agricultural) sector to the secondary (industrial) sector and finally to the tertiary sector (services).

Many researchers, however, argue that the descendant part of the EKC occurs because the polluting industries tend to move from developed countries to the underdeveloped ones, due to the restrictions imposed by the legislation, which encourages this displacement. (Suri; Chapman, 1998; Arrow et al., 1995; Stern et al., 1996). This theory is known in the literature as the Pollution Haven hypothesis. Despite the evidence for the EKC existence, some authors, such as De Bruyn et al. (1998) argue that this relationship is only sustained in the short term. In the long run, there is another turning point in which per capita income growth leads once again to environmental degradation. Therefore, an "N" -shaped curve and not the inverted "U" shape would better represent the relationship between development and environment. In addition, according to the author, there is the possibility of EKC assuming other formats beyond the usual, making necessary this verification for each specific case.

In the specific case of using deforestation as a variable of environmental degradation, the focus of this paper, there is no consensus about the existence of a traditional EKC inverted "U" format. Shafik and Bandyopadhyay (1992), in a pioneering investigation, for example, have not found statistically significant relationships between deforestation and economic growth. On the other hand, analyzing this relationship for three continents, Africa, Latin America and Asia, Cropper and Griffiths (1994) found statistically significant results for the first two. Bhattarai and Hammig (2001) conducting a similar study for the three continents found statistically significant results for all between growth and forest cover, with an inverted "U" relationship.

According to the authors, at low levels of development, the structure of demand as, for example, the consumption of firewood, cause deforestation. On the other hand, as economic growth occurs, such demand structure tends to change, moving to goods that affect less the environment. In addition, income growth induces an increase in replanting efforts, which ends up reversing the deforestation process in the long run. On the other hand, Koyuncu and Yilmaz (2009) found that the increase in demand for arable land also has a significant impact on deforestation along economic growth.

For Brazil, some studies sought to identify the existence of the Environmental Kuznets Curve (EKC) using deforestation. Among the papers for Legal Amazon, we have a controversial empirical evidence, which varies according to the analyzed year or method adopted. For example, Gomes and Braga (2008), Prates (2008), Santos et al. (2008), Polomé and Trotignon (2016), Tritsch and Arvor (2016) found evidence of an inverted "U" relationship while Araújo et al. (2009) and Jusys (2016) captured an EKC in "U"; Oliveira et al. (2011) and Oliveira and Almeida (2011) identified a relationship in the "N" format. Therefore, the results are not conclusive and more studies are necessary to reach a definitive conclusion.

3. METHODOLOGY

3.1 Exploratory Spatial Data Analysis (ESDA) and Spatial Econometrics

The ESDA capture effects of spatial dependence and heterogeneity, association patterns (spatial clusters) and indicate how the data are distributed. The Moran's I seek to capture the degree of spatial correlation between a variable across regions. Mathematically, we have

$$I = \frac{n}{S_o} \frac{\sum_i \sum_j w_{ij} z_i z_j}{\sum_{i=1}^{n} z_i^2} \quad (1)$$

where n is the number of regions, S_0 is a value equal to the sum of all elements of matrix W, z is the normalized value for deforestation in the present paper. However, the Moran's I statistic can only capture global autocorrelation, not identifying association at a local level. In this context, we use the LISA statistic to capture local spatial autocorrelation and clusters,

$$I_i = z_i \sum_{j-1}^{J} w_{ij} z_j \quad (2)$$

where z_i represents the variable of interest of the standardized region i, w_{ij} is the spatial weighting matrix element (W) and z_j is the value of the variable of interest in the standardized region j. The local Moran I (LISA) can represent four spatial clusters: High-High (AA), Low-Low (BB), High-Low (AB) and Low-High (BA).

In an econometric model, it is possible to incorporate the spatial component through spatially lagged variables. It is possible to propose a general spatial model that, by imposing restrictions on the parameters, can achieve the desired specifications. Such a model are

$$y = \rho W y + X\beta + WX\tau + \xi \quad (3)$$
$$\xi = \lambda W \xi + \varepsilon$$

where X is the matrix of explanatory variables; β is the vector k × 1 of regression coefficients; ε is the error term with mean zero and constant variance. The Spatial Autoregressive Model (SAR) is obtained by imposing the following constraints on the model (16): $\rho \neq 0$, $\tau = 0$ and $\lambda = 0$. In this paper, the SAR model will seek to identify if the deforestation rate of a given municipality is influenced by the value of its neighbors, determined according to a spatial weight matrix. If $\rho > 0$ and significant, there is evidence of positive spatial autocorrelation, while a significant $\rho < 0$ indicates the presence of negative spatial autocorrelation. The model suffers from the problem of endogeneity of the lagged variable, then, it estimated through instrumental variables, which are WX.

The Spatial Error Model (SEM) emerges if $\rho = 0,\ \ \tau = 0$ and $\lambda \neq 0$, that is, when spatial dependence manifests itself in the error term. The estimation by OLS is not adequate, since the bias in the error term makes the estimations of the model parameters inefficient. Therefore, the SEM model must be estimated by maximum likelihood (MV) or by the generalized method of moments (MGM). The Spatial Lag of X model (SLX) occurs when $\rho = 0,\ \ \tau \neq 0$ and $\lambda = 0$, it seeks to capture the presence of spatial spillover from the explanatory variables. The model does not present the problem of endogeneity, and it is therefore possible to estimate by Ordinary Least Squares. The Spatial Durbin Model (SDM) and the Spatial Durbin Error Model (SDEM) are a combination of the previous models. SDM is obtained if $\rho \neq 0,\ \ \tau \neq 0$ and $\lambda = 0$ while the SDEM occurs if $\rho = 0,\ \ \tau \neq 0$ and $\lambda \neq 0$.

3.2 Empirical Design and Database

Deforestation is the proxy for environmental degradation in this paper and the data comes from the *Mapbiomas Project*. We considered the proportion of the microregions forests and natural areas deforested until 2017. In other words, it considered all cleared area regardless of the year of occurrence. We also consider 2017 for all the explanatory variables, except for per capita income, which the data is available only up to 2016. Additional variables inclusion aimed to improve the EKC model specification, as well as better represent structurally the region and explain deforestation in Brazil. This procedure follows the Stern (2017), avoiding poor specification and spurious regressions - recurrent in the EKC models. The per capita income is also included in its squared and cubic version to verify the existence of other formats for the EKC (Grossman and Krugman, 1991, 1995; De Bruyn et al., 1998). Chart 1 brings the variables description that we used in the econometric modelling.

Chart 1: Variables description.

Abbreviation	Description	Unit	Source
DEFOREST	Deforestation (km²) / Microregion Area (km²)	%	MABIOMAS/IBGE
GDP	Per capita GDP	R$	SIDRA/IBGE
GDP²	GDP Squared		-
GDP³	GDP Cube		-
ROAD.DENSITY	Roads extension (km) / Microregion Area (km²)	km²	CSR
RAIL	Rail extension (km) / Microregion Area (km²)	km²	CSR
DEM.DENSITY	Demographic density (inhabitants/km2)	km²	IBGE
AGRIC.GDP	Agricultural participation in GDP	%	IBGE
IND.GDP	Industry participation in GDP		
OPEN.TRADE	Openness to trade.((Export +Import)/GDP)	R$	IPEA/IBGE
MACHINERY	Machinery for farm	Count	IBGE
PASTURE	Pasture (km²) / Microregion Area (km²)	%	IBGE
CROP	Crop (km²) / Microregion Area (km²)	%	IBGE
CATTLE	Cattle Productivity	Count/km²	IBGE
SUGARCANE	Sugarcane Productivity	kg/ha	IBGE
MAIZE	Maize Productivity	kg/ha	IBGE
SOYBEAN	Soy Productivity	kg/ha	IBGE
ALTITUDE	Average Altitude	m	IPEA

TEMPERATURE	Average Temperature	ºC	IPEA
RAINFALL	Average annual precipitation	mm	CPRM
SOIL	Soil suitability for farming	%	MMA/IBGE
RIVER	Rivers extension (km) / Microregion Area (km²)	km²	CSR
PROTECTED.A	Protected Area	%	CSR

Source: research data.

In addition to the variables directly linked to the agricultural frontier expansion in Brazil, we also consider some geographic and structural variables for control purpose, due to their importance indicated by the literature. Among them, it was used some vector data to construct variables specifically to this empirical design: ROADS, RAIL, RAINFALL, SOIL, RIVER, PROTECTED. Measurements were constructed using the spatial joint tool in the GIS software (ArcMap 10.3). Some explanations about these variables are worth mentioning.

The SOIL variable was construct using the *Mapa de Potencial Agrícola do Brasil*, complied by the *Instituto Brasileiro de Geografia e Estatística (IBGE)* and made available by the *Ministério do Meio Ambiente (MMA).* The Brazilian territory are classified according to the agricultural potential of its soils, considering factors such as: fertility, physical and morphological characteristics, main limitations and topography. Merging the agricultural potential map with the Brazil map, we identified the predominant type of soil that exists in the microregions. Finally, A weighted average with higher weights for more commonly used soils was calculated, which resulted in an indicator that the closer to one, the greater is suitability. This procedure seeks to verify if municipalities with greater agricultural potential soils have higher rates of deforestation. In an indirect way, it will be possible to identify if microregions with greater agricultural potential soils have deeper changes in land use.

The RAINFALL is composed of average annual precipitation data (1977 to 2006), from the national hydrometeorological network, compiled by the *Serviço Geológico do Brasil (CPRM)* and made available by the Pluviometric Atlas of Brazil. The ROADS, RAIL, RIVERS and PROTECTED.A data vectors was made available by the *Centro de Sensoriamento Remoto da Universidade Federal de Minas Gerais (CSR-UFMG)*. Finally, it is possible mention a recurrent problem in the EKC model: multicollinearity, which can invalidate statistical inferences. Stern (2017) argues that most of the additional variable included in the model are highly correlated with per capita income. Was checked the correlation between the variables used in the EKC and from them; we notice high correlations that could compromise the estimation of the EKC model between the per capita income, farm machinery and industry participation in GDP along with soybean and maize productivity. For that reason, we consider only the per capita income and soybean productivity in the econometric model, in order to avoid the problem.

The forest conversion and land use changes may present spatial interactions that result in significant spillovers, influencing the economic agent decision. This spatial spillover may occur due to the presence of centripetal forces, generated by productivity difference and transport costs that can cause significant regional differences; attracting productive activities, especially agricultural and livestock (Maddison, 2006; Weinhold and Reis, 2008; Robalino and Pfaff, 2012). On other words, the presence of spatial spillovers may be one important factor inducing the economic agents to push the agricultural frontier expansion, resulting deforestation. Therefore, we represent the model estimated as

$$DEFOREST_i = \beta_0 + \beta_1 GDP_i + \beta_2 GDP^2{}_i + \beta_3 GDP^3{}_i + \beta_k Z_i + \tau WS + \varepsilon_i \quad (4)$$

where $DEFOREST$ is the percentage of the microregion that was cleared.; GDP is the per capita income; i refers to the microregion; Z is the matrix of k additional explanatory variables included in the model (described in Chart 1); S is a vector containing elements that represents the agricultural frontier expansion, which is: ROADS, PASTURE and CROP. The spatial dependence matrix W, which represents the structural configuration between the regions, capture the presence of spatial spillovers in the variables.

The EKC format is related to the signs and significance presented by the coefficients β_1, β_2 and β_3 in the model (1). It is a sufficient condition for the curve to present a linear format, a significant $\beta_1 > 0$, while β_2 and β_3 are not significant. For an inverted "U" shape, it is sufficient that $\beta_1 > 0$, $\beta_2 < 0$ and that both are significant while β_3 is not. In case of $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 > 0$, all statistically significant, is configured as a necessary and sufficient condition for an "N" curve shape. According to Stern (2017), if the model presents a β_1 and β_2 statistically significant, it is possible to find the point of the curve that is called the "turning point", which is where the curve reaches its maximum value (in the case of inverted "U" format) or minimum value (if formatted as "U"). The turning point equation is $\tau = -\frac{\beta_1}{2\beta_2}$

4. RESULTS AND DISCUSSION

Deforestation in Brazil has significant negative impacts on the environment, affecting adjacent localities and potentially global climatic stability. Therefore, the search for its determinants are fundamental for the development of inhibitory measures, especially considering the road network expansion that allows access to previously isolated areas, affecting the degradation rhythm. The Figure 1 shows the deforestation and road density spatial distribution in Brazil and we can note a spatial concentration for both variables in the country. Deforestation and road density are both concentrated in the *Centro-Sul* and Northeast, which may indicate a close relationship between the variables. According to Freitas et al. (2010), this spatial configuration reflects the Brazilian colonization and occupation process that occurred more intensely in Southeast and Northeast.

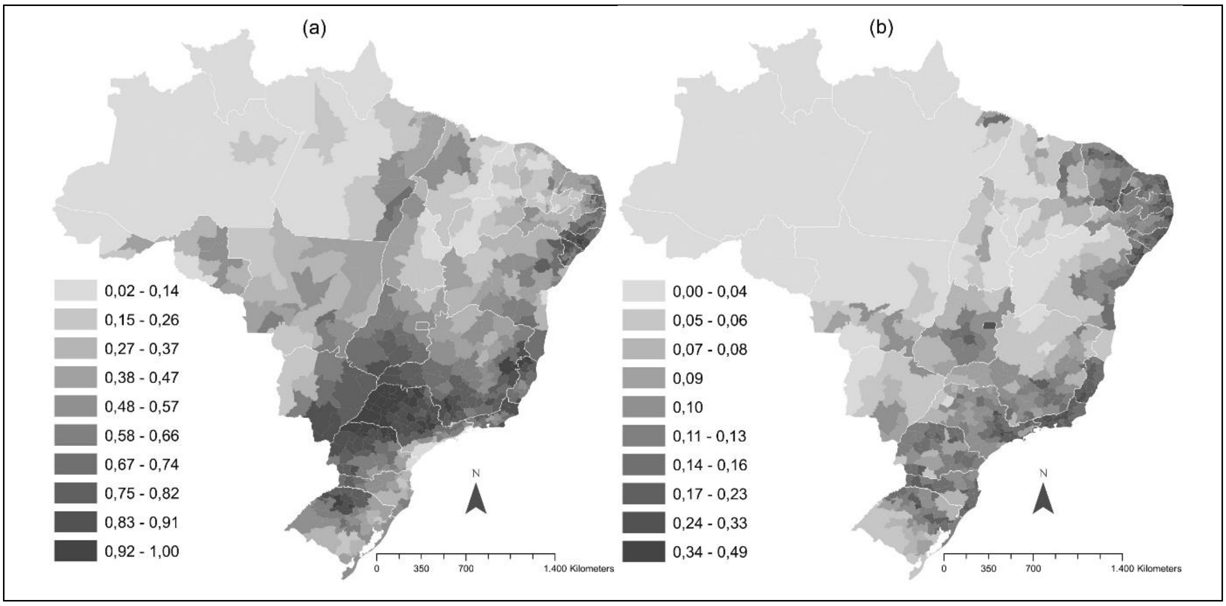

Figure 1: Spatial Distribution of deforestation and Road Density in Brazil, 2017.

Source: research data.

The Moran's I statistic presented in Table 1 ratifies the spatial concentration for deforestation and road density, with positive and statistically significant coefficients - independent of the convention matrix applied. Theoretically, the deforestation spatial concentration may result from spatial interactions, which can reinforce it. This phenomenon are also evidenced by several empirical papers for Legal Amazon (Igliori, 2006; Pfaff et al., 2007; Oliveira and Almeida, 2011; Oliveira et al., 2011; Andrade De Sá et al., 2015; Jusys, 2016; Amin et al., 2019).

Table 1: Moran's I for Deforestation and Road Density in Brazil, 2017.

	Weights Matrix					
	Queen	Rook	Three neigh.	Five neigh.	Seven neigh.	Ten neigh.
Deforestation	0.48*	**0.49***	0.40*	0.38*	0.35*	0.31*
Road Density	0.46*	**0.47***	0.33*	0.37*	0.32*	0.28*

Source: research data. Note: * Level of significance of 1%.

Figure 2 confirms this spatial phenomenon for deforestation (a) and road density for Brazil (b), with similar spatial configuration from Figure 1. We have a High-High cluster for both variables in the *Centro-Sul* and Northeast along with a Low-Low cluster in the North.

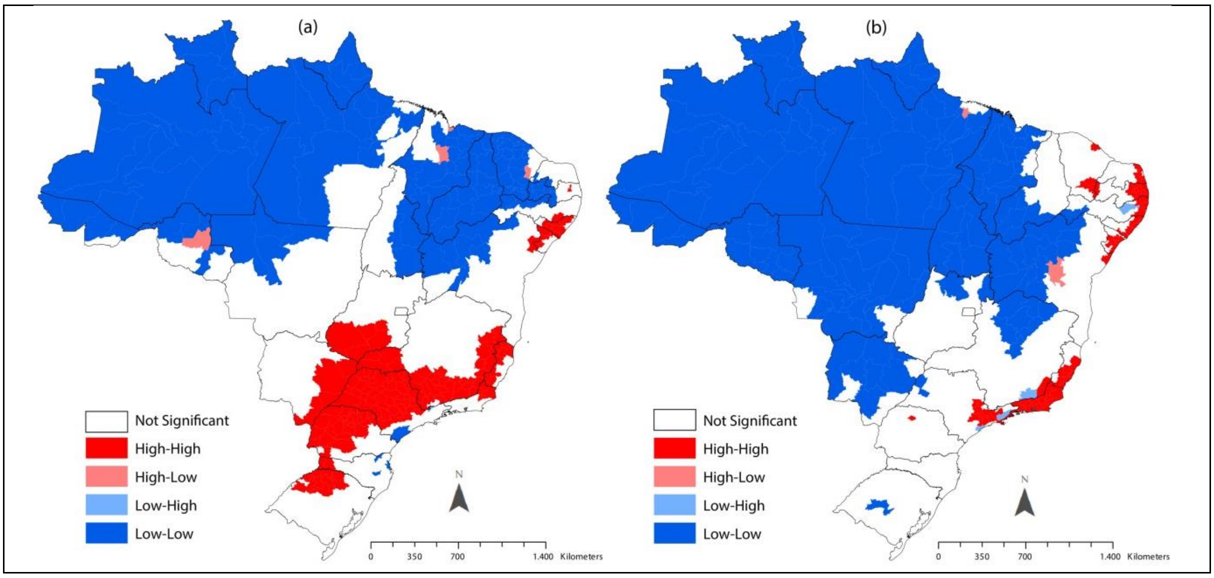

Figure 2: LISA Map for Deforestation and Road Density in Brazil, 2017.
Source: research data. *Note:* Empirical pseudo-significance based on 99,999 random permutations.

With the basic deforestation characteristics in the Legal Amazon identified, in terms of its spatial distribution, the next step is to find its determinants. It was estimated the EKC model and Table 2 presents the estimations. Furthermore, from the Jarque-Bera test it was not possible to reject the null hypothesis of normality in the residuals. Regarding the variance, the Koenker-Bassett test reject the homoscedasticity hypothesis, indicating the presence of a non-constant variance in the residuals. Therefore, the spatial models, due to the normality in the residuals, are estimated with maximum likelihood (MV). In addition, White's robust error (1980) are employed in the models SAR, SLX and SDM, and the robust error of Keleijan and Prucha (2010) for models SEM and SDEM, both aiming to control the presence of heteroscedasticity.

The best model, according to the Akaike information criterion, is the SDM, which captures spatial spillovers from deforestation and agricultural frontier expansion. In addition, the best spatial model is the one that minimize the spatial autocorrelation in the residuals. Considering the Moran's I in the EKC spatial models residuals (Appendix A), the SDM presented the lowest coefficients for this statistics, indicating the model controlled the spatial dependence problem. Since the models have statistically significant economic development proxies with coefficients, $\beta_1 > 0, \beta_2 < 0$, we have an inverted-"U" relationship between deforestation and development for Brazil. This fact demonstrates that deforestation will increase until a certain threshold as the country develops, from which it begins to fall. According to Grossman and Krueger (1991; 1995) at low levels of development, growth initially causes a scale effect by increasing natural resources use, which leads to deforestation. However, after a "turning point", the composition and technical effects became large enough to mitigate the scale effect, reducing environmental degradation.

Table 2: EKC Spatial models for deforestation in Brazil.

	OLS	SAR	SEM	SLX	**SDM**	SDEM
CONSTANT	-0.3447**	-0.1402*	0.0760	-0.3742	**-0.0773**	-0.0226
GDP	1.09E-05**	4.90E-06**	7.80E-06**	8.30E-06	**5.80E-06****	7.10E-06**
GDP²	-0.0E+00**	-0.0E+00*	-0.0E+00**	-0.0E+00	**-0.00E+00****	-0.0E+00**
ROAD.DENSITY	0.7369**	0.3880**	0.1820*	0.3457	**0.2292***	0.2925**
RAIL	0.3268	0.0873	-0.0770	0.1085	**-0.0693**	0.0522
AMAZON	0.1052**	0.0890**	0.0215	0.1459	**0.0829****	0.0577
CERRADO	0.0191	-0.0042	-0.0065	0.0317	**0.0035**	0.0018
DEM.DENSITY	0.0001**	4.27E-05**	0.0001**	4.52E-05	**4.28E-05****	0.0001**
AGRIC.GDP	-0.0012	-0.0016**	-0.0012*	-0.0016	**-0.0014****	-0.0013**
OPEN.TRADE	-0.0881**	-0.0610**	-0.0386	-0.0812	**-0.0469**	-0.0319
CROP	0.0061**	0.0035**	0.0052**	0.0052	**0.0052****	0.0053**
PASTURE	0.0083**	0.0046**	0.0072**	0.0070	**0.0068****	0.0072**
CATTLE	0.0004	0.0004	0.0003	0.0004	**0.0004***	0.0003
SUGARCANE	9.00E-07**	4.00E-07*	6.00E-07**	6.00E-07	**4.00E-07**	5.00E-07*
SOYBEAN	-2.01E-05**	-8.50E-06	1.60E-06	-1.42E-05	**-3.60E-06**	1.90E-06
ALTITUDE	0.0001**	0.0001**	0.0001*	0.0001	**0.0001****	0.0001*
TEMPERATURE	0.0229**	0.0096**	0.0083*	0.0206	**0.0060****	0.0072*
RAINFALL	-0.0001**	-0.0001**	-0.0001**	-0.0001	**-0.0001****	-0.0001**
RIVER	-0.0603	-0.0484	-0.0628*	-0.0595	**-0.0623***	-0.0522
SOIL	0.0300	-0.0028	0.0164	0.0737	**0.0280**	0.0345
PROTECTED.A	0.0567	0.1143**	0.0960**	0.0838	**0.1080****	0.0983**
ρ	-	0.5860**	-	-	**0.6909****	-
λ	-	-	0.7864**	-	**-**	0.7500**
W_ROAD.DENSITY				0.8291	**0.2785***	0.5699**
W_RAIL				0.7757	**0.1562**	0.6620
W_PASTURE				0.0019	**-0.0041****	0.0008
W_CROP				0.0010	**-0.0031****	0.0008
Jarque-Bera	4.3500					
Koenker-Bassett	57.4500**					
Akaike info crit.	-607.3390	-922.503	-965.207	-639.803	**-990.466**	-982.876
Moran's I	0.5624**	0.0999**	0.7304**	0.5807**	**0.0231**	0.6348**

Source: research results. *Note:* ** Significant at 1%; * Significant at 5%.

One can highlight the statistical significance in the SDM model for the following variables: road density, demographic density, agricultural GDP, crop, pasture, cattle altitude, temperature, rainfall, river, protected area. Regarding the spatial spillovers from the agricultural frontier expansion, we have the road density, pasture and crop, in addition to the spillovers from forest conversion. Considering the significant variables, is worth explaining some of the empirical evidences, especially from transport network, agricultural frontier expansion and spatial spillovers.

The road density and its spatial spillovers have a positive impact on deforestation in Brazil. One possible explanation is that road network expansion allows access to previously isolated areas by creating corridors to the region, reducing transportation costs and pushing the agricultural frontier further by intensifying the migration and occupation of the territory, leading to deforestation (Assunção and Bragança, 2015; Bragança, 2018; Araújo et al., 2019). However, the rail density do not affect significantly the deforestation, a fact that may reflects the minor importance of this mode of transport. This empirical evidence are an important contribution to the literature on deforestation in Brazil, since there are no papers that address directly this for the whole country.

The coefficients ρ (Rho) are significant, indicating the presence of spatial spillover from deforestation, indicating the importance of spatial interactions in forest conversion and land use changes. (Weinhold and Reis, 2008; Robalino and Pfaff, 2012; Assunção and Bragança, 2015). The crop and pasture areas presented a positive statistical significance and a negative spillover. Therefore, its expansion causes forest area reduction in Brazil, a fact that reflects the negative environmental impacts from the agricultural frontier expansion. On the other hand, the empirical evidences suggest the expansion in a region diminishes its neighbor's deforestation in a negative spatial spillover effect. The demographic density presented a statistical significant positive sign, indicating that densely populated municipalities tend to deforested more. This result evidence is in line with Grossman and Krueger (1995), Cropper and Griffiths (1994). The protected area variable presented a significant positive impact, contradicting the idea that conservation units acts as inhibitor deforestation. This demonstrates a need for government supervision over conservation areas in Brazil, since the status granted to these localities do not serve as inhibitors of deforestation.

5. FINAL CONSIDERATIONS

This paper aimed to investigate the relationship between economic development, road density and deforestation in Brazil, using the Environmental Kuznets Curve hypothesis. The exploratory analysis pointed to spatial concentration for deforestation and road density, which its high values are concentrated in the *Centro-Sul* and Northeast, indicating a close relationship between the variables. This spatial configuration reflects the Brazilian colonization and occupation process that occurred more intensely in those regions, evidenced by areas with high population concentration. Thus, following this idea, the Brazilian agricultural frontier region tends to occur higher deforestation rates.

Initially, it was estimated the models using conventional and spatial econometrics techniques in order to control the spatial dependence in the residuals. The model that best captured the EKC relationship, according to the Moran's I in the spatial models residuals and the Akaike

Information Criterion, are the SDM model. It was found an inverted "U" format for EKC, corroborating the initial hypothesis. In other words, economic development, although it initially lead to deforestation, it occurs until a certain level, from which the relationship reverses and induces a sustainable development.

It was also identified many variables, especially related to the agricultural frontier expansion, which affects negatively environment. Among the main influences, it was have the roads expansion and its spatial spillovers, which attracts migratory waves and agricultural activities due its cost reduction; the crop and pasture area, demographic density and protected area, all with a positive impact. On the other hand, the productivities variables do not affect significantly the deforestation. Therefore, a possible solution for conciliate the agricultural production growth with environmental protection is to incentive intensification in existing agricultural areas, which would enable Brazil to reduce significantly its deforestation and greenhouse gas emissions and still maintain agricultural production growth.

REFERENCES

Alphan, H. *Analysis of road development and associated agricultural land*. Springer International Publishing AG, part of Springer Nature 2017

Amin, A., Choumert, J., Combes Motel, P., Combes, J.C., Kéré, N.E, Ongono-olinga, J.G. Sfchwartz, s. *Neighborhood effects in the Brazilian Amazônia: Protected areas and deforestation.* Journal of Environmental Economics and Management, volume 93, pp. 272-288, 2019.

Andrade De Sá, S., Palmer, C., Di Falco, S. *Dynamics of indirect land-use change: empirical evidence from Brazil.* Journal of Environmental Economics and Management, 65(3), 377e393, 2013.

Andrade De Sá, S., Delacote, P. Kéré, E. N. *Spatial Interactions in Tropical Deforestation: An Application to the Brazilian Amazon.* Etudes et Documents No. 3, CERDI, 2015.

Arrow, K.; Bolin, B.; Costanza, R.; Dasgupta, P.; Folke, C.; Holling, C.S.; Jansson, B. O; Levin, S. *Economic Growth, carrying capacity, and the environment*. Science, Stanford, vol. 268, p. 520-521, 1995.

Araujo, C.; Bonjean, C.; Combes, J. P.; Reis, E. *Property rights and deforestation the Brazilian Amazon*. Ecological Economics. 68, pg. 2461-2468, 2009.

Araújo, M. L. S.; Sano, E. E.; Bolfe, E. L.; Santos J. R. N.; Santos, J. S.; Silva, F. B. *Spatiotemporal dynamics of soybean crop in the Matopiba region, Brazil (1990–2015)*, Land Use Policy, v. 80, 57-67, 2019.

Assunção, J; Gandour, C; Rocha, R. *Deforestation slowdown in the legal Amazon: Prices or Policies?* Environment and Development Economics, 20(6), 697-722, 2015.

Barros, P. H., Stege, A. L. *Deforestation and Human Development in the Brazilian Agricultural Frontier: an Environmental Kuznets Curve for MATOPIBA.* XXII Encontro de Economia da Região Sul – ANPEC SUL, 2019.

Bhattarai, M., Hamming, M. *Institutions and the Environmental Kuznets Curve for deforestation: a cross-country analysis for Latin America, Africa, and Asia.* World Development, 29 (6), 995 – 1010, 2001.

Bragança, A. A. *The Economic Consequences of the Agricultural Expansion in Matopiba.* Revista Brasileira de Economia, Rio de Janeiro, v. 72, n. 2, p. 161-185, jun. 2018.

Cropper, M.; Griffiths G. *The Interaction of Population, Growth and Environmental Quality.* American Economic Review, v.84, p.250-254, 1994.

Culas, R. J. *Deforestation and Environmental Kuznets Curve: an Institutional Perspective.* Ecological Economics, v. 61, p. 429-437, 2007.

De Bruyn, S. M.; Van Den Bergh, J. C. J. M.; Opschoor, J. B. *Economic Growth and Emissions: reconsidering the empirical basis of environmental Kuznets curves.* Ecological Economics, v 25, p. 161-175, 1998.

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

Freitas, S. R; Hawbaker, T. J; Metzger, J. P; *Effects of roads, topography, and land use on forest cover dynamics in the Brazilian Atlantic Forest.* Forest Ecology and Management, v. 259, 3, p. 410-417, 2010.

Gill, H. K., Lantz, T. C., O'Neill, B., & Kokelj, S. V. *Cumulative impacts and feedbacks of a gravel road on shrub tundra ecosystems in the Peel Plateau, Northwest territories, Canada.* Arctic Antarctic and Alpine Research, 2014.

Godar, J; Tizado, E; Pokorny, B. *Who is responsible for deforestation in the Amazon? A spatially explicit analysis along the Transamazon Highway in Brazil*. Forest Ecology and Management, 267, 58-73, 2012.

Gomes, S.C.; Braga, M.J. *Desenvolvimento Econômico e Desmatamento na Amazônia Legal: uma análise econométrica.* In XLVI SOBER, 2008.

Grossman, G.; Krueger, A. *Environmental impacts of a North American free trade agreeme*nt. NBER (National Bureau of Economic Research Working Paper 3914)., Cambridge, MA, 1991.

Grossman, G.; Krueger, A. *Economic growth and the environment*. Quarterly Journal of Economics, Massachussetts, v. 110, n. 2, p. 353-377, 1995.

Igliori, D. C. *Deforestation, growth and agglomeration effects: Evidence from agriculture in the Brazilian Amazon.* Anais: *XXXIV Encontro Nacional de Economia*, ANPEC, 2006.

IBAMA. Available in:<http://www.mma.gov.br/ > Acessed on 10/03/2018.

INPE - Acessed on 03/12/2018 through the link: <http://www.obt.inpe.br/cerrado>.

Jusys, T. *Fundamental causes and spatial heterogeneity of deforestation in Legal Amazon*. Applied Geography, 2016.

Koyuncu, C. Yilmaz, R. *The impact of corruption on deforestation: A cross-country evidence.* Journal of Developing Ideas 42 (2): 213–22, 2009.

Maddison, D. *Environmental Kuznets curves: A spatial econometric approach*. Journal of Environmental Economics and Management. Volume 51, pp. 218-230, 2006.

Myers, N.; Mittermeier, R.; Mittermeierm C.; Fonseca, G.; Kent, J. *Biodiversity hotspots for conservation priorities.* Nature 403: 853-858, 2000.

Nepstad, D.; Carvalho, G.; Barros, A. C.; Alencar, A.; Capobianco, J.P.; Bishop, J.; Moutinho, P.; Lefebvre, P.; Silva, U. L.; Prins, E.. *Road paving, fire regime feedbacks, and the future of Amazon forests*. Forest Ecology and Management, n. 154, p. 395–407, 2001

Oliveira, R. C., Almeida, E. *Deforestation in the Brazilian Amazonia and Spatial Heterogeneity: a Local Environmental Kuznets Curve Approach.* In 57th Regional Science Association International, 2011.

Oliveira, R.C.; Almeida, E.; Freguglia, R. S.; Barreto, R. C. S. *Desmatamento e Crescimento Econômico no Brasil: uma análise da Curva de Kuznets Ambiental para a Amazônia Legal.* Revista Economia e Sociologia Rural vol.49 no.3 Brasília Julho/Setembro. 2011.

Pfaff, A., Robalino, J.A., Walker, R., Aldrich, S., Caldas, M., Reis, E. Pers, S., Bohrer. *Road Investments, Spatial Spillovers and Deforestation in the Brazilian Amazon*. Journal of Regional Science, 47: 109-123, 2007.

Prates, R.C. *O desmatamento desigual na Amazônia brasileira: sua evolução, suas causas e conseqüências para o bem-estar.* Tese, Universidade de São Paulo, 2008.

Robalino, J.A.; Pfaff, A. *Contagious Development: Neighbor Interactions in Deforestation*. Journal of Development Economics, 97: 427-436, 2012.

Santos, R.B.N., Diniz, M. B., Diniz, M. J. T., Rivero, S. L. M., Oliveira Júnior, J. N. *Estimativa da Curva de Kuznets Ambiental para a Amazônia Legal*. In XLVI SOBER, 2008.

Shafik, N., Bandyopadhyay, S. *Economic growth and environmental quality:a time series and cross-country evidence*. Journal of Environmental Economics and Management, v. 4, p.1-24, 1992.

Selden, T.M.; Song, D. *Environmental quality and development: is there a Kuznets Curve for air pollution emissions?* Journal of Environmental Economics and Management, v. 27, n. 2, p. 147-162, 1994.

Soares-Filho, B.; Alencar, A. Nepstad, D.; Cerqueira, G.; Vera-Diaz, M.; Rivero, S.; Solórzano, L. Voll, E. *Simulating the Response of Land-Cover Changes to Road Paving and Governance along a Major Amazon Highway: The Santarem-Cuiaba Corridor.* Global Change Biology. 10. 745 – 764, 2004.

Stern, D. I.Common, M. S.; Barbier, E. B. *Economic growth and environmental degradation: the Environmental Kuznets Curve and sustainable development.* World Development, 1151-1160, 1996.

Stern, D. I. *The environmental Kuznets curve after 25 years.* Journal of Bioeconomics, 19: 7, 2017

Suri, V.; Chapman, D. *Economic growth, trade and energy: implications for the environmental Kuznets curve.* Ecological Economics, v. 25, p.195-208, 1998.

Tritsch, I., Arvor, D. *Transition in environmental governance in the Brazilian Amazon: emergence of a new pattern of socio-economic development and deforestation.* Land Use Policy, 59, 446-455, 2016.

Vardei, M. H., Salmanmahiny, A., Monavari, S. M., & Zarkesh, M. M. K. (2014). *Cumulative effects of developed road network on woodland—a landscape approach.* Environmental Monitoring and Assessment, 186(11),

Walker, R.; Arima, E.; Messina, J.; Soares-Filho, B.; Perz, S.; *Modeling spatial decisions with graph theory: Logging roads and forest fragmentation in the Brazilian Amazon.* Ecological applications, 239-54, 2013.

Weinhold, D., Reis, E. *Transportation Costs and the Spatial Distribution of Land Use in the Brazilian Amazon.* Global Environmental Change, 18: 54-68, 2008.

White, H. *A Heteroskedasticity-Consistent Covariance Matrix Estimator and a Direct Test for Heteroskedasticity*. Econometrica, Vol. 48, No. 4, pp. 817-838, 1980.

Appendix

Appendix A: Moran's I for the EKC models residuals.

	Weights Matrix					
	Queen	Rook	Three neigh.	Five neigh.	Seven neigh.	Ten neigh.
OLS	0.5127*	0.5159*	0.5624*	0.4934*	0.4618*	0.4068*
SAR	0.1631*	0.1697*	0.0999*	0.1270*	0.1381*	0.1152*
SEM	0.6861*	0.6876*	0.7304*	0.6685*	0.6464*	0.6093*
SLX	0.5163*	0.5199*	0.5807*	0.4963*	0.4585*	0.3993*
SDM	**0.0845***	**0.0912***	**0.0231**	**0.0551**	**0.0717***	**0.0573**
SDEM	0.6223*	0.6243*	0.6776*	0.6026*	0.5698*	0.5258*

Source: research data. *Note:* * Level of significance of 1%.