Deforestation and Human Development in the Brazilian Agricultural Frontier: an Environmental Kuznets Curve for MATOPIBA

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ABSTRACT: This paper aims to estimate an Environmental Kuznets Curve (EKC) for the current Brazilian agricultural frontier, located in the region known as MATOPIBA. The question to be answered can be summarized as: How does human development affect the region's environment, captured by deforestation? Specifically, we analyzed the presence of spatial dependence and heterogeneity, as well as the existence of clusters between the 337 municipalities of MATOPIBA in 2010, using exploratory spatial data analysis (ESDA) and spatial econometrics. We identified the presence of spatial dependence for deforestation, which led to the incorporation of this effect into the econometric modeling, which resulted in the SLX as the best spatial model. In addition, we get an inverted "U" format for the EKC, thus deforestation increases until a certain threshold, as the region develops, from which it begins to fall. The “turning point”, where development reaches its maximum impact on the environment, is a HDI of 0.57 and 28.18% of the municipalities are below this value, which highlights environmental concerns, since its development could boost degradation. To worsen this scenario, we identified many variables, especially related to the agricultural frontier expansion, which induces deforestation in the MATOPIBA.

Keywords: Environmental Kuznets Curve (EKC). Brazilian Agricultural Frontier. MATOPIBA. Spatial Dependency.

RESUMO: Este trabalho busca estimar uma Curva Ambiental de Kuznets (CKA) para a atual fronteira agrícola brasileira, localizada na região conhecida como MATOPIBA. A pergunta a ser respondida pode ser resumida em: como o desenvolvimento humano impacta o meio ambiente da região, captado pelo desmatamento? De forma específica, analisou-se a presença de dependência e heterogeneidade espacial, bem como a existência de clusters entre os 337 municípios do MATOPIBA em 2010, utilizando-se da análise exploratória de dados espaciais (AEDE) e econometria espacial. Identificou-se a presença de dependência espacial, fato que levou à incorporação desse efeito na modelagem econométrica, procedimento que resultou no SLX como melhor modelo. O formato encontrado para a CKA foi de “U” invertido, isto é, o desenvolvimento tende a elevar o desmatamento até certo patamar, a partir do qual a relação se inverte, resultando na queda do impacto ambiental. O “ponto de virada”, onde o desenvolvimento atinge seu máximo impacto, é um IDH de 0.57, sendo que 28.18% dos municípios estão abaixo desse valor, fato que levanta preocupações ambientais, pois o desenvolvimento pode acelerar o desmatamento. Para piorar esse cenário, identificou-se diversas variáveis, principalmente relacionadas ao avanço da fronteira agrícola, que induzem o desmatamento no MATOPIBA.


JEL: Q01, Q56

Área 4: Economia Agrária e Ambiental

1. Introduction

The MATOPIBA is the main region of the current Brazilian agricultural frontier. According to Araújo et al. (2019), agricultural frontier are a region dominated by natural vegetation that is facing intensive agriculture-related land occupation. The term "MATOPIBA" refers to the initial syllables of the
states that comprise this region: Maranhão, Tocantins, Piauí and Bahia. The agricultural frontier in the region has been expanding due to the implementation of technologies adapted to local conditions, which allows an increase in productivity for the agricultural production. The low price of land and the easy adoption of technologies have attracted investments and intensified their occupation, resulting in an expressive growth in local production, mainly of grains like soybeans and maize. (MIRANDA et al., 2014; BRAGANÇA, 2018; ARAÚJO et al., 2019).

Recognizing the region's strategic importance in Brazilian agribusiness, the country's government created Decree No. 8447 on May 6, 2015 with the main objective of establishing an Agricultural Development Plan for MATOPIBA, which seeks to guide federal projects and actions specifically for the region (BRASIL, 2015).

The intensive occupation of MATOPIBA for agricultural production began in the 1980, and the process is still underway. The existence of underutilized land, which adopt low productivity techniques, allows the increase in production with adoption of technology. In addition, there are areas, where native forests of the Cerrado prevail, which are possible its incorporation into the dynamic areas of MATOPIBA, as the agricultural frontier advances. (BATISTELLA and VALLADARES, 2009; STUDTE, 2008; BOLFE et al., 2016; ARAÚJO et al., 2019). According to Chagas and Andrade (2017), economic agents located in agricultural frontier areas face a considerable opportunity cost by not clearing forest areas for economic use, in light of possible present and future returns.

According to Bolfe et al. (2016) and Bragança (2018), the increase in the use of high-capacity land, combined with the adoption of productivity-enhancing technologies, has enabled the region to present significant increases in its production levels and consequently economic growth. Thus, the existence of underutilized and/or not yet occupied land, together with the agricultural frontier expansion and the economic development in the MATOPIBA, may result, in the coming years, in a process of deforestation. In fact, according to Borges and Santos (2009), the current deforestation of the Cerrado has been located mainly in these sparsely occupied areas, as the MATOPIBA, due the establishment of new agricultural frontiers.

The factors mentioned have enabled the MATOPIBA to present increasing levels of production, especially in soybean culture, and local economic growth (BOLFE et al, 2016; ZANIN and BACHA, 2017; BRAGANÇA, 2018; ARAÚJO et al. 2019). To illustrate this, according to Araújo et al. (2019), the MATOPIBA had a significant growth in soy production, from 260,624 t in 1990 to 10,758,927 t in 2015, an increase of 4028% in the period.

In this context, this paper aims to analyze the relationship between economic development and deforestation in the MATOPIBA, with a special focus on its relationship with the agricultural frontier expansion, in view of its importance for the economic growth of the region. In addition, we investigate the spatial distribution of deforestation, as well as the formation of spatial clusters and the presence of spatial dependence. One of the hypotheses is that there is a spatial effect in deforestation, with centripetal forces acting in the attraction of productive activities, especially agricultural, and consequently generating spatial autocorrelation in this variable. These forces are generated by the existence of different techniques of production, climate, topography and soil conditions among the municipalities of MATOPIBA, factors that leads to regional differences.

The basic hypothesis between economic development and deforestation comes from the pioneering work of Grossman and Krueger (1991) which state that at low levels of development, a growth in per capita income leads to an increase in the environment degradation. However, from a certain level, this logic would reverse itself, with an increase in per capita income leading to a decrease in environmental degradation. The curve that represents this relationship has an inverted "U" format, known in the literature as the Environmental Kuznets Curve (EKC).

However, a recurrent problem in the literature, often not considered in the estimations of EKC, is the per capita income use as proxy for economic development, which is inadequate by capturing only one aspect of development. (HILL and MAGNANI, 2002; JHA and BHANU MURTH, 2003; COSTANTINI and MONNIM 2008; STIGLITZ ET AL., 2009; COSTANTINI and MARTIGINI, 2010; KUBISZEWSKI ET AL., 2013; NEVE and HAMAIDE, 2017). Therefore, the present paper proposes to solve this problem by replacing the per capita income by the Human Development Index (HDI) of the MATOPIBA.

Although there are several papers that sought to estimate an EKC for Brazil using several indicators of environmental degradation, none used the HDI as a proxy for economic development. Moreover, we have the deforestation use in some studies for the Amazonian and Cerrado biomes, but there are no works specifically developed for the MATOPIBA region. Therefore, this paper proposes to fill both gaps in the literature.

Finally, the work is structured into four sections, including this introduction. In the second section, we have the theoretical framework on the environmental curve of Kuznets and the relationship between economic development and environmental degradation. 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

Grossman and Krueger (1991) attempted to decompose the effects that are behind the relationship between economic growth and environmental quality in the Environmental Kuznets Curve, resulting in the identification of three main effects: scale, composition, and technical. The scale effect occurs due to the production increase, which causes a pressure on the environment, since there are greater use of natural resources. The composition effect is the change that occurs in the composition of the goods and services produced. 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. The descending part of the environmental Kuznets Curve, therefore, occurs due this overlay of effects (GROSSMAN and KRUEGER, 1991).

Several authors have attempted to broaden the understanding of why 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), Stern et al. (1996), Suri and Chapman (1998), De Bruyn et al. (1998), Culas (2007). Shafik and Bandyopadhyay (1992) conducted an empirical study and most of the indicators showed results similar to those found by Grossman and Krueger (1991). Selden and Song (1994), in turn, argue that the environmental pressure is due to increases in income and consumption, which lead to greater use of natural resources. However, the authors claim that there are some damping factors that could mitigate the negative effects on the environment, and even reverse it in the long run. 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 composition of production and consumption and technological innovations that increase productivity, induced by market competition and / or adjustments to imposed legislation.

Many researchers, however, argue that the descendant part of the EKC occurs because the polluting industries tend to move from developed countries to underdeveloped, due to the restrictions imposed by the legislation, which encourages this displacement. (SURI and CHAPMAN, 1998; STERN et al., 1996). This theory is known in the literature as the Pollution Haven hypothesis. In the other hand, Institutional changes, according to Culas (2007), is an important element to explain the relationship in "U" inverted between environmental degradation and per capita income. As income increases, factors such as increased utility from undeveloped areas, population awareness of the importance of environmental sustainability, strengthening government capacity for environmental protection helps to explain the decline in environmental impact.

Despite the evidence for the existence of an EKC, some authors, such as De Bruyn et al. (1998) argue that this relationship is not sustained in the long run, since there is another turning point in which per capita 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, being necessary this verification for each specific case.
According to Neve and Hamaide (2017), the use of per capita income as a proxy for economic development is not the most adequate to verify the relationship with environmental degradation, given that the per capita income only partially capture the development of a region. In this context, Hill and Magnani (2002), Jha and Bhanu Murth (2003), Stiglitz et al. (2009), Kubiszewski et al. (2013) and Neve and Hamaide (2017) recommend using a variable that is more related to well-being in general than just economic performance. This occurs because several indicators can lead to increased social welfare, resulting in less environmental damage, without necessarily occurring income growth.

Hill and Magnani (2002) and Jha and Bhanu Murth (2003) sought to avoid this problem by using the Human Development Index (HDI) as a proxy for economic development, replacing the per capita income in the EKC model. The authors also verified that when using the HDI, there are an improvement in the environmental degradation prediction in relation to the per capita income, suggesting that the HDI is able to capture better the relationship with the environment. From the pioneering works by Hill and Magnani (2002), Jha, and Bhanu Murth (2003), many authors have sought to replace per capita income by the HDI, or similar indicators, in their estimates. In general, they have verified an improvement in the models adjustment (COSTANTINI and MONNI, 2008; COSTANTINI and MARTINI, 2010; LAMB and RAO, 2015; NEVE and HAMAIDE, 2017).

In the context there is no consensus about the existence of a traditional EKC in "U-inverted" format for deforestation (SHAFIK and BANDYOPADHYAY, 1992; SHAFIK, 1994; CROPPER and GRIFFITHS, 1994; BHATTARAI and HAMMING, 2001; KOYUNCU and YILMAZ, 2009). Chiu (2012) states that the empirical results is controversial and argues that an analysis must be carried out for each locality, since it is not possible to infer causality of studies for other regions.

There is no consensus on the literature in relation to existence of a traditional EKC in the format of an inverted "U" for deforestation. Shafik and Bandyopadhyay (1992) and Shafik (1994) 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. Bhattacharai 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 cause deforestation, but 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. 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, we have studies that sought to identify the existence of the Environmental Kuznets Curve (EKC) using deforestation. However, practically all the papers focus on the Legal Amazon, with only one paper in the literature for the Cerrado and no paper specifically for MATOPIBA. For Amazon, we have a controversial empirical evidence, which varies according to the analyzed year or method adopted. 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"; and Oliveira et al. (2011) and Oliveira and Almeida (2011) identified a relationship in the "N" format. For the Cerrado, the paper by Colusso et al. (2012) are the only paper that estimate an EKC for this biome. The authors estimated several spatial models, which corroborated significant results for an "N" shaped curve for the Cerrado, indicating that, in the long run, the economic growth is not sufficient to prevent the deforestation of the biome.

However, among the paper for Brazil, we do not have one that specifically seeks the existence of an EKC for the MATOPIBA region. Therefore, based on Chiu (2012), it is clear that we need a specific work for the Brazilian agricultural frontier in the Cerrado. The purpose of the next section is to describe the occupation dynamics in the Cerrado, as well as its agricultural frontier expansion.
2.1. Cerrado Occupation and the Agricultural Frontier Expansion

The Cerrado is located in the central region of Brazil, occupying about 25% of the national territory, with an area of approximately 2,039,243 km², covering 1,389 Brazilian municipalities. The biome is the richest savanna in the world and of much importance to the balance of the global ecosystem. However, its intensive occupation, especially after the 1970 with the advancement of the Brazilian agricultural frontier, has caused serious damage to the biome, with many irreparable environmental losses (MYERS et al., 2000).

The Brazilian government played an active role in the occupation and expansion of the agricultural frontier in the Cerrado. This role began in the 1970 with the military governments, especially after the II Plano Nacional de Desenvolvimento – PND. In practice, the incentive for the occupation of the Cerrado, especially the Central-West, was through the Agricultural Frontier expansion. The basic instrument used was the subsidized rural credit offer, combined with the implementation of an infrastructure that enabled the territory occupation. Such incentives and measures resulted in rapid changes in land coverage and use in the region. There is a close relationship between agricultural frontier expansion and the opening of roads, which allows the creation of access corridors to the region and possibly to deforestation of native because the road network expansion allows access to previously isolated areas, affecting its environmental degradation rhythm. (PIRES, 2000; BECKER, 2001; ASSUNÇÃO and BRAGANÇA, 2015; BRAGANÇA, 2018). Nevertheless, we have no papers in the literature that sought to analyses this impact of roads on deforestation on MATOPIBA, or even Cerrado.

According to Chagas and Andrade (2017), human presence in forest areas itself represents a deforestation vector, since the population demand local resources for their subsistence, income growth and material well-being. The agricultural frontier expansion is, in turn, an inductive factor of the occupation in the Cerrado, which increases the pressure to open new areas. This scenario have led to a progressive depletion of the natural resources of the region, making this biome the second that suffered more changes due to anthropogenic actions in Brazil, after the Atlantic forest. Despite this, conservation units protect only 7.44% of its territory, which has served to aggravate the intensive use of its natural resources (SANTOS et al., 2009; BORGES and SANTOS, 2009; IBAMA, 2010).

In historical terms, the state that presented greater deforestation in Cerrado is São Paulo, with 90% of the total. Then we have Mato Grosso do Sul with 75.87%, Federal District, 70.63%, Paraná, 70%, Goiás, 65.11%, Minas Gerais, 56.84%, Mato Grosso, 42.83%, Bahia, 36.45%, Tocantins, 26.4%, Maranhão, 22.85, Piauí, 15.1%, and Rondônia with 2.88% (IBAMA, 2010). Although the MATOPIBA states are those with the smallest deforested area, except Rondônia, the current deforestation in the Cerrado has been located mainly in Piauí, Bahia, Tocantins and Maranhão, states that suffered considerable land use changes after 2000s (BORGES and SANTOS, 2009). Table 2 shows the ten municipalities with the largest deforestation in 2010; we can note that all are located in the states belonging to MATOPIBA region.

### Table 1 – Municipalities of the Cerrado that presented greater deforestation in 2010.

<table>
<thead>
<tr>
<th>Municipality</th>
<th>State</th>
<th>Suppression (km²)</th>
<th>Area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baixa Grande do Ribeiro</td>
<td>PI</td>
<td>394,29</td>
<td>5,05%</td>
</tr>
<tr>
<td>Uruçuí</td>
<td>PI</td>
<td>203,48</td>
<td>2,41%</td>
</tr>
<tr>
<td>Formosa do Rio Preto</td>
<td>BA</td>
<td>143,92</td>
<td>0,89%</td>
</tr>
<tr>
<td>São Desidério</td>
<td>BA</td>
<td>119,85</td>
<td>0,81%</td>
</tr>
<tr>
<td>Mateiros</td>
<td>TO</td>
<td>93,06</td>
<td>0,97%</td>
</tr>
<tr>
<td>Barreiras</td>
<td>BA</td>
<td>88,39</td>
<td>1,12%</td>
</tr>
<tr>
<td>Balsas</td>
<td>MA</td>
<td>85,24</td>
<td>0,65%</td>
</tr>
<tr>
<td>Santa Quitéria</td>
<td>MA</td>
<td>73,88</td>
<td>3,85%</td>
</tr>
<tr>
<td>Codó</td>
<td>MA</td>
<td>69,91</td>
<td>1,60%</td>
</tr>
<tr>
<td>Riachão das Neves</td>
<td>BA</td>
<td>68,81</td>
<td>1,18%</td>
</tr>
</tbody>
</table>

Source: IBAMA (2010).

In this context, the Brazilian Government adopted measures to combat and inhibit the deforestation in the Cerrado. In 2009, for example, the Brazilian government released the Plano de Ação para Prevenção...
e Controle do Desmatamento e das Queimadas no Bioma Cerrado (PCCerrado) which aims to reduce continuously and permanently the rate of deforestation, as well as forest fires and wildfires in the Cerrado. In 2014, it launched the second phase of the plan in order to guide the actions, in addition to ratifying the importance of the conservation of the natural resources of the region. An essential element of the plan is the Política Nacional de Mudanças Climáticas, Law nº 12.187/2009, which seeks the reduction of greenhouse gas emissions in the atmosphere. It also established a goal of 40% reduction in deforestation rate in the biome.

The intensive occupation of Matopiba for agricultural production began in the 1980, and this process is not yet completed. This is due to the existence of many underutilized land, which adopt low productivity production techniques. The region own conditions facilitate this process of occupation, such as: good climate for agriculture, flat land that enables the adoption of land productivity enhancing machinery, cheap labor, easy-to-fix soils and low price land. In addition, many spaces are not occupied, where native forests of the Cerrado prevail. Therefore, this availability makes it possible to incorporate these regions into the most dynamic areas of Matopiba, as the agricultural frontier advances. (BATISTELLA and VALLADARES, 2009; STUDTE, 2008; BOLFE et al., 2016; BRAGANÇA, 2018; ARAÚJO et al., 2019).

The low price of land and the easy adoption of mechanized and large-scale agriculture have attracted labor along with investments in capital, which intensified their occupation, resulting in an expressive growth in local production, mainly of grains like soybeans and maize (MIRANDA et al., 2014; ASSUNÇÃO and BRAGANÇA, 2015; BRAGANÇA, 2018; ARAÚJO et al. 2019). However, according to Garcia and Vieira Filho (2018), approximately 68% of the agricultural expansion in the region between 2002 and 2014 was due to the conversion of native areas.

In 2017, for example, the region accounted for approximately 11% of the national soy production, a figure that may increase in the future as the agricultural frontier in the region expands (ZANIN and BACHA, 2017; ARAÚJO et al., 2019). Therefore, the existence of underutilized and/or not yet occupied land, together with the agricultural frontier expansion and the economic development of the Matopiba, may maintain the deforestation process in the region in the following years. To make matters worse, Garcia and Vieira Filho (2018) point out that due inadequate soil management, which causes their progressive degradation, resulted in approximately 9 million and 591 thousand hectares of area with moderate and high degree of desertification, respectively.

The agricultural frontier expansion in Matopiba, however, faces some natural challenges, especially at transitioning areas with the Caatinga biome. A transition area normally presents diverse ecosystems, climatic conditions and lower natural fertility. The soybean, for example, is not suitable in regions with annual average rainfall below 1000mm, which occur in Cerrado areas near the semi-arid. In other words, the annual average rainfall acts as a natural barrier for the agricultural frontier expansion, a scenario that could be reversed with the development of new varieties of soy that supports rainfall between 1000 - 800 mm. However, this technological innovation could boost deforestation along with agricultural production in Matopiba (ARAÚJO et al., 2019).

Considering the agricultural frontier expansion in the MATOPIBA and the economic development in the region, the present paper aims to search its relationship with the deforestation.

3 Methodology

3.1. Database and region covered

The Empresa Brasileira de Pesquisa Agropecuária (Embrapa) elaborated the MATOPIBA demarcation, having as its main criterion the presence or not of the Cerrado in the four states, as well as other socioeconomic factors, which resulted in 337 municipalities from 31 microregions with an area of 73 million hectares. Among the states in the MATOPIBA, the one with the highest area is Tocantins, with 37.95% of the total (139 municipalities), followed by Maranhão with 32.77% (135 municipalities), Bahia with 18.06% (30 municipalities) and Piauí with 11.21% (33 municipalities) (EMBRAPA, 2017). Figure 1 brings the MATOPIBA location within the Brazilian territory.
According to the Ministério da Agricultura (2017), the MATOPIBA region reached an 11% share in the total produced by Brazilian agribusiness in 2015. Recognizing the region's strategic importance in the future of the country's agribusiness, the Brazilian Government created Decree No. 8447 in 2015 with the main objective of establishing an agricultural development plan for MATOPIBA, with the purpose of guiding Federal projects specifically for the region (BRASIL, 2015).

Figure 1 – MATOPIBA* Location in Brazil.

According to the population census held by IBGE (2010), the MATOPIBA has about 6 million inhabitants, and 35% resides in the rural area, considerably above the Brazilian average of 15.3%. Among the States in the region, the most populous is the Maranhão with 57.6% of the total, followed by Tocantins with 25.30%, Bahia with 12.72% and 4.75% in Piauí. In relation to the income, the region had in 2010, a per capita income of only 40% compared to the Brazilian average, R$8,000 in MATOPIBA against a value of R$19,878.00 for Brazil. However, if considered only Tocantins and Bahia the percentage would go up to approximately 60% (BOLFE et al., 2016).

The data used concerning the deforestation of the Cerrado in the MATOPIBA region are obtained in the Relatório Técnico de Monitoramento do Desmatamento no Bioma Cerrado do IBAMA 2010. Therefore, the deforestation variable (DEFOREST) are used as proxy for environmental degradation, the dependent variable on the EKC model for the 337 municipalities of MATOPIBA. We consider 2010 as a reference year for deforestation, as well as for all the explanatory variables. We used this timeframe due to the limitation of data in the disaggregated form to the municipalities of the region, which made it impossible to have a more extensive temporal analysis. For the economic development proxy, we used the HDI variable, in line with the methodological advances in the estimation of EKC HILL and MAGNANI, 2002; JHA and BHANU MURTHI, 2003; COSTANTINI and MONNIM 2008; STIGLITZ ET AL., 2009; COSTANTINI and MARTIGINI, 2010; KUBISZEWSKI ET AL., 2013; NEVE and HAMAIDE, 2017).

We included the HDI in a square and cube format in the estimations to search the existence of other formats for EKC, i.e. a quadratic or cubic function. The variables described above, as well as the other explanatory variables used in this paper are in Chart 1. The variables inclusion aimed to improve the econometric model specification, as well as better structurally represent the region and identify possible relationships that they may have with the deforestation. In addition to the variables directly linked to the agricultural frontier expansion, we also consider some geographic and structural features for control purpose. Among them, we used some vector data to construct the variables specifically to this empirical design: ROADS, RAINFALL, SOIL, FEDERAL.RES and INDIGN.RES. We construct the measures using the spatial joint tool in the GIS software (ArcMap 10.3). Some explanations, however, are worth mentioning.
The SOIL variable was constructed using the Mapa de Potencial Agrícola do Brasil, compiled by the Instituto Brasileiro de Geografia e Estatística (IBGE) and made available by the Ministério do Meio Ambiente (MMA). The Brazilian territory is classified according to the agricultural potential of its soils, considering: fertility, physical and morphological characteristics, main limitations and topography. The effort resulted in five basic classifications: i) good; ii) regular; iii) restricted; iv) unfavorable; and (v) inadvisable. Merging the agricultural potential map with the MATOPIBA map, we identified the predominant type of soil that exists in the municipalities. Finally, we created a binary variable, in which the number 1 was assigned to municipalities with i) good or regular soil and 0 for others. The basic purpose of this procedure is 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 the Brazilian agricultural frontier expansion in MATOPIBA, caused by the conversion of forests into arable areas, is occurring in municipalities with greater agricultural potential.

Chart 1 – Variables description, all for 2010.

<table>
<thead>
<tr>
<th>VARIABLE</th>
<th>DESCRIPTION</th>
<th>UNIT</th>
<th>SOURCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEFOREST</td>
<td>Deforested area</td>
<td>ha</td>
<td>IBAMA</td>
</tr>
<tr>
<td>HDI</td>
<td>Human Development Index (HDI)</td>
<td>cent</td>
<td>IPEA</td>
</tr>
<tr>
<td>HDI²</td>
<td>HDI Squared</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDI³</td>
<td>HDI Cube</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RURAL CREDIT</td>
<td>Total rural credit</td>
<td>RS (BRL)</td>
<td>BACEN</td>
</tr>
<tr>
<td>DEM.DENSITY</td>
<td>Demographic density (inhabitants/km²)</td>
<td>km²</td>
<td>SIDRA/IBGE</td>
</tr>
<tr>
<td>AGRIC.GDP</td>
<td>Agricultural participation in GDP</td>
<td>%</td>
<td>SIDRA/IBGE</td>
</tr>
<tr>
<td>CATTLE</td>
<td>Cattle herd size</td>
<td>count</td>
<td>SIDRA/IBGE</td>
</tr>
<tr>
<td>CROP</td>
<td>Total crop area</td>
<td>ha</td>
<td>SIDRA/IBGE</td>
</tr>
<tr>
<td>SUGARCANE</td>
<td>Sugarcane Productivity</td>
<td>kg/ha</td>
<td>SIDRA/IBGE</td>
</tr>
<tr>
<td>MAIZE</td>
<td>Maize Productivity</td>
<td>kg/ha</td>
<td>SIDRA/IBGE</td>
</tr>
<tr>
<td>SOYBEAN</td>
<td>Soy Productivity</td>
<td>kg/ha</td>
<td>SIDRA/IBGE</td>
</tr>
<tr>
<td>ROADS</td>
<td>Roads extension</td>
<td>km</td>
<td>MAPBIOMAS</td>
</tr>
<tr>
<td>RAINFALL</td>
<td>Average annual precipitation</td>
<td>mm</td>
<td>CPRM</td>
</tr>
<tr>
<td>SOIL</td>
<td>Good or regular soil suitability for farming</td>
<td>binary</td>
<td>MMA/IBGE</td>
</tr>
<tr>
<td>FEDERAL.RES</td>
<td>Federal Reserve</td>
<td>binary</td>
<td>CSR</td>
</tr>
<tr>
<td>STATE.RES</td>
<td>State Reserve</td>
<td>binary</td>
<td>CSR</td>
</tr>
<tr>
<td>INDIGEN.RES</td>
<td>Indigenous Reserve</td>
<td>binary</td>
<td>CSR</td>
</tr>
<tr>
<td>FOREST.COVER</td>
<td>Remaining forest cover</td>
<td>%</td>
<td>MAPBIOMAS</td>
</tr>
</tbody>
</table>

Source: research data.

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 refers to the extension in kilometers of state and federal highways in a given municipality. The data vector are made available by the Mapbiomas project, using data provided by the Brazilian government. We obtained information on protected areas, which generated the binary variables FEDERAL.RES, STATE.RES and INDIGEN.RES, from the Centro de Sensoriamento Remoto da Universidade Federal de Minas Gerais (CSR-UFMG). Joining the MATOPIBA municipalities with the protected area shape files, it was possible to obtain the presence or not of these areas for each municipality, considering only those created until 2010.

3.2 Descriptive Statistics

In order to investigate the municipality’s characteristics in MATOPIBA and its changes in the period, Table 3 reports the descriptive statistics for the variables used in the EKC model. In terms of deforestation, we have an average of 15,91 ha of cleared area in 2010 and 5,360 ha in all MATOPIBA region. Forest cover, in turn, we have an average of 60% of forest remnants, with some municipalities
having 98% of its area composed of native forests. The variables related with economic development, as HDI and per capita GDP, we have an average of 0.61 and R$7,359.64. In addition, we have a considerable different in the municipalities’ in the characteristics when considering the maximum and minimum value, which may reflect the differences in the occupation stage.

Table 2 - Descriptive statistics.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Dev.</th>
<th>Min</th>
<th>Max</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEFOREST</td>
<td>15.91</td>
<td>26.25</td>
<td>0.00</td>
<td>227.34</td>
<td>5,360.80</td>
</tr>
<tr>
<td>HDI</td>
<td>0.61</td>
<td>0.05</td>
<td>0.44</td>
<td>0.70</td>
<td>-</td>
</tr>
<tr>
<td>GDP</td>
<td>7,359.64</td>
<td>5,817.02</td>
<td>2,292.04</td>
<td>52,736.02</td>
<td>2,480,199.95</td>
</tr>
<tr>
<td>RURAL CREDIT</td>
<td>11,500,000.00</td>
<td>37,700,000.00</td>
<td>5,045.50</td>
<td>485,000,000.00</td>
<td>3,872,740,512.53</td>
</tr>
<tr>
<td>DEM.DENSITY</td>
<td>13.43</td>
<td>18.56</td>
<td>0.23</td>
<td>180.79</td>
<td>-</td>
</tr>
<tr>
<td>AGRIC.GDP</td>
<td>30.07</td>
<td>14.78</td>
<td>0.62</td>
<td>74.86</td>
<td>-</td>
</tr>
<tr>
<td>CATTLE</td>
<td>44,540.95</td>
<td>46,843.11</td>
<td>1,300.00</td>
<td>423,650.00</td>
<td>15,010,299.00</td>
</tr>
<tr>
<td>CROP</td>
<td>12,573.65</td>
<td>37,616.84</td>
<td>68.00</td>
<td>441,164.00</td>
<td>4,237,320.00</td>
</tr>
<tr>
<td>SUGAR CANE</td>
<td>22,048.66</td>
<td>21,816.03</td>
<td>0.00</td>
<td>100,000.00</td>
<td>-</td>
</tr>
<tr>
<td>MAIZE</td>
<td>2,048.35</td>
<td>1,716.39</td>
<td>85.00</td>
<td>8,617.00</td>
<td>-</td>
</tr>
<tr>
<td>SOYBEAN</td>
<td>1,020.65</td>
<td>1,317.37</td>
<td>0.00</td>
<td>3,449.67</td>
<td>-</td>
</tr>
<tr>
<td>ROADs</td>
<td>149.77</td>
<td>101.40</td>
<td>7.50</td>
<td>623.70</td>
<td>50,472.79</td>
</tr>
<tr>
<td>RAINFALL</td>
<td>1,456.08</td>
<td>277.71</td>
<td>800.00</td>
<td>2,100.00</td>
<td>-</td>
</tr>
<tr>
<td>FOREST.COVER</td>
<td>0.60</td>
<td>0.20</td>
<td>0.04</td>
<td>0.98</td>
<td>-</td>
</tr>
</tbody>
</table>

Source: research data.

We can also highlight some total values for the MATOPIBA, which are related with the agricultural frontier expansion region. The offer of rural credit reach an value of approximately R$3,8 billion. The cattle heard and crop area, in turn, reach 15 million heads and 4.2 ha, respectively. Finally, we have 50,472 km² in roads extension. A recurrent problem in the EKC model: multicollinearity, which can invalidate statistical inferences. The Appendix A shows the correlation between the variables used. From them, we can notice no extremely high correlations that could compromise the estimation of the EKC model, with the exception of the variable CROP and RURAL.CREDIT\(^1\). Therefore, we included in the econometric model only the crop area.

3.3 Exploratory Spatial Data Analysis (ESDA) and Spatial Econometrics

The Exploratory Spatial Data Analysis (ESDA) are techniques used to identify spatial effects, specifically those of spatial dependence and heterogeneity. Both, if identified, should be treated to avoid problems in econometric models, such as bias and inconsistency (ALMEIDA, 2012). The Moran’s I statistic seeks to capture the spatial autocorrelation between a variable across the regions. The expected value of this statistic is \(E(I) = -1/(n-1)\) and statistically larger (minor) values, relative to expected, indicate positive spatial autocorrelation (negative). Mathematically, we have

\[
I_t = \frac{n}{S_0} \left( \frac{z_t' W z_t}{z_t' z_t} \right) \quad t = 1, \ldots n
\]  

where \(n\) is the number of regions, \(S_0\) is a value equal to the sum of all elements of \(W\), \(z\) is the value of the standardized variable analyzed, \(Wz\) is the average values of the standardized variable in the neighbors according to a weighting matrix \(W\). The local Moran’s I (LISA), in turn, are

\(^1\) In other words, there are a strong relation between the amount of rural credit destined for the region and the cultivated area.
\[ l_i = z_i \sum_{j=1}^{l} w_{ij} z_j \]  

where \( z_i \) represents the region's \( i \) standardized variable, \( w_{ij} \) is the element of the spatial weighting matrix \( (W) \) and \( z_j \) is the region's \( j \) standardized variable.

The spatial component is incorporated into the econometric model with spatially lagged variables. It is possible to propose a general spatial model that, by imposing restrictions on parameters, you can obtain the desired specifications. Such a model are

\[
y = \rho Wy + X\beta + WX\tau + \xi
\]

\[
\xi = \lambda W\xi + \varepsilon
\]

where \( X \) is the matrix of explanatory variables; \( \beta \) is the vector \( k \times 1 \) of regression coefficients; \( \varepsilon \) is the error term with average zero and constant variance.

The Spatial Autoregressive Model (SAR) is obtained by imposing the following restrictions on the model (3): \( \rho \neq 0 \), \( \tau = 0 \) and \( \lambda = 0 \). The SAR model seeks to capture the spatial autocorrelation effects of the dependent variable between neighboring units. Therefore, it is included as an explanatory variable in the econometric model the spatially lagged dependent variable \((\rho Wy)\), which can be interpreted as the average value of that variable in neighboring units. In this paper, the SAR model seeks to identify, if the deforestation rate of a given municipality is influenced by the value of that variable of its neighbors, determined according to a spatial weight matrix. If we get a significant \( \rho > 0 \), we have a positive spatial autocorrelation while \( \rho < 0 \) is a negative spatial dependence. The model will suffer from the endogeneity problem of the lagged variable, therefore, it should be estimated with instrumental variables, which are the lagged explanatory variables \((WX)\).

The Spatial Error Model (SEM) emerges if \( \rho = 0 \), \( \tau = 0 \) and \( \lambda \neq 0 \); when spatial dependence manifests itself in the error term. The closer to one is the parameter \( \lambda \), greater is the effect of this shock on the neighborhood. The estimation by OLS is not adequate, because the error bias makes the model parameters inefficient. According to Kelejian and Prucha (1999), we should estimated the model with maximum likelihood (MV) or by the generalized method of the moments (MGM). The Spatial Lag of \( X \) Model (SLX) occurs when \( \rho = 0 \), \( \tau \neq 0 \) and \( \lambda = 0 \). The model seeks to capture the spatial spillovers from the independent variables, using a matrix of spatial weights \( W \) as a spatial lag operator. This lag is exogenous because the variables are determined outside the model. For this reason, the model not present endogeneity problem, thus it is possible to estimate by OLS.

The Spatial Durbin Model (SDM) and the Spatial Durbin Error Model (SDEM) are a combination of the previous ones. The SDM occurs when \( \rho \neq 0 \), \( \tau \neq 0 \) and \( \lambda = 0 \), with the spatial autocorrelation in the dependent and the explanatory variables. The SDEM, in turn, \( \rho = 0 \), \( \tau \neq 0 \) and \( \lambda \neq 0 \), when spatial dependence manifests itself in the explanatory variables and the error term. The model choice, however, is not arbitrary, because the spatial effects can manifest in just one of the forms, in some combination of them or even in all. The present paper will choose the model that are able to minimize the spatial autocorrelation in the models’ residuals, following Almeida (2012).

### 3.4. Empirical strategy

In this paper, the MATOPIBA deforested area are included as a dependent variable in the EKC model. The municipalities HDI are used as proxy for the level of economic development. In addition, to better verify the relationship between environmental degradation and economic development, we estimate EKC with quadratic and cubic format. Therefore, the general equation is

\[
\text{DEFOREST}_i = \beta_0 + \beta_1 \text{HDI}_i + \beta_2 \text{HDI}^2_i + \beta_3 \text{HDI}^3_i + \epsilon_i
\]  

(4)
Where $\text{DEFOREST}$ is the percentage of deforested area of Cerrado in municipality $i$; $\text{HDI}$ is the Human Development Index. The incorporation of additional explanatory variables is important to avoid the problem of omission of relevant variable. Therefore, geographical, structural and agricultural variables are included, as in Chart 1. Hence, in a general format, the model is

$$\text{DEFOREST}_i = \beta_0 + \beta_1 \text{HDI}_i + \beta_2 \text{HDI}_i^2 + \beta_3 \text{HDI}_i^3 + \beta_k Z_i + \epsilon_i$$  \hspace{1cm} (5)$$

where $Z$ is a matrix with the $k$ of additional explanatory variables included in the model.

The Environmental Kuznets Curve format is related to the signs and significance presented by the coefficients $\beta_1, \beta_2$ and $\beta_3$ in the model (6). It is a sufficient condition for the curve to present a linear format when we get a significant $\beta_1 > 0$ or $\beta_1 < 0$, while $\beta_2$ and $\beta_3$ are not. In this configuration, the increase of the HDI is linearly related to deforestation. For the inverted U-shape, it is sufficient to $\beta_1 > 0$, $\beta_2 < 0$, while for U-shape $\beta_1 < 0$, $\beta_2 > 0$; both significant with $\beta_3$ not. Finally, in the case of $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 > 0$ or $\beta_1 < 0$, $\beta_2 > 0$ and $\beta_3 < 0$, being all statistically significant, it is a necessary and sufficient condition for a N-shape or inverted N-shape, respectively.

4. Results and discussion

To verify the relationship between deforestation and forest cover, Figure 2 shows, the spatial distribution of deforestation (Figure a) and native forest remnants (Figure b). The municipalities with high cleared area (Figure a) are concentrated especially in western Bahia, the central area of the Matopiba, southwest of Tocantins and, finally, the northern part of Maranhão. Araújo et al. (2019) argue that these regions, especially the first two, have undergone an intense modernization of their agricultural activity, especially of soy, resulting in significant increases in its production and yield after 2000s. According to the authors, this phenomenon may be one of the explanations for the recent deforestation in the region.

Figure 2 - Distribution of deforestation (a) and native forest (b) in the MATOPIBA.

Regarding the native forests (Figure b), we can see that most of the municipalities with more than 80% of their territory covered by forest are located east in transition areas with the Caatinga biome. According to Araújo et al. (2019), a transition area normally presents diverse ecosystems, climatic conditions and lower natural fertility. In addition, the authors argue that soybean cultivation, the main driver of Matopiba occupation, is suitable only in areas with annual average rainfall above of 1000mm,
which does not occur in Cerrado areas near the semi-arid region. Therefore, the agricultural expansion future in this region depends on the development of new varieties of soy that supports rainfall between 1000 - 800 mm and, if this occurs, we can expect profound land use changes with reductions in forest cover.

The spatial concentration of deforestation is visible in Figure 2, indicating the existence of patterns, which may result in spatial dependence and heterogeneity. To verify this hypothesis, Table 3 presents the Moran’s I statistic, according to several spatial matrices conventions. We confirm the existence of spatial dependence for deforestation, regardless of the convention adopted, indicating that deforestation tend to be spatially concentrated. Theoretically, this may result from spatial spillovers, resulting from productive links and concentration of human and physical capital.

Table 3 - Moran’s I for deforestation in MATOPIBA.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Deforestation</td>
<td>0.29*</td>
<td>0.30*</td>
<td>0.31*</td>
<td>0.22*</td>
<td>0.22*</td>
<td>0.15*</td>
</tr>
</tbody>
</table>

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

Figure 3 shows the LISA maps of spatial clusters for deforestation. It presented two significant High-High clusters for deforestation (Figure a); one in western Bahia and the other in the Southwest of Piauí. For the native forest (b), we have spatial clusters located especially in the east transitional areas with the semi-arid biome. Therefore, the clusters presented a similar spatial pattern than in Figure 2, corroborating the Araújo et al. (2019) arguments.

Figure 3 – LISA maps for deforestation (a) and native forest (b) in the MATOPIBA.

Source: research data.

Regarding the Environmental Kuznets Curve, we estimated the model in its quadratic and cubic version using the classical linear regression model estimated by the OLS method. Table 5 presents the estimations. This procedure is necessary to verify the existence of spatial dependence, captured by the Moran’s I of the residuals, which are significant for all estimated models in Table 5.

The best model estimated, according to the Akaike information criterion, is one that incorporates a quadratic relationship between the HDI and deforestation, i.e. the HDI (2). Therefore, this model will be the base for the following analyses and we confirm that the HDI is a better proxy for economic development in line with Hill and Magnani (2002), Jha and Bhanu Murth (2003), Costantini and Monni (2008),

2 The software used to estimate the models are the GeoDaSpace made available by the Center for Spatial Data Science - University of Chicago.
Costantini and Martini (2010), Lamb and Rao (2015). Since deforestation, agricultural and geographic variables usually suffer from spatial interactions, the Moran’s I statistic presented a statistical significance of 1% as expected, which indicates the presence of spatial autocorrelation in the model residuals. In this context, the estimates may not be consistent, which requires the adoption of specific econometric methods to address the presence of spatial effects (ALMEIDA, 2012). Therefore, the next step is estimate HDI (2) by incorporating spatially lagged variables, aiming at control spatial dependence in the residuals.

Table 5 - Econometric results for the EKC estimated with OLS.

<table>
<thead>
<tr>
<th></th>
<th>HDI (2)</th>
<th>HDI (3)</th>
<th>GDP (2)</th>
<th>GDP (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CONSTANT</td>
<td>-180.1141***</td>
<td>-180.5291***</td>
<td>-11.6019**</td>
<td>-9.7553*</td>
</tr>
<tr>
<td>HDI</td>
<td>587.5692***</td>
<td>601.7303**</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HDI²</td>
<td>-511.8558***</td>
<td>-558.5114**</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>HDI³</td>
<td>-</td>
<td>39.5611</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>GDP</td>
<td>-</td>
<td>-</td>
<td>-0.0001</td>
<td>-0.0008</td>
</tr>
<tr>
<td>GDP²</td>
<td>-</td>
<td>-</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>GDP³</td>
<td>-</td>
<td>-</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>DEM.DENSITY</td>
<td>-0.0815</td>
<td>-0.0840</td>
<td>-0.1180**</td>
<td>-0.1153***</td>
</tr>
<tr>
<td>AGRIC.GDP</td>
<td>-0.0562</td>
<td>-0.0548</td>
<td>-0.0061</td>
<td>0.0001</td>
</tr>
<tr>
<td>CATTLE</td>
<td>0.0001***</td>
<td>0.0001***</td>
<td>0.0001***</td>
<td>0.0001***</td>
</tr>
<tr>
<td>CROP</td>
<td>0.0004***</td>
<td>0.0004***</td>
<td>0.0004***</td>
<td>0.0004***</td>
</tr>
<tr>
<td>SUGARCANE</td>
<td>0.0001**</td>
<td>0.0001*</td>
<td>0.0001*</td>
<td>0.0001*</td>
</tr>
<tr>
<td>MAIZE</td>
<td>0.0014*</td>
<td>0.0014*</td>
<td>0.0013</td>
<td>0.0015*</td>
</tr>
<tr>
<td>SOYBEAN</td>
<td>0.0006**</td>
<td>0.0006**</td>
<td>0.0006**</td>
<td>0.0006**</td>
</tr>
<tr>
<td>ROADS</td>
<td>0.0273***</td>
<td>0.0273***</td>
<td>0.0223***</td>
<td>0.0232**</td>
</tr>
<tr>
<td>RAINFALL</td>
<td>0.0020</td>
<td>0.0020</td>
<td>0.0016</td>
<td>0.0016</td>
</tr>
<tr>
<td>SOIL</td>
<td>-1.1945</td>
<td>-1.1981</td>
<td>-1.5379</td>
<td>-1.4392</td>
</tr>
<tr>
<td>FEDERAL.RES</td>
<td>6.5379**</td>
<td>6.5600**</td>
<td>7.1074***</td>
<td>7.0777***</td>
</tr>
<tr>
<td>ESTATE.RES</td>
<td>-0.4191</td>
<td>-0.5988</td>
<td>-1.2974</td>
<td>-1.4553</td>
</tr>
<tr>
<td>INDIGEN.RES</td>
<td>-1.0752</td>
<td>-1.1256</td>
<td>-1.5783</td>
<td>-1.7170</td>
</tr>
<tr>
<td>FOREST.COVER</td>
<td>14.3776***</td>
<td>14.4532***</td>
<td>15.9287***</td>
<td>15.8401***</td>
</tr>
</tbody>
</table>

Source: research results. Note: *** Significant at 1%; ** Significant at 5%. * Significant at 10%.

Furthermore, from the Jarque-Bera test it was possible to reject the null hypothesis of normality in the residuals with a significance level at 1%. Regarding the variance, the Koenker-Bassett test reject the homoscedasticity hypothesis, indicating the presence of a non-constant variance in the residuals. The spatial models in Table 6, due to the non-normality in the residuals, are estimated with the Generalized Method of the Moments of Kelejian and Prucha (1999). In addition, White's robust error (1980) are employed in the models SAR, SLX and SDM, and the robust error of Kelejian and Prucha (2010) for models SEM and SDEM, both aiming to control the presence of heteroscedasticity. In addition, following Baumont (2004), we chose the spatial lag matrix that generated the largest Moran’s I coefficient for the HDI (2) residues (Appendix B) to estimate the spatial models, opting for the rock matrix.

According to Almeida (2012) and Raiber and Candido (2018), the best spatial model is the one that minimize the spatial autocorrelation in the residuals. Therefore, considering the Moran’s I in the EKC spatial models residuals (Appendix B), the SLX and SDEM models presented the lowest coefficients for this statistics, indicating that they are the models that best controlled the spatial dependence problem. In other words, the approach, by incorporation relevant spatial spillovers related to deforestation and the agricultural frontier expansion, was able to minimize the spatial dependence.

However, the SDEM model in Table 6, the spatial lag of the error term (Wξ) did not presented statistical significance, indicating that only the spatial spillovers from the explanatory variables are
important to explain deforestation in the MATOPIBA. In any case, all the statistical significant variables in the SLX and SDEM model are the same and the coefficients are similar, indicating the robustness of the results. In addition, according to Almeida (2012), structural stability in the models parameters is a sign that the spatial heterogeneity is not present in an extent that invalidate the results. In this context, we considered the SLX model in the following analyses.

Since the quadratic 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 in the MATOPIBA. Therefore, this fact demonstrates that deforestation will increase until a certain threshold as the region develops, from which it begins to fall in line with Grossman and Krueger (1991; 1995). In addition, we can cite the robustness of the results, because all the models that included the HDI in its linear and quadratic form had significant coefficients. This empirical evidence differs from Colusso et al. (2012) that identified an “N” relationship when analyzing the whole biome, which highlight that MATOPIBA may present different characteristics regarding the impact from economic development in the environment.

According to Grossman and Krueger (1991; 1995) at low levels development, growth initially causes a scale effect by increasing natural resources use, which leads to deforestation. However, after a

3 Oliveira et al. (2011) proposed the procedure for deforestation in the EKC model for Legal Amazon, which improved econometric estimates.
“turning point”⁴, the composition and technical effects became large enough to mitigate the scale effect, reducing environmental degradation. Considering the results for the SLX model in Table 6, the turning point for MATOPIBA is a HDI of 0.57, slightly below the region’s average of 0.61. Therefore, 71.82% of the municipalities in the current Brazilian agriculture frontier have a HDI above the turning point, which indicates that deforestation will decrease its pace as these counties develops. On the other hand, we still have a trade-off between development and forest conservation for the remaining 28.18% that are below the turning point, since its development will boost deforestation.

In addition, we highlight the statistical significance in the SLX model for the following additional variables: demographic density, cattle herd, crop area, maize productivity, roads extension, Federal Reserve and forest area. Regarding the spatial spillovers from the agricultural frontier expansion, we have the demographic density, crop area and sugarcane productivity with statistical significance. With the exception of the demographic density and spillovers from crop area, all the variables presented a positive relationship with deforestation, with its increase leading to deforestation in the MATOPIBA.

The roads extension have a positive impact on deforestation in MATOPIBA. One possible explanation is that road network expansion allows access to previously isolated areas by creating corridors to the region, reducing transportation costs and push the agricultural frontier further by intensifying the migration and occupation of the territory, which causes deforestation (PIRES, 2000; BECKER, 2001; ASSUNÇÃO and BRAGANÇA, 2015; BRAGANÇA, 2018; ARAÚJO et al., 2019). This empirical evidence are an important contribution to the literature on deforestation in Brazil, since there are no papers that address directly this issue for the region.

The cattle herd is also an important deforestation inductor in MATOPIBA. According to Bragança (2018) this phenomenon are explained mainly by land use changes due to the soybean and sugarcane cultivation advancement in recent periods in Brazil, which adopts more technologically advanced inputs, with greater potential to generate profits. This have been leading to a displacement of cattle ranching to agricultural frontier regions with lower land prices, causing deforestation.

The crop area presented a positive statistical significance and a negative spillover in the Matopiba. Garcia and Vieira Filho (2018) argues that its expansion – the soy cultivation in particular – is occurring in a considerable part due forest area reduction, especially at the agriculture frontier. According to the authors, 68% of the agricultural expansion in Matopiba between 2002 and 2014 was due to the conversion of native areas. On the other hand, the empirical evidences suggests that crop area expansion in a municipality diminishes its neighbor’s deforestation in a negative spatial spillover effect. The productivity spillovers from maize and sugarcane presented significant positive impact on deforestation in MATOPIBA. One possible reason is that both crops recently gained market value due to the increase in the national and international demand for animal feed and biodiesel, which resulted in high profitability and environmental degradation.

The demographic density and its spatial spillovers, in turn, presented a statistical significant negative sign, indicating that less densely populated municipalities tend to be deforested more than those with large demographic density. This result contradicts those found by Grossman and Krueger (1995) and especially those of Cropper and Griffiths (1994), which used deforestation as an indicator of environmental degradation. On the other hand, in the Brazilian context, in Oliveira et al. (2011) and Colusso et al. (2012) the demographic density variable did not present statistical significance, indicating that it may not be relevant to explain deforestation in Brazil. Despite this, the result found in this paper highlights a different characteristic for MATOPIBA region.

The remaining forest cover in the municipality are statistical significant, indicating that higher deforestation is associated with greater proportion of native forests. This fact makes logical sense, since some municipalities may deforest less because they do not have much remaining forest area to do it. In addition, higher proportion of forests are related to regions where the agricultural activities, basic infrastructure and migratory attraction did not reach its full potential yet (BOLFE et al., 2016; ZANIN and BACHA, 2017; ARAÚJO et al, 2019). In other words, these factors growth translates into the agricultural frontier expansion, which are the main environmental degrader in Cerrado (GARCIA and VIEIRA, 2018).

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⁴ A region where the curve reaches its maximum value. We can obtained the “turning point” with: \( \tau = -\beta_1/2\beta_2 \)
In addition, according to IBAMA (2010), the Cerrado biome has only 7.44% of its territory as conservation units, which has served to aggravate deforestation. However, in Matopiba regime, the Federal Reserve variable presented a significant positive impact, contradicting the idea that conservation units acts as inhibitor deforestation. This demonstrates a need for the government supervision expansion over conservation areas in Matopiba, since the status granted to these localities do not serve as inhibitors of deforestation.

It is worth mentioning that the soil characteristics in MATOPIBA region do not affect land use changes. In other words, deforestation occur independent if the soil is indicated or not for agricultural production, corroborating Bolfe et al (2016) evidences that a considerable part forest conversion on Matopiba did not occur on soils with agricultural suitability.

5. Final Considerations

This paper aimed to investigate the relationship between human development and environmental degradation at the current Brazilian agricultural frontier, a region known as MATOPIBA. The hypothesis used are the Environmental Kuznets Curve, which states that the level of environment degradation initially increases with economic development, but, after a certain level, the relationship reverses, with an increase in development leading to a degradation reduction.

The municipalities with high cleared area in MATPIBA are concentrated especially in western Bahia, the central area of the region, southwest of Tocantins and the northern part of Maranhão. These regions have undergone an intense modernization of their agricultural activity, especially of soy, resulting in significant increases in its production and yield after 2000s. In addition, we confirm the spatial dependence presence for deforestation, indicating that deforestation tend to be spatially concentrated, which lead to the adoption of spatial econometrics.

The dependent variable used as proxy for environmental degradation are the deforestation of the Cerrado in the MATOPIBA region for the year 2010. In addition, we used the Human Development index (HDI) as proxy for economic development, which is considered more appropriate to represent development, when compared to per capita income usually adopted by the literature, according to methodological advances in the estimation of EKC. The explanatory variables included in the EKC model, in addition to the HDI in its linear, quadratic and cubed form, are: cattle herd, demographic density, productivities of maize, sugarcane and soybean, crop area, agricultural participation in GDP, roads extension, average annual precipitation, soil suitability, and presence of federal, state and indigenous reserve, all set at municipal level.

Initially, we estimated the models using conventional econometrics techniques to identify the presence of spatial effects in the residuals. We also estimated several spatial models in order to verify the robustness of the results: SAR, SEM, SLX, SDM and SDEM. The model that best captured the EKC relationship, according to the Moran’s I in the spatial models residuals, are the Spatial Lag of X Model (SLX), since this model are the one that minimize the spatial dependence. In the estimations, we found an inverted "U" format to the EKC, corroborating the initial hypothesis between economic development and environmental degradation for the current Brazilian agricultural frontier. Therefore, human development, although it initially lead to deforestation, this process occur until a certain level, from which the relationship reverses and induces a sustainable development. The EKC curve turning point, where economic development reaches its maximum impact on the environment, is a HDI of 0.57, which is slightly below the region’s average of 0.61. Therefore, 71.82% of the municipalities in the current Brazilian agriculture frontier have a HDI above the turning point, which indicates that deforestation will decrease its pace as these municipalities, develops. On the other hand, we still have a trade-off between development and forest conservation for the remaining 28.18% that are below the turning point, which highlights environmental concerns for the regions, since its development could boost degradation on these underdeveloped municipalities.

To worsen this scenario, we identified many variables, especially related to the agricultural frontier expansion in the MATOPIBA, which affects negatively environment. Among the main influences, we have the roads expansion, which attracts migratory waves and agricultural activities due its cost reduction, the
cattle herd, crop area, maize productivity, Federal Reserve and forest area. Regarding the spatial spillovers from the agricultural frontier expansion, we have the demographic density, crop area and sugarcane productivity with statistical significance. With the exception of the demographic density and spillovers from crop area, all the variables presented a positive relationship with deforestation, with its increase leading to deforestation in the MATOPIBA.

The empirical evidences from this paper can help to identify the deforestation determinants and possible outcomes in MATOPIBA and to construct focused agricultural and environmental policies that consider idiosyncratic characteristics of the region along with spatial and displacement effects. However, it is worth mentioning some possible limitations in the present paper. For example, the IBAMA database adopted in this paper has a limited timeframe, which makes it difficult to analyze more broadly the deforestation phenomenon in MATOPIBA. In addition, we recommend the adoption of alternative methodologies as the Geographically Weighted Regression (GWR) in order to map the local effects from the agricultural frontier expansion in the region.

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MAPBIOMAS. Accessed on 02/01/2019 through the link: <Mapbiomas.org>.


### Appendix A – Correlation for the variables.

<table>
<thead>
<tr>
<th></th>
<th>HDI</th>
<th>GDP</th>
<th>MAIZE</th>
<th>R.CREDIT</th>
<th>SOY</th>
<th>CANE</th>
<th>CROP</th>
<th>AG.GDP</th>
<th>CATTLE</th>
<th>RAINF</th>
<th>ROADS</th>
<th>F.COVER</th>
<th>D.DENS</th>
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Source: research results.

### Appendix B - Moran’s I for the EKC Models - convention matrix decision.

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<th>Five neigh.</th>
<th>Seven neigh.</th>
<th>Ten neigh.</th>
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Source: research data. *Note: * Level of significance of 1%.

### Appendix C - Moran’s I for the ECK Spatial Models residuals.

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<td>SLX</td>
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Source: research data. *Note: * Level of significance of 1%.