Revista Agrogeoambiental, Pouso Alegre, v. 13, n. 2, p. 300-314, jun. 2021. DOI: http://dx.doi.org/10.18406/2316-1817v13n220211617

Economic growth and sustainability: An analysis of the Environmental Kuznets Curve on the Legal Amazon

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Received in: March 24, 2021 | **Accepted in:** July 2, 2021

Abstract

The objective of this work was to analyze how deforestation of the Legal Amazon (AMZ-L) is affected by the economic growth of the states it covers, from 2000 to 2017. This study is based on the Environmental Kuznets Curve theory (EKC), proposed by Grossman and Krueger (1991). We used the panel data method considering the fixed effects to answer the research problem. The hypothesis of the EKC, in fact, happens in the initial stage, showing that, with the increase in income, deforestation rates drop, causing the curve to reverse, taking an inverted "U" shape. However, at high-income levels, deforestation increases again, thus the curve takes an "N" shape. Considering this scenario, we can conclude that the increase in income alone does not guarantee deforestation reduction. However, we must emphasize that deforestation rates are lower than in the initial stage at high-income levels, showing the government intervention is needed.

Keywords: Economic growth. Sustainability. Environmental Kuznets Curve. Panel data.

Introduction

Since the 1990s, when the Earth Summit took place in Rio de Janeiro, also called ECO-92 or Rio-92, much has been discussed about global warming and humanity's unsustainable growth model. The accumulation of greenhouse gases in the atmosphere, the reduction of natural forests, and their impacts on the ecosystem worldwide were consequences of the advance of agricultural and livestock exploitation, extractivism, fires, or natural events (ARRAES; MARIANO; SIMONASSI, 2012).

Besides these debates, the concern of the world community has begun to seek alternative means for industrial production to promote economic growth in the countries sustainably, as described in the *Brundtland Report*. Conceptually, sustainable development (SD) is the conscious consumption of natural resources in the present so that future generations have the same level of satisfaction as the current generation (UNITED NATIONS, 1987).

In 47 years of discussions about the unsustainable way the world develops, little progress has actually been made on the actions foreseen by the global government agendas. World leaders have neglected the urgent nature of adopting sustainable measures provided for in the United Nations conventions (GUIMARAES; FONTOURA, 2012).

In a scenario of seeking a balance between economic development and sustainability, Brazil stands out with an essential role within the conventions. Works such as the ones of Guimarães and Fontoura's (2012) and Lago's (2006) showed Brazil as one of the most active countries regarding sustainability within the conventions held by the United Nations, however the same authors described that the measures adopted are still uncertain and insufficient.

Although Brazil has added efforts to comply with the principles and agreements established since ECO-92, authors such as Fearside (2006) and Coelho and Ferreira (2015) have shown deforestation of Brazilian forests is growing continuously, especially in the Amazon Forest, pointing as the leading causes the government decisions (FEARSIDE, 2006) and economic and social inequalities (LAKE, 2006).

The global focus on Brazil is mainly on the Amazon because although the forest extends to other countries, Brazil has most of it. For example, 59 % of the Amazon rainforest is in Brazil, followed by Peru,13 %, and smaller shares in Colombia, Venezuela, Ecuador, Bolivia, Guyana, Suriname, and French Guiana (IBGE, 2010).

In Brazilian territory, the Amazon rainforest is part of the Legal Amazon (AMZ-L), created by Law no. 5.173 /1966 (BRASIL, 1966), for political and rather than geographical reasons, strategically to develop that region economically. The AMZ-L is composed not only of moist forests but also of Cerrado and open Ombrophilous forest, which involves almost all of the farming activity (MARTHA JUNIOR; CONTINI; NAVARRO, 2011).

The territory of the Legal Amazon is 5,217,423 km^2 and corresponds to approximately 61 % of the national land, 8,514,877 km^2. The region includes, in its entirety, the states of Acre, Amapá, Amazonas, Mato Grosso, Pará, Roraima, Rondônia, and Tocantins anda part of the state of Maranhão (meridian 44th west). (FEARSIDE, 2006). Figure 1 shows the limits of the Brazilian Legal Amazon.

Figure 1: Demonstrative map of the limits of the Brazilian Legal Amazon.

Legal Amazon Limite   State Border

Source: Ferreira (2011).

The states that compose the AMZ-L, according to IBGE (2010), have a population of approximately 24 million inhabitants, distributed in 775 municipalities, holding 1/3 of the humid tropical forests and the most extensive genetic bank on the planet, besides holding 1/5 of all drinking water in the world. Moreover, at the national level, it contains 45 % of all groundwater in the country. As for the economic sector, the average gross domestic product (GDP) *per capita* of the states covered by the AMZ-L corresponds to about 63 % of the national GDP. Because of such representativeness and influence on the planet's balance, Arraes, Mariano, and Simonassi (2012) pointed out that the 1970s were marked by intense territorial occupation and opening of virgin forests for the Transamazon highway project.

AMZ-L has characteristics that favor the degradation of the region: the agricultural and livestock sector, encouraged by geography and rainfall index above average (MARGULIS, 2003), and the extraction and illegal appropriation of territory, which occur when there is infrastructure improvement, facilitating the exit of wood, land invasion and falsification of deeds by settlers, who occupy lots and sell them. The invasions happen because the infrastructures add value to the properties, which often escape from government control (FEARSIDE, 2006). Furthermore, according to the author, the social inequality of that region also contributes to degradation, and the country's economic aspects are directly reflected in the AMZ-L area.

In contrast to income inequality, the economic growth of the agricultural and livestock, and extractive sector has caused pressure on AMZ-L, alerting the scientific community even more about the risks to which society will be exposed if sustainable means of production are not met. In this sense, Grossman and Krueger (1991), with the concept of the Environmental Kuznets Curve (EKC), established an inverse "U" relationship between economic growth and sustainability, explaining in their study that, in the beginning, when there are economic advances and an increase in income *per capita*, environmental degradation also increases; however, at some point, as income and economy increase, environmental degradation tends to decrease. Thus, there is a positive expectation regarding the changes in economic growth taking place in the country and, at the same time, the need to improve income and technology to mitigate the impacts on the environment.

With the advances in the exploration of AMZ-L and the imminent risk of causing an imbalance in this ecosystem, this article aimed to identify the extent to which the economic growth of the states that make up the Legal Amazon has impacted deforestation in the region in the period 2000-2017.

Sustainable Development

Although sustainable development has been used as a concept since the mid-20th century, it appeared in 1713. The term was used for the first time by the German author Hans Carl Von Carlowitz in his study on the inconsequential exploitation of wood in Germany. Von Carlowitz suggested *Nachhaltende Nutzung* (sustainable use) of forests, implying that, in logging, there should be enough young trees to replace those that would be removed, considering that wood was consumed as fuel and was part of almost all production processes until the 18th century.

The 18th century was marked by the expansion of the world's population mass, which also drew the researchers' attention to sustainability and the future quality of life, because as the population increased, the needs and consumption of raw material increased too, as described by Malthus (1798), in his *Essay on the principle of population.*

With the arrival of the 19th century, the energy reserves became scarce, as energy originated primarily from coal, and the reserves were compromised. In this sense, Jevons (1866), in his work *The Coal Question: An inquiry concerning the progress of the nation, and the probable exhaustion of our coal-mines,* warned against the irresponsible consumption of coal, showing that it would be in a shortage in less than a hundred years in England if the scenario remained unchanged, which would cause that country to lose its industrial dominance.

According to the theoretical path presented, Pisani (2006) concluded that the theme of sustainable development has been addressed by scholars in the area long before the Brundtland Report. According to the author, sustainability issues have become popular with the rapid advance in irresponsible consumption caused by population growth and how the population has been developing.

Birth (2012) explained the two sides on which sustainable development originated. The first side is linked to ecology, which refers to the ability of ecosystems to recover from human or nature-induced aggression (earthquakes, tsunamis, volcanoes, fire, etc.). The second is related to the economic means, through the perception of the mode of consumption, production, and population expansion, which, in the long term, would compromise the availability of resources, making them scarce. According to the author, since the beginning of the promotion of sustainable development, the concept has been open and varies according to the political and ecological interests of those who study it.

As previously seen, the scarcity of natural resources was already realized centuries ago, and the reduction in the availability of these resources is linked to the economy, as shown by Jevons (1866).

Environmental Kuznets Curve

In 1955, in his study *Economic growth and income inequality*, Simon Kuznets proposed that income inequality and technology deficiency contributed to increasing environmental degradation. In line with Kuznets's (1955) studies, Grossman and Krueger (1991) were the pioneers in proving the authenticity of the existence of the inverted "U", which presents a positive correlation between economic growth and the environment. According to the authors, when a given society reaches high levels of income and technology, environmental degradation tends to reduce.

A historical redemption by Montibeller Filho (2007) reported that since the middle of the last century, economic growth was seen as a villain of nature because it was held responsible for the consumption of natural resources. O'Connor (1998) pointed out that when there is growth in the economy, environmental degradation, pollution, and depletion of natural resources are triggered; however, when the economy is shrinking, the environment continues to be degraded. In this perspective, the lack of economic growth has been used as a justification for the little care about the environment in several countries because, in a scenario of economic downturn, the preservation of the environment represents additional costs (MONTIBELLER FILHO, 2007).

This lack of respect for the environment has produced studies that show elements that harm the quality of human life, the main ones being carbon dioxide (CO_2), sulfur dioxide (so_2), and nitrous oxide (NO), and this has caused an increase in pressure on developing countries since the 1970s (CARVALHO; ALMEIDA, 2010). Non-governmental organizations and environmental activists have intensified pressure worldwide for governments to adopt measures for sustainable exploitation of natural resources (CARVALHO *et al.*, 2015; LAGO, 2006; MONTIBELLER SON, 2007). Those international demands made that the debates on the future quality of life be wide-ranging. Given the premise that environmental degradation would harm future generations, the first United Nations Climate Conference in Stockholm was convened in 1972, initiating a process that seeks to develop the economy in an optimal way (LAKE, 2006).

In this scenario, there are countries seeking development, and, on the other hand, they are suffering pressures for environmental preservation. The hypothesis of the Environmental

Kuznets Curve divides opinions. Some believe that we must not sacrifice economic growth for the environment to thrive and, in return, some others believe that consumption and economic growth are, until last resort, responsible for environmental degradation (CARVALHO, 2013).

In fact, Grossman and Krueger's (1991, 1995) studies showed empirical evidence that the curve can also have an "N" shape. The authors estimated EKC for sulfur dioxide, black smoke, and suspended particles. In the first two, they found an inverted "U" ratio based on a *per capita* income of US$ 5,000. About suspended particles, the *per capita* value is even lower, however, when *per capita* income is between US$ 10,000 and U$$ 15,000, the levels of pollutants studied have increased again, indicating that the curve has an "N" format.

When studying the EKC, besides using variables such as sulfur dioxide, nitrogen oxides, and solid particulate matter (waste generated by the industry), Panayotou (1993) used the variable deforestation. The results obtained showed that the deforestation EKC turning point happens in the interval U$ 800 - U$ 1,200, against U$ 3,800 - U$ 5,500 for the other variables. The author argued that this fact occurs because deforestation for agricultural expansion occurs at an early stage of development before heavy industrialization.

The format described by the EKC is attributed to several factors in the literature. The inverted "U" is explained by Selden and Song (1994), by: a) Income elasticity for environmental demand, indicating that the higher the income, the greater the attention to the quality of environmental life they want to enjoy, consuming healthier products; b) Scale effect, technology/technique and structure/composition (the scale effect or growth in production implies greater consumption of resources and energy, contributing positively to degradation; as for the technological aspect, income improvement replaces old with innovated and improved production techniques to reduce pollutants; on the other hand, the structure or composition factor tends to improve gradually with the increase in income, opting for sustainable activities (GROSMANN; KRUEGER, 1991); c) International trade, that is one of the main factors that explain the EKC, however, environmental quality tends to fall with the increase in trade, mainly in exports; on the other hand, when economy grows, degradation also grows, however, those effects can be eliminated by using technique, or by the effect of composition (DINDA, 2004); d) Market mechanisms, in which Shafik and Bandyopadhyay (1992) suggested that the existence of an endogenous self-regulatory market for natural resources marketed in the market could mitigate the effects of environmental degradation.

However, we must emphasize that the studies by Grosmann and Krueger (1991) revealed that the EKC, from a certain point on, can take the "N" format, which demonstrates that economic growth alone does not guarantee the reversal of the curve. Carvalho and Almeida (2010) stated that degradation increases and then decreases with economic growth. According to them, developing countries are incipient in sustainability, and it is necessary to adopt "green" policies to reverse the EKC path.

According to Ávila and Diniz (2015) and Diniz (2007), the reversal of the EKC trajectory will not happen if the scale effect prevails, since it overlaps the technical and composition aspects. The predominant scale effect in developing countries explains why the curve does not revert, since seeking economic growth is the main objective, *a priori*. In developed countries, the relationship is the opposite: technique and composition effects prevail.

As previously seen, there are adverse factors that interfere with the EKC convergence. In this sense, there are some criticisms about the model. Stern, Common, and Barbier (1996) pointed out three problems in the estimation of the EKC: a) Simultaneity: the EKC derives from an economic model in which there is no feedback from the status of the environment for economic growth; according to the authors, pollution and deforestation are seen as harmful to the quality of life, but there is no possibility of production; in this sense, Porter and Van Der Linde (1995) proposed a reverse analysis of the EKC, in which the preservation of the environment causes economic and technical growth, so that the income factor is endogenous, and the environmental quality is a source of economic growth. Statistically, the concurrency between production factor and environmental damage produces biased and inconsistent estimates; b) International trade: for Stern, Common, and Barbier (1996), countries such as the United States and Japan reduced environmental damage by exporting industrialization to developing countries, which also biases estimates; c) Data problems: according to Stern, Common, and Barbier (1996), the studies by Grossman and Krueger (1991) and Shafik and Bandyopadhyay (1992) use urban-area pollution data and disregard pollutants from natural ecosystems, which also impact human health. According to Shafik and Bandyopadhyay (1992), the data used in the EKC will possibly give rise to heteroscedasticity in estimation, making the ordinary least squares method (OLS) inefficient, even though it is impartial.

With Panayotou's (1993) critical eye regarding the validity of the EKC, we must ask: i) What income level per *capita* is the turning point? ii) When did the environmental damage occur, and how could it have been avoided? (iii) Would any ecological limit be reached in such a way that it would be irreversible with the increase in income? (iv) Is the improvement of the quality of the environment automatic when income is increased, or does it need a "green" policy intervention? v) How can developing countries achieve the level of environmental quality enjoyed by developed countries?

Khanna and Plassmann (2004) also questioned that income growth in developing countries could cause the worsening of global pollution. According to the authors, only emitters that attract public interest due to pollution levels and impacts can obtain the EKC.

Related Studies

In this section, we discuss the previous studies that address the EKC. We collected authors, the dependent variable, methodology, the location studied, and the periods. Finally, we verified whether the EKC was found, as shown in Table 1.

Table 1- Correlated studies on EKC

Authors	Dependent variable	Methodology	Sample	EKC
Santos *et al.* (2008)	Deforestation	Panel Data (Fixed effect)	AMZ-L municipalities (2000-2004)	Yes
Oliveira *et al.* (2011)	Deforestation	Panel Data with spatial dependence	AMZ-L municipalities (2001-2006)	Inverted "U"
Gomes and Braga (2008)	Deforestation	Panel Data (Random effect)	AMZ-L states (1990-2004)	Yes
Caldas *et al.* (2003)	Deforestation	Cross-Section	Small properties along the Transamazon highway (1996 and 2000)	Yes
Prates (2008)	Deforestation	Panel Data (Fixed effect)	AMZ-L municipalities (2000-2004)	Yes

Source: Elaborated by the authors (2020).

Methodologic Procedure

For this work, the methodology adopted was the panel data model. This model has some advantages over cross-section or time series models, such as the ability to circumvent the data heterogeneity problem and consider the individual variables of each Brazilian state that make up the Legal Amazon (HSIAO, 1986). Besides these advantages, the model allows us a more significant number of observations, increasing the degree of freedom and decreasing the collinearity problem among the explanatory variables.

The general template for panel data is given by:

$$Y_{it} = \beta_{0it} + \beta_k x_{1it} + \dots + \beta_{nit} x_{kit} + \epsilon_{it} \quad (1)$$

Thus, the underwritten i indicates the different individuals, which are the states of the Legal Amazon, and t is the period studied. β_0 represents the intercept parameter, while β_k corresponds to the angular coefficient of the k-th explanatory variable.

Therefore, the adapted model for this work will be as follows:

$$Y_{it} = \alpha_{it} + \beta_0 + \beta_1 PIB_{it} - \beta_2 PIB_{it}^2 + \beta_3 PIB_{it}^3 + X_{it} + \epsilon_{it} \quad (2)$$

At which: Y_{it} represents the dependent variable, which is the deforestation area in the Legal Amazon; α_{it} it is the coefficient of the fixed effect; β_0, the intercept; β_i, the parameters to be estimated; X_{it}, the explanatory variables; and ϵ_{it} is the error term.

The vector of explanatory variables (X_{it}) was composed by the GDP *per capita* squared and is included to capture the hypothesis of the EKC because, according to Kuznets theory, deforestation tends to grow at low-income levels. From the moment a society reaches a higher level of income, the situation reverses, and deforestation tends to decline, taking the form of an inverted "U".

The GDP *per capita* cubed was also tested because, as shown by Grosmann and Krueger (1991), the curve can assume positive values for degradation again when the income reaches high levels, making the EKC take an "N" shape.

Besides the GDP explanatory variable, the literature still addresses several other variables to explain the EKC. For this study, the population density and cattle herd of the states belonging to the Legal Amazon will be used as control variables. Previous studies addressed these two variables as influencing deforestation, such as Marengo (2007), Margulis (2003), and Martha Junior, Contini, and Navarro (2011). Population density is used in several areas that study the EKC and is pointed out by the authors cited as important for the study its impacts on environmental degradation. Therefore, it also applies to this research. The variable cattle herd is included here because it represents the main activity in the states covered by the Legal Amazon and is considered one of the leading causes of deforestation (MARGULIS, 2003).

For the GDP variable, a positive signal is expected. For the quadratic form of GDP, a negative sign is expected. However, the cubed form can take a negative sign, as proposed by Kuznets (1955), or positive, as evidenced by Grossman and Krueger (1991). For the control variables, population density and cattle herd, the expected sign is positive.

The data used for empirical research were obtained from the Brazilian Institute of Geography and Statistics of Automatic Recovery (SIDRA). The inflationary correction of monetary variables was based on the General Price Index (GPI), provided by the Getúlio Vargas Foundation (FGV) portal.

Results and discussion

In this subsection, the results obtained from the econometric model are discussed, based on the data collected from the SIDRA. To choose the best model to be adopted in the estimation, which are fixed effect model, random effect, or pooled model, we applied the Hausman test (1978), whose null hypothesis (H_0) states there is no statistical difference between the two estimators. The test result allowed us to reject the null hypothesis at a significance level of 1 %. Thus, the proper model for the estimation was the one with a fixed effect.

Table 2 presents the estimation of the fixed, random, and pooled effect models to demonstrate the robustness of the estimated coefficients. We found that there were no significant variations and no exchange of signs among the models of random and fixed effect, unlike the pooled model. However, by the Hausman test (1978), the fixed effect was the model indicated for estimation.

Table 2 – Estimation of the model in panel data.

Variables	Random effect	Fixed effect	Pooled effect
Log GDP	18.087** (8.091)	19.649** (7.810)	-22.377^{NS} (17.163)
Log GDP^2	-1.866** (0.838)	-2.031** (0.808)	2.293^{NS} (1.177)
Log GDP^3	0.060** (0.082)	0.066** (0.027)	-0.077^{NS} (0.060)
Log DDP	0.607** (0.331)	1.074* (0.402)	-0.485* (0.147)
Log Bov	0.712*** (0.191)	0.585*** (0.323)	0.682*** (0.066)
Constant	-60.447** (25.862)	-63.915** (24.972)	68.356^{NS} (54.971)

Source: Elaborated by the authors (2020)

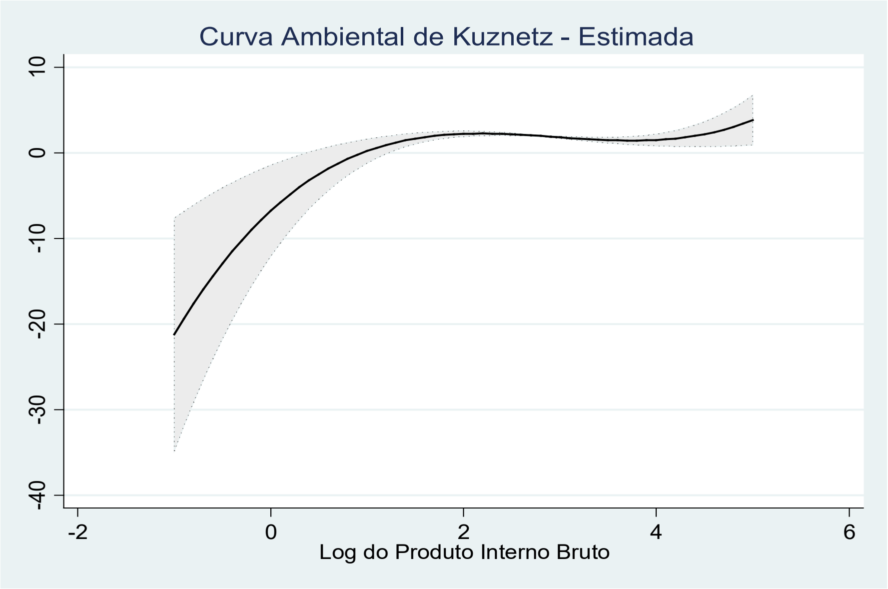
Note: ^{NS} = not significant; * significant at 1%; ** significant at 5%; *** significant at 10%. Value in brackets is the standard deviations.

According to the estimation of the fixed effect model, the coefficients of GDP, GDP^2, and GDP^3 showed statistical significance at 5 %, the population density was significant at 1 %, and the cattle herd at 10 %, which corroborates that these variables directly impact deforestation process. The signs of the coefficients were already expected. For GDP, the positive sign indicates that deforestation has grown with an increase in income, but GDP^2, with a negative sign, shows that deforestation tends to reduce by reaching a certain amount of income. For GDP^3, the sign becomes positive again, indicating that high-income values would cause an increase in deforestation.

The fixed-effect model showed that for the squared and cubed GDP variable, a curve obtained takes an "N" shape, which differentiates it from the form of the inverted "U", as proposed by the Environmental Kuznets Curve (1955), i.e., when the income reaches a certain value, it causes deforestation to decrease (FIGURE 2). However, while income continues to increase, the curve reverses again, showing that deforestation is growing again. These results are similar to those Grossman and Krueger (1991) found.

Results obtained from the estimate by the fixed effect model showed that, initially, when *per capita* GDP increases by 1 %, deforestation increased by 19.64 %. However, the deforestation rising path in relation to *per capita* GDP is not continuous; it presents a reversal when *per capita* GDP is squared. Thus, the estimates showed that, for every 1 % increase in *per capita* GDP, there was a reduction of 2.03 % in deforestation. This implies that the EKC is valid and that it is possible to grow sustainably to a certain amount of income, since, when *per capita* GDP is raised to the cube, a reversal occurs again, but

Figure 2 – Environmental Kuznets Curve format found



Source: Research data (2020).

this time, with less impact, with the 1 % increase in *per capita* GDP rising by 0.62 %.

Regarding the variables population density and cattle herd, there is a positive relationship with deforestation. The estimates pointed out that a 1 % increase in population density caused an increase of 1.07 % in deforestation. For the variable cattle herd, growth of 1 % resulted in a 0.58 % rise in deforestation. These results corroborate the statistical analyses presented previously. This positive relationship is clearly noted, especially between the states of Mato Grosso and Pará, where the population is more dispersed, and the cattle market has expanded rapidly.

In the first stage of the EKC, we expect that increasing population density, agricultural production, and GDP cause higher degradation (scale effect). However, it is possible to mitigate the impacts of growth by using the technique and composition effects (CARVALHO; ALMEIDA, 2008; GROSSMAN; KRUEGER, 1991). By reaching higher income, society would supposedly be willing to pay for lower environmental cost products, suggesting that the production of "green" products needs composition and technological effect. Applying this theory to AMZ-L, the trend is that when *per capita* income increases, the production system is modernized, optimizing the use of soil. This tends to happen because there is social pressure for products of sustainable origin (composition effect) (STERN, 2004).

However, to ensure that the effects of income do not follow in parallel with deforestation (scale effect), technological commitment is needed, especially in agriculture and livestock, which are prevailing activities in the AMZ-L region (composition effect), reducing the margins of deforestation as income increases, by optimizing production, according to Torras and Boyce's theory (1998).

There is a theoretical issue as to the validity of the EKC, which is based on the possibility of exporting polluting industries to developing countries and importing semi-processed raw materials. For this reason, rich countries have obtained the EKC in the form of an inverted "U" (CARVALHO; ALMEIDA, 2008). If this assumption is valid, in the case of AMZ-L, the curve may not be sustained, which explains the "N" shape found. This result reflects Cole's (2004) studies, stating that even if all developing countries reach a high level of technology, the dynamics in which wealth diminishes environmental degradation tend to end.

The results found parallel De Bruyn, Van Den Bergh, and Opschoor's (1998) statement that the EKC cannot be sustained in the long term, so the inverted "U" would be only in the initial phase between economic growth and sustainability. In fact, in this study, the findings point out that, after high-income levels, the curve will invert again, assuming an "N" shape.

A possible explanation for the curve taking the "N" shape, as shown by the econometric model, is linked to the limits of technological resources. As technological resources tend to run out to sustain growth, there is a need for greater exploitation of natural resources, i.e., the first phenomenon of the EKC is temporary, as explained by Biage and Almeida (2015). Regarding the second stage, the explanation is guided by Opschoor's study (1990), in which we see that the increasing reversal of the curve can be the result of a *deficit* achieved in the process of technological improvements, or that the cost of deploying the technology to the means of production becomes costly.

Previous EKC studies, such as Santos *et al.* (2008), already noted that technological improvements in the Legal Amazon, after a certain point, would cause environmental degradation. Thus, the agricultural and livestock production model and the effects of colonization may present technological limits, which would contribute to the second inversion.

On the other hand, on the assumptions of the second EKC inversion, shown in the present study, the authors Roca and Serrano (2007) question the validity of the curve, saying that no country targeted in the EKC studies reached such high levels of *per capita* income that the curve inverts for the second time, showing that in practice it is not possible to know whether this would actually occur.

As this is an empirical study showing the possible relationship between growth and environmental degradation, in which the curve takes the form of an "N", deforestation tends to be lower at higher income levels, as shown by the results presented. Likewise, Beckerman (1992) stated that however much environmental degradation grows with increased income in the first stage, the option that allows for lower environmental impacts is to make the country rich.

Final considerations

The econometric model applied in this paper showed that, at first, EKC takes an inverted "U" shape, i.e., deforestation grows from the increase in income. However, by reaching a certain level of income, deforestation tends to decrease, according to the EKC theory.

When the cubed form is applied to the model, the EKC presents a new inversion, suggesting that deforestation rates tend to escalate with an "N" form at higher income levels, proving that economic growth alone does not guarantee a reduction in deforestation levels, making exogenous actions necessary.

We must emphasize that public policies are needed to counteract the second reversal of the EKC. "Green laws" must be passed, and society must take other actions to mitigate the impacts caused by human activity. The efficiency of such actions could be seen in deforestation: when the government intervenes through environmental laws, it causes a gradual drop in deforestation levels.

This study also included two variables, population density, and cattle herd, both positively impacting deforestation in the Legal Amazon. The climate and topography favorable to the expansion of the cattle herd create cycles that feed the local economy and, consequently, foster the evolution of the population and livestock farming, attracted by the intense trading activity. For future work, we suggest exploring the influence of international trade and environmental legislation on deforestation in the Legal Amazon.

References

ARRAES, R. A.; MARIANO, F. Z.; SIMONASSI, A. G. Causas do desmatamento do Brasil e seu ordenamento no contexto mundial. **Revista Economia e Sociologia Rural**, Piracicaba-SP, v. 50, n. 1, p. 119-140, jan/mar., 2012. DOI: http://dx.doi.org/10.1590/S0103-20032012000100007. Disponível em: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0103-20032012000100007. Acesso em: 02 set. 2019.

ÁVILA, E. S.; DINIZ, E. M. Evidências sobre a curva ambiental de Kuznets e convergência das emissões. **Estudos Econômicos**, São Paulo, v. 45, n. 1, p. 97-126, jan.- mar. 2015. DOI: http://dx.doi.org/10.1590/0101-4161201545197ese. Disponível em: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0101-41612015000100097. Acesso em: 17 nov. 2019.

BECKERMAN, W. Economic growth and the environment: Whose growth? whose environment? **World Development**, [*S.l.*], v. 20, n. 4, p.481-496, 1992. Disponível em: https://www.sciencedirect.com/science/article/abs/pii/0305750X9290038. Acesso em: 14 nov. 2020.

BIAGE, M; ALMEIDA, H. J. F. Desenvolvimento e impacto ambiental: uma análise da curva ambiental de Kuznets. **Pesquisa e Planejamento Econômico**, [*S.l.*], v.45, n. 3, p. 505-556, 2015. Disponível em: http://repositorio.ipea.gov.br/bitstream/11058/6100/5/PPE_v45_n03_Desenvolvimento.pdf. Acesso em: 04 ago. 2015.

BRASIL. Lei 5.173, de 27 de outubro de 1966. Dispõe sobre o Plano de Valorização Econômica da Amazônia; extingue a Superintendência do Plano de Valorização Econômica da Amazônia (SPVEA), cria a Superintendência do Desenvolvimento da Amazônia (SUDAM), e dá outras providências. Diário Oficial [da] República Federativa do Brasil, Brasília, DF, 27 out 1966. Disponível em: L5173 (planalto.gov.br). Acesso em: 21 jun. 2021.

CALDAS, M.M. WALKER, R.; SHIROTA, R.; PERZ, S.; SKOLE, D. Ciclo de vida da família e desmatamento na Amazônia: combinando informações de sensoriamento remoto com dados primários. **Revista Brasileira de Economia**, Rio de Janeiro, v. 57, n. 4, p.1806-9134, 2003. Disponível em: https://www.scielo.br/scielo.php?pid=S0034-71402003000400002&script=sci_abstract. Acesso em: 02 jul. 2020.

CARVALHO, N.L.; KERSTING, C.; ROSA, G.; FRUET, L.; BARCELLOS, A.L. Desenvolvimento sustentável x desenvolvimento econômico. **Revista Monografias Ambientais**, Santa Maria, v. 14, n. 3, p. 109—117, set-dez. 2015. Disponível em: https://periodicos.ufsm.br/remoa/article/view/17768. Acesso em: 25 nov. 2019.

CARVALHO, S.S. **A Relação entre Crescimento e meio ambiente:** uma reavaliação da Curva de Kuznets Ambiental. Brasília: Ipea, 2013. Disponível em: http://www.ipea.gov.br/portal/index.php?option=com_content&view=article&id=2076. Acesso em: 20 out. 2019.

CARVALHO, T.S.; ALMEIDA, E. **A hipótese da curva de Kuznets ambiental Global**: uma perspectiva econométrico-espacial. 2008. Tese (Mestrado em Economia Aplicada) Universidade Federal de Juiz de Fora, 2008.

CARVALHO, T.S.; ALMEIDA, E. A Hipótese da Curva de Kuznets Ambiental Global: uma perspectiva econométrico-espacial. **Revista Estudos Econômicos**, São Paulo, v. 40, n. 3, p. 587-615, jul. set. 2010. DOI: http://dx.doi.org/10.1590/S0101-41612010000300004. Disponível em: http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0101-41612010000300004. Acesso em: 22 set. 2019.

COELHO, A.B.; FERREIRA, M.D.P. Desmatamentos recentes nos Estados da Amazônia Legal: uma análise da contribuição dos preços agrícolas e das políticas governamentais. **Revista Economia e Sociologia Rural**, Piracicaba, v. 53, n. 1, p. 097-102, 2015. Disponível em: https://www.scielo.br/pdf/resr/v53n1/0103-2003-resr-53-01-00091.pdf. Acesso em: 16 jul. 2020.

COLE, M. A. Trade, the pollution haven hypothesis and the environmental Kuznets curve: examining the linkages. **Ecological Economics.** v. 48, p. 71-81, 2004.

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**, Amsterdam, v. 25, n. 2, p. 161-175, 1998. Disponível em: https://www.sciencedirect.com/science/article/abs/pii/S092180099700178X. Acesso em: 25 nov. 2020.

DINDA, S. Environmental Curve Kuznets Hypothesis: A Survey. **Ecological Economics**, Beldanga, v. 49, p.431-455, jul. 2004. DOI: https://doi.org/10.1016/j.ecolecon.2004.02.011. Disponível em: https://www.sciencedirect.com/science/article/abs/pii/S0921800904001570. Acesso em: 20 set. 2019.

DINIZ, E. M. Lessons From The Kyoto Protoc. **Ambiente e Sociedade**, Campinas, v.10, n. 1, p. 27-38, jan.-jun. 2007. DOI: http://dx.doi.org/10.1590/S1414-753X2007000100003. Disponível em: http://www.scielo.br/scielo.php?pid=S1414-753X2007000100003&script=sci_abstract. Acesso em: 05 out. 2019.

FEARSIDE, P.M. Desmatamento na Amazônia: dinâmicas, impactos e controle. **Revista ACTA amazônica**, v. 36, n. 3, p. 395-400, maio 2006. DOI: http://dx.doi.org/10.1590/S0044-59672006000300018. Disponível em: http://www.scielo.br/scielo.php?pid=S0044-59672006000300018&script=sci_abstract&tlng=pt. Acesso em: 14 set. 2019.

FERREIRA, M.D.P. **Impactos dos preços das commodities e das políticas governamentais sobre o desmatamento na Amazônia Legal.** Dissertação (Mestrado em Economia Aplicada) – Universidade Federal de Viçosa, Viçosa, MG, 2011.

FUNDAÇÃO GETÚLIO VARGAS (FGV). **Indicadores de Preços.** 2020. Rio de Janeiro: FGV. Disponível em: http://portalibre.fgv.br/main.jsp?lumChannelId=402880811D8E34B9011D92AF56810C57. Acesso em: 15 out. 2020.

GOMES, S.C.; BRAGA, M.J. Desenvolvimento econômico e desmatamento na Amazônia Legal: uma análise econométrica. *In:* CONGRESSO DA SOCIEDADE BRASILEIRA DE ECONOMIA, ADMINISTRAÇÃO E SOCIOLOGIA RURAL. 46., 2008, Rio Branco. **Anais eletrônicos** [...]. Rio Branco, 2008. Disponível em: https://ideas.repec.org/p/ags/sbrfsr/103095.html. Acesso em: 17 abr. 2020.

GROSSMAN, G. M.; KRUEGER, A. B. **Environmental Impacts of a North American Free Trade Agreement**. Cambridge: National Bureau of Economic Research. 1991. *Ebook*.

GROSSMAN, G.; KRUEGER, A. B. Economic growth and the environment. **Quarterly Journal of Economics**, Oxford, v. 110, n. 2, p. 353-377, maio, 1995. Disponível em: https://academic.oup.com/qje/article/110/2/353/1826336. Acesso em: 11 set. 2019.

GUIMARÃES, R. P.; FONTOURA, Y. S. dos R. Rio +20 ou Rio -20? Crônicas de um fracasso anunciado. **Revista Ambiente e Sociedade**, São Paulo, v.15, n. 3, p. 19-39, set/dez. 2012. DOI: http://dx.doi.org/10.1590/S1414-753X2012000300003.

HAUSMAN, J. A. Specification tests in Econometrics. **The Econometrics Society**, v. 46, n. 6, p. 1251-1271, 1978. Disponível em: https://www.researchgate.net/publication/264382660_Hausman_1978/link/53da891a0cf2e38c63371ff4/download. Acesso em: 01 nov. 2020.

HSIAO, C. **Analysis of Panel Data.** Cambridge: Editora Cambridge University Press, 1986. *Ebook.*

INSTITUTO BRASILEIRO DE GEOGRAFIA E ESTATÍSTICA (IBGE). **"Geoestatísticas", revelam patrimônio ambiental da Amazônia Legal**. 2010. Disponível em: https://censo2010.ibge.gov.br/noticias-censo?busca=1&id=1&idnoticia=1887&t=geoestadisticas-revelan-patrimonio-ambiental-la-amazonia-legal&view=noticia. Acesso em: 03 out. 2019.

JEVONS, W.S. **The Coal Question.** Londres, 1866. *Ebook.*

KHANNA, N.; PLASSMANN, F. The demand for environmental quality and the environmental Kuznets Curve hypothesis. **Ecological Economics.** v. 51, p. 225-236, 2004.

KUZNETS, S. Economic Growth and Income Inequality. **The American Economic Review**, v. 45, n. 1, p. 1-28. 1995. Disponível em: https://www.jstor.org/stable/1811581?seq=1. Acesso em: 25 out. 2019.

LAGO, A.A.C. do**. Estocolmo, Rio, Joanesburgo:** o Brasil e as três conferências ambientais das Nações Unidas. Brasília: Editora Fundação Alexandre Gusmão, 2006. *Ebook*.

MALTHUS, T. **An Essay on the Principle of Population**. Londres. 1798. *Ebook*.

MARENGO, J. A. **Mudanças climáticas globais e seus efeitos sobre a biodiversidade**: caracterização do clima atual e definição das alterações climáticas para o território brasileiro ao longo do século XXI. 2. ed. Brasília, DF: Editora Ministério do Meio Ambiente, 2007. *Ebook*.

MARGULIS, S. **Causas do desmatamento na Amazônia**. Brasília: Editora Banco Mundial, 2003. *Ebook*.

MARTHA JUNIOR, G.B.; CONTINI, E.; NAVARRO, Z. **Caracterização da Amazônia Legal e macrotendências do ambiente externo**. Brasília: Editora EMBRAPA, 2011.*Ebook*.

MONTIBELLER FILHO, G. Crescimento econômico e sustentabilidade. **Revista Sociedade e Natureza**, Uberlândia, v. 19, n. 1, p. 81-89, jun. 2007. Disponível em: http://www.seer.ufu.br/index.php/sociedadenatureza/article/view/9343. Acesso em: 22 out. 2019.

NASCIMENTO, E.P. Trajetória da sustentabilidade: do ambiente ao social, do social ao econômico. **Revista Estudos Avançados**, Brasília, v.26, n. 74, p. 51-64, 2012. Disponível em: http://www.revistas.usp.br/eav/article/view/10624. Acesso em: 11 maio 2020.

O 'CONNOR, J. **Natural Causes**: essays in Ecological Marxism. New York: Editora The Guilfor Press, 1998. *Ebook*.

OLIVEIRA, R.C.; ALMEIDA, E.; FREGUGLIA, R.S.; BARRETO, R.C. Desmatamento e crescimento econômico no Brasil: uma análise da Curva de Kuznets Ambiental para Amazônia legal. **Revista Economia e Sociologia Rural**, Piracicaba, SP, v. 49, n. 03, p. 709-740, jul.-set. 2011. DOI: http://dx.doi.org/10.1590/S0103-20032011000300008. Disponível em: Acesso em: 12 out. 2019.

OPSCHOOR, J. B. Ecologische duurzame economische ontwikkeling: een theoretisch idee en een weerbarstige praktijk. *In*: NIJKAMP, P.; VERBRUGGEN, H. (Eds.). **Het Nederlands Milieu in de Europese Ruimte**: preadviezen van de koninklijke vereniging voor staathuishoudkunde. Stenfert Kroese, Leiden, p. 77-126, 1990.

PANAYOTOU, T. **Empirical Tests and Policy Analysis of Environmental Degradation at Different Stages of Economic Development**. Geneva: Editora International Labour Office, 1993. *Ebook*.

PISANI, J. A. D, Sustainable development – historical roots of the concept. **Environmental Sciences**, África do Sul, v. 3, n. 2, p. 83-96, 2006.

PORTER, M. E.; VAN DER LINDE, C. Toward a new conception of the environment-competitiveness relationship. **Journal of Economic Perspectives,** v. 9, n. 4, p. 97-119, 1995.

PRATES, R.C. **O desmatamento desigual na Amazônia brasileira**: sua evolução, suas causas e consequências sobre o bem-estar. 2008. Tese (Doutorado em Economia Aplicada) – Escola Superior de Agricultura, Piracicaba, 2008.

ROCA, J.; SERRANO, M. Income growth and atmospheric pollution in Spain: an input–output approach. **Ecological Journal**, v. 63, p. 230-242, 2007.

SANTOS, R. B.; DINIZ, M.B.; RIVERO, S.L.M.; OLIVEIRA JUNIOR, J.N. .Estimativa da curva de kuznets ambiental para a Amazônia Legal. *In:* CONGRESSO BRASILEIRO DA SOCIEDADE DE ECONOMIA, ADMINISTRAÇÃO E SOCIEDADE RURAL, 47., 2008, Pará. **Anais eletrônicos [...]**. Pará, 2008. Disponível em: https://ideas.repec.org/p/ags/sbrfsr/113968.html. Acesso em: 16 out. 2020.

SELDEN, T. M.; SONG, D. Environmental quality and development: is there a Kuznets Curve for air pollution emissions? **Journal of Environmental Economics and Management**, New York, v.27, n. 2, p. 147-162, 1994. DOI: https://doi.org/10.1006/jeem.1994.1031. Disponível em: https://www.sciencedirect.com/science/article/abs/pii/S009506968471031X. Acesso em: 16 out. 2019.

SHAFIK, N.; BANDYOPADHYAY, S. **Economic Growth and Environmental Quality**. Time-Series end Cross-Country evidence. Washington, D. C: Editora the World Bank, 1992. *Ebook*.

STERN, D. I.; COMMON, M. S.; BARBIER, E. B. Economic Growth and Environmental Degradation: The Environmental Kuznets Curve and Sustainable Development. **World Development**, [*s.l.*], v. 24, n. 7, p. 1151-l 160, 1996. DOI: https://doi.org/10.1016/0305-750X(96)00032-0. Disponível em: Acesso em: 15 nov. 2019.

STERN, D., The Rise and Fall of the Environmental Kuznets Curve. **World Development**, Now York, v. 32, n. 8, p. 1419-1439, 2004. Disponível em: https://www.sciencedirect.com/science/article/pii/S0305750X04000798. Acesso em: 14 set. 2020.

TORRAS, M.; BOYCE, J. K. Income, inequallity, and pollution: a reassessment of the environmental Kuznets Curve. **Ecological Economics**, v. 25, p. 147-160, 1998.

UNITED NATIONS. **Our Common Future**. Report of the World Commission on Environment and Development. 1987. *Ebook*.

VIANA, A.L.D.; MACHADO, C.V.; BAPTISTA, T.W.F.; LIMA, L. D.; MENDONÇA, M.H.M.; HEIMAN, L.S.; ALBUQUERQUE, M.V.; IOZZI, F.L.; DAVID, V,C,. IBAÑEZ, P.; FREDERICO, S. Sistema de Saúde universal e território: desafios de uma política regional para a Amazônia Legal. **Caderno de Saúde Pública**, Rio de Janeiro, v. 23, p. 117-131, 2007.

VON CARLOWITZ, H.C. **Sylvicultura economica**. [*s.l.*: *s.n.*], 1713. *Ebook.*