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Relationship Between Economic Growth and Environmental Degradation: Is there an Environmental Evidence of Kuznets Curve for Brazil?

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ABSTRACT

This study investigates the relationship between CO_2 emissions, economic growth, energy use and electricity production by hydroelectric sources in Brazil. To verify the environmental Kuznets curve (EKC) hypothesis we use time-series data for the period 1971-2011. The autoregressive distributed lag methodology was used to test for cointegration in the long run. Additionally, the vector error correction model Granger causality test was applied to verify the predictive value of independent variables. Empirical results find that there is a quadratic long run relationship between CO_2 emissions and economic growth, confirming the existence of an EKC for Brazil. Furthermore, energy use shows increasing effects on emissions, while electricity production by hydropower sources has an inverse relationship with environmental degradation. The short run model does not provide evidence for the EKC theory. The differences between the results in the long and short run models can be considered for establishing environmental policies. This suggests that special attention to both variables -energy use and the electricity production by hydroelectric sources- could be an effective way to mitigate CO_2 emissions in Brazil.

Keywords: Environmental Kuznets Curve, Energy, Hydroelectric Power, Brazil
JEL Classifications: C32, O54, Q50, Q56

1. INTRODUCTION

Kuznets (1955) originally proposed the hypothesis about economic growth and income inequality where an inverted U-shaped curve can be used to describe the relationship between these variables. As a country's economy grows, inequality rises up to a turning point in which the trend inverts. In the last two decades, a series of studies have emerged, based on an extension of the Kuznets curve (KC), to the relationship between environmental quality and economic growth, the environmental KC (EKC). The EKC hypothesis states that as an economy grows[1], environmental degradation[2] worsens (increases) until the economy reaches such level of performance that its negative impact reduces, as a result of improved income inequality.

Research in the area is extensive. The first study on EKC was completed by Kraft and Kraft (1978). They found a unidirectional causality running from energy consumption to economic growth for the United States. A similar result has been reported in several studies based on panels of nine South American countries, 16 Asian countries and the G7 group (Apergis and Payne, 2010; Lee and

1 GDP at constant prices.

2 Indicator of a recognized and measurable negative impact on the environment, such as CO2 or N2O emissions (IPCC, 1995; US EPA, 2015) and deforestation.

Chang, 2008; Lean and Smyth, 2010; Narayan and Smyth, 2008), whereas other studies found the inverted causality relationship for Turkey, China, Malaysia and fourteen low income countries (Lise and Van Montfort, 2007; Zhang and Xu, 2012; Ang, 2008; Ozturk et al., 2010); and a bi-directional causality are found for 37 middle income countries (Ozturk et al., 2010) and six Central American countries (Apergis and Payne, 2009). Other works have extended the analysis to include the effects of foreign trade (Jalil and Mahmud, 2009; Nasir and Ur Rehman, 2011; Hossain, 2011), urbanization (Zhang and Cheng, 2009), and the disaggregation of energy consumption into oil, coal, gas and electricity (Saboori and Sulaiman, 2013). Another case of disaggregation has been renewable energy and non-renewable energy (Flórez-Orrego et al., 2014; Jebli et al., 2015; Al-Mulali and Ozturk, 2016). Though that the EKC hypothesis does not hold for every country (Akbostanci et al., 2009; Lacheheb et al., 2015; Martínez-Zarzoso and Bengochea-Morancho, 2004), its analysis can at least demonstrate the cointegration of economic and environmental variables in the long-term (Liao and Cao, 2013). Saboori and Sulaiman (2013) mention that there are three research paths on the relationship of energy consumption and economic growth with environmental degradation. The first group corresponds to the actual test of the EKC hypothesis; the second approach focuses on the energy consumption and output nexus where economic growth shows a close and positive relationship with energy consumption (Ozturk, 2010). The third approach combines the first and second standpoints already mentioned. These results suggest the higher economic development, the higher the energy consumption. However, energy consumption may be related to efficient use of energy. This efficiency requires therefore a higher level of economic development (Ang, 2007).

Regarding the implementation of applied research, environmental degradation can be measured as CO_2 emissions (Azomahou et al., 2006; Shahbaz et al., 2015; Ozturk and Uddin, 2012; Apergis and Ozturk, 2015), deforestation rates (Bhattarai and Hammig, 2001; Bulte and Van Soest, 2001) and municipal wastes (Mazzanti et al., 2006). In accordance to the different options to choose the dependent variable that represents the environmental degradation, the importance of the use of an adequate variable for each research is relevant because in some cases selecting the right dependent variable in empirical work is effective to find the EKC relationship (Bulte and Van Soest, 2001). Analyzing the EKC literature it is clear that there is not a single policy that could reduce pollutants emissions by the income increase. However, what EKC actually reveals is how a technically specified measurement of environmental quality could be affected by the increase of the wealth of a country (Dinda, 2004).

The purpose of this paper is to investigate the EKC hypothesis taking Brazil as a case study. Brazil's managed to decrease deforestation rates by 70% between 2005 and 2013, which implies an approximate reduction of 3.2 Gt of CO_2 emissions (Nepstad et al., 2014). Furthermore, Brazil's commitment to environmental causes may be evidenced in additional measures adopted by the country, such as the decision to outweigh the environmental impact of the 2014 FIFA World Cup, hosted in Brazil, by redeeming certified emission reductions from domestic emission reduction projects (UNFCCC, 2014).

Despite Brazil's evident endeavors to suppress its environmental impact[3], the world's seventh largest economy (World Bank, 2014) and alleged "leader against the Climate Change" (Howard, 2014; The Economist, 2014) is ironically the sixteenth global CO_2 emitter as well (EDGAR, 2014). Investigating the relationship between growth and environmental degradation might shed some light on the future of this country, whose relevance as global- and especially to South America - Reference today will certainly attract or discourage neighboring nations to follow its lead towards sustainability. For instance, furthering pro-environmental actions to reduce a particular impact and then experiencing an economic lag - Due to a unidirectional causality between that variable and economic growth- would mislead other countries about the impacts caused by such policies. Testing an EKC curve hypothesis for Brazil is thus, considerably important.

Testing for an EKC curve allows the consideration of more than one relevant variable. For this study, we have considered four and their justifications are unfolded throughout the following sections. We use time series data for the period 1971-2011 for gross domestic product (GDP), CO_2 emissions, energy use and energy produced from hydroelectric sources. Additionally, we apply the autoregressive distributed lag (ARDL) method to take advantage of its robust estimation when treating data for short time series.

Pao and Tsai (2011), examine the dynamic relationship of these variables in Brazil, supporting the EKC hypothesis where they find a U-shaped relationship between energy consumption-economic growth. Ewing et al. (2007) mention that it is not possible to identify the impact of a specific type of energy with aggregate data. Considering more than three quarters of the energy produced in Brazil is obtained from hydropower plants (Flórez-Orrego et al., 2014), this study includes electricity production from hydroelectric sources as a determinant of CO_2 emissions in Brazil.

The paper is organized as follows: Section 2 describes the situation of the Brazilian economy; Section 3 introduces the data and describes the variables and methodology; Section 4 reports the empirical results; and Section 5 concludes.

2. BRAZILIAN CONTEXT

More than 81% of the electricity produced in Brazil comes from hydropower plants (Flórez-Orrego et al., 2014). In fact, Brazil hosts the second largest hydropower plant in the world, the Itaipu Dam, which supplies more than 20% of the Brazilian energy consumption (Ribeiro and da Silva, 2010). Understanding the importance of hydroelectric power within Brazil's energetic mix is particularly crucial for the country's commitment to mitigate actions against climate change[4]. Increased temperatures elevate the risk of uncontrolled wildfires, which in turn threatens the

3 It was internationally praised by such achievements, and even referred to as a "global leader against the climate change" (Howard, 2014; The Economist, 2014).

4 In 2008, Brazil publicly announced the National Plan on Climate Change, whose most echoed objective was a 70% reduction of deforestation by 2017. In 2009, they extended the National Climate Change Policy, which socialized "voluntary GHGs reduction targets" by 2020 (The World Bank, 2010).

Brazilian rainforests and potentially alters the occurrence of natural cycles. Reduced precipitation patterns would impact the amount of water (input) for Brazilian hydropower plants, justifying the relevance of the so-called "Amazon forest dieback" (The World Bank, 2010), which refers to a drastic change that is expected to happen in 2050, when Amazonian forests turn from their status of carbon absorber into a carbon emitter or source (Cox et al., 2000; 2004). This situation hence becomes matter of public- and even global-importance, considering that almost 60% of the Brazilian territory is covered by the Amazon rainforest, which represents one of the Earth's largest carbon pool ecosystems (Brienen et al., 2015).

We consider relevant to graphically present pre-treatment data in order to illustrate a general scenario of the Brazilian situation. Figure 1 shows the trends for the data series for the natural logarithms of CO_2 emissions, GDP per capita and energy use. As evidenced, CO_2 presents an increasing tendency. In fact, the country's participation in global CO_2 emissions has increased from an account of 0.97% in 1990 to 1.40% in 2014, as reported in the Emission Database for Global Atmospheric Research (EDGAR, 2014). Brazilian income has likewise periodically increased (Perobelli et al., 2015). A third aspect worth noting is the particular behavior of electricity production. Although hydroelectric power represents more than three quarters of the total energy produced in Brazil - Reason why it is used in the model, its incidence has seemingly decreased in the last two decades. Reasons behind such change in tendency may be drawn from the fact that Brazil is increasingly being affected by harsh climatic conditions, especially droughts. In 2014, the country experienced the worst drought in more than 40 years (Iceland, 2015; Rocha, 2015), which, in addition to structural transitions to a diversified renewable energy matrix-especially sugar cane and wind power, helps to explain the negative trend observed (Flórez-Orrego et al., 2014; Ministério de Minas e Energia, 2014).

3. ECONOMETRIC METHOD

3.1. Data Variables and Model

We follow Ang (2007), Wu et al. (2014), Jebli and Youssef (2015) and Bölük and Mert (2015) to test whether there is a long run relationship between CO_2 emissions, economic growth and energy use in Brazil. We include electricity production from hydroelectric sources because of its participation of its share in Brazil's energetic mix. In addition, Saboori and Sulaiman (2013) concluded the results showed that the EKC is not supported using aggregated data, however using disaggregated energy data, there is evidence of EKC. In this context, Equation 1 states that CO_2 emissions (CO_{2t}) in Brazil depend on GDP (GDP_t), square of GDP

$$CO_2 = f\left(GDP_t, GDP_t^2, EPH_t, ENU_t\right) \quad (1)$$

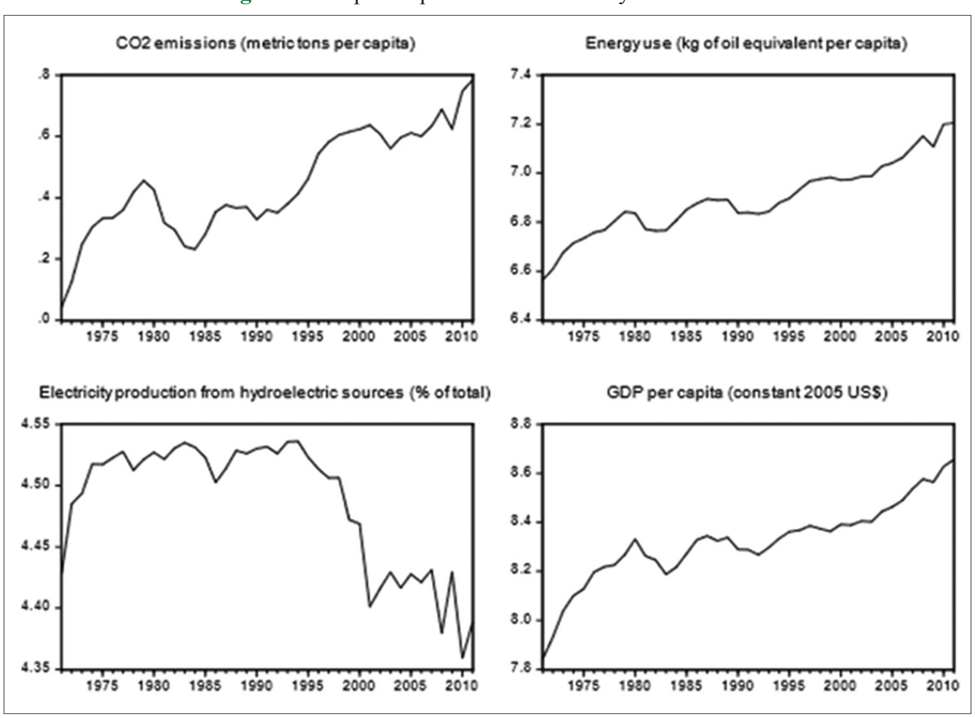
To test the validity of EKC hypothesis, the model is represented in the log-linear as follows:

$$LCO_{2t} = \beta_1 + \beta_{GDP} LGDP_t + \beta_{GDP^2} LGDP_t^2 + \beta_{EPH} LEPH_t + \beta_{ENU} LENU_t + \mu_t \quad (2)$$

Where CO_2 is the carbon dioxide emissions per capita (measured in metric ton per capita), GDP is per capita GDP (in constant 2005 US Dollar), GDP^2 is the square of GDP, EPH stands for the electricity production from hydroelectric sources (percentage of total production), ENU represents energy use (kilograms of oil equivalent per capita) and μt stands for residual or error term. The annual time series data in all variables were obtained from the World Development Indicators online database for Brazil over the time period between 1971 and 2011.

The EKC hypothesis suggests that the coefficient β_{GDP} is expected to be positive, and β_{GDP^2} negative. The positive sign in β_{GDP} suggests

Figure 1: Graphic representations of analyzed variables



that the higher the economic growth, the higher the CO_2 emissions. A negative β_{GDP^2} indicates that there is a turning point where the relation is inverted, and a higher economic growth derives into a decrease of CO_2 emissions where GDP equals $exp^{\beta_{GDP}/2\beta_{GDP^2}}$ +. In turn, if β_{GDP^2} is statistically non-significant, then an increase in economic growth always leads to an increase in pollutants' emissions (Grossman and Krueger, 1995). The sign of β_{EPH} is expected to be negative because electricity production from renewable resources replaces the need to produce it by traditional means i.e., oil burning, coal or natural gas - and consequently reducing emissions of greenhouse gas (GHGs) into the atmosphere (Lacheheb et al., 2015; Stern, 2004). Under the null hypothesis, economic activity is positively stimulated by an increase in energy use, which implies increases in GHG emissions. The sign of the coefficient β_{ENU} is expected to be positive, as justified by Ang (2007) indicating that more energy use results in more energy emissions.

3.2. Cointegration Method

For cointegration analysis we use the ARDL bounds testing approach developed by Pesaran and Pesaran (1997), Pesaran et al. (2000; 2001). The ARDL examines the long and short run relationships between CO_2 emissions, economic growth, energy use and electricity production from hydroelectric sources. The main advantage of this method is that it allows different integration orders for each series. This was the main restriction of previous approaches based on residuals (Engle and Granger, 1987) or ordinary least squares procedures (Phillips and Hansen, 1988). Haug (2002) argues that the ARDL approach has better properties for short sample data sets as the ARDL model allows regressors to be stationary in different levels. These features allow the estimation of a long run relationship among the series. Pesaran and Shin (1999) state that the appropriate modification of the orders of ARDL model is sufficient to correct residual serial correlation and endogeneity. The ARDL unrestricted model can be written as follows:

$$\Delta \ln CO_2 = \beta_1 + \beta_{GDP} \ln GDP_{t-1} + \beta_{GDP^2} \ln GDP^2_{t-1} + \beta_{EPH} \ln EPH_{t-1} + \beta_{ENU} \ln ENU_{t-1} + \sum_{i=1}^{p} \beta_i \Delta \ln CO_{2t-i} + \sum_{j=0}^{q} \beta_j \Delta \ln GDP_{t-j} + \sum_{k=0}^{m} \beta_k \Delta \ln GDP^2_{t-k} + \sum_{l=0}^{n} \beta_l \Delta \ln EPH_{t-l} + \sum_{r=0}^{o} \beta_r \Delta \ln ENU_{t-r} + \mu_t \quad (3)$$

The long run relationship among the variables is verified by means of the ARDL bounds test where he null hypothesis representing no cointegration is $\beta_{GDP} = \beta_{GDP^2} = \beta_{EPH} = \beta_{ENU} = 0$; and the alternative hypothesis representing cointegration is $\beta_{GDP} \neq \beta_{GDP^2} \neq \beta_{EPH} \neq \beta_{ENU} \neq 0$. The calculated F-statistics value is compared with lower critical bound and higher critical bounds from Pesaran et al. (2001). Narayan (2005) suggested alternative critical values which fit better for small sample sizes. For cointegration it is required that the null hypothesis is rejected. The selection of the optimal lag length is analyzed through the Schwarz information criteria. Assuming there is cointegration, the next step is to estimate the long run and short run relationship. For short run estimation, the ARDL model includes an error correction term (ECT_{t-1}) as follows:

$$\Delta \ln CO_{2t} = \delta_1 + \sum_{i=1}^{p} \delta_{1i} \Delta \ln CO_{2t-i} + \sum_{j=0}^{q} \delta_{2j} \Delta \ln GDP_{t-j} + \sum_{k=0}^{m} \delta_{3k} \Delta \ln GDP^2_{t-k} + \sum_{l=0}^{n} \delta_{4l} \Delta \ln EPH_{t-l} + \sum_{r=0}^{o} \delta_{5r} \Delta \ln ENU_{t-r} + \gamma ECT_{t-1} + \varepsilon_t \quad (4)$$

The ECT coefficient (γ) in Equation 4 is interpreted as the speed of adjustment parameter, which represents how quickly the model achieves a long run equilibrium. This coefficient is expected to be negative and statistically significant.

Finally, additional diagnostics tests must be applied in order to verify correct specification of the model, such as the Jarque-Bera normality test, Breusch-Godfrey serial correlation LM test, ARCH hetoscedasticity test, Ramsey RESET test and cumulative sum/-squared (CUSUM/CUSUMSQ) test.

3.3. Granger Causality

The ARDL model does not determine the direction of causality among the variables, thus it is necessary to specify a vector error correction model (VECM) to investigate for cointegrated variables. We test Granger-causality following two step procedure of Engle and Granger (1987). The VECM allows testing two forms of causality, namely the short-run and long-run causal relationships. If the lagged differenced explanatory variables are significant, we can say that there is a short-run granger-causal relationship, whereas if the lagged ECT is significant, then there exists long-run granger-causal relationship (Masih and Masih, 1996).

For implementation, the first step consists on estimating the residuals of the long-run model as a proxy of the ECT; the second step correspond to the estimation of the VECM as follows:

$$\begin{bmatrix} \Delta \ln CO_{2t} \\ \Delta \ln GDP_t \\ \Delta \ln GDP^2_t \\ \Delta \ln EPH_t \\ \Delta \ln ENU_t \end{bmatrix} = \begin{bmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \\ \mu_4 \\ \mu_5 \end{bmatrix} + \begin{bmatrix} \varphi_{11,1} & \varphi_{12,1} & \varphi_{13,1} & \varphi_{14,1} & \varphi_{15,1} \\ \varphi_{21,1} & \varphi_{22,1} & \varphi_{23,1} & \varphi_{24,1} & \varphi_{25,1} \\ \varphi_{31,1} & \varphi_{32,1} & \varphi_{32,1} & \varphi_{34,1} & \varphi_{35,1} \\ \varphi_{41,1} & \varphi_{42,1} & \varphi_{43,1} & \varphi_{44,1} & \varphi_{45,1} \\ \varphi_{51,1} & \varphi_{52,1} & \varphi_{53,1} & \varphi_{54,1} & \varphi_{55,1} \end{bmatrix} \begin{bmatrix} \Delta \ln CO_{2t-1} \\ \Delta \ln GDP_{t-1} \\ \Delta \ln GDP^2_{t-1} \\ \Delta \ln EPH_{t-1} \\ \Delta \ln ENU_t \end{bmatrix} + \begin{bmatrix} \omega_1 \\ \omega_2 \\ \omega_3 \\ \omega_4 \\ \omega_5 \end{bmatrix} ECT_{t-1} + \begin{bmatrix} e_{1t} \\ e_{2t} \\ e_{3t} \\ e_{4t} \\ e_{5t} \end{bmatrix} \quad (5)$$

Where the vector of e_t's is white noise, and ECT is the ECT. The ω_k are interpreted as the speed of adjustment which represent the response of the dependent variable to deviations from the long-run equilibrium.

Table 1: Unit root test

Variables	ADF test statistics			
	I(0)	*k*	*I*(1)	*k*
None				
$\ln CO_{2t}$	1.0476	1	−3.5618***	1
$\ln GDP_t$	1.9457	1	−3.4405***	1
$\ln GDP_t^2$	1.9692	1	−3.3619***	1
$\ln EPH_t$	−0.9443	1	−3.9575***	1
$\ln ENU_t$	2.4021	1	−3.0188***	1
Intercept				
$\ln CO_{2t}$	−1.0618	1	−3.8068***	1
$\ln GDP_t$	−1.4086	1	−3.6197***	4
$\ln GDP_t^2$	−1.2998	1	−3.5643***	4
$\ln EPH_t$	0.3748	1	−4.1276***	1
$\ln ENU_t$	−0.6225	1	−3.6118***	2

***Indicate statistical significance at 5% and 1% levels, respectively. *k* is the lag length specified by Authors. *I*(0) represents level and *I*(1) represents 1st difference

Table 2: Lag Length selection criteria

Lag combination	SIC	F-statistic	P value
(2,2,2,2,2)	−3.8517	3.9082	0.0142
(2,2,2,2,1)	−3.9398	4.2228	0.0095
(2,2,2,2,0)	−3.9978	4.4807	0.0067
(2,2,2,1,0)	−4.0555	4.9575	0.0047
(2,2,2,0,0)	−3.8929	3.0533	0.0305
(2,2,1,1,0)	−3.9108	3.1568	0.0269
(2,2,0,1,0)	−3.8175	2.1806	0.0916
(2,1,2,1,0)	−3.9051	3.1118	0.0284
(2,0,2,1,0)	−3.8097	2.125	0.0987
(1,2,2,1,0)	−4.1068	4.8374**	0.0039
(1,0,0,0,0)	−4.0245	1.5395	0.2097

SIC: Schwarz information criteria, **indicates statistical significance at 5% level

4. RESULTS

Following the work of Pesaran et al. (2001), which assumes that the order of integration of the variables does not exceed the first difference *I*(1), the augmented Dickey Fuller test, a unit root test, is applied on the natural logarithms at the levels and first differences of the variables. Table 1 shows the estimated F-statistics resulting from contrasting the null hypothesis of non-stationarity against the alternative. As observed, the variables are all stationary at their first differences, signaling their first order of cointegration and allowing the application of the ARDL test.

The next step is to conduct the ARDL bound test for cointegration. In order to verify a long-run relationship between the considered variables i.e. cointegration, a two-step procedure must first be completed. In an attempt to avoid any classical assumption violation, the maximum lag length for each variable has been determined using the Bayesian information criterion minimization criteria[5]. Table 2 presents several of the combination sets of lags, including the selected one: (1, 2, 2, 1, 0).

Based on the chosen lag combination for the variables and the Wald Test, the cointegration test is calculated. Table 3 shows the estimated F-statistic of cointegration in Equation 3. Since the calculated value exceeds the upper bound of the critical values proposed by Narayan (2005), the null hypothesis is rejected: A cointegration relationship between CO_2 emissions, GDP, Energy use and Electricity production can be justified. Table 3 also shares the results of additional diagnostics tests applied in order to verify correct specification, such as Jarque-Bera normality Test, Breusch-Godfrey serial correlation LM test, ARCH test, Ramsey RESET Test and cumulative sum/-squared (CUSUM/CUSUMSQ) test.

5 Previous studies have given special attention to an adequate length specification, arguing that F-test results are "sensitive to the number of lags imposed" (Saboori and Sulaiman, 2013) and important to prevent biased results (Shahbaz et al., 2015).

Table 3: Cointegration tests results

Bounds testing to cointegration	
Estimated equation	$CO_2 = f\left(GDP_t, GDP_t^2, EPH_t, ENU_t\right)$
Optimal lag structure	(1,2,2,1,0)
F-Statistics	4.8374**
Diagnostic check	Probability
R^2	0.8908
Adjusted-R^2	0.8163
F-Statistics (P)	0.0000
J-B Normality test	0.6200
B-G LM test (2)	0.6770
ARCH test (2)	0.9943
Ramsey RESET	0.3347
CUSUM	Stable
CUSUMQ	Stable

**Indicates statistical significance at 5% level. The optimal LAG structure is determined by Schwarz criterion

Table 4: Long run estimates

Depend variable: $\ln CO_{2t}$			
Variable	Coefficient	Standard error	T-statistic
Constant	−21.7725	8.1906	−2.6582**
$\ln GDP_t$	3.7121	2.0147	1.8424*
$\ln GDP_t^2$	−0.2406	0.1242	−1.9359*
$\ln EPH_t$	−0.2639	0.1312	−2.0107***
$\ln ENU_t$	1.3319	0.1916	6.9494***
Diagnostic checks			
R-squared	0.99779		
AIK	−4.3613		
SIC	−4.108		
F-statistic	301.3392		
B-G LM test (2)	0.3937		
ARCH test (2)	0.1397		
J-B normality test	0.0395		
Ramsey RESET	0.5223		

*,**,***Indicate statistical significance at 10%, 5% and 1% levels, respectively. AIK: Akaike information criterion, SIC: Schwarz information criteria

The long run estimation is reported in Table 4. The results are consistent with the expected signs of the study. The linear term of GDP is positive and the non-linear term negative, which proves the existence of the inverted-U relationship between economic growth and CO_2 emissions. Both terms are highly significant at a 95% confidence level. A 1% rise in the GDP per capita will increase CO_2 emissions by 3.77%, ceteris paribus.

The coefficient of energy use is positive and statistically significant, indicating the contribution of this variable to the environmental degradation in the long run. A rise of 1% in the Energy use in Brazil leads to around 1.33% in per capita CO_2 emissions.

The long run elasticity of CO_2 emissions with Electricity production from hydroelectric sources is −0.26%, indicating that an increase of 1% in per capita electricity production based on hydroelectric sources, means a decrease in the CO_2 emissions.

The evidence confirms that, in the long run, CO_2 emissions increase along with economic growth up to a turning point at which emissions start to decline. This result is consistent with various studies that examine such relationship (Dogan, 2015; Shahbaz et al., 2015).

The short run model is presented in Table 5. In this case, the EKC hypothesis is not verified. The GDP is statistically non-significant for the model. For the variables Energy use and Electricity production from hydroelectric sources, the signs are positive and negative respectively - As in the long-run model. A rise in 1% in Energy use increases the dependent variable in 0.84%, considering a 1% level of significance. On the other hand, a 1% increase in Electricity production from hydroelectric sources will reduce CO_2 emissions by 0.63%. The short run results are consistent with other studies that do not hold the EKC in the short-run model but do verify the hypothesis in the long run (Saboori and Sulaiman, 2013).

Table 5: Short run estimates

Dependent variable: Delta lnCO_{2t}			
Variable	**Coefficient**	**Standard error**	**T-statistic**
Constant	−0.0079	0.0051	−1.5291
$\Delta\ln GDP_t$	−9.6108	9.9780	−0.9632
$\Delta\ln GDP_t$	0.5851	0.6028	0.9706
$\Delta\ln EPH_t$	−0.6308	0.2409	−2.6168**
$\Delta\ln ENU_t$	0.8464	0.2591	3.2667***
ECT_{t-1}	−0.1650	0.0843	−1.9578*
Diagnostic checks	Probability		
R^2	0.8002		
AIK	−4.4027		
SIC	−3.8856		
F-statistic	9.4668		
B-G LM test (2)	0.2978		
ARCH test (2)	0.3310		
J-B normality test	0.9427		
Ramsey RESET	0.5801		

*,**,***Indicate statistical significance at 10%, 5% and 1% levels, respectively.
SIC: Schwarz information criteria, AIK: Akaike information criterion

The ECT is negative and statistically significant at 10%, and thus supports the cointegration of the variables included in the long run model (Pesaran et al., 2001). The properties of such ECT suggest that deviations from the mean in CO_2 emissions are corrected by 16.50% within a year.

The CUSUM and CUSUMSQ are employed to verify both the short run and long run stability of the coefficients. Figures 2 and 3 show that the estimated coefficients are stable within the 5% critical level. This stability suggests that the model presented can be used for policy decision purposes.

Table 6 shows the results of granger-causality tests. There exits unidirectional causality running from GDP to CO_2 emissions in the long run. These results are consistent with the EKC existence, and concur with the findings of Shahbaz et al. (2015), Nasir and Ur Rehman (2011) and Jalil and Mahmud (2009). On the other hand, the unidirectional causality is also found running from GDP to energy use. About this, many studies have verified their relationship (Erol and Yu 1987; Masih and Masih 1996; Hondroyiannis et al., 2002; Lee and Chang 2008).

5. CONCLUSIONS AND POLICY IMPLICATIONS

The EKC theory has been tested in the Brazilian economy. Based on data for the period 1971-2011, the results justify a long-run relationship i.e., cointegration among the considered variables:

Figure 2: Plot of cumulative sum of recursive residuals

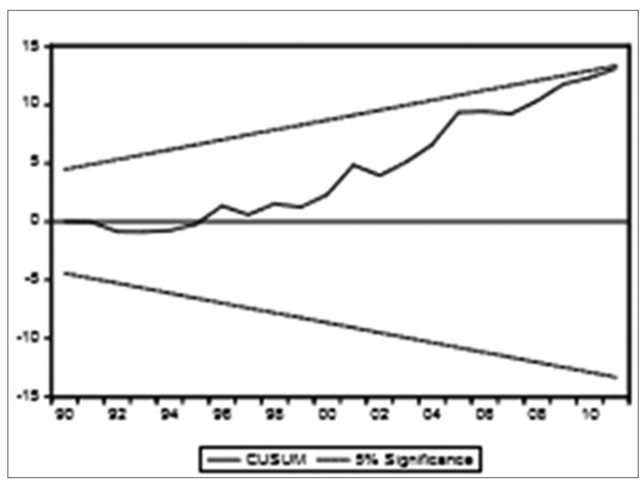
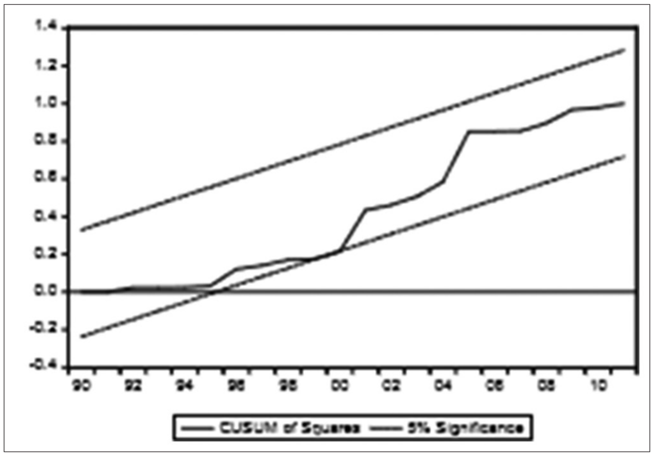


Table 6: Granger causality test results (short and long-run estimates)

Dependent variable	Short run					Long run
	$\Delta\ln CO_{2t}$	$\Delta\ln GDP_t$	$\Delta\ln GDP_t^2$	$\Delta\ln EPH_t$	$\Delta\ln ENU_t$	ECT_{t-1}
$\Delta\ln CO_{2t}$	-	12.3428***	7.4294**	3.2341*	22.3214**	-0.5523***
$\Delta\ln GDP_t$	0.2777	-	1.8412*	0.7623	1.0342	-
$\Delta\ln GDP_t^2$	0.3874	1.4523	-	1.0276	0.0823	-
$\Delta\ln EPH_t$	0.3429	0.7432	0.3421	-	1.0312	-
$\Delta\ln ENU_t$	0.2218	0.4928	0.1412	1.1197	-	−0.6721**

***,**,*Indicate statistical significance at 1%, 5% and 10% levels respectively

Figure 3: Plot of cumulative sum of squares of recursive residuals



CO_2 emissions, GDP per capita, Energy use and Electricity production from hydropower sources. Results suggest that CO_2 emissions increase as the economy grows, but eventually start decreasing once the per capita figure reaches a certain threshold. At the turning point, environmental degradation will decrease, as the country reaches certain level of development at which previous urgent issues such as inequality will have been overcome. No evidence for EKC in the short-run was obtained, suggesting that the considered variables must be actively watched upon and guided towards a long run performance that will in fact allow the EKC to unfold.

The tests yielded the estimation of coefficients whose signs have verified the expected long run relationship between such variable and environmental degradation measured by CO_2 emissions. In the long run, as the negative coefficient suggests, Electricity production from hydroelectric sources reduces the negative impact in the environment. The results are particularly important for Brazil, as it is highly vulnerable to climate change, for its rainforests take up a considerable portion of its territory, and its energy matrix is mostly fueled by renewable sources (hydropower), who's effective performance rely on the normal functioning of resources cycles.

The fact that the EKC theory states that in the long run, as Brazil grows, its negative impact on the environment would reduce, should not convince authorities to simply wait until the economy reaches the turning point. As the trajectory a country follows is designed by its resource administrators' short-run choices (He, 2007). The results shown by the Granger causality test reveal that the GDP per capita Granger causes CO_2 emissions in the long run; in other words, data about GDP yield predictive value to estimate CO_2 emissions. These results should render valuable info input for authorities. Despite the fact there is no evidence to justify a permanent positive relationship between economic growth and environmental degradation, by no means should it be interpreted as a result favoring the liberal conception of "economic growth."

Brazil's profile in terms of environmental performance, despite not being discouraging, might be frowned upon if one considers the rough figures of increasing CO_2 incidence in global figures. There are definitely additional measures to be considered or continue to be promoted, especially the diversification of the energetic mix and deforestation-mitigating policies. The understanding of the EKC theory calls upon careful revision of resource allocation today, in terms of finances destined to environmental-friendly projects. Furthering projects irrespective of environmental concerns (e.g., quality of energetic source, deforestation, GHGs emissions) might deviate Brazil from the path predicted by the EKC.

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