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Analysis of Causality between Economic Growth and Carbon Emissions: The Case of Mexico 1971-2011

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***Abstract*—**This paper analyzes the Environmental Kuznets Curve (EKC) hypothesis to test the causality relationship between economic activity, trade openness and carbon dioxide emissions in Mexico (1971-2011). The results achieved in this research show that there are three long-run relationships between production, trade openness, energy consumption and carbon dioxide emissions. The EKC hypothesis was not verified in this research. Indeed, it was found evidence of a short-term unidirectional causality from GDP and GDP squared to carbon dioxide emissions, from GDP, GDP squared and TO to EC, and bidirectional causality between TO and GDP. Finally, it was found evidence of long-term unidirectional causality from all variables to carbon emissions. These results suggest that a reduction in energy consumption, economic activity, or an increase in trade openness would reduce pollution.

***Keywords*—**Energy consumption, environmental Kuznets curve, economic growth, causality, co-integration.

I. Introduction

THIS paper analyzes the relationship between economic growth and carbon emissions. Importantly, world population increased from 4,400 to 6,000 million during 1980 to 2000, and it is expected to increase to 6,900 million in 2015 [39]. In addition, 6 out of 7 people could be classified as low and middle-income in the world. Consequently, population growth increases the demand for goods and services, as well as production, trade, the use of new technologies that in turn increase the demand for energy. However, some scholars have stressed the importance of analyzing energy consumption, production and international trade trends, and hence the relationships between these variables [24]. In this regard, trade liberalization in emerging economies allows importing advanced technologies from developed countries, which are more efficient and less intensive in energy consumption. In fact, energy can affect trade openness, given that energy is an important input in the production process, and it is required in machinery and equipment. In addition, imports and exports of manufactured goods and raw materials require energy for transportation. Importantly, if energy plays an important role to explain the flows of trade, then energy conservation policy aiming to reduce consumption may negatively affect the flows of trade [24]. On the other hand, the relationship between economic growth and environmental pollution (or degradation) has been one of the most important hypotheses empirically tested in the literature of ecological economics during the last decades. The importance of this relationship is evident since it is recognized that emissions of carbon dioxide is the main factor affecting global warming [23]. In fact, this paper analyzes the relationship between economic growth and environmental degradation through the EKC hypothesis, as well as the causal link that can be established between economic activity, energy, trade openness and emissions of carbon dioxide in Mexico from 1971 to 2011.

In addition to this introduction, the paper is organized into six sections. Section II reviews the most relevant literature on environmental degradation and pollution. Section III shows an econometric model to test the EKC hypothesis in the case of Mexico. Section IV discusses the results achieved in this research. Finally, Section V presents some conclusions.

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II. Literature Review

The EKC hypothesis establishes that there is a U-inverted relationship between pollution and per-capita income [10]. The amount and intensity of environmental degradation is restricted to the level of subsistence of economic activity with low levels of economic development. However, when economic development accelerates (e.g. agriculture development, resources exploitation and other industrial activities), the rates of resource depletion exceeds the rate of resource recovery, and thus waste generation increases in quantity and toxicity. In the same way, when higher levels of economic development appear (e.g. information-intensive and services industries development with more environmental spending), the application of environmental regulations and the use of more efficient technologies are favoured in order to gradually reduce environmental degradation [28]. In this regard, in the initial stages of economic development, the environmental pressures increase faster than income [10]. In this regard, in the first stage of industrialization, faster economic growth may cause an intensive use of natural resources and pollution emissions that negatively impact environmental conditions. In this stage, people are so poor to pay for pollution with significant consequences on the environment. After the industrialization stage, per-capita income increase and thus people are more willing to appraise environment conditions that in turn makes regulatory institutions more effective and pollution levels decrease [10].

The EKC hypothesis suggests that during the early stages of economic development with low income levels, there is a positive relationship between income and environmental degradation in a country. This process continues until the country reaches a higher level of economic development, and thus the relationship between the two variables becomes negative [1]. Therefore, the EKC hypothesis suggests that [10]:

$$y_t = \beta_1 + \beta_2 x_t + \beta_3 x_t^2 + \beta_4 x_t^3 + \beta_5 z_t + e_t \quad (1)$$

where y_t is an indicator of environmental degradation, x_t means the level of income, and z_t are other variables that influence the environment. From (1), it can be tested various forms of relationships between environmental conditions and economic growth [10]:

1. $\beta_2 = \beta_3 = \beta_4 = 0$, there is not relationship between x_t y y_t.
2. $\beta_2 > 0 \; y \; \beta_3 = \beta_4 = 0$, there is a lineal or an increasing monotonic relationship between x and y_t.
3. $\beta_2 < 0 \; y \; \beta_3 = \beta_4 = 0$, there is a decreasing monotonic relationship between x_t and y_t.
4. $\beta_2 > 0, \beta_3 < 0 \; y \; \beta_4 = 0$, there is U-inverted relationship between x_t and y_t.
5. $\beta_2 < 0, \beta_3 > 0 \; y \; \beta_4 = 0$, there is a decreasing monotonic relationship between x_t and y_t.
6. $\beta_2 > 0, \beta_3 < 0 \; y \; \beta_4 > 0$, there is an N-shape relationship between x_t and y_t.
7. $\beta_2 < 0 \; y \; \beta_3 > 0 \; y \; \beta_4 < 0$, there is an N-inverted relationship between x_t and y_t.

The EKC hypothesis is tested when the number 4 is satisfied ($x^* = -\frac{\beta_1}{2\beta_2}$). The EKC hypothesis states that the emission of carbon dioxide in a country is a function of its income with a unidirectional causality from income to carbon dioxide emissions [4].

The acceptance of EKC hypothesis has important policy implications: (i) Environmental degradation can be observed when economic development accelerates, especially during the process of industrialization, and (ii) When the level of income per capita increases in a country, economic growth becomes a friendly environmental process [28]. However, economic growth in emerging economies seems to be a powerful engine that improves environmental quality, and thus public policies (e.g. trade, macroeconomic, social, and so forth) should stimulate economic growth [27]. Consequently, the political implication of the EKC hypothesis suggests that the promotion of economic growth is a sufficient criterion for safeguarding the environment [10]. Moreover, it seems that in the long run, the best way to improve environment conditions is to become a developed country [5]. On the other hand, the impact of trade openness on the environment conditions is analyzed through three different channels: (i) The scale effect that states how trade openness increases market size, production, and therefore emissions, (ii) The technical effect that refers to the importance of technology on more efficient and friendly environment conditions, and (iii) The composition effect that states how trade openness can reduce or increase emissions, depending on whether the country has developed a comparative advantage in clean or dirty industries [3]. However, in the latter case, the ultimate impact is ambiguous because it depends on how the stronger impact dominates the other.

The very first paper on the U-inverted relationship hypothesis tested the relationship between environmental degradation and economic development along with policy implications on employment, technology transfer and development assistance [28]. Using cross-sectional data, the results in this research supported the U-inverted hypothesis for a sample of developed and developing countries. The results achieved here were called the EKC because of its similarity to the relationship between inequality and development. Since then there have been many empirical works in relation to the EKC hypothesis [12]-[14], [20], [25], [26], [29], [31]-[35]. while the studies that do not show evidence in favor of the EKC hypothesis are [6], [16], [27], [36], [38]. In this sense, in a more comprehensive analysis, 70% of the papers reviewed in a research show evidence of the EKC hypothesis [1]. Other studies analyze the causal relationship between economic growth and carbon dioxide emissions without finding conclusive results on this relationship [2], [7], [8], [37], [40]. Also, in the analysis of the relationship between economic growth and carbon dioxide emissions, some analyses have included additional economic variables to avoid omitted variable problems, such as energy, capital, labor, exports, imports, trade openness, foreign direct investment (FDI), and so forth [1], [4]. However, in the case of Mexico, the results achieved in this country are mixed. For example, there is a study that analyzes the influence of corruption on the level of income and the EKC hypothesis for sulfur with a panel data of 94 countries (including Mexico) during 1980-2000 [19]. These results show that the EKC hypothesis is true for sulphur and the corruption coefficient is a statistically negative determinant of income. Other works investigate the EKC hypothesis for 43 developing countries (including Mexico) based on the short-term and long-term income elasticity [23]. If the long-term income elasticity is less than the short-term income elasticity, there is evidence of reduced emissions of carbon dioxide when income increases at country level. These results show evidence that in the long-term carbon dioxide emission has fallen for about 35% of countries in the sample (including Mexico). In this regard, a regional panel data sample demonstrated evidence only for a group of countries in the Middle East and South Asia.

Other researches examine the long-term and short-term relationship between economic growth, energy consumption, population density, trade openness, and carbon dioxide emissions in the case of Brazil, China, Egypt, Japan, Mexico, Nigeria, South Korea and South Africa [24]. The results show that the U-inverted hypothesis holds in the case of Japan and South Korea, while in the other six countries the long-term relationship between carbon dioxide emissions and economic growth follows a N-shape path. Finally, the effect of economic growth, consumption of renewable energy and financial development on CO_2 emissions was analyzed in the case of Latin America and the Caribbean countries during the period of 1980-2010 (including Mexico) [1]. Using panel data methods, the results demonstrate the existence of a U-inverted relationship between CO_2 and GDP, accepting the EKC hypothesis in the case of these countries.

III. Econometric Model

Following the empirical literature on the EKC hypothesis, carbon dioxide emissions per capita (CO) depends on energy consumption per capita (EC), Gross Domestic Product (GDP) per capita, GDP squared per capita, and trade openness (TO) in this research:

$$CO_t = \beta_1 + \beta_2 CE_t + \beta_3 PIB_t + \beta_4 PIB_t^2 + \beta_5 TO_t + e_t \qquad (2)$$

It is important to know the integration order and test for co-integration between the variables in a time series model in order to avoid spurious results. The tests applied to these series were the Augmented Dickey-Fuller (ADF) test [9], the Phillips-Perron (PP) test [31], the Lagrange Multiplier (LM) test [18], [19] and the Residual Augmented Least Squares (RALS)-LM test [21] in the case of one or two structural breaks.

To test whether there is a co-integration relationship or a long-term equilibrium between the variables, the Autoregressive Distributed Lag (ARDL) was used [30]. This method allows testing co-integration independently of whether the regressors are integrated of order one I(1) or order zero I(0), or mutually co-integrated. It provides two sets of critical values, one when all regressors are integrated of order zero, and other when all regressors are integrated of order one. It is important to mention that these critical values are not valid for variables of order two I(2). The test involves estimating an unrestricted error correction model:

$$\Delta CO_t = \alpha_1 + \sum_{i=1}^{m}\alpha_{2i}\Delta CO_{t-i} + \sum_{i=1}^{m}\alpha_{3i}\Delta EC_{t-i} + \sum_{i=1}^{m}\alpha_{4i}\Delta PIB_{t-i} + \sum_{i=1}^{m}\alpha_{5i}\Delta PIB_{t-i}^2 + \sum_{i=1}^{m}\alpha_{6i}\Delta TO_{t-i} + \beta_1 CO_{t-1} + \beta_2 EC_{t-1} + \beta_3 PIB_{t-1} + \beta_4 PIB_{t-1}^2 + \beta_5 TO_{t-1} + e_t \qquad (3)$$

where Δ is the first differential and e_t is an error term.

The Akaike Information Criterion (AIC) is applied to determine the size of the lag of the variables in first differentials. This procedure is based on the F-statistic to test the hypothesis of no co-integration, $H_0 : \beta_s = 0$, against the alternative hypothesis, $H_1 : \beta_s \neq 0$, $s = 1,..,5$. If the value of the F-statistic is located outside the critical values, the hypothesis can be accepted or rejected without knowing the order of integration. However, the null hypothesis is rejected if it is located above the critical values and accepted if it is located below them. In this regard, it is important to know the integration order of the series if the F-statistic falls between the upper and lower critical values. Some authors argue that the critical values in this test are based on large-size samples and it should not be used for small samples [22]. To solve this problem, these authors have proposed critical values for data sets between 30 and 80 observations that are used in this research.

IV. Results

Data of GDP per capita (constant dollars of 2005), energy consumption per capita (measured in kilograms of oil equivalent), carbon dioxide emissions per capita (metric tons), openness (ratio of exports plus imports between GDP) were used in this model [39]. All variables are expressed in natural logarithms. In order to know the integration order, unit root tests were applied to these variables. Table I shows the results of the DFA test, and PP test. The null hypothesis of unit root could not be rejected for all variables in levels, and thus they are stationary in first differences at 1% level of significance. However, the presence of structural breaks not taken into account in the econometric model may produce erroneous results. In this sense, the LM test and LM-RALS test for one and two structural breaks were applied. Table II shows the results from applying the LM test with one structural break. The results show evidence that all variables have unit root in levels, except the EC that is stationary. In the case of the RALS-LM test, the CO and TO are stationary in levels.

TABLE I
UNIT ROOT TEST WITHOUT STRUCTURAL BREAKS

Variable	Deterministic Parameters	ADF Test	PP Test
CO	CT	-2.40	-2.37
EC	CT	-2.97	-2.85
GDP	CT	-2.83	-2.82
GDP squared	CT	-2.83	-2.82
TO	CT	-1.69	-1.93
First difference			
ΔCO	C	-7.02*	-6.97*
ΔEC	C	-4.43*	-4.47*
ΔGDP	C	-4.65*	-4.65*
ΔGDP squared	C	-4.65*	-4.65*
ΔTO	C	-4.53*	-4.45*

Note: * denotes significance at the 1% level. C is a constant and CT is constant and trend.

TABLE II
UNIT ROOT TEST WITH ONE STRUCTURAL BREAK

Variable	Model	LM Statistic and Break	RALS-LM Statistic and Break
CO	C	-3.96 (1982)	-4.09 (1989)**
EC	C	-4.37 (1984)***	-2.11 (1982)
GDP	C	-3.25 (1985)	-2.23 (1982)
GDP squared	C	-3.59 (1986)	-2.53 (1982)
TO	C	-3.08 (1992)	-3.43 (1986)***
First difference			
ΔCO	A	-7.70 (1980)*	-7.70 (1980)*
ΔEC	A	-5.87 (1982)*	-5.87 (1982)*
ΔGDP	A	-5.76 (1982)*	-5.76 (1982)*
ΔGDP squared	A	-5.89 (1982)*	-5.89 (1982)*
ΔTO	A	-5.16 (1987)*	-5.17 (1987)*

Note: *, ** and *** denote rejection of the null hypothesis at the 1%, 5% and 10% levels, respectively. The critical values for LM and RALS-LM tests are obtained from [19], and [21], respectively.

The two tests demonstrate that all variables are stationary in first differences at 1% level of significance. Applying the LM test, all variables are stationary with two structural breaks, except CO, while for RALS-LM test all variables are stationary (Table III). All variables are stationary in first differences. This shows inconclusive results, and evidence that the variables are of a different order of integration and the traditional co-integration tests [11], [17] could not be applied. An alternative is the suggested by [30], which has the advantage that it allows testing whether the regressors are integrated of one order I(1), zero order I(0) or mutually co-integrated.

TABLE III
UNIT ROOT TEST WITH TWO STRUCTURAL BREAKS

Variable	Model	LM Statistic and Break	RALS-LM Statistic and Break
CO	C	-4.98 (1979/1995)	-4.47 (1981/1989)*
EC	C	-6.67 (1984/2003)*	-5.86 (1981/1988)*
GDP	C	-5.22 (1984/1998)***	-3.85 (1980/1989)*
GDP squared	C	-5.14 (1984/1998)***	-3.25 (1982/1999)***
TO	C	-5.85 (1983/1995)***	-5.92 (1986/1999)*
First difference			
ΔCO	A	-7.72 (1980/1992)*	
ΔEC	A	-6.06 (1980/1992)*	
ΔGDP	A	-5.98 (1982/1996)*	
ΔGDP squared	A	-6.08 (1982/1996)*	
ΔTO	A	-5.83 (1979/1987)*	

Note: *, ** and *** denote rejection of the null hypothesis at the 1%, 5% and 10% levels, respectively. The critical values for LM and RALS-LM tests are obtained from [18], and [21], respectively.

Table IV shows the results of ARDL models. The dummy variables to improve the specification model were included. The dummy variables take values of 1 for the year indicated and 0 otherwise: d73 (1973); d78 (1978); d82-83 (1982 y 1983); d83 (1983); d86 (1986); d90 (1990); d95 (1995); d99 (1999); d09 (2009). Accordingly, the results of the F-statistic show evidence of three long-term relationships between CO, EC, GDP, GDP squared and TO in the case of Mexico at 5% level of significance with TO and CO as dependent variables, and at 1% level of significance with EC as a dependent variable.

TABLE IV
THE RESULTS OF ARDL CO-INTEGRATION TEST

Estimated Models	F-Statistics
F(CO|EC,GDP,GDP squared,TO,d89,d95)	4.89**
F(EC|CO,GDP,GDP squared,TO)	7.27*
F(GDP squared|EC,CO,GDP,TO,d95,d09)	0.44
F(GDP|EC,CO,GDP squared,TO,d86,d95)	0.98
F(TO|EC,CO,GDP,GDP squared,d82)	5.70**

Note: * and ** denote rejection of the null hypothesis at the 1%, 5% and 10% levels, respectively. The critical values (CV) for the lower I(0) and upper I(1) bounds are taken from [22].

According to Table V, the long-run elasticity of the EC with respect to CO is positive at 1% level of significant as expected. This means that an increase in energy consumption also increases carbon emissions. However, the EKC hypothesis was not supported by the results, since $\beta_3 < 0$ and $\beta_4 > 0$. Actually, the results achieved in this model were contrary to the expected signs that would be implying a monotonically decreasing relationship between CO and GDP [10]. Meanwhile $\beta_5 < 0$ and at 5% level of significant, which means that trade openness contributes to the reduction of pollutant emissions.

TABLE V
COEFFICIENTS ESTIMATED

Regressors	Long-term elasticity
EC	0.60 (4.31)*
GDP	-5.38 (-2.42)**
GDP squared	0.11 (2.67)**
TO	-0.09 (-2.50)**
Constant	60.71 (2.06)**
Trend	-0.01 (-4.37)*
D86	0.04 (3.79)*
D89	0.17 (12.78)*
Diagnostic test	
JB Normal	0.85 [0.65]
LM test	2.77 [0.24]
White test	10.63 [0.15]
Ramsey test	0.97 [0.33]

Note: * y ** denote statistical significance at the 1 and 5 per cent levels, respectively. The values in () are t-ratios and in [] are p-values.

It is important to mention that the analysis of co-integration in this research determine the existence of a long-term relationship between these variables, but does not prove the direction of causality between them. Some authors suggest that when these variables are co-integrated, there must be a causal link in at least one direction, and the VEC (Vector Error Correction) must be estimated instead of a VAR for Granger causality test, since the latter would be wrong specified and may lead to incorrect conclusions of causality [15]. Accordingly, Table VI shows evidence of causality of GDP and GDP squared to CO in the short term at 5% level of significance. In the sense, economic activity has important information that help predict the behavior of CO. As expected, there is also a causality relationship from GDP, GDP Squared and TO to EC at 1% significance level which means that trade openness and economic activity boost energy consumption.

TABLE VI
GRANGER CAUSALITY TEST RESULTS

Variable	ΔCO	ΔEC	ΔGDP	ΔGDP Squared	ΔTO
ΔCO	-	0.11	0.29	0.23	0.88
ΔEC	0.01	-	0.07	0.00	0.04
ΔGDP	4.23**	8.94*	-	9.84*	4.86*
ΔGDP squared	4.46**	8.53*	9.35*	-	5.00**
ΔTO	0.34	5.57*	3.43*	2.77***	_
ECT-1	-0.90**	0.43	0.25	15.17	0.57
Dummy	D89,D95	D83,D95	D95	D95,D09	D82,D09
Diag. tests					
JB Normal	1.94	0.63	1.58	0.21	0.77
LM test	3.88	5.47	0.87	3.68	3.11
White test	11.30	5.08	3.67	5.33	7.43
Ramsey test	0.12	0.00	0.61	1.05	0.12

Note: *, ** and *** denote significance at the 1%, 5% and 10% levels, respectively. ECT-1 denotes the estimated coefficient of the lagged error correction term.

Finally, there is a bidirectional causality between TO and GDP at 5% level of significance which means that trade liberalization affects economic activity, and the latter variable contains information that helps predict the former. These results support the conservation hypothesis stating that economic growth causes energy consumption, and energy conservation policies have little or no impact at all on growth. In the long term, there is evidence of unidirectional causality from EC, GDP, GDP squared and TO to CO at 5% level of significance, meaning that these variables contains information contributing to predict carbon emissions.

V. CONCLUSION

It is expected that the demand for goods and services, production, trade and technological development increase when population rises that in turn they increase the demand for energy. In addition, the relationship between economic growth and environmental pollution (or degradation) is one of the most important hypotheses empirically tested in ecological economics during the last decade. This article analyzes the relationship between economic growth and environmental degradation through testing the EKC hypothesis, as well as the causal relationship established between economic activity, energy, trade openness and emissions of carbon dioxide in Mexico from 1971 to 2011. Unit root, co-integration and causality tests were used. The results show evidence that the variables are of a different order of integration, and most of them are stationary incorporating structural breaks. The evidence suggests that there are three long-term relationships between CO, EC, GDP, GDP squared and TO at 5% level of significance. The EKC hypothesis was not supported by the results achieved in this research since there is a monotonically decreasing relationship between CO and GDP. In the short term, there is evidence of causality in following cases: (i) unidirectional from GDP and GDP squared to CO, (ii) from GDP, GDP squared and TO to EC, and (iii) bidirectional between the TO and the GDP. Consequently, these results support the conservation hypothesis where economic growth cause to energy consumption. In the long run, there is evidence of unidirectional causality meaning that a reduction in energy consumption in economic activity (or trade openness) will reduce emissions. Therefore, in terms of the implications for energy policy to reduce energy consumption without affecting production, it should be explored other energy policies related to reducing energy intensity, promote the generation and consumption of cleaner energy.

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