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ANALYSIS OF THE RELATIONSHIP BETWEEN CO2 EMISSIONS GROWTH AND ECONOMIC GROWTH

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ABSTRACT

This paper has analysed the contribution of economic growth on CO2 emissions. Economic development is a multifactorial concept where many variables are involved, and studying the effect of the whole on the increase in emissions presents a scientific challenge. For the analysis, Ecuador has been taken as the object of study, because it is a country which has experienced notable variations in economic indicators between 1970 and 2014. During this period, GDP per capita, index of economic freedom and national production of barrels of oil have been analyzed. Multivariate models have been tested where the influence of each economic variable and the overall effect on emission as a whole are detected. It has been proven that linear models applied by other researchers do not fit adequately in developing countries, where asymptotic growth is evident.

Keywords: Economic growth, Economic development, Income distribution, Environmental economics, Environmental impact assessment.
JEL Classification: F43, O01, O15, Q05, Q51

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INTRODUCTION

Urteaga (2009) states that the term sustainable development, despite having multiple interpretations, is omnipresent in the thinking and actions of the actors involved in environmental and development activity. We can affirm that sustainable development according to Brundtland's (1987) criterion requires a production system that presents the idea of preserving the environment. Despite this, Bermejo (2014) exposes the misuse that States give to the term sustainable development, defending unlimited growth, proposing strategies for economic growth, leaving aside the conservation of social, natural and diverse life. Beckerman (1972) describes that although economic growth generates a deterioration in the environment in the initial stage, in the long term it is reasonable that countries should enrich themselves in order to have adequate environmental policies. This idea that keeps increasing in the direction of environmental protection has been developed by the neoclassicists since 1970, until reaching the studies of Grossman and Krueger (1993, 1995) which, with an empirical basis, establish a correlation between economic growth and environmental evolutions, stating that polluting emissions increase with the increase in per capita income, before decreasing.

These theories are similar to Kuznets' hypothesis (1955) of the Environmental Curve, when exploring the relationship between economic growth and environmental quality, which attempts to establish two stages: a short-term stage where economic growth promotes greater environmental deterioration, and a long-term stage, where it states that as economies have higher incomes, and their economic growth benefits the environment, establishing the idea that the quality of the environment improves with the increase in income. This evidence is supported by findings in developed countries (Correa et al., 2005).

According with the stated ideas, this study aims to establish whether variables such as per capita income, population density, economic freedom and national production of barrels of oil generate an impact on the environment. Understanding the use of existing multiple regression of forecasting variables and response variables. This empirical analysis seeks to present new contributions to the existing dilemma between economic growth and the environment in the case of Ecuador, for the benefit of its economic and environmental policy, and to establish the degree of influence of independent variables on the degree of pollution registered in our country.

The research design embodied in the document seeks to characterize the relationship between economic growth and environmental degradation under the theory of sustainable development through the review of literature by authors who have developed similar studies, and then establish the methodological framework that encompasses the development of the empirical study. Subsequently, the results of the research will be presented with the presentation of the multiple regression model that evidences the identification of the explanatory variables of economic growth and their interaction with the emission of carbon dioxide.

The conclusions contain the analysis of the environment in which the results of the research were developed. The reference contains a list of the scientific works cited in this document, which have been used to outline the study and its results.

LITERATURE REVIEW

Brundtland (1987) brings together social, economic and sustainability dimensions by defining the concept of sustainable development as development that meets current needs without compromising the ability of future generations to provide for self-sufficiency. It is this term which, despite not presenting a defined identity, is part of the international lexicon and accepted by governments, international organizations, businessmen and society (Bermejo, 2014).

Mainly because the adverse effects generated on the environment are due to economic activities such as agriculture and industry, and energy consumption. There is therefore a relationship between environmental pollution and economic growth and population density; understanding that when per capita income increases, the higher the level of consumption of raw materials and energy, and with the high population rate, greater amounts of waste are generated (Falconí et al., 2016).

Urteaga (2009) describes that, within the economic theories of sustainable development, the optimistic current since the environmental economics of the neoclassics in 1970 promotes the idea of necessary and sufficient growth, understanding that continuous growth presents in its long term a correlation with environmental protection, authors such as Barnett (1979) promote this idea and even manifest the idea as general and that it can be used by "poor" countries.

Medina and Ayaviri (2017) state that this thinking lays its foundations in relation to the research of the fifties where economic growth and inequality in the distribution of income were studied (Ahluwalia, 1976; Alesina & Rodrik, 1994; Barro, 2000; Galindo, 2002; Álvarez, 2007; Núñez, 2016), mainly with the contribution of Kuznets (1955), who understands according to Araujo and Cabral (2015) that economic growth is far from being the only and most accurate measure of well-being; in one of his investigations on the relationship between economic growth (measured by GDP per capita[5]) and income distribution; It is postulated that these variables have an inverted U-shaped relationship. This is understood as the increase in income in the long term generates less inequality (Correa et al., 2005).

This hypothesis, together with Malenbaum's theoretical framework (1978) on the intensity of use, relates the income and demand for materials to an inverted u-shape; They promoted new research approaches, leading neoliberal economists such as Beckerman (1972) and Barnett (1979) to promote an existing relationship between economic growth and environmental quality by relating these variables in the form of an inverted u.

The empirical contribution of Grossman and Krueger (1993) in which per capita income was correlated with measures of air and water pollution, in these documents these authors express that polluting emissions increase with the increase in per capita income, before decreasing.

There is an extensive study carried out to establish the relationship between economic growth and environmental deterioration, understanding this as empirical evidence with models that adapt to the variables recorded by the various authors.

Grossman and Krueger (1992) set their research in Mexico, establishing a relationship between the North American Free Trade Agreement (NAFTA) and the level of pollution under the hypothesis that the reduction in trade barriers affects the environment, expanding the scale of economic activity, altering the composition of its activity, and causing a change in production techniques. They used comparable measures of SO2 and smoke with GDP per capita in a representative sample of urban areas located in 42 countries.

Panayotou (1993) argues that environmental degradation and economic growth are subject to change due to the use of policies such as energy and agrochemical subsidies, industry protection, and undervaluation of natural resources; the author adds that developed countries can contribute to lowering the Kuznets inclination in developing countries by creating mechanisms such as the United Nations Global Environment Facility.

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[5] Also known as per capita income is an economic indicator that measures the relationship between a country's income level and its population

Selden and Song (1994) corroborated the relationship between pollution and economic development from other studies by evaluating emissions of four major air pollutants, particulate matter, sulfur dioxide, nitrogen oxides, and carbon monoxide from a multi-nation panel database.

Holtz-Eakin and Selden (1995) using global panel data examined the relationship between GDP per capita and CO2 emissions, establishing that there is a decrease in the Marginal Propensity to Emit – MPE CO2 as economic development increases; Despite establishing this assumption, the author mentions that over the years CO2 emissions will remain at 1.8% per year, a value that does not correspond to the average GDP growth, due to the inference created by the countries with lower PEM but which present a notable increase in their GDP and population.

Stern (1996) discusses how the relationship between environmental degradation and per capita income has been used to implicate economic growth in the eventual correction of the environmental impacts of the early stages of economic development. Stern et al. (1996) generated a critique of the relationship between environmental degradation and per capita income, arguing that the concept depends on an economic model in which there is no commentary on environmental quality or production possibilities, and that trading has a neutral effect on environmental degradation; in addition, it generated an econometric model with World Bank – WB forecasts to 2025 establishing that SO2 emissions will continue to increase and that forest loss stabilizes before the end of the period, but tropical deforestation will continue at a steady rate.

Ekins (1997) econometrically evaluates the relationship between certain indicators of environmental quality and income and shows a poor relationship presenting a monotonously increasing relationship; he concludes, from the point of view of environmental sustainability, that the relationship between income and the environment remains problematic and merits an environmental policy that links future income growth with sustainable development.

Moomaw and Unruh (1997) compared two models of the relationship between environmental quality and economic growth among sixteen industrial countries evaluated. He stablished that CO2 emissions do not decrease with higher income and even less with the existence of a tipping point, decreasing CO2 emissions do not correlate with income levels but with time, understanding that this reacts to external shocks.

Stokey (1998) outlines a theoretical model with a relationship between per capita income and environmental quality, showing that tax and quota schemes have an advantage over direct regulation because they provide the right incentives for capital accumulation. Jaeger and College (1998) described that environmental damage will first increase and then fall with increasing incomes; The author explains that, in most natural environments, two distinct types of services, one rival or private and one non-rival or public, create a fundamental asymmetry in value aggregation.

Bruyn et al. (1998) investigated the empirical basis of the relationship between economic growth and the environment, establishing as a first hypothesis that the relationship between revenues and emissions estimated from the panel data does not have to be valid for specific countries over time, for the analysis CO2 is used as a variable. NOX and SO2 in four republics: the Netherlands, the United Kingdom, the United States and West Germany; finding that the timing patterns of these emissions are positively correlated with economic growth and that emissions reductions may have been achieved as a result of structural and technological changes in the economy.

Bradford et al. (2000) reported the use of other models or specifications on the basis established by the study by Grossman and Krueger (1995); the new specifications made it possible to generate conclusions for the estimation of fixed effects in the analysis of some polluting variables.

Cavlovic et al. (2000) evaluated 25 studies using meta-analysis[6], obtaining 121 observations for empirical study; these demonstrate that methodological choices can significantly influence outcomes. Heil and Selden (2001) established the historical relationship between carbon emissions and GDP, adding to the study a GDP and population projection model that establishes the emissions horizon, adding the oil price variable.

Friedl and Getzner (2003) explored the relationship between economic development and CO2 emissions in the case of a small, open, industrialized country such as Austria; the authors find a cubic N-shaped relationship with a structural breakdown in the mid-1970s justified by the price of oil.

Soytas et al. (2007) assess the causal relationship between income, energy consumption, carbon emissions, labor, and gross fixed capital formation from data obtained by the United States; research shows that income does not, in Granger's terms (1969), cause carbon emissions in the long run, but rather energy use does, stating that income growth cannot become a solution to environmental problems.

Sheldon (2007) reevaluates the estimation and analysis developed by Holtz-Eakin and Selden (1995) and adds about 20 years and 45 countries to the sample; the author validates the aforementioned research and states that the predictions are higher than the original estimation. Huang et al. (2008) analyzed the energy consumption and GDP of 82 countries, data provided by the World Bank, which were evaluated through a GMM[7] approach for the estimation of panel data by the VAR[8] model; the authors state that there is no causal relationship between energy consumption and economic growth, middle-income countries suggest energy consumption positively, high-income countries generate energy consumption with a negative trend.

He and Richard (2010) evaluate the inverse relationship between economic growth and the environment stating that fully parametric quadratic or cubic regression models traditionally used for analysis are not incorrect, but this approach lacks flexibility as it may not detect the true form of the relationship, for the analysis the authors used nonlinear parametric modeling methods, semi-parametric for validating hypothesis.

Dinda (2004) develops an application of growth theory to provide a theoretical explanation of the inverse relationship of economic growth and the environment by using the envelope theorem, understanding that, in a process of economic development, technology first diffuses, then becomes regulated, and finally is eliminated by another new technology.

Nasir and Ur Rehman (2011) use Johansen's cointegration method (1988) to investigate the relationship between Pakistan's carbon emissions, income, energy consumption, and international trade; The authors find that there is a long-term quadratic relationship between carbon emissions and revenues. Goldman (2012) uses meta-analysis to better understand the specific factors affecting the relationship between economic growth and environmental quality, using panel data and global data; the author states that there is no statistically significant evidence indicating an increase or decrease in the probability of encountering a Kuznets curve.

[6] A set of statistical tools, which are useful for synthesizing data from a collection of studies.

[7] A generic econometric technique for estimating parameters of a regression equation, developed as an extension of the method of moments.

[8] Autoregressive Vector Model, a model of simultaneous equations formed by a system of equations of reduced form without constraint.

Fosten et al. (2012) use the nonlinear threshold cointegration methodology[9] and a VEC[10] model for the case of the United Kingdom; the authors show that there is no inverse relationship between CO2 per capita, SO2 emissions and GDP.

Ahmed et al. (2014) summarize the literature review by stating that the Kuznets Environmental Curve hypothesis has been used in empirical studies and in various statistical tests it has been applied to panel data and time series. Techniques used with groups of countries, and individual countries.

METODOLOGY

This research is framed in a type of inductive reasoning with the application of econometric tests to measure the contribution of socioeconomic growth variables in environmental pollution, manifested in CO2 and CO2 emissions per capita.

For the analysis, a time series database of annual frequency was used with an evaluation period from 1970 to 2014 of the homologated variables CO2, CO2 per capita, GDP per capita, index of economic freedom[11] and the National Production of Barrels of Oil, whose base was obtained from the Central Bank of Ecuador – ECB and the World Bank – WB. The methodological proposal of the research is a multiple regression model that establishes the partial regression coefficients that which demonstrate the contribution of the independent variables.

For the analysis, economic growth has been divided into the stages that Ecuador has experienced.

To measure the contribution of economic growth to Ecuador's environmental deterioration, two functions were carried out in which the GDP per capita, the index of economic freedom and the National Production of Oil Barrels were taken as independent variables; while, as a dependent variable of the first function, CO2 and CO2 per capita of the second function, obtaining the following models:

$$(1)\quad \mathrm{CO_2} = f(\text{GDP per capita} + \text{Index of Economic Freedom} + \text{National Production of Barrels of Oil})$$

$$(2)\quad \mathrm{CO}_{2per\ capita} = f(\text{GDP per capita} + \text{Index of Economic Freedom} + \text{National Production of Barrels of Oil})$$

Gujarati and Porter (2010) stated that the ordinary least squares method of the German mathematician Carl Friedrich Gauss is considered to be the classic or standard model of linear regression – MCRL, this being the basis of econometric theory, on which the simple regression and multiple regression models are generated, models in which there is more than one explanatory or regressor variable.

Generalizing the population regression function (PRF):

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[9] It characterizes a discrete fit, such that the cointegration relationship between a set of variables only appears within a certain range, although the system will quickly reach long-run equilibrium if that critical threshold is exceeded.

[10] An Error Correction Vector – VEC model is a constrained VAR model that has cointegration constraints included in its specification, so it is designed to be used with series that are not stationary, but are known to be cointegrated.

[11] A series of ten economic measures created by the Heritage Foundation and The Wall Street Journal. Its stated aim is to measure the degree of economic freedom in the countries of the world.

$$(1)\quad Y_t = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \mu_t$$

For Notational Symmetry Purposes:

$$(2)\quad Y_t = \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \mu_t$$

Y is the dependent variable, X1, X2, and X3 are the explanatory variables, β1, β2, and β3 are called the partial regression coefficient, μ is the stochastic perturbation term, and t is the t-th time-series observation.

Gujarati and Porter (2010) described that the term multicollinearity is attributed to Ragnar (1934), who called multicollinearity the "perfect" or exact linear relationship between some or all of the explanatory variables of a regression model.

Stock and Watson (2012) stated that perfect multicollinearity is manifested when one of the regressors is a perfect linear combination of the rest of the regressors, whereas imperfect multicollinearity occurs when one of the regressors is highly correlated, but not perfectly correlated, with the other regressors. Imperfect multicollinearity differs from perfect multicollinearity because it does not impede the estimation of the regression, nor does it imply a logical problem in the selection of the regressors.

Partial correlation is an estimation of the relationship between two variables, removing from them the effects of another mediating or intervening variable, this premise is the one that enables the use of the partial correlation matrix to establish the existence of a perfect multicollinearity.

Farrar and Glauber (1967) propose that partial correlation coefficients should be observed in the regression of Y over X2, X3 and X4; if $R^2_{1.234}$ is found to be very high, but $r^2_{12.34}$, $r^2_{13.24}$ and $r^2_{14.23}$ are comparatively low, this may suggest that the X2, X3 and X4 variables are highly intercorrelated and that at least one of these variables is superfluous[12] (Gujarati & Porter, 2010).

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Generalizing the population regression function (PRF):

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Wooldridge (2010) establishes the assumption of homoscedasticity when the variance of the unobservable error, μ, conditional on the explanatory variables, is constant. White (1980) establishes a test that aims to test the forms of heteroscedasticity that invalidate the usual standard errors of Ordinal Least Squares (OLS) and the usual test statistics.

If the model contains k = 3 independent variables, White's test is based on

$$\hat{u}^2 = \delta_0 + \delta_1 X_1 + \delta_2 X_2 + \delta_3 X_3 + \delta_4 X_1^2 + \delta_5 X_2^2 + \delta_6 X_3^2 + \delta_7 X_1 X_2 + \delta_8 X_1 X_3 + \delta_9 X_2 X_3 + error \quad (3)$$

White's test for heteroscedasticity is the ML statistic[14] to prove that all δj in the equation are zero, except for the intercept, proving as such nine constraints. This hypothesis can be used in Test F; both tests have asymptotic justification (Wooldridge, 2010), the Ordinal Least Squares – MCO and the usual test statistics.

RESULTS AND DISCUSSION

Figure 1 shows the changes in national production of barrels of oil, index of economic freedom (ILE), CO2 per capita and GDP per capita. It can be seen that there is an overall increase in the period studied, however, there are oscillations in which local maximums and minimums are assumed in specific years. Irregular behavior foreseen by the socio-political alterations registered by the Ecuadorian state, which has repercussions on its economy and mainly on the ILE.

[13] That does not fulfill or perform a function
[14] Lagrange Multipliers

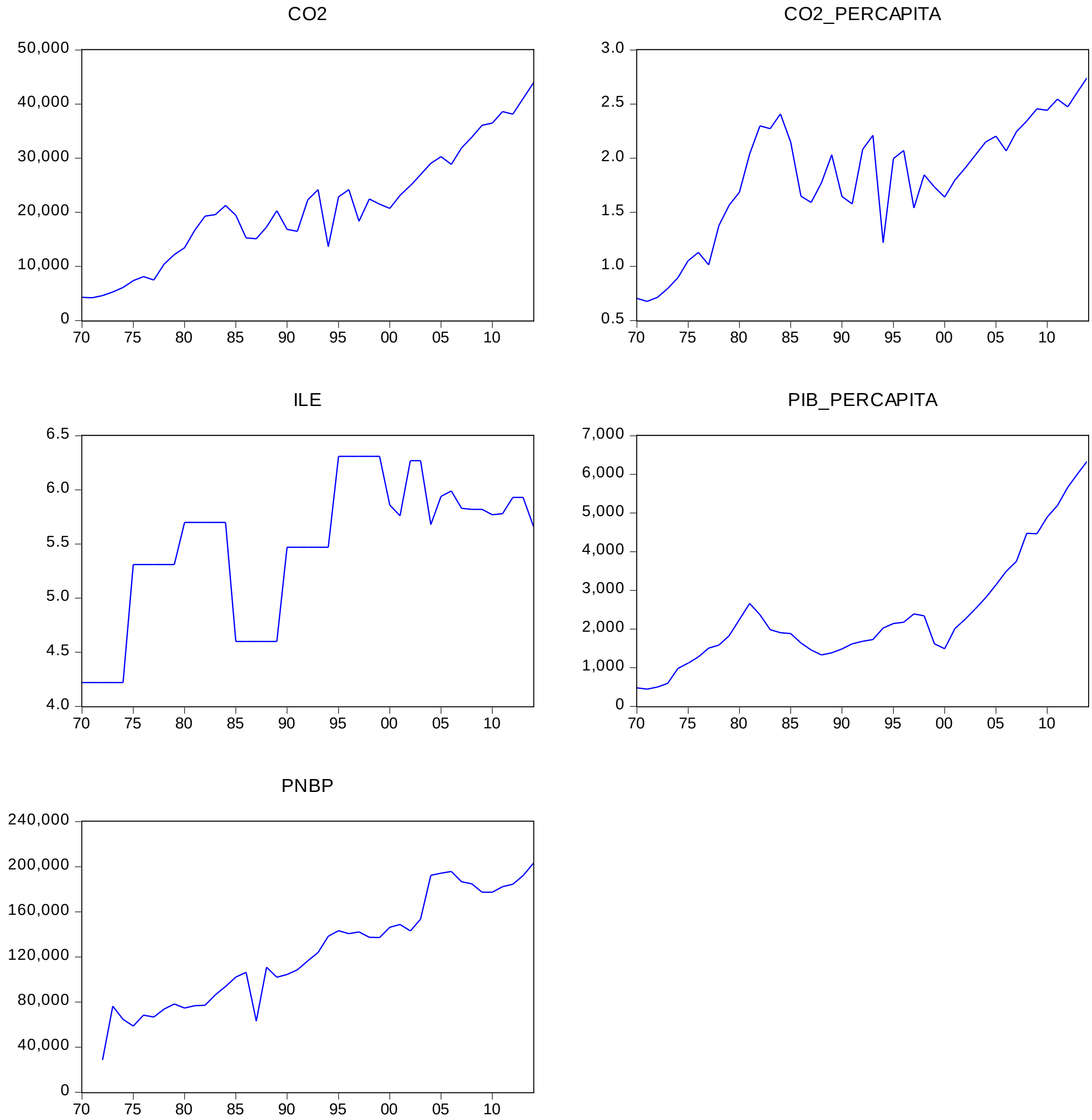

Fig. 1. CO_2, CO_2 per capita, GDP per capita, Index of Economic Freedom and National Production of Barrels of Oil

The first model favors the result of the values obtained in R2, achieving greater coverage in terms of explanatory capacity, Prob (F-statistic) which seeks a reduction in the probability of committing the type I error and the non-existence of serial correlation that evaluates the Durbin-Watson test when determining the independence of the data; placing them above the values obtained in the Akaike info criterion and Schwarz criterion tests, which have a relatively high value (Table 1).

Table 1. Parameter Estimation and Statistical Testing

R^2	Prob (F-statistic)	Durbin-Watson	Akaike	Schwarz
0.917163	0.000000	1.418035	18.95153	19.11536

The partial correlation matrix demonstrates the non-existence of multicollinearity since the independent variables studied are not closely related, with none of them having a value greater than 0.8 (Table 2). Despite this, there is a close relationship between the dependent variable CO2 and the independent variables GDP per capita and National Production of the Barrel of Oil.

Table 2. Partial Correlation Matrix

	CO2	IEF	GDP_PERCAPITA	NPBO
CO2	1			
IEF	0.571113	1		
GDP_PERCAPITA	0.905279	0.473972	1	
NPBO	0.904236	0.615561	0.786249	1

The White test corroborates the assertion that the model studied is homoscedastic, i.e. that the perturbations have the same variance, and this variance is constant for the different regressors (Table 3).

Table 3. White Test

Heteroskedasticity Test: White			
F-statistic	0.941158	Prob. F(20,23)	0.5038
Obs*R-squared	8.782840	Prob. Chi-Square(20)	0.4576
Scaled explained SS	7.079044	Prob. Chi-Square(20)	0.6289

The final model is $CO_2 = f$ (GDP per capita + index of economic freedom + National Production of Barrels of Oil), which in terms of substitution of coefficients generates the result.

$$CO2 = 528.698471673*IEF + 3.55754556684*GDP\_PERCAPITA + 0.102794080062*NPBO - 2985.45037827 \quad (3)$$

The results show an analysis and interpretation within the ordinal range as there are no alterations in the variables that are part of this model. The value expressed by the term stochastic disturbance does not contribute directly to the development of CO2, unlike the variables taken into account for the analysis that contribute to the production of Carbon Dioxide, mainly an index of economic freedom.

This equation shows a standard deviation of 2909.01; a coefficient of asymmetry close to zero and a kurtosis that tends to three, values that corroborate what was shown by the Jarque-Bera test, which establishes a proximity to the normal distribution with Maximum Likelihood estimators (Figure 2).

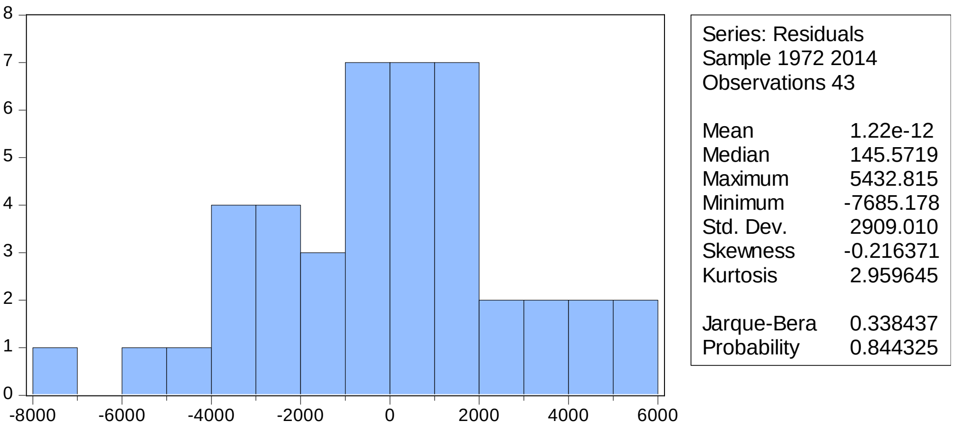

Fig. 2. Histogram – Model 1. Normality Test

The second model presents relatively unfavorable results of the values obtained, the R2 presents a low coverage in terms of explanatory capacity, Prob (F-statistic) shows a reduction in the probability of committing the type I error, the Durbin-Watson test exposes the possible existence of positive autocorrelation, together with low values obtained in the Akaike info criterion and Schwarz tests (Table 4).

Table 4. Parameter Estimation and Statistical Testing

R^2	Prob (F-statistic)	Durbin-Watson	Akaike	Schwarz
0.634310	0.000000	0.828682	0.661682	0.825514

The partial correlation matrix shows the non-existence of multicollinearity since the independent variables studied are not closely related, with none of them having a value greater than 0.8 (Table 5).

Table 5. Partial Correlation Matrix

	CO2_PERCAPITA	IEF	GDP_PERCAPITA	NPBO
CO2_PERCAPITA	1			
IEF	0.529874	1		
GDP_PERCAPITA	0.768256	0.473972	1	
NPBO	0.707426	0.615561	0.786249	1

The White test corroborates the assertion that the model studied is homoscedastic, i.e. that the perturbations have the same variance, and this variance is constant for the different regressors (Table 6).

Table 6. White Test

Heteroskedasticity Test: White			
F-statistic	1.557601	Prob. F(20,23)	0.1693
Obs*R-squared	12.82033	Prob. Chi-Square(20)	0.1709
Scaled explained SS	9.128621	Prob. Chi-Square(20)	0.4255

The final model is CO2 per capita = *f* (GDP per capita + index of economic freedom + National Production of Oil Barrels), which in terms of substitution of coefficients generates the result.

$$\text{CO2\_PERCAPITA} = 0.137049071733*\text{IEF} + 0.000198425159859*\text{GDP\_PERCAPITA} + 1.81660180446e\text{-}06*\text{NPBO} + 0.387319505091 \quad (4)$$

The results show an analysis and interpretation within the ordinal range as there are no alterations in the variables that are part of this model. The variables have a common denominator in contributing positively to the production of Carbon Dioxide, mainly the national production of barrels of oil.

The second equation shows a standard deviation of 0.310; and it is related to the first by presenting an asymmetry coefficient close to zero and a kurtosis that tends to three, values that corroborate what was shown by the Jarque-Bera test, which establishes a proximity to the normal distribution with Maximum Likelihood estimators (Figure 2).

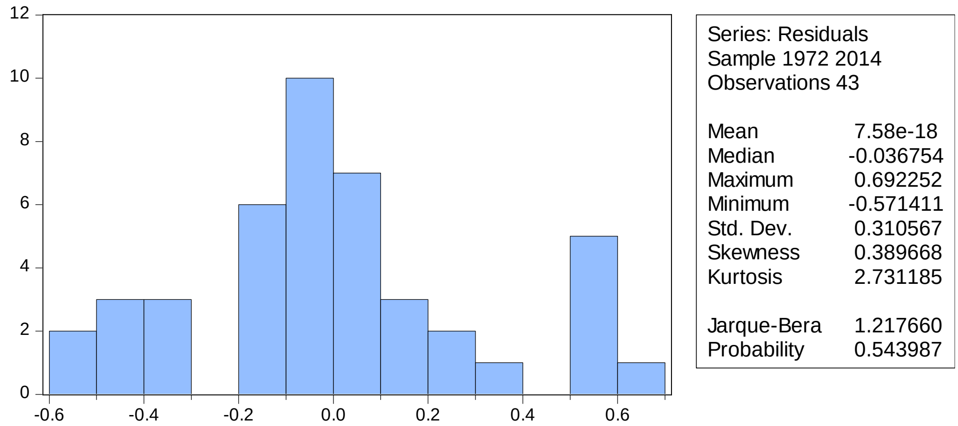

Fig. 2. Histogram – Model 2. Normality Test

CONCLUSIONS

There is an empirical relationship between countries' levels of environmental pollution and their extent in terms of economic development, without establishing the existence of a direct and constant relationship or an inverted relationship either in U, V or N.

Statistical analysis shows that, in the case of Ecuador, CO2 production is in the first stage of the environmental curve.

The models under study differentiated only by the dependent variable are similar, although the one that presents CO2 per capita as the response variable does not have a high explanatory capacity.

There is a direct and influential relationship between the freedom of the rule of law, the size of government, regulatory efficiency and the opening of markets; expressed in the Index of Economic Freedom and the exploitation of CO2 in the environment of the Ecuadorian territory. While Ecuador has a higher degree of economic freedom, it generates 528.69 kilotons of CO2 in the environment.

In the case of CO2 per capita, the national production of barrels of oil is the most influential variable. By increasing an additional barrel of oil from domestic production, it generates 1.82 tons of CO2 per capita.

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