The relationship between economic growth and environment. Testing the EKC hypothesis for Latin American countries.

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May 25, 2021

Abstract

We employ an ARDL bounds testing approach to cointegration and Unrestricted Error Correction Models (UECMs) to estimate the relationship between income and CO₂ emissions per capita in 21 Latin American Countries (LACs) over 1960-2017. Using time series we estimate six different specifications of the model to take into account the independent effect on CO₂ emissions per capita of different factors considered as drivers of different dynamics of CO₂ emissions along the development path. This approach allows to address two concerns. First, the estimation of the model controlling for different variables serves to assess if the EKC hypothesis is supported by evidence in any of the LACs considered and to evaluate if this evidence is robust to different model specifications. Second, the inclusion of control variables accounting for the effect on CO₂ emissions is directed at increasing our understanding of CO₂ emissions drivers in different countries. The EKC hypothesis effectively describes the long term income-emissions relationship only in a minority of LACs and, in many cases, the effect on CO₂ emissions of different factors depends on the individual country experience and on the type and quantity of environmental policies adopted. Overall, these results call for increased environmental action in the region.

JEL Codes: C32, Q32, Q50, Q56

Keywords: Environmental Kuznets Curve, Inverted-U-shaped curve, Linear relationship, CO₂ per capita emissions, GDP per capita, Latin American countries, ARDL bounds testing, time series analysis.

Acknowledgment: The first author acknowledges financial support from Erasmus+/KA1 Grant number 2019/109282 and the second author acknowledges financial support from the Spanish Ministry of Science

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and Technology Grant ECO2015-70331-C2-1-R. and Spanish Government Project PID2019-108079GBC22.
Declarations:

1. Ethics approval and consent to participate Not applicable

2. Consent for publication Not applicable

3. Availability of data and materials: The data used in this manuscript are available at the sources included in table 1 of the manuscript and are also available from the authors upon request.

4. Competing interests: The authors declare that they have no competing interests.

5. Funding:
   C. Seri acknowledges financial support from Erasmus+/KA1 Grant number 2019/109282.
   A de Juan acknowledges financial support from the Spanish Ministry of Science and Technology Grant ECO2015-70331-C2-1-R. and Spanish Government Project PID2019-108079GBC22.

6. Authors’s contribution.
   AdJ has developed the results, doing the estimation of the models
   CS has interpreted the results.
   Both authors have contributed in writing the manuscript. Both authors read and approved the final manuscript.
1 Introduction

The relationship between economic growth and environment has been a matter of interest for many years and collected academic contributions that date back to the 1950s. While during the seventies the prevailing view was that of growth having net adverse environmental impacts (Ehrlich and Holden (1971); Meadows et al. (1972); Nordhaus (1977)), the stance during the eighties was more optimistic and was mainly based on the concept of sustainable development (Brundtland (1987)). The formulation of the Environmental Kuznets Curve (EKC) hypothesis in the early nineties marked a significant turning point in this debate and is currently one of its main focus. The growth-environment relationship ceased being considered a monotonic one – whether of positive or negative sign – and a number of authors began to argue that the impact of growth on the environment could change along the course of economic development. According to the EKC hypothesis, first stated by Grossman and Krueger (1991), in the early stages of economic growth environmental degradation and pollution increase, but beyond some level of income per capita the trend reverses with additional income growth leading to environmental improvement. In analogy with the relationship between income and income inequality described by Kuznets (1955), the relationship between economic growth and environmental degradation could thus be described as an inverted U-shaped curve, hence the name. A number of elements related to the process of development – changes in the economic structure, technological progress, changes in preferences and increased environmental awareness, among others – would be at the basis of such a relationship.

Shafik and Bandyopadhyay (1992) provided a first empirical confirmation of the hypothesis and popularized the concept. Since then a large stream of empirical literature flourished using a variety of econometric techniques to test the hypothesis for different countries, environmental variables and time periods. Despite a massive empirical literature, the results are highly heterogeneous and given their sensitivity to the samples and variables chosen, it could be said that the EKC is not so much an empiric regularity as it has been believed to be\footnote{1Moreover, even when the EKC is supported by evidence, in some cases the estimated turning points for income are so high that environmental conditions will still deteriorate for a long time before income reaches the level required to revert the trend (Selden and Song (1994); Shafik (1994); Holtz-Eakin and Selden (1995); Stern and Common (2001)).}. However, despite many criticisms, the hypothesis still is among the main approaches to the study of the relationship between growth and the environment (Stern, 2017). Moreover, its implications for the design of environmental policies and the increasingly urgent climate crisis call for a better understanding of these patterns.

Against this background, in this paper we study the relationship between income and CO₂ emissions per capita in twenty-one Latin American Countries (hereinafter LACs) over 1960-2017. We test the EKC hypothesis employing Autoregressive Distributed Lag (hereafter, ARDL) bounds testing approach to cointegration based on Unrestricted Error Correction Model (hereinafter,
UECM). We estimate this model separately in each Latin American country in our sample and controlling for the effect of different explanatory variables, following a time series approach. Indeed, while many studies already tested the EKC hypothesis, studies testing the hypothesis in Latin America are fewer in number (for example, Martínez-Zarzoso and Bengochea-Moranch (2003); Poudel et al. (2009); Sánchez and Caballero, 2019); Zilio and Caraballo (2014)) and the vast majority of them use panel data approach, despite the superiority of time series techniques to investigate the existence of the EKC has been claimed for a long time (De Bruyn et al. (1998); Lindmark (2002); Stern et al. (1996); Unruh and Moomaw, (1998); Vincent, (1997)). We estimate six different models for each country, in order to control for different variables. These variables are chosen to account for the effect of a number of elements discussed in the theoretical literature as possible causes to increases or reductions of $CO_2$ emissions: output structure, commodity dependence, population density, external relationships (trade and FDI), agricultural land, rural population and the energy mix. This approach allows us to address two important issues. First, we can address the robustness of the results across different model specifications, and conclude if the EKC hypothesis is a robust description of the income-emission pattern in some country of the region or what other pattern seems to describe this dynamic. Second, the effect on $CO_2$ emissions dynamics of these relevant factors is assessed, providing a better understanding of the underlying causes of environmental damage. This is a crucial step to start understanding how to mitigate environmental impact of growth. The reminder of the paper is structured as follows. Section 2 briefly reviews the theoretical foundations of the hypothesis and highlights some related criticisms. In Section 3 the econometric methodology as well as the data employed in the analysis are presented. In Section 4 we present and discuss the results of the models carried out. Section 5 concludes the paper and provides some insights for policy recommendations on the basis of our results.

2 Theoretical basis of the EKC hypothesis and some related criticisms

The theory underlying the EKC hypothesis is based on the existence of a number of time-related effects occurring along the development process. Indeed, all other things remaining unchanged, greater economic activity would necessary imply a higher use of resources hence higher environmental impact. However, this effect, known as scale effect, can be mitigated and even offset, in the later stages of development, by the dynamic implications of growth.

A number of underlying factors to the EKC hypothesis have been identified and different authors have alternatively highlighted the relative importance of one or the other. Among the direct determinants of the EKC already identified by Grossman and Krueger (1991), the changes occurring in the economic structure at different levels of income per capita (i.e. structural change)
could explain a growth-environment inverted U-shaped relationship. Indeed, as throughout the development process economic structures traditionally shift from low-polluting agriculture to energy-intensive industry to lighter manufacture and services, the impact of growth on environmental quality is expected to change at different levels of income. This factor has been considered as crucial in explaining the EKC relationship by many influential authors (Panayotou et al. (2000), for example) and its relevance has been recently reaffirmed as the “first and foremost” analytical base of the EKC (Savona and Ciarli (2019), p. 247). However at least two criticisms can be directed to the environmentally beneficial impact of structural change. A first issue is related to the actual level of dematerialization brought about by a switch to a service economy. Indeed, the idea that the service sector uses a lesser amount of resources has been questioned (Fix (2019)). This criticism is related both to the strong interrelation existing among different sectors of activity, which should be considered as complements rather than substitutes (Jespersen (1999)) and to the existing difference between production and consumption patterns. Even if in terms of production an economy that switches to services can dematerialize, its consumption patterns will not change accordingly meaning that, when taking a vertically integrated approach, that is when indirect emissions are accounted for (“consumption perspective”), the overall decrease in environmental pressure related to structural change towards services is substantially reduced (Marin and Zoboli (2017)). A second issue related to the composition effect, particularly relevant when the EKC is applied to explain the income-emissions patterns in developing countries, is related to the type of structural change the EKC theory refers to. Indeed, the idea that economies switch from agriculture to industry and finally services is based on the transformations that occurred in the now developed countries during the nineteenth and twentieth centuries. However, in the face of a very different context and of the existence of many experiences of so-called “premature de-industrialization” (Palma (2014); Rodrik (2016)) it is possible to believe that those steps are not being followed by developing countries in current times, with the related implications in environmental terms. Another element essential to the occurrence of environmental quality improvement as income rises is the technological progress that is generally associated with development. This factor, that refers both to general productivity improvements and emission specific changes in process that lead to an improvement in energy efficiency, has been considered as crucial and become known as technique effect. It is worth mentioning that the results reached by most studies of decomposition analysis – another stream of literature that seeks to study the income-emissions relationship by decomposing emissions into their sources of changes (Stern (2017)) – show that the within-sector technological change plays the most important role in explaining energy intensity changes. This conclusion is reached by both multiple (Voigt et al. (2014) andJimenez and Mercado (2014) among others) and single-country (Sinton and Levin (1994); Zhang (2003); Ma and Stern (2008); Ke et al. (2012) for China and Bhattacharya and Shyamal (2001) for India) studies. However, while technological progress is so important in explaining environmental improvement, it is also very unlikely to occur auto-
matically in developing countries (Zilio (2012)). This may be due to a number of constraints that range from import of obsolete technologies and poor own development of new technologies due to low incentives to firms eco-innovation and meagre public R&D expenditure.

Along with these more traditional elements explaining the EKC, a number of additional factors have been taken into account. Input mix changes and particularly the improvement in the energy mix, which has been found to occur with income growth (Semieniuk (2018) confirming the “energy ladder hypothesis”), could explain a reduced environmental impact of production at higher levels of per capita income. The role of education along with increasing environmental awareness and changes in consumer preferences have also been identified as underlying factors to the EKC, given that environmental quality has been considered a luxury good. Finally, the role of the implementation of stricter environmental regulations in more developed countries has also been highlighted, even if some criticisms have been raised to this respect. In particular, it has been claimed that even if stricter environmental regulation could explain the reduction in environmental damage in some countries, it would hardly support the existence of an EKC at the global level. Indeed, once stricter regulations are enforced in one country, firms may relocate their more polluting activities to countries with laxer rules – typically developing countries – rather than invest in eco-innovation and reduce their total emissions. This effect, known as the “pollution-haven hypothesis” (PHH), could be further magnified by trade liberalization which would reduce the costs of offshoring the “dirty” production. In fact, this assumption has been further developed through the “pollution offshoring hypothesis”, explicitly linking firms decisions to relocate highly polluting production to trade liberalization. These concerns triggered a stream of literature studying the effect of trade and international relocation of industries on the environment particularly in developing countries. However, mixed evidence has been found with respect to the PHH hypothesis, possibly due to the employment of different empirical approaches.

3 Methodology and data

3.1 Methodology

A very large stream of empirical literature used different econometric techniques to test the EKC hypothesis in the last three decades. In particular,
both methodological criticisms directed towards the early studies ignoring the possible existence of unit root in the data (Stern (2004)) and the long run nature of the relationship (Dinda (2004)), promoted the implementation of different univariate and multivariate techniques to test for long run cointegrating relationships. Among these, the (1) Engle and Granger (1987) residual based approach to test for cointegrating relationships; 2) the full information maximum likelihood method developed by Johansen and Juselius (1990) and 3) the fully modified OLS procedure developed by Phillips and Hansen (1990) have been used. However, Narayan and Smith (2005) showed that these tests may be inappropriate when the sample size is relatively small.

Against this background, in this paper we use Autoregressive Distributed Lag (hereafter, ARDL) bounds testing approach to cointegration based on Unrestricted Error Correction Model (hereinafter, UECM) to analyze the long run relationships. The error correction terms from the UECM are used to test for the direction of Granger-Causality and to conduct generalized variance decomposition analysis.

The ARDL bounds test procedure has been extensively used to test the EKC relationship. For example, using data panel, Fuihas et al. (2017) used this procedure to test the impact of renewable energy policies on CO$_2$ emissions in a panel of ten LACs and Apergis and Payne (2009) applied this methodology for Central American countries. Using time series data, this methodology has been used in Amri (2018) in a study for Tunisia, in Bölük and Mert (2015) to test for the EKC relationship controlling for renewable energy in Turkey, in Onafowora and Owoye (2014) to test the EKC for several countries including Brazil and Mexico, in Zambrano-Monserrate et al. (2016) to explore the relationship between carbon dioxide emissions, economic growth, energy use and hydroelectric electricity production in Brazil and in Zambrano-Monserrate et al. (2018) testing the EKC hypothesis in Peru controlling for renewable electricity, petroleum and dry natural gas consumption. However, none of these studies has considered a large number of Latin American countries as we do in this paper.

The ARDL method, developed by Pesaran and Shin (2001), has some advantages:

1) The ARDL procedure can be applied to any time series, irrespective of the order of integration of the variables. That is, the time series can be I(0) or I(1), so that the uncertainty associated with pretesting the order of integration is eliminated.

2) This procedure is valid for small samples, avoiding the problem of asymptotic distributions.

3) The technique can distinguish between dependent and independent variables and generates estimates for the long run and the short run simultaneously, eliminating the problem generally associated with omitted variables and autocorrelation.
The ARDL model can be written as:

\[
\nabla \ln e_t = \beta_0 + \sum_{i=1}^{m} \beta_{3i} \nabla \ln e_{t-i} + \sum_{i=0}^{n} \beta_{3r} \nabla \ln y_{t-i} + \sum_{i=0}^{r} \beta_{3s} \nabla \ln (y_{t-i})^2 \\
+ \sum_{i=1}^{s} \beta_{4i} \nabla \ln (y_{t-i})^3 + \sum_{j=5}^{p_j} \sum_{i=0}^{r} (\nabla \ln x_{j,t-j}) \\
+ \delta_1 \ln e_{t-1} + \delta_2 \ln y_{t-1} + \delta_3 \ln (y_{t-1})^2 + \delta_4 \ln (y_{t-1})^3 \\
+ \sum_{j=1}^{p_j} \delta_j x_{j,t-1} + u_t
\]

The lags included in each term of the right hand side are selected using any Information Criteria. In this expression, the \( \beta_j \) represent the short run error correction dynamics, while the terms \( \delta_j \) \( (j = 1, 2, ..., p_j) \) correspond to the long run relationship.

We test for cointegration relationship between the variables in the system, using the bounds test, developed by Pesaran and Shin (1999, 2001). We use an F-statistic to determine whether the variables are cointegrated by testing the joint significance of the lagged level coefficients; that is:

\[
H_0 : \delta_i = 0 \ (i = 1, 2, ..., q), \text{ there is no cointegration} \\
H_1 : \delta_i \neq 0; \text{ there is cointegration}
\]

In the presence of cointegration, one should fail to accept the null hypothesis.

Narayan (2005) and Narayan and Narayan (2010) derived exact critical values for the bounds test developed in Pesaran and Shin (2001). They show that there can be three possible situations. They derived a lower and an upper bound so that if the F-statistic is lower than the lower bound, there is not a cointegration relationship. If the F-statistic lies between the lower and the upper bound, the result of the test is inconclusive and we should use other techniques to analyze the cointegration. Finally, if the F-statistic is higher than the upper bound, then we cannot reject that a cointegration relationship exists.

We use Schwarz information criteria to identify the optimal order of the ARDL components, that is the logs of the differenced variables (short run dynamics) Once the optimal lag length are selected and the long run relationship is confirmed, then the UECM can be estimated:

\[
\nabla \ln e_t = \omega_0 + \sum_{i=1}^{m} \omega_{1i} \nabla \ln e_{t-i} + \sum_{i=0}^{n} \omega_{2i} \nabla \ln y_{t-i} + \sum_{h=0}^{r} \omega_{3h} \nabla \ln (y_{t-i})^2 \\
+ \sum_{k=1}^{s} \omega_{4ik} \nabla \ln (y_{t-i})^3 + \sum_{j=5}^{p_j} \sum_{i=0}^{r} (\nabla \ln x_{j,t-j}) + \varphi EC_{t-1} + \mu_t
\]

where \( \varphi \) is the speed of adjustment parameter and \( EC_{t-1} \) is the one period lagged error correction term. This coefficient indicates the speed of adjustment.
back to equilibrium after a shock in the system and it should have statistically significant negative sign.

3.2 Data

We used data obtained from the World Bank, CEPALSTAT and Latin American Energy Organization. The $CO_2$ emissions per capita, GDP per capita and population density data are obtained from the World Bank Development Indicators. The data on agriculture, industry and services value added to GDP are also obtained from the World Bank Development Indicators, and the data on the share of primary products exports are obtained from CEPALSTAT. GDP per capita, agriculture, industry and services data are expressed in constant 2010 US dollars. The share of primary exports refers to the share of total exports of a number of commodities including food, live animals, mineral fuels, lubricants and related materials. We consider annual data series for 21 LACs over the period 1960-2017. Other variables included in the analysis are related with the external relationships of the LACs through trade – measured by exports and imports of goods and services – and foreign direct investment (FDI). We also consider variables related with the extension of the agricultural sector in the region (agricultural land and percentage of rural population) and variables related with energy consumption (electricity, gasoline, diesel and fuel consumption). A description of the variables, including the related source and the sample is provided in table 1.

Insert table 1 around here

4 Results

4.1 Estimation of the basic EKC relationship

In this first model we estimate the basic relationship between income and $CO_2$ emissions per capita, including the level and the square of the income term to test for the EKC using the ARDL specification and the bound tests. The results of these estimations are shown in table 2. The main findings are:

- Only in five out of the twenty-one LACs considered, cointegration between the variables is found;
- Of these five countries, only three cases (Costa Rica, Ecuador and Mexico) show inverted U-shaped relationships supporting the EKC – that is,

3The LACs considered are: Argentina (ARG), Bolivia (BOL), Brazil (BRA), Chile (CHI), Colombia (COL), Costa Rica (COS), Cuba (CUBA); Dominican Republic (R.DOM), Ecuador (ECU), El Salvador (EL SAL), Guatemala (GUA), Haiti (HAI), Honduras (HON), Jamaica (JAM), Mexico (MEX), Nicaragua (NIC), Panama (PAN), Paraguay (PAR), Peru (PERU), Uruguay (URU) and Venezuela (VEN).

4In some of the estimations, the sample period starts in 1970 due to data availability.
positive parameter of the income in level and negative parameter related to the squared income term. In two countries (Argentina and Peru) the income parameters are non-significant at the 5% level;
- Only in the case of Haiti the results of the bound test are inconclusive.

A first conclusion to be drawn is that only in three out of the twenty-one countries considered we found results supportive of the EKC. In these cases the turning points are located inside the sample. In these cases the speed of adjustment parameter is negative and significant, being around 0.50 in absolute value. This is an evidence in favor of a cointegration relationship among the variables \((e_t, y_t, y_t^2)\). The speed of adjustment represents the proportion by which the long run disequilibrium in the dependent variable is corrected in each short time period. For the other countries showing a cointegrating relationship, the estimated coefficients are not significant, so the EKC relationship is not supported by the data. Finally, for most of the countries no cointegration is found in this estimation. We can conclude that these estimations do not yield very much support to the EKC hypothesis. However, some econometric problems, such as those outlined in Müller-Fürstenberger and Wagner (2007) may be present in these estimations influencing the results. For example, we might be missing relevant variables that explain CO\(_2\) emissions independently from income per capita, hence suffering a misspecification error. In order to address this concern and establish if the relationships found are robust across different specifications we estimate again the relationships including additional variables in the following ARDL models.

### 4.2 Estimation of the EKC relationship controlling for production structure

As we have seen, the composition effect, that is the shift of production structures from agriculture to industry and finally to the service sector along the development path, has been considered among the most important causes to the EKC hypothesis. In fact, a greater importance of the agriculture and services sectors in an economy are expected to be grounds for less CO\(_2\) emissions with respect to the industrial sector, typically considered the most polluting economic activity. However, we also highlighted some criticisms that have been raised challenging the composition effect as causing the EKC. On the one hand the actual extent to which a greater service sector implies a lesser amount of resources used by the economy has been questioned (Fix (2019); Marin and Zoboli (2017)). On the other, criticisms with respect to the occurrence of similar structural change processes in developed countries then and developing countries now have also been raised. In this respect, it should be considered that Latin American economics
– that never reached high industrialization levels5 – experienced a generalized de-industrialization process since about the mid-1970s and that since then the service sector has been increasingly important. Given that industry is the most polluting sector and that it does not play a central role in LACs’ production structure, we might expect a stronger evidence for the EKC in these countries once output structure is taken into account. Therefore, in this second model, we include agriculture, industry and services value added to GDP as additional explanatory variables. We prefer these variables as proxy for the output structure and its changes over time against the sectoral contributions to GDP to minimize eventual collinearity problems among the covariates. The results of these second estimates are displayed in table 3.

Compared with the previous model, once output structure is taken into account we find only three cases of not cointegrating relationships. Both the number of countries with inconclusive situations and cointegrating relationships increase. In some of these cases, however, the income parameters are non-significant, so we cannot draw conclusions on the existence of support for the EKC for these countries6. Among the cointegrating relationships for which the income parameters are significant we find Colombia, Costa Rica, Jamaica and Mexico. In those countries the signs of the parameters support the EKC hypothesis. It seems important to note that for Costa Rica and Mexico we find similar results as in the first estimation, meaning that those results are likely to be robust, hence describing the real income-emissions relationship in those countries. The income parameters are also significant in Venezuela, but the estimated signs point to a U-shaped relationship in this case.

4.3 Estimating the EKC controlling for output structure through the share of primary products exports: investigating the environmental impact of commodity dependence

Commodity dependence is a long-time feature of Latin American economies. With different nuances7, all LACs’ output and export structures are strongly concentrated in primary products and mostly due to the well-known boom of

5The occurrence of de-industrialization in many developing countries whose industrial sector was not fully developed yet has been considered a cause of concern by different authors and was even referred to as “premature de-industrialization” (Palma (2014); Rodrik (2016)).

6Argentina and Peru, for which this result is the same as in the previous model; Ecuador, for which in the first estimation we found support for the EKC and Cuba, Haiti and Honduras.

7Andean economies, which include countries from Venezuela to Chile are mostly specialized in oil, gas and minerals whereas the rest of South America is agriculture-based (Ocampo (2017)).
commodity prices, this pattern was even exacerbated in recent years.
Surely, commodity dependence has a number of different implications and its analysis goes far beyond the objectives of this paper. However, given the great importance of this pattern in the region, it may have an impact on LACs’ emissions dynamics and their relation with income that is worth considering.

Therefore, we estimate again the model controlling for the export share of primary products. We choose this variable against the product share of these goods to minimize the risk of collinearity among the covariates. In this estimation we also control for population density, which many have considered as a potential underlying factor to $CO_2$ emissions dynamics. However, there is not complete agreement over the expected impact of this factor. Some deem increasing population density to reduce, ceteris paribus, a country’s emissions, due to the reduction in transportation and electric networking costs that it would imply (Panayotou et al., 2000). In contrast, others have believed that increasing population density increases emissions given that “more dense populations will burn more fuel”. (Poudel et al. 2009, p. 19).

Results in table 4 show the bounds tests and long run estimates of the cointegrating relationships controlling for population density and exports of primary goods. In this estimation the number of countries for which we find cointegration increases again, but only in some of them (Colombia, Costa Rica, Ecuador, El Salvador, Mexico, Paraguay) we find significant income parameters. In all these six cases the income parameters signs provide support to the EKC hypothesis.

With respect to the control variables included in this model we find that the share of commodity exports parameter, when significant (in Jamaica, Mexico, Paraguay and Peru) always shows positive sign. This implies that a higher share of commodity exports is related to a higher environmental impact as measured by $CO_2$ emissions per capita. This result is in line with the neo-extractivism literature denouncing the high environmental pressure caused by commodity dependent economies (Lander (2014); Svampa (2019)). In the light of these results and the fact that a large part of the environmental impact of this economic model is not captured by $CO_2$ emissions dynamics, the analysis in environmental economics perspective of this production model is an interesting field to be explored by future research.

Turning to the effect of population density on $CO_2$ emissions per capita our estimations yield mixed results supporting both postures expressed by the literature, depending on the country. In most of the cases for which the population

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8In 2017 primary products exports accounted on average for 65.1% of total exports in the region, according to CEPALSTAT data. We should also note that, among the LACs in our sample, only Mexico and El Salvador have partially diversified their export structure away from agriculture over the study period of 1963-2017. In 2017 the exports of primary products accounted for 17.9 and 23.9 percent of total exports in these two countries respectively.
density parameter is significant (Cuba, El Salvador, Haiti, Mexico, Paraguay, Peru) it has positive sign, implying that a higher density of population – which is also likely to be associated to higher urbanization – increases carbon dioxide emissions per capita. However, in some cases, for example in Mexico, the estimated sign is negative. In this country, the large extension of the territory may be explaining this result. Given its geographical characteristics indeed, it is likely that the benefits in terms of transportation and networking savings overwhelm the negative environmental effects of increasing population density.

4.4 Estimating the EKC controlling for external relationships and agricultural land

As already mentioned, the effect of trade on environmental quality has been extensively discussed, and the idea that trade has a negative impact on the environment in developing countries has been formulated in the PHH hypothesis. In order to control for the eventual influence of trade and other external relationships of LACs, in this model we include FDI inflows, as well as exports and imports as a share of GDP. Moreover, in this estimation we also control for the share of agricultural land area, since we suppose that this variable, reflecting important characteristics of each country, might be influencing the way their external relations are shaped.

In this model, the number of cointegrating relationships increases with respect to the first model. Indeed, we find cointegration for fourteen countries in the sample, being only three and four respectively the cases for which either no cointegration or inconclusive results are found. However, of the countries for which we found cointegration, only eight (Brazil, Ecuador, El Salvador, Honduras, Jamaica, Mexico, Nicaragua, Panama) show significant income parameters, and six an inverted U-shaped relationship (all but Honduras and Nicaragua for which the signs are indicating a U-shaped relationship). In all the cases where the EKC is supported, the speed of adjustment in the short run relationship is negative and clearly statistically significant.

Turning to the analysis of the control variables of this model, we find that the FDI related parameter is significant in four (Argentina, El Salvador, Jamaica and Venezuela) out of the fourteen countries for which we find cointegration. In all these countries except in Jamaica, the sign of the parameter is positive which might be indicating that FDI are mainly directed towards polluting sectors, at least in these countries. Indeed, pollution-intensive sectors attract a large share of total FDI inflows in the region (Blanco et al. (2013)) and many studies investigating the environmental impact of FDI found that, in most cases, environmental damage and pollution are linked to or caused by increasing FDI inflows (Hoffmann et al. (2005); Merican et al. (2007); Acharyya (2009); Lee (2009)).
In relation to the variables related to trade we find that the export parameter is significant in only four countries (Honduras, Jamaica, Mexico, Nicaragua), in most cases showing a negative sign. It seems that a greater share of exports has a positive environmental effect, if any. With respect to imports, the parameter is significant in only five countries (Brazil, El Salvador, Jamaica, Mexico, Nicaragua) and shows mixed signs. Overall, we don’t find clear evidence of an univocal environmental impact of trade and our findings do not support the PHH hypothesis in the region. Rather, it seems that the environmental impact of trade is different in each country and it is likely to depend on a variety of issues, ranging from inherent characteristics of the country to specific regulations implemented. This result is consistent with the findings of previous literature looking for the impact of trade in the region and particularly with the conclusions reached by Jenkins (2003). Analyzing the environmental effect of the openness to trade after the liberalization process of mid-80s/early 90s in Argentina, Brazil and Mexico he found that not a unique effect could be found. In Argentina and Brazil opening to trade resulted in an exacerbation of their existing specialization in polluting industries. Conversely in Mexico – which was the only country among these to implement environmental regulations together with commercial liberalization – increasing trade had beneficial environmental effects. That is, these and our results suggest that it is likely that the environmental impact of greater commercial activity is determined by the context within which trade is increased rather than by trade itself.

Finally, with respect to the parameter related to agricultural land it is significant in seven countries (Argentina, El Salvador, Honduras, Jamaica, Mexico, Nicaragua and Venezuela), having positive sign in all of them, except for Honduras and Mexico. The fact that a greater share of agricultural land seems to lead to greater emissions can be related to different factors. It can be related to the fact that greater agricultural activity is environmentally damaging, differently from what could be expected and this might be due to the type of agricultural practices carried out. This is likely to be case of Argentina, for example, in which the agricultural activity is very much related to an environmentally impacting agro-industry.

4.5 Estimating the EKC controlling for renewable energy production population density and rural population

Among the many factors that determine the possibility of different environmental impacts of growth, the energy mix plays an important role. In particular, when energy is obtained from renewable and clean sources the impact on the environment is reduced. Fuinhas et al (2017) studied the effect of renewable energy policies on CO₂ emissions in ten Latin American countries and found that, while higher levels of primary energy consumption per capita lead to higher emissions levels, those can be reduced in the long run by the implementation of renewable energy policies. Also, a decomposition analysis by Sheinbaum et al (2011) showed that, despite energy intensity reductions in Colombia and Mexico – and to a lesser extent in Argentina and Brazil –, the increasing dependence
on fossil fuels for energy generation in these countries has hindered a reduction in $CO_2$ emissions to occur.

Against this background we include renewable energy production in the model that estimates the relationship between income and carbon dioxide emissions per capita to control for the effect of renewable sources of energy on the environmental impact of growth. In this estimation, we also control for the independent effect on $CO_2$ emissions of population density and the share of rural population.

The results are displayed in table 6.

First of all, we note that, as observed for other models, when more control variables are included the number of countries for which a cointegrating relationship is found increases. Of the seventeen countries for which we find cointegration in this estimation, only eleven show significant income parameters and six (Ecuador, El Salvador, Jamaica, Mexico, Paraguay and Peru) have signs supporting the EKC hypothesis.

With respect to the control variables included, we observe that the parameter related to renewable energy production is significant and negative in most of countries for which cointegration is found. This result is not surprising considering that renewable energy production generates a lesser amount of emissions than energy obtained from fossil fuels. However, it is interesting to note that in Paraguay, where hydroelectric energy generation is particularly important, the parameter related to renewable energy production has positive sign, implying that this energy production is increasing $CO_2$ emissions in this country. This issue should be further investigated.

The population density parameter is significant in twelve countries in this estimation, with mixed signs. Again, our results support the idea that higher population density tends to increase emissions in small countries – for example, Cuba, Dominican Republic El Salvador and Jamaica for which the parameter has positive sign – whereas it might have a beneficial impact on emissions in countries like Chile where more dense populations can significantly reduce transportation costs and emissions.

Finally, we observe that the share of rural population also seems to have an impact on emissions per capita. Not surprisingly, a higher share of rural population is generally leading to lower levels of $CO_2$ emissions per capita – in most countries in our sample, the parameter is significant and negative.

4.6 Estimating the EKC relationship controlling for energy consumption

The importance of energy consumption and the different sources of energy generation has already been discussed. In this model we use the bound tests and
ARDL specification to estimate the long run relationships testing the EKC hypothesis controlling for electricity, gasoline, diesel and fuel consumption. The results of these estimations are found in table 7.

We found cointegration in fourteen out of twenty-one countries in the sample, and significant income parameters in eight of these countries. However, according to the signs of the parameters, we only find support for the EKC in Costa Rica, Cuba, El Salvador and Mexico.

With respect to the variables included to control for energy consumption we find that they are significant in most countries. Overall, the signs are as expected. Indeed, the parameters related to diesel, gasoline and fuel consumption are significant and positive in the vast majority of cases: not at all surprisingly fossil fuel consumption increases $CO_2$ emissions per capita. Conversely, mixed results are found for the electricity consumption parameter that is positive or negative depending on the country. This is likely to depend on the source of electricity generation in each country as well as on the extent to which electricity is substituting energy consumption from other more or less environmentally damaging sources.

4.7 Discussion of the results

The results of the estimates performed point out to mixed results. We find that the number of countries for which we find cointegration in the different model specifications, varies depending on the variables we control for. When the model includes more control variables we observe an increase in the number of countries that show cointegrating relationships. In the cases in which we find cointegration, not always the income parameters are significant for all countries. As a consequence, in some cases it is not possible to define which pattern carbon dioxide emissions follow as income grows. Moreover, even when the income parameters are significant, not always they have the signs predicted by the EKC hypothesis. Overall, our results do not support the EKC hypothesis for most countries in the region, implying that we cannot expect an automatic reduction of $CO_2$ emissions per capita with income growth, even in the long term. However, there is a minority of countries for which we find fairly consistent results supporting the EKC hypothesis. In the case of Mexico, we find support for the EKC in all the six models performed and the estimated turning points are also stable, ranging from a minimum of 8993 US$ in model 4 to a maximum of 11312.9 US$ in model 6. The turning point estimated is located inside the sample in models shown in tables 2, 3, 5 and 6. Similar results are obtained for Costa Rica and El Salvador. In these cases we find support for the EKC in four out of the six models performed and the values estimated for the income parameters also are quite robust resulting in pretty stable turning point
estimates – at about 9000 US$ and 2800 US$ in Costa Rica and El Salvador respectively. In Ecuador, the EKC hypothesis is confirmed in four out of six cases as well, but the estimates for the turning points are less robust, ranging from 4498 to 9059 US$. In the case of Costa Rica, the turning points are inside the sample in models shown in tables 4 and 7. The same happens in the case of El Salvador for models shown in tables 4 to 7. Conversely in the case of Ecuador, the turning points are inside the sample in models shown in tables 3 and 5. In other countries we also observe results confirming the EKC hypothesis, but those results are not robust across different model specifications. Overall, we can conclude that in most of the countries of the region the EKC is not supported by evidence. However, there are some countries – namely Mexico, Costa Rica, El Salvador and Ecuador – for which the relationship between CO₂ emissions and income per capita seems to be described by an inverted U-shaped curve in the long term.

With respect to the control variables included in the different models we observe that these are in general significant meaning that not considering them might create problems of omitted variables bias. Even if not all control variables are significant in all the countries considered and even if in some cases the results are mixed, the signs of the parameters are as expected in most cases. This allows us to draw some conclusions about the environmental impact of some elements related to the process of development that have been considered as either causing environmental damage or allowing environmental improvement, independently from income growth.

With respect to the investigation of the composition effect in LACs, our results do not provide evidence of a unique effect of the environmental impact of the industrial and service sectors. However, we find that the primarization of LACs’ economies tends to have a negative impact on the environment, as measured by CO₂ emissions. This conclusion is supported by the observation that both the share of commodity exports and the share of agricultural land tend to increase CO₂ emissions per capita. Considering that a higher share of rural population is found to reduce CO₂ emissions per capita, we consider this result as related to the commodities production model in the region rather than to the sector itself. In this sense, the primary sector that could be modestly impactful on the environment, ends up exerting high environmental damage due to the way it is deployed in the region – in the form of mining activities or agroindustry.

Among the factors that are also found to be relevant in determining the environmental impact of growth we find the energy mix to play an important role. Indeed, if on the one hand a higher consumption of fossil fuel produced energy tends to increase CO₂ emissions, they are reduced if a higher share of renewable energy is produced. As a consequence, the environmental effect of economic growth is not only determined by the level of such growth, but the way the additional income is produced is also extremely important.

With respect to other elements considered in our analysis, we find more mixed results. Indeed, the environmental effect of both population density and external relationships seems to highly depend on the individual country consid-
ered. As a general consideration, we might say that population density tends to reduce \( CO_2 \) emissions only in those countries that have a geographical configuration that makes the benefits of more dense population – in terms of networking and reduction of transportation costs – particularly important. Moreover, with respect to the effect of FDI inflows and trade related variables, we observed that not a common pattern exists. Our results provide some evidence that FDI inflows tend to increase \( CO_2 \) emissions in most countries of the region, but no clear support for the PHH is provided by our results.

5 Conclusions

Based on the influential Environmental Kuznets Curve hypothesis, in this paper we employed an ARDL bounds testing approach to cointegration and Unrestricted Error Correction Models to estimate the relationship between income and \( CO_2 \) emissions per capita in twenty-one Latin American Countries over 1960-2017. Following a time series approach we performed a separate estimation for each one of the countries in our sample. We estimated six different specifications of the model for each country, to take into account the independent effect on \( CO_2 \) emissions per capita of different factors other than income. The analysis performed in this paper was aimed at addressing two specific concerns. First, through the estimation of the model controlling for different variables, we wanted to assess if the EKC hypothesis was confirmed in any of the LACs considered, and if its validity was robust across different model specifications, given that the high volatility of the estimates is one of the main criticisms concerning the EKC hypothesis. Second, the inclusion of control variables accounting for the effect on \( CO_2 \) emissions of a number of relevant factors, should serve to increase our understanding of the causes of change of emissions in different countries, which is an important premise to design effective mitigation policies.

With respect to the first point, we might say that the EKC hypothesis is not supported by evidence in most countries in the region. However, we also found that in a minority of countries in our sample the EKC hypothesis seems to effectively describe the income-emissions relationship in the long term. Indeed, we find robust results supporting the EKC hypothesis in Mexico, Costa Rica, El Salvador and Ecuador. The finding that different patterns for the dynamics of \( CO_2 \) emissions at different levels of income per capita apply to different countries in the region enhances the importance of analyzing this relationship at the country level. Indeed, there is not a unique pattern that describes this relationship for all countries even in the same region, and individual experiences are extremely important in defining the dynamics of \( CO_2 \) emissions per capita along the development path. In this sense, we observed that the inherent geographical characteristics of the country and the policies implemented, particularly environmental regulations, are likely to explain different effects on \( CO_2 \) emissions of population density and trade, respectively. On the other hand, we also observed that some common patterns in the region, particularly commodity dependence and the specific production models of these primitized economies,
exert similar negative effects on environmental quality. In this respect, the promotion of a production and export structure less concentrated in commodities is advisable in the region. This virtuous structural change, if pursued, could provide these countries with better environmental performance, in addition to more stable growth. Moreover, the development of a greener energy mix, particularly through the fostering of renewable energy production, is advisable in consideration of the reduced environmental impact of energy consumption from these sources, against fossil fuel produced energy.

In conclusion, both the observation that the EKC hypothesis describes the income-emissions pattern only in a minority of countries in the region and the manifest importance of some country-specific policies in determining a lesser environmental impact of growth, call for environmental policy in the region. These policies, in the form of promotion of renewable energy production, fostering of greener sectors of economic activity or environmental standards to be implemented in conjunction to increased international openness, can strongly influence the impact of growth on CO$_2$ emissions in these countries allowing them to capture the economic benefits of it without exerting ever increasing environmental damage.

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Tables:

Table 1: Data employed in the analysis. Definition, sample periods and sources.

| Variable | Definition | Source | Sample |
|----------|------------|--------|--------|
| $e_t$    | CO$_2$ per capita emissions - tonnes per capita | World Bank Development Indicators | 1960 - 2017 |
| $y_t$    | GDP per capita - 2010 Constant $\$ | World Bank Development Indicators | 1960 - 2017 |
| $x_{1,t}$| Agriculture value added to GDP- Constant 2010 US $\$ | World Bank Development Indicators | 1970 - 2017 |
| $x_{2,t}$| Industry value added to GDP- Constant 2010 US $\$ | World Bank Development Indicators | 1970 - 2017 |
| $x_{3,t}$| Services value added to GDP- Constant 2010 US $\$ | World Bank Development Indicators | 1970 - 2017 |
| $x_{4,t}$| Exports of primary goods as a share of total exports | CEPAL - CEPALSTAT | 1963 - 2017 |
| $x_{5,t}$| Population Density Persons by Km$^2$ | World Bank Development Indicators | 1960 - 2017 |
| $x_{6,t}$| Foreign Direct Investment - net inflows -% of GDP | World Bank Development Indicators | 1970 - 2018 |
| $x_{7,t}$| Exports of good and services - % of GDP | World Bank Development Indicators | 1960 - 2018 |
| $x_{8,t}$| Imports of good and services - % of GDP | World Bank Development Indicators | 1960 - 2018 |
| $x_{9,t}$| Agricultural land - % of land area | World Bank Development Indicators | 1970 - 2018 |
| $x_{10,t}$| Renewable Electricity Production - per capita | CEPAL - CEPALSTAT | 1970 - 2017 |
| $x_{11,t}$| % of Rural Population | Latin American Energy Organization | 1970 - 2018 |
| $x_{12,t}$| Diesel oil consumption - per capita | Latin American Energy Organization | 1970 - 2018 |
| $x_{13,t}$| Electricity consumption - per capita | Latin American Energy Organization | 1970 - 2018 |
| $x_{13,t}$| Gasoline oil consumption - per capita | Latin American Energy Organization | 1970 - 2018 |
| $x_{14,t}$| Fuel oil consumption - per capita | Latin American Energy Organization | 1970 - 2018 |
Table 2: Results of the bounds test and estimation of the long-run relationship for the quadratic EKC relationship $e_t = \beta_0 + \beta_1 y_t + \beta_2 y_t^2 + u_t$

| Country | ARDL model | Bounds test | Conclusion | $\beta_0$ | $\beta_1$ | $\beta_2$ | Turning point | $EC_{t-1}$ |
|---------|------------|-------------|------------|---------|---------|---------|---------------|-------------|
| ARG     | (2, 0, 0)  | CI          | 33.64      | -7.777  | 0.665   |          | 4282.96       | -0.7396$^a$ |
| BOL     | (1, 0, 1)  | NOT CI      |            |         |         |         |               |             |
| BRA     | (1, 0, 1)  | NOT CI      |            |         |         |         |               |             |
| CHI     | (1, 0, 1)  | NOT CI      |            |         |         |         |               |             |
| COL     | (1, 1, 0)  | NOT CI      |            |         |         |         |               |             |
| COS     | (1, 3, 0)  | CI          | -87.567$^a$| 19.277$^a$| -1.0556$^a$| 9235.41 | -0.6301$^a$ |
| R.DOM   | (1, 1, 0)  | NOT CI      |            |         |         |         |               |             |
| CUBA    | (3, 0, 0)  | NOT CI      |            |         |         |         |               |             |
| ECU     | (3, 0, 0)  | CI          | -254.90$^a$| 60.048$^a$| -3.524$^a$| 5013.55 | -0.4492$^a$ |
| ELSAL   | (2, 2, 0)  | NOT CI      |            |         |         |         |               |             |
| GUA     | (1, 0, 1)  | NOT CI      |            |         |         |         |               |             |
| HAI     | (1, 1, 1)  | CI          | -185.57$^a$| 41.005$^a$| -2.2446$^a$| 9265.93 | -0.5117$^a$ |
| JAM     | (3, 0, 0)  | NOT CI      |            |         |         |         |               |             |
| MEX     | (1, 0, 0)  | CI          | -37.453$^c$| 8.0952  | -0.4265 | 13230.76| -0.5212$^a$ |
| NIC     | (1, 1, 0)  | NOT CI      |            |         |         |         |               |             |
| PAN     | (1, 0, 0)  | NOT CI      |            |         |         |         |               |             |
| PAR     | (1, 0, 0)  | NOT CI      |            |         |         |         |               |             |
| PERU    | (3, 0, 2)  | NOT CI      |            |         |         |         |               |             |
| VEN     | (1, 0, 0)  | NOT CI      |            |         |         |         |               |             |

Narayan (2005)'s bounds test critical values: 1%: lower bound = 4.8; 1% upper bound = 5.725; 5% lower bound = 3.368; 5% upper bound = 4.205.

$^a$significant parameter at 1%; $^b$significant parameter at 5%; $^c$significant parameter at 10%; $e_t = \ln(CO_{2,pc}); y_t = \ln(GDP); y_t^2 = (\ln(GDP))^2; EC_{t-1}$ : estimation of the cointegration error in the short run relationship or speed of the adjustment in the UECM for $\nabla e_t$.}
Table 3: Results of the bounds test and estimation of the long-run relationship for the quadratic EKC relationship controlling for output structure

\[ e_t = \beta_0 + \beta_1 y_t + \beta_2 y_t^2 + \beta_3 x_{1,t} + \beta_4 x_{2,t} + \beta_5 x_{3,t} + u_t \]

| Country | ARDL model | Bounds test | Conclusion | \( \beta_0 \) | \( \beta_1 \) | \( \beta_2 \) | \( \beta_3 \) | \( \beta_4 \) | \( \beta_5 \) |
|---------|------------|-------------|------------|-------------|-------------|-------------|-------------|-------------|-------------|
| ARG     | (1, 0, 0, 0, 0) | 7.195      | CI         | 27.592      | 8.700       | 0.488       | 0.132       | 0.680b)     | -0.299c)    |
| BOL     | (1, 0, 0, 0, 1) | 3.435      | Inconclusive |             |             |             |             |             |             |
| BRA     | (1, 0, 1, 0, 0) | 1.308      | NOT CI     |             |             |             |             |             |             |
| CHI     | (1, 0, 0, 0, 1) | 3.454      | Inconclusive |             |             |             |             |             |             |
| COL     | (1, 0, 0, 0, 0) | 4.113      | CI         | -49.40a)    | 16.50a)     | -0.823a)    | -0.410      | 0.066       | -0.910b)    |
| COS     | (2, 0, 0, 0, 0) | 4.976      | CI         | -161.0a)    | 37.184a)    | -2.038a)    | 0.323b)     | -0.511      | -0.140c)    |
| CUBA    | (2, 0, 0, 0, 0) | 5.308      | CI         | 25.51       | 10.533      | -0.377      | -0.271      | -1.056      | -2.307d)    |
| R.DOM   | (1, 1, 0, 0, 0) | 3.388      | Inconclusive |             |             |             |             |             |             |
| ECU     | (2, 0, 0, 1, 0) | 8.115      | CI         | -19.789     | -0.515      | 0.033       | -1.032a)    | 0.417       | 1.673a)     |
| ELSAL   | (2, 1, 0, 0, 0) | 3.207      | Inconclusive |             |             |             |             |             |             |
| GUA     | (1, 0, 0, 0, 0) | 3.155      | Inconclusive |             |             |             |             |             |             |
| HAI     | (2, 1, 1, 2, 0) | 4.164      | CI         | -180.42     | 42.822      | -3.804      | 2.411b)     | -1.344a)    | 0.483       |
| HON     | (1, 0, 2, 0, 1) | 6.189      | CI         | 91.425      | -9.406      | 0.646       | -28.638a)   | -0.058      | 0.233       |
| JAM     | (2, 0, 1, 0, 0) | 6.997      | CI         | -822.2a)    | 193.12a)    | -11.35a)    | 1.145       | 0.420       | -1.400d)    |
| MEX     | (1, 0, 1, 1, 0) | 10.267     | CI         | -189.4      | 42.557a)    | -2.323a)    | -0.334a)    | 0.084       | 0.039       |
| NIC     | (4, 4, 4, 3, 3) | 2.626      | NOT CI     |             |             |             |             |             |             |
| PAN     | (1, 0, 0, 0, 0) | 3.242      | Inconclusive |             |             |             |             |             |             |
| PAR     | (1, 0, 0, 0, 0) | 1.594      | NOT CI     |             |             |             |             |             |             |
| PERU    | (1, 0, 0, 0, 0) | 6.674      | CI         | -0.033      | -0.633      | 0.098       | -0.126      | -0.317      | 0.382       |
| URU     | (3, 1, 2, 0, 1) | 2.894      | Inconclusive |             |             |             |             |             |             |
| VEN     | (1, 0, 2, 0, 2) | 6.139      | CI         | 264.11a)    | -54.28a)    | 2.836a)     | 0.019       | -0.507      | 0.356       |

Narayan (2005)’s bounds test critical values: 5% lower bound = 2.694; 5% upper bound = 3.829.

a) significant parameter at 1%; b) significant parameter at 5%; c) significant parameter at 10%; \( e_t = \ln(CO_{2,pc}); y_t = \ln(GDP); y_t^2 = (\ln(GDP))^2; x_{1,t} = \text{Agriculture added value to GDP}; x_{2,t} = \text{industry added value to GDP}; x_{3,t} = \text{services added value to GDP}; E_{t-1} \text{: estimation of the cointegration error in the short run relationship. or speed of the adjustment in the UECM for } \nabla e_t \)
| Country | ARDL model | Bounds test | Conclusion | $\beta_0$ | $\beta_1$ | $\beta_2$ | $\beta_3$ | $\beta_4$ | Tu  |
|--------|------------|--------------|------------|----------|----------|----------|----------|----------|-----|
| ARG    | (1, 1, 0, 0, 0) | 2.876 | Inconclusive |         |          |          |          |          |     |
| BOL    | (1, 1, 0, 1, 1) | 4.694 | CI | -50.033 | 11.895 | -0.729 | -0.208 | 1.023 |     |
| BRA    | (1, 1, 0, 0, 0) | 1.400 | NOT CI |         |          |          |          |          |     |
| CHI    | (2, 2, 0, 0, 0) | 2.118 | NOT CI |         |          |          |          |          |     |
| COL    | (1, 0, 0, 0, 0) | 4.634 | CI | -54.593 | 12.575 | -0.663 | 0.128 | -1.291 |     |
| COS    | (1, 3, 0, 0, 0) | 4.468 | CI | -91.038 | 20.095 | -1.103 | -0.018 | 0.004 |     |
| CUBA(*) | (2, 0, 3, 0) | 6.387 | CI | 9.308 | 0.468 | 0.018 |          | -2.901 |     |
| R.DOM  | (1, 2, 2, 3, 0) | 3.726 | Inconclusive |         |          |          |          |          |     |
| ECU    | (3, 0, 0, 0, 1) | 6.217 | CI | -111.81 | 35.513 | -1.960 | -8.848 | -1.830 |     |
| ELSAL  | (1, 0, 1, 0, 0) | 4.363 | CI | -331.85 | 80.845 | -5.082 | 0.004 | 1.824 |     |
| GUA    | (1, 0, 1, 0, 0) | 2.058 | NOT CI |         |          |          |          |          |     |
| HAI    | (1, 1, 1, 0, 0) | 4.099 | CI | 13.089 | -8.832 | 0.708 | 0.209 | 1.495 |     |
| HON    | (1, 0, 0, 0, 2) | 2.626 | NOT CI |         |          |          |          |          |     |
| JAM    | (2, 2, 2, 0, 4) | 10.586 | CI | -277.69 | 66.447 | -3.626 | 0.106 | 0.294 |     |
| MEX    | (1, 0, 0, 0, 2) | 4.991 | CI | -125.74 | 27.960 | -1.508 | 0.092 | -0.577 |     |
| NIC    | (4, 2, 0, 0, 2) | 3.167 | Inconclusive |         |          |          |          |          |     |
| PAN    | (4, 1, 1, 2, 3) | 3.010 | Inconclusive |         |          |          |          |          |     |
| PAR    | (1, 1, 0, 1, 0) | 9.040 | CI | -9.813 | 4.354 | -0.277 | 2.499 | 1.043 |     |
| PERU   | (1, 0, 0, 2, 0) | 10.067 | CI | -29.063 | 3.983 | -0.196 | 1.807 | 0.447 |     |
| URU    | (1, 0, 0, 0, 0) | 3.422 | Inconclusive |         |          |          |          |          |     |
| VEN    | (1, 1, 0, 0, 0) | 2.628 | Inconclusive |         |          |          |          |          |     |

Narayan (2005)’s bounds test critical values: 5% lower bound = 2.763; 5% upper bound = 3.813.

*significant parameter at 1%; b) significant parameter at 5%; c) significant parameter at 10%; $e_t = \ln(CO_{2,te})$; $y_t = \ln(GDP)$; $y_{-1}^2 = (\ln(GDP))^2$; $x_{4,t}$ = exports of primary goods; $x_{5,t}$ = population density; $EC_{t-1}$ : estimation of the cointegration error in the short run relationship; or speed of the adjustment in the UECM for $\nabla e_t$; (*): The model for CUBA does not include exports of primary goods due to the lack of data.
Table 5: Results of the bounds test and estimation of the long-run relationship for the quadratic EKC relationship controlling for external funds, external relationships and agricultural land. $e_t = \beta_0 + \beta_1 y_t + \beta_2 y_t^2 + \beta_3 x_{6,t} + \beta_4 x_{7,t} + \beta_5 x_{8,t} + \beta_6 x_{9,t} + u_t$

| Country  | ARDL model  | Bounds test | Conclusion | $\beta_0$  | $\beta_1$  | $\beta_2$  | $\beta_3$  | $\beta_4$  | $\beta_5$  |
|----------|-------------|-------------|------------|------------|------------|------------|------------|------------|------------|
| ARG      | (2, 0, 0, 0, 0, 0) | 6.644 | CI         | -60.362    | 12.305     | -0.664     | 0.010$^a$ | 0.013      | -0.068     |
| BOL      | (3, 3, 4, 0, 0, 4, 4) | 6.160 | CI         | -731.36    | 186.67     | -12.286    | 0.027      | -0.015     | -8.823     |
| BRA      | (1, 4, 4, 3, 4, 2, 3) | 11.032 | CI         | -480.70    | 108.10$^c$ | -5.497$^c$ | -0.167     | -0.411     | 0.515$^c$  |
| CHI      | (1, 0, 1, 0, 0, 0, 1) | 2.694 | Inconclusive |           |           |           |           |           |           |
| COL      | (1, 0, 0, 2, 0, 1, 1) | 2.149 | NOT CI     |           |           |           |           |           |           |
| COS      | (3, 4, 4, 4, 4, 4, 3) | 4.421 | CI         | -47.82     | 8.433      | -0.392     | 0.005      | -0.585     | 1.001      |
| CUBA$^c$ | (2, 1, 0, 0, 3, 0) | 4.448 | CI         | 14.862     | -3.911     | 0.254      | 0.259      | 0.117      |           |
| R.DOM    | (1, 1, 0, 0, 0, 0, 0) | 1.386 | NOT CI     |           |           |           |           |           |           |
| ECU      | (3, 0, 0, 2, 3, 0) | 7.267 | CI         | -572.85$^a$ | 135.99$^a$ | -8.084$^c$ | -0.046     | -2.306     | 4.079      |
| ELSAL    | (2, 1, 0, 0, 4, 0, 2) | 5.684 | CI         | -301.72$^a$ | 71.29$^a$  | -4.468$^a$ | 0.027$^a$  | -0.225     | -0.910$^a$ |
| GUA      | (1, 0, 1, 0, 0, 0, 0) | 1.338 | NOT CI     |           |           |           |           |           |           |
| HAI      | (1, 1, 1, 1, 0, 0, 0) | 3.165 | Inconclusive |           |           |           |           |           |           |
| HON      | (1, 0, 0, 0, 0, 0, 1) | 4.286 | CI         | 76.37      | -21.516$^c$ | 1.537$^b$  | 0.016      | 0.482$^a$  | 0.001      |
| JAM      | (4, 0, 1, 4, 4, 3, 4) | 11.032 | CI         | -376.69$^a$ | 85.37$^a$  | -4.954$^a$ | -0.028$^a$ | -0.008$^a$ | -0.909$^a$ |
| MEX      | (3, 4, 4, 3, 2, 2, 4) | 8.849 | CI         | -320.91$^a$ | 77.04$^b$  | -4.231$^b$ | 0.126      | -0.830$^c$ | 0.431$^c$  |
| NIC      | (4, 4, 4, 2, 4, 4, 2) | 6.362 | CI         | 21.442$^c$ | -8.204$^b$ | 0.607$^b$  | 0.004      | -0.267$^a$ | 0.230$^a$  |
| PAN      | (4, 4, 4, 2, 2, 4, 4) | 6.125 | CI         | -162.68$^c$ | 33.39$^b$  | -2.117$^c$ | 0.048      | 0.700      | -0.170     |
| PAR      | (4, 2, 2, 0, 0, 1, 0) | 2.728 | Inconclusive |           |           |           |           |           |           |
| PERU     | (1, 0, 0, 0, 0, 0, 0) | 4.808 | CI         | -34.55     | 7.447      | -0.378     | -0.002     | -0.096     | -0.081     |
| URO      | (1, 2, 0, 0, 0, 0, 0) | 3.201 | Inconclusive |           |           |           |           |           |           |
| VEN      | (1, 0, 1, 1, 0, 0, 0) | 4.660 | CI         | 155.63     | -35.03     | 1.87       | 0.280$^a$  | 0.014      | -0.262     |

Narayan (2005)'s bounds test critical values: 5% lower bound = 2.591; 5% upper bound = 3.766.

$^a$significant parameter at 1%; $^b$significant parameter at 5%; $^c$significant parameter at 10%; $e_t = \ln(CO_{2,pe}); y_t = \ln(GDP); y_t^2 = (\ln(GDP))^2; x_{6,t} = $ Foreign Direct Investment (FDI); $x_{7,t} = $ Exports; $x_{8,t} = $ Imports; $x_{9,t} = $ Agricultural land; $E_{C,t-1} :$ estimation of the cointegration error in the short run relationship, or speed of the adjustment in the UECM for $\nabla e_t$; $^{(*)}$ Model for CUBA does not include Foreign Direct Investment due to the lack of data.
Table 6: Results of the bounds test and estimation of the long-run relationship for the quadratic EKC relationship controlling for renewable energy production, population density and rural population $e_t = \beta_0 + \beta_1 y_t + \beta_2 y_t^2 + \beta_3 x_{10,t} + \beta_4 x_{5,t} + \beta_5 x_{11,t} + u_t$

| Country | ARDL model | Bounds test | Conclusion | $\beta_0$ | $\beta_1$ | $\beta_2$ | $\beta_3$ | $\beta_4$ | $\beta_5$ |
|---------|------------|-------------|------------|---------|---------|---------|---------|---------|---------|
| ARG     | (1, 0, 0, 1, 0) | 9.980       | CI         | -43.222 | 10.594  | -0.544  | -0.293$^a$ | -1.122  | -1.098  |
| BOL     | (1, 1, 0, 0, 0) | 3.133       | Inconclusive |         |         |         |         |         |         |
| BRA     | (1, 0, 1, 0, 0, 1) | 3.115      | Inconclusive |         |         |         |         |         |         |
| CHI     | (1, 0, 0, 0, 0, 0) | 7.025       | CI         | -1.552  | -3.422  | 0.265$^c$ | -0.220  | -1.929$^b$ | 2.718$^a$ |
| COL     | (1, 0, 0, 1, 0, 0) | 2.800       | Inconclusive |         |         |         |         |         |         |
| COS     | (1, 0, 1, 0, 1) | 9.213       | CI         | -42.189 | 9.017   | -0.414  | -0.589$^a$ | -0.850$^a$ | 0.506   |
| CUBA    | (1, 2, 4, 0, 2, 4) | 16.173      | CI         | -68.743$^a$ | -1.710 | 0.174   | -0.047  | 11.302$^a$ | 6.166$^a$ |
| R.DOM   | (4, 4, 4, 4, 0) | 12.568      | CI         | 30.699  | -12.566$^c$ | 0.766$^c$ | 0.788$^c$ | 2.901$^a$ | 0.920   |
| ECU     | (3, 0, 0, 0, 0, 0) | 4.566       | CI         | -270.80$^b$ | 64.25$^b$ | -3.626$^b$ | -1.423  | -1.239  | 1.667   |
| ELSAL   | (1, 0, 1, 0, 1, 0) | 4.202       | CI         | -342.55 | 87.777$^a$ | -5.272$^a$ | -0.061  | 1.780$^a$ | -0.010  |
| GUA     | (1, 0, 1, 0, 0, 0) | 1.234       | NOT CI     |         |         |         |         |         |         |
| HAI     | (2, 2, 1, 1, 3, 0) | 7.066       | CI         | 496.01$^a$ | -91.263$^a$ | 6.745$^a$ | -14.681$^a$ | -9.329$^a$ | -12.29$^b$ |
| HON     | (1, 0, 0, 2, 0, 0) | 4.312       | CI         | 329.38$^b$ | -87.795$^b$ | 6.014$^b$ | -1.622$^c$ | -0.182  | 0.155   |
| JAM     | (1, 2, 2, 0, 4, 0) | 8.630       | CI         | -288.79$^b$ | 56.634$^b$ | -3.269$^b$ | -0.274$^b$ | 3.442$^b$ | 6.915$^a$ |
| MEX     | (1, 0, 0, 0, 0, 0) | 4.915       | CI         | -146.37$^a$ | 33.694$^a$ | -1.816$^a$ | -0.041  | -1.001  | -1.095  |
| NIC     | (1, 2, 2, 0, 0, 0) | 10.018      | CI         | 8.811   | -14.435$^a$ | 1.036$^a$ | -1.229$^a$ | -2.77$^a$ | 9.921$^a$ |
| PAN     | (3, 0, 0, 0, 1, 0) | 5.732       | CI         | 74.405$^a$ | -5.933$^a$ | 0.378$^c$ | 0.028   | -5.921$^a$ | -7.201$^a$ |
| PAR     | (1, 0, 0, 0, 0, 0) | 4.629       | CI         | -141.11$^a$ | 50.365$^a$ | -3.133$^a$ | 0.971$^c$ | -5.701$^a$ | -13.915$^a$ |
| PERU    | (1, 0, 0, 0, 0, 0) | 8.489       | CI         | -30.358 | 11.046$^a$ | -0.622$^c$ | -0.368$^b$ | -2.411$^b$ | -2.744$^b$ |
| URU     | (1, 0, 0, 1, 0, 0) | 5.062       | CI         | 5.621   | 4.590   | -0.180  | -0.542$^a$ | -8.960$^a$ | -1.241$^a$ |
| VEN     | (1, 1, 0, 0, 0, 0) | 5.520       | CI         | -61.55  | 16.09   | -0.857  | 0.013   | -0.966  | -1.208$^b$ |

Narayan (2005)’s bounds test critical values: 5% lower bound = 2.67; 5% upper bound = 3.78.

$^a$ significant parameter at 1%; $^b$ significant parameter at 5%; $^c$ significant parameter at 10%; $e_t = \ln(CO_{2,pc})$; $y_t = \ln(GDP)$; $y_t^2 = (\ln(GDP))^2$; $x_{10,t} =$ Renewal energy production; $x_{5,t} =$ Population density; $x_{11,t} =$ Rural population; $EC_{t-1}$ : estimation of the cointegration error in the short run relationship, or speed of the adjustment in the UECM for $\nabla e_t$
Table 7: Results of the bounds test and estimation of the long-run relationship for the quadratic EKC relationship controlling for energy consumption
\[ e_t = \beta_0 + \beta_1 y_t + \beta_2 y_t^2 + \beta_3 x_{12,t} + \beta_4 x_{13,t} + \beta_5 x_{14,t} + \beta_6 x_{15,t} + u_t \]

| Country | ARDL model | Bounds test | Conclusion | \( \beta_0 \) | \( \beta_1 \) | \( \beta_2 \) | \( \beta_3 \) | \( \beta_4 \) | \( \beta_5 \) |
|---------|------------|-------------|------------|----------------|----------------|----------------|----------------|----------------|----------------|
| ARG     | (2,1,1,2,1,3,3) | 4.935       | CI         | 131.32\(^a\)  | -29.334\(^a\) | 1.654\(^a\)   | 0.213          | -0.041         | -0.145\(^b\)  |
| BOL     | (2,2,0,2,0,0,0) | 3.605       | Inconclusive |                |                |                |                |                |                |
| BRA     | (1,2,3,0,4,0,0) | 13.097      | CI         | 143.59\(^b\)  | -29.701\(^b\) | 1.531\(^b\)   | 2.083\(^a\)   | -0.114         | 0.164\(^c\)   |
| CHI     | (1,0,1,4,0,0,0) | 7.879       | CI         | 109.49\(^a\)  | -22.116\(^a\) | 1.101\(^a\)   | 0.028          | 1.836\(^a\)   | 1.369\(^a\)   |
| COL     | (1,0,0,0,2,0,0) | 2.065       | NOT CI     |                |                |                |                |                |                |
| COS     | (1,4,0,1,0,0,0) | 6.717       | CI         | -48.84\(^a\)  | 11.646\(^c\)  | -0.694\(^b\) | 1.033\(^a\)   | -0.204         | 0.286\(^a\)   |
| CUBA    | (1,3,3,4,2,4,4) | 7.927       | CI         | -106.37        | 25.943\(^b\)  | -1.563\(^b\) | -0.360\(^c\)  | 0.134          | 0.003          |
| R.DOM   | (1,0,0,0,0,1,0) | 3.619       | Inconclusive |                |                |                |                |                |                |
| ECU     | (3,3,1,4,3,4,3) | 6.210       | CI         | 185.36         | -39.82         | 2.162          | -3.637         | 3.540          | 2.556\(^b\)   |
| ELSAL   | (1,0,1,0,0,0,0) | 7.451       | CI         | -181.33\(^a\) | 46.124\(^a\)  | -2.826\(^a\)  | 0.454\(^a\)   | 0.113\(^b\)   | 0.317\(^a\)   |
| GUA     | (3,0,0,1,2,2)   | 4.007       | CI         | 97.32          | -25.728\(^c\) | 1.701\(^c\)   | 0.516\(^a\)   | -0.316\(^c\)  | 0.553\(^a\)   |
| HAI     | (1,1,0,0,0,4,1) | 7.999       | CI         | -21.951        | 5.772          | -0.371         | 0.579\(^a\)   | 0.212\(^a\)   | 0.145          |
| HON     | (1,0,0,0,0,3,0) | 7.914       | CI         | 26.904         | -7.140         | 0.496          | 0.631\(^a\)   | -0.174\(^a\)  | 0.865\(^a\)   |
| JAM     | (3,0,3,0,4,3,3) | 2.423       | NOT CI     |                |                |                |                |                |                |
| MEX     | (1,4,2,0,1,3,0) | 5.663       | CI         | -138.6         | 30.021\(^a\)  | -1.608\(^a\)  | 0.131          | -0.126\(^a\)  | -0.037         |
| NIC     | (1,3,0,0,0,0,4) | 19.661      | CI         | -5.465         | 2.233          | -0.187         | 0.871\(^a\)   | -0.316\(^c\)  | 0.725\(^a\)   |
| PAN     | (1,0,0,0,0,0,0) | 3.455       | Inconclusive |                |                |                |                |                |                |
| PAR     | (1,1,0,0,1,1,0) | 9.758       | CI         | -17.98         | 5.512          | -0.402         | 0.452\(^a\)   | 0.290\(^a\)   | 0.300\(^a\)   |
| PERU    | (1,0,0,0,0,0,0) | 6.194       | CI         | -23.792        | 4.682          | -0.216         | 0.125          | -0.302         | 0.083          |
| URU     | (1,0,0,0,0,1,0) | 1.779       | NOT CI     |                |                |                |                |                |                |
| VEN     | (3,0,0,0,0,1,0) | 3.098       | Inconclusive |                |                |                |                |                |                |

Narayan (2005)’s bounds test critical values: 5% lower bound = 2.591; 5% upper bound = 3.766.

\(^a\)significant parameter at 1%; \(^b\) significant parameter at 5%; \(^c\) significant parameter at 10%; \( e_t = \ln(CO_{2,pc}); y_t = \ln(GDP); y_t^2 = (\ln(GDP))^2; x_{12,t} = \) Diesel consumption; \( x_{13,t} = \) Electricity consumption; \( x_{14,t} = \) Gasoline consumption; \( x_{15,t} = \) Fuel consumption; \( EC_{t-1} \) : estimation of the cointegration error in the short run relationship. or speed of the adjustment in the UECM for \( \nabla e_t \)