The energy-growth nexus in 3 Latin American Countries within the framework of the EKC: in case of Argentina, Brazil, and Chile

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Abstract

In this paper, we examine the effects of economic growth and different types of energy consumption on environmental quality in terms of carbon dioxide emissions (CO2) in the framework of the Environmental Kuznets Curve (EKC) in three Latin American countries, namely Argentina, Brazil, and Chile from 1975 to 2018. Specifically, four different types of energy sources were considered (oil, natural gas, hydroelectricity, and renewable energy) in addition to agricultural lands and trade openness as our control variables.

Before applying ARDL technique, we reviewd the cointegration relationship among the variables by using cointegration bounds test, and, verified the validity of the EKC hypothesis and the impacts of the variables in the short and long run alike through the Autoregressive Distributed lag (ARDL) in the form of Error Correction Mechanism (ECM). Lastly, after ARDL-ECM estimation, we carried out Toda-Yamamoto Granger causality test to identify the direction of causality between the variables.

Our estimation results confirm that there is a cointegration relationship exists between CO2 emissions and our explanatory variables, in all cases, which is supported by the fact that the results of the F-statistics of cointegration bounds test were above the upper bound critical value at 1% significance level. In ARDL-ECM estimation, we only could verify the EKC hypothesis (inverted U-shaped curve between income growth and CO_2 emissions) in Argentina in the long run but not in both Brazil and Chile, where the opposite patterns (U-shaped curves) were observed in the long run. Moreover, we could found the evidence of a long-run equilibrium relationship among the variables in ARDL-ECM estimation based on the fact that the Error Correction Term had a negative sign and statistically significant at 1% level in all three models for each country we analyzed, which supports the results of our previous cointegration bounds test. Furthermore, we could observe that fossil fuel energy, especially oil consumption, had a strong negative impact on environmental quality caused by increasing CO2 emissions both in the short and the long term in all three countries. As for natural gas, we found that it also contributes to increasing CO2 emissions but to a significantly lesser extent than oil both in the short and the long term in Argentina, Brazil, and Chile. In relation to hydroelectricity, it had a significant negative impact on CO2 emissions only in both Brazil and Chile. Finally, renewable energy consumption had a statistically significant negative impact on CO_2 emissions only in Chile while in Brazil, it had a positive impact in the long run. Regarding to the Toda-Yamamoto Granger Causality test, it tells us that oil consumption can be drastically reduced and replaced by other clean energy sources which emit significantly less amounts of CO_2 emissions in accordance with their economic growth in Argentina, Brazil, and Chile since the conservation hypothesis tells us that the reduction in oil consumption does not hinder economic growth in these countries. Therefore, energy consumption from natural gas, hydropower, and renewables leads to economic growth in Argentina and Chile (these 3 types of energy all granger caused economic

growth in Chile while only hydropower did in case of Argentina), thus promotion of their consumption might help to boost economic growth along with achieving environmental protection goal in both Argentina and Chile.
The findings of our study tell that renewable energy might have a great potential to reduce CO_2 emissions in the future but this advantage is not fully exploited since we found only a significant negative impact on CO_2 emissions in Chile. Our findings also suggest that other less carbon-intensive energy sources such as natural gas and hydropower combined with renewable energy might produce synergetic effect and they can contribute to not only enhancing energy security (by diversifying energy mix and reducing the risk of intermittency of renewable energy) but also achieving successful low-carbon energy transition in Argentina, Brazil, and Chile.

Keywords: Environmental Kuznets Curve, CO_2 emissions, ARDL, Latin America, economic growth, energy consumption

1.Introduction

Growing damages inflicted by climate changes and global warming have been drawing initiatives and collaborations at the global level to challenge them in collective approaches. The greenhouse gases, mainly CO_2 emissions produced by anthropogenic activities (by burning fossil fuels such as coal, oil, and gas, unsustainable farming practices and deforestation) are known as the major contributor to global warming. Seriousness and severity of the problem urged many international initiatives to be taken since 1990 to deal with climate changes and global warming, such as the United Nations Conference on Environment and Development (UNCED) celebrated in Rio de Janeiro in 1992, the Kyoto Protocol in 1997, the World Summit on Sustainable Development in Johannesburg in 2002, the Paris Agreement in 2015 and recently celebrated COP 26 in Glasgow in 2021 among others.

In this context, attentions growing globally among academia and policymakers advocate needs for new economic growth model in which not only GDP growth, but also the improvement of social welfare and the preservation of environment, known as sustainable development, should be encompassed given that the irreversibility of climate changes will accompany enormous economic and social costs without timely addressing. Especially in Latin American countries, both decoupling economic growth from environmental degradation and achieving sustainable development are particularly challenging in two reasons: their relatively low-income levels (compared to industrialized countries) among with high inequality prevailing in the region and their high vulnerability to weather events (especially for Caribbean countries).

First, the LAC region mainly consists of middle- and low-income developing countries. It means that they have an urgent need to keep growing their economy to close the social gap with advanced countries and enhance standards of living of people by reducing high levels of poverty and income inequality prevailing in the region. However, economic growth is usually accompanied by more energy demand and energy consumption following due to economic activities increasing. This implies more CO_2 emissions if country´s energy mix is highly dependent on polluting and dirty energy sources such as fossil fuels. Consequently, the country´s environmental quality will be getting worse. Although the LAC region has one of the cleanest electricity mixes in the world thanks to the high share of hydropower in their electricity generation process[1],the use of this kind of energy brings a lot of controversies since it can produce a negative impact on local environment during the process of construction of dams with destroying ecosystem and reducing biodiversity by displacement of natural habitats and changes in water flows. Also, hydro energy production is very sensitive to weather conditions (during the dry season, its capacity of electricity generation is seriously affected). Furthermore, the CO_2 emitted by energy sectors has increased remarkably and it is expected to continue growing by 132 percent between 2010 and 2050 (BID,2014).

Second, LAC is highly vulnerable to extreme weather events[2] even though the region´s contribution to the global GHG emissions is only 8,3% of the global GHG emissions (Cárdenas et al.2021).During the last twenty years, the average temperature in LAC region has increased by 0,1º C per decade in average and the effects of climate change are already becoming more evident around the world in diverse forms of natural disasters such as prolonged dry season, a change in the hydrological cycle (change in pattern of precipitation,), rising sea levels due to melting glaciers, and consequently, a serious risk of floods, especially in Central American and Caribbean countries (IPCC,2013).

Based on our observation and analysis, diversifying energy mix of LAC countries by incorporating more renewable energy sources (not only conventional renewable energy sources like hydropower but also non-conventional renewables such as solar, wind, geothermal, tidal) can be a good strategy to keep their economy growing while reducing environmental degradation at the same time. This is because renewable energy provides numerous advantages such as energy security in the sense that it contributes to reducing the high dependence on fossil fuels (for oil export countries like Mexico, Colombia, Venezuela and Ecuador, renewable energy depends less on the volatility of commodity prices in their balance of payments while in the countries importing oil, namely most of the Caribbean countries, it can provide opportunities for reducing dependencies on importing energy by availability of abundant renewable sources in the region),increasing accessibility to energy for poor households in remote areas, reducing the GHG emissions and consequent enhancement of environmental quality and taking attractions of foreign investments on energy sectors and creating green jobs by investments on renewable energy deployment (BID,2016).

In this study, the Environmental Kuznets Curve (EKC) hypothesis during the period of 1975-2018 in 3 Latin American countries was examined, namely Argentina, Brazil, and Chile. Our selection of target countries is based on the followings: On the one hand, they represent the lion´s share of the Latin American economy due to their large size of GDP in the region[3].On the other, they are emerging economies with the highest CO_2 emissions in LAC region[4] and because of its status as emerging economies, their carbon emissions are expected to grow hand in hand with economic growth in the next decade due to an increase in energy demand (in which large share of it

[1] According to IRENA, the renewables share in electricity generation in South America and Central America & Caribbean in 2015 were 64,2% and 29,4% respectively while the world average was just only 22,8 %)

[2]According to World Meteorological Organization (WMO,2021), In LAC region, more than 27% of the population live in coastal areas where 6–8% of them are exposed to high or very high risk of being suffered by coastal hazards. This is especially true for low lying Caribbean states.

[3] According to the World Bank Data in 2020, Brazil was ranked first in terms of GDP at constant 2015 US dollars while Argentina and Chile were ranked third and fifth respectively.

[4] According to the World Bank Data in 2020.Brazil, Argentina, and Chile were ranked second, third, and fifth largest emitters of CO_2 emissions measured in kilotons respectively.

is expected to be met by fossil fuel sources).Therefore, our analysis of the nexus between economic growth, energy consumption and CO_2 emissions in these three countries might not only provide a valuable insight for these 3 countries but also has implications for other emerging economies as well. Through the examination of the EKC hypothesis, we try to determine whether economic growth in these 3 countries is on a sustainable path or not, namely decoupling economic growth from environmental deterioration and the impacts of each source of energy consumption on carbon emissions.

The major contributions of our study can be summarized in two parts:

First, to best of our knowledge, it is the first study that investigates the impacts of energy consumption in a disaggregated manner (oil, natural gas, hydro, and renewable energy) in Argentina, Brazil, and Chile such that it allows us to examine more specifically the impact of each of them on environmental quality in the framework of the EKC in these 3 LAC countries.

Second, as a novelty, the variable LnAgriland was added to our estimation as a proxy for land use change (due to the expansion of agricultural lands and subsequent deforestation). The land use change is an important driver of CO_2 emissions, but it is largely ignored in the existing EKC studies, so controlling for the land use change in our regression allows us to provide more precise estimation and avoid the omitted variable bias issue.

The organization of our paper is as followed. Section 2 provides reviews of the literature survey. Section 3 describes the data. Section 4 presents the methodology, models used and estimation results. Section 5 concludes with some policy recommendations.

2.Literature review

The formal analysis of the nexus between income growth and environmental degradation began with the study of Grossman and Krueger (1991). According to the study, the income growth may affect environmental quality by three different effects: scale, composition, and technological effects (Shahbaz et al.2019). At the initial stage of economic development, there is an upsurge in energy consumption and resource use due to a rise in economic activities known as scale effects which lead to more carbon emissions and environmental degradation. As income grows, economy meets a series of structural change known as composition effect following: During the initial stage of industrialization, the economy shifts from agricultural sector to industrial sector and brings about accelerated economic growth together with a rapid environmental deterioration caused by energy-intensive polluting industries which gives rise to a growing concern about environmental quality. Therefore, polluting industries are gradually replaced by those with clean energy technology and knowledge-intensive service sector grown up at the later stage of industrialization (Shahbaz et al.2019). Consequently, CO_2 emission levels begin to decrease and the relation between economic growth and pollution level turns into negative after reaching a certain threshold income (turning point of EKC). At this moment, lavish investments in innovative technology and green infrastructure are made to prevent environmental degradation which leads to further improvement in environmental quality. This is known as a technological effect.

Regarding to validity of the EKC, there has been no consensus among the researchers. The estimation results differ largely across country or region, the time period considered, and econometric technique used. Some researchers found evidence of the EKC relationship in both developed and in developing countries[5] (Akram et

[5] Excluding LAC countries

al.(2020) for selected South Asian, Asian and most of the African countries; Cantos et al.(2011) for Spain; Destek et al. (2020) for OECD countries; Kahn et al.(2021) for USA; Narayan and Narayan (2010) for the Middle Eastern and South Asian countries; Sarkodie et al.(2018) for Australia; Shah et al.(2021) for Western Asia and North African countries in case of ecological footprint as dependent variable; Shahbaz et al.(2019) for Vietnam in the long run) while others could not verify the EKC (Dogan et al.(2020) for Brazil, Russia, India, China, South Africa, and Turkey; Liu et al. (2017) for Indonesia Malaysia, the Philippines and Thailand).

In relation to LAC region, the presence of the EKC is ambiguous. Some authors found only partial validation of the EKC. Albulescu et al. (2019) investigated the relationship between income, environmental deterioration and FDI for 14 LAC countries from 1980 to 2010 by using panel quantile regression and they could not verify the EKC hypothesis in lower-income countries. Seri et al. (2021) also confirm partial validation of the EKC hypothesis in the region. They studied the nexus between income and per capita carbon dioxide emissions in 21 LAC economies from 1960 to 2017 using the ARDL bounds testing and the UECM and found that the EKC is validated only in a few of LAC countries.

No evidence of the EKC in LAC countries was also confirmed in several studies. Zilio and Recalde (2011) analyzed the nexus between economic growth and energy consumption for 21 LAC countries from 1970 to 2007 by using cointegration approach and they could not verify the EKC hypothesis because of the absence of long - run relationship between the variables. Pablo-Romero et al. (2016) studied the nexus between economic growth and energy consumption in 22 LAC countries from 1990 to 2011 by using absolute energy consumption as a proxy for environmental pressure and they found no evidence of the EKC in the LAC region. Jardón et al. (2017) examined the EKC relationship in a set of 20 LAC countries from 1971 to 2011 by using the FMOLS and the DOLS and they could not verify existence of the EKC due to a lack of long-run equilibrium relationship between the variables.

However, Hanif (2017) could verify the EKC by investigating the EKC relationship in a panel of 20 middle and lower-middle income countries from 1990 to 2015 by using the system GMM with a two-step estimator. He also found that renewable energy consumption contributes to meeting growing energy demand and reducing the trade deficit in the LAC region. In the study of Anser et al. (2020) the EKC was examined in 16 middle and lower-middle income countries in LAC region using panel data analysis. They chose fossil fuels consumption, renewable energy use and industrial growth index as variables in their regression model and applied a two-step GMM robust estimator as econometric technique. They confirm the existence of the EKC and found that both consumption of fossil fuels and industrial growth contribute to an increase in pollution levels (CO_2 emissions) in the LAC region.

3. Data

In our investigation, the relationship between energy consumption, economic growth, and environmental quality in the framework of the EKC was examined in three Latin American countries, namely Argentina, Brazil, and Chile over the period from 1975 to 2018. For this purpose, nine variables were used in total, namely per capita carbon dioxide emissions, per capita GDP and squared GDP per capita, per capita energy consumption (oil, gas, hydroelectricity, and renewable energy), in addition to agricultural land, and trade openness as control variables in our regression model (see Table 1). The reason behind the selection of these four types of energy consumption is because they constitute four main energy sources with high shares in final energy consumption in Argentina, Brazil, and Chile (although the share of each energy source varies from one country to another). Table 1 summarizes the descriptions of variables used in our analysis.

Table 1. Variables description

Var*iable*	Definition	Source
LnCO2pc	Carbon dioxide emissions per capita (million tonnes of carbon dioxide per capita)	British Petroleum (BP)
LnGDPpc	Per capita GDP (constant 2015 US dollars)	World Development Indicators (World Bank)
LnGDPpc2	Squared per capita GDP (constant 2015 US dollars)	World Development Indicators (World Bank)
LnOCpc	Oil consumption per capita (KWh per capita)	British Petroleum (BP)
LnNGaspc	Natural gas consumption (KWh per capita)	British Petroleum (BP)
LnHydropc	Hydroelectricity consumption (KWh per capita)	British Petroleum (BP)
LnRECpc	Renewable energy consumption (KWh per capita)	British Petroleum (BP)
LnAgriland	Agricultural land (% of land area)	World Development Indicators (World Bank)
LnTrade	Trade (% of GDP)	World Development Indicators (World Bank)

Note: in case of different sources of energy consumption (oil, natural gas, hydro, and renewable energy), energy units were converted from exajoules to KWh.

4. Methodology and estimation results

In this section, we proceed to estimate the impacts of different energy consumption and economic growth on environmental quality in the framework of EKC in 3 Latin American countries, namely Argentina, Brazil, and Chile. To this end, 3 models were estimated using the following equations:

$LnCO_2 = f(LnGDP_{pc}, LnGDP_{pc}^2, LnOC_{pc}, LnNGas_{pc},\ LnHydro_{pc}, LnREC_{pc})$ (1)

$LnCO_2 = f(LnGDP_{pc}, LnGDP_{pc}^2, LnOC_{pc}, LnNGas_{pc},\ LnHydro_{pc}, LnREC_{pc}, LnAgriland)$ (2)

$LnCO_2 = f(LnGDP_{pc}, LnGDP_{pc}^2, LnOC_{pc}, LnNGas_{pc},\ LnHydro_{pc}, LnREC_{pc}, LnAgriland, Ln\,Trade)$ (3)

In model 1, we include only GDP, squared GDP, and different sources of energy consumption in our regression model while in model 2 and 3, we added the variable Agricultural land and Agricultural land and Trade respectively as our control variables to test the robustness of our estimation results.

Our estimation strategy consists of six steps: unit root test, cointegration bounds test, ARDL-ECM estimation, postestimation tests, CUSUM and CUSUMSQ tests, and lastly, Granger causality test (in this paper, for the sake of brevity, we present only the results of cointegration bounds test, ARDL-ECM, and the Toda-Yamamoto Granger causality test)

- Unit root test

To test the stationarity and the presence of unit root problem in formal manner, we performed the Zivot-Andrews test (Zivot and Andrews,1992) which is shown in Table 2. The advantage of using this type of test is that it allows to check unit root in the presence of one structural break compared to traditional unit root tests like Augmented Dickey-Fuller and Phillips-Perron (1998) tests which do not consider structural break when testing the unit root hypothesis. As we can see in Table 2, all variables are stationary at first differences without exception, namely all of them are integrated of order 1 or I(1) (in case of LnTrade and LnRECpc in Argentina and Brazil, they are even integrated of order 0 or I(0)) and none of them seem to have an order of integration greater than 1.The condition above mentioned is very important before performing bounds test and ARDL model since variables integrated of order 2 or superior are not allowed (Menegaki,2020).

Table 2 Unit root tests

Argentina					
Variables	Level		First difference		Order of integration
	t-statistic	Structural break	t-statistic	Structural break	
LnCO2pc	-3.941	1989	-5.996***	2003	I(1)
LnGDPpc	-2.775	1985	-6.349***	2003	I(1)
LnGDPpc2	-2.775	2005	-6.372***	2003	I(1)
LnOCpc	-3.357	1989	-5.419**	2004	I(1)
LnNGaspc	-2.907	1995	-6.599***	1985	I(1)
LnHydropc	-2.834	1982	-8.312***	1990	I(1)
LnRECpc	-4.543	1996	-7.448***	1996	I(1)
LnAgriland	-2.976	2004	-6.739***	2003	I(1)
LnTrade	-6.649***	2002	-8.236***	2004	I(0)/I(1)
Brazil					
Variables	Level		First difference		Order of integration
	t-statistic	Structural break	t-statistic	Structural break	
LnCO2pc	-4.096	1988	-6.455***	2010	I(1)
LnGDPpc	-3.562	1990	-5.686***	1984	I(1)
LnGDPpc2	-3.528	1990	-5.638***	1984	I(1)
LnOCpc	-3.037	1983	-5.230**	2010	I(1)
LnNGaspc	-3.075	2001	-7.215***	1999	I(1)
LnHydropc	-3.762	2010	-6.798***	2003	I(1)
LnRECpc	-6.588***	2007	-7.053***	1990	I(0)/I(1)
LnAgriland	-4.465	1997	-6.481***	1986	I(1)

LnTrade	-4.231	1999	-5.855***	1990	I(1)
Chile					
Variables	Level		First difference		Order of integration
	t-statistic	Structural break	t-statistic	Structural break	
LnCO2pc	-3.602	1988	-5.304**	1984	I(1)
LnGDPpc	-4.289	1991	-6.926***	1984	I(1)
LnGDPpc2	-4.252	1991	-6.757***	1984	I(1)
LnOCpc	-2.899	2006	-5.570**	1986	I(1)
LnNGaspc	-3.779	2007	-6.011***	2005	I(1)
LnHydropc	-3.972	2005	-7.283***	1991	I(1)
LnRECpc	-3.365	1998	-8.790***	1993	I(1)
LnAgriland	-3.951	2002	-6.263***	2001	I(1)
LnTrade	-3.510	2004	-6.438***	2009	I(1)

Note: *,** ,and *** denote 10%,5%, and 1% statistical significance level respectively; Zivot-Andrews unit root test was carried out under the specification of intercept and trend

- Cointegration bounds test

To examine the evidence of cointegration relationship between dependent and independent variables in our regression (CO2, GDP, squared GDP, different sources of energy consumption, agricultural land, and trade openness) Cointegration bounds test was done and its results are shown in Table 3.

Table 3. Cointegration bounds test

Argentina						
Models	Lags order selection	Critical value bounds			F-statistic	Decision
		10%	5%	1%		
1	ARDL(1,2,2,0,2,0,1)	2.321-3.697	2.796-4.363	3.944-5.957	16.966***	cointegration
2	ARDL(2,2,2,0,1,0,2,0)	2.229-3.645	2.681-4.296	3.779-5.868	32.176***	cointegration
3	ARDL(1,1,1,0,1,1,1,0,1)	2.167-3.554	2.590-4.164	3.613-5.630	27.357***	cointegration
Brazil						
Models	Lags order selection	Critical value bounds			F-statistic	Decision
		10%	5%	1%		
1	ARDL(1,1,1,0,2,1,2)	2.321-3.697	2.796 -4.363	3.944 -5.957	24.088***	cointegration
2	ARDL(2,1,1,0,0,0,2,1)	2.242-3.620	2.691-4.257	3.774-5.785	22.557***	cointegration
3	ARDL(1,1,1,0,0,0,1,0,1)	2.179-3.530	2.599-4.126	3.608-5.553	23.212***	cointegration
Chile						

Models	Lags order selection	Critical value bounds			F-statistic	Decision
		10%	5%	1%		
1	ARDL(1,2,2,1,2,2,2)	2.292-3.747	2.774-4.442	3.950-6.124	4.530**	cointegration
2	ARDL(2,2,2,1,1,2,0,1)	2.216-3.670	2.672-4.336	3.784-5.951	8.536***	cointegration
3	ARDL(1,1,0,1,1,0,0,1,0)	2.179-3.530	2.599-4.126	3.608-5.553	7.598***	cointegration

Note: *,** ,and *** denote 10%,5%, and 1% statistical significance level respectively;regarding optimal lag selection, we used Bayesian Information Criterion (BIC) and set as maximum lags of 2 for model 1 and 2 respectively and maximum lag of 1 for model 3 to avoid multicollinearity issue; we also carried out cointegration tests by using t-statistics and we found that the calculated t-statistics exceeded the upper-bounds critical values at 5% statistical significance level in all cases confirming the cointegration relationship among the variables.

- ARDL-ECM estimation

To estimate the short-run and the long-run elasticities of variables, the ARDL-ECM was used. The ARDL method was first developed by Pesaran and Shin (1999) and since then, it is widely used in the field of energy economics. Compared to another econometric methods, ARDL offers several advantages (Menegaki,2020): First, ARDL is easy to implement, and it allows to estimate the short-run and the long-run elasticities simultaneously in the single structure equation (Bayer and Hanck,2013). Second, it allows to estimate parameters in the framework of optimal lag criteria which eliminates serial correlation issue (Ali et al.,2017) and it provides unbiased estimator even if the model suffers from endogeneity problem (Harris and Solis,2003).Third, ARDL model is highly flexible because it can be estimated regardless of integration order (I(0),I(1) or mix of them) as long as the variables do not have an order of integration greater than one.

Three ARDL-ECM models used in our estimation can be written as following[6]:

$$\triangle LnCO_{2pc} = \sigma_1 + \sum_{i=1}^{l} \varphi_{11} \triangle LnCO_{2pc,t-i} + \sum_{i=1}^{m} \varphi_{12} \triangle LnGDP_{pc,t-i} + \sum_{i=1}^{n} \varphi_{13} \triangle LnGDP_{pc2,t-i} + \sum_{i=1}^{o} \varphi_{14} \triangle LnOC_{pc,t-i} + \sum_{i=1}^{p} \varphi_{15} \triangle LnNGas_{pc,t-i} + \sum_{i=1}^{q} \varphi_{16} \triangle LnHydro_{pc,t-i} + \sum_{i=1}^{r} \triangle \varphi_{17} LnREC_{pc,t-i} + \theta_{11} LnCO_{2pc,t-1} + \theta_{12} LnGDP_{pc,t-1} + \theta_{13} LnGDP_{pc2,t-1} + \theta_{14} LnOC_{pc,t-1} + \theta_{15} LnNGas_{pc,t-1} + \theta_{16} LnHydro_{pc,t-1} + \theta_{17} LnREC_{pc,t-1} + \varepsilon_{1t} \quad (4)$$

$$\triangle LnCO_{2pc} = \sigma_2 + \sum_{i=1}^{l} \varphi_{21} \triangle LnCO_{2pc,t-i} + \sum_{i=1}^{m} \varphi_{22} \triangle LnGDP_{pc,t-i} + \sum_{i=1}^{n} \varphi_{23} \triangle LnGDP_{pc2,t-i} + \sum_{i=1}^{o} \varphi_{24} \triangle LnOC_{pc,t-i} + \sum_{i=1}^{p} \varphi_{25} \triangle LnNGas_{pc,t-i} + \sum_{i=1}^{q} \varphi_{26} \triangle LnHydro_{pc,t-i} + \sum_{i=1}^{r} \triangle \varphi_{27} LnREC_{pc,t-i} + + \sum_{i=1}^{s} \triangle \varphi_{28} LnAgriland_{,t-i} + \theta_{21} LnCO_{2pc,t-1} + \theta_{22} LnGDP_{pc,t-1} + \theta_{23} LnGDP_{pc2,t-1} + \theta_{24} LnOC_{pc,t-1} + \theta_{25} LnNGas_{pc,t-1} + \theta_{26} LnHydro_{pc,t-1} + \theta_{27} LnREC_{pc,t-1} + \theta_{28} LnAgriland_{,t-1} + \varepsilon_{2t} \quad (5)$$

$$\triangle LnCO_{2pc} = \sigma_3 + \sum_{i=1}^{l} \varphi_{31} \triangle LnCO_{2pc,t-i} + \sum_{i=1}^{m} \varphi_{32} \triangle LnGDP_{pc,t-i} + \sum_{i=1}^{n} \varphi_{33} \triangle LnGDP_{pc2,t-i} + \sum_{i=1}^{o} \varphi_{34} \triangle LnOC_{pc,t-i} + \sum_{i=1}^{p} \varphi_{35} \triangle LnNGas_{pc,t-i} + \sum_{i=1}^{q} \varphi_{36} \triangle LnHydro_{pc,t-i} + \sum_{i=1}^{r} \triangle \varphi_{37} LnREC_{pc,t-i} + + \sum_{i=1}^{s} \triangle \varphi_{38} LnAgriland_{,t-i} + \sum_{i=1}^{t} \triangle \varphi_{38} LnTrade_{,t-i} + \theta_{31} LnCO_{2pc,t-1} + \theta_{32} LnGDP_{pc,t-1} +$$

[6] Equation (4), (5), and (6) correspond to model 1 ,2, and 3 respectively.

$\theta_{33} LnGDP_{pc2,t-1} + \theta_{34} LnOC_{pc,t-1} + \theta_{35} LnNGas_{pc,t-1} + \theta_{36} LnHydro_{pc,t-1} + \theta_{37} LnREC_{pc,t-1} + \theta_{38} LnAgriland_{,t-1} + \theta_{39} LnTrade_{,t-1} + \varepsilon_{3t}$ (6)

Where Δ represents first difference, σ_k denotes intercept, φ_k, θ_k represent the coefficients of parameter, and ε_t represent error term. The ECT (Error Correction Term) lagged once is given by the coefficient of $LnCO_2pc$ (-1), namely, θ_{11}, θ_{21}, and θ_{31} for model 1,2, and 3 respectively. Table 4 shows ARDL_ECM estimation results of three models in a separate column according to three countries for their comparison.

Table 4. ARDL-ECM estimation results of Argentina

Argentina						
	Model 1 (1,2,2,0,2,0,1)		Model 2 (2,2,2,0,1,0,2,0)		Model 3 (1,1,1,0,1,1,1,0,1)	
Variable	Coefficient	t-statisitc	Coefficient	t-statisitc	Coefficient	t-statisitc
ECT(-1)	-0.7683351*** (0.0866933)	-8.86	-0.8787117*** (0.0686229)	-12.80	-0.7900327*** (0.0646232)	-12.23
Long-run estimations						
LnGDPpc(-1)	7.436119** (3.536188)	2.10	13.30518*** (2.987095)	4.45	5.535668* (3.065336)	1.81
LnGDPpc2(-1)	-0.4069416** (0.1924509)	-2.11	-0.7263499*** (0.1634268)	-4.44	-0.3065657* (0.1662582)	-1.84
LnOCpc(-1)	0.7401964*** (0.1115497)	6.64	0.7152715*** (0.0775447)	9.22	0.7873526*** (0.0738874)	10.66
LnNGaspc(-1)	0.2944676*** (0.0613933)	4.80	0.271748*** (0.0451976)	6.01	0.2927168*** (0.0374369)	7.82
LnHydropc(-1)	-0.0329108 (0.0199846)	-1.65	-0.0161355 (0.0133974)	-1.20	-0.0124894 (0.0120663)	-1.04
LnRECpc(-1)	0.019054** (0.0072742)	2.62	0.0085822 (0.0056672)	1.51	-0.0022279 (0.0050666)	-0.44
LnAgriland(-1)	-	-	0.5246465*** (0.1381332)	3.80	0.3350252** (0.130934)	2.56
LnTrade(-1)	-	-	-	-	0.0532344*** (0.0136882)	3.89
Short-run estimations						
DLnGDPpc	-0.6005088 (2.817552)	-0.21	4.012602 (2.523129)	1.59	2.746488 (2.178388)	1.26
DLnGDPpc(-1)	-6.326025** (2.762895)	-2.29	-8.378995*** (2.177885)	-3.85	-	-
DLnGDPpc2	0.0376745 (0.1525642)	0.25	-0.2171816 (0.1377169)	-1.58	-0.1490937 (0.1183577)	-1.26
DLnGDPpc2(-1)	0.3454021** (0. .1494719)	2.31	0.4530866*** (0.1179829)	3.84	-	-
DLnOCpc	0.5687189*** (0.0826463)	6.88	0.6285174*** (0.0630712)	9.97	0.6220343*** (0.0576803)	10.78
DLnNGaspc	0.3273578*** (0.0486701)	6.73	0.2783659*** (0.0427926)	6.51	0.3283875*** (0.041295)	7.95
DlnNGaspc (-1)	-0.0183502 (0.0457669)	-0.40	-	-	-	-
DLnHydropc	-0.0252865 (0.0156832)	-1.61	-0.0141785 (0.0118523)	-1.20	-0.0058453 (0.0158058)	-0.37

DLnRECpc	0.0173852 (0.0115891)	1.50	0.0132259 (0.0084847)	1.56	0.0047392 (0.0067088)	0.71
DLnRECpc(-1)	-	-	-0.0087892 (0.0089028)	-0.99	-	-
DLnAgriland	-	-	0.461013*** (0.1241534)	3.71	0.2646809** (0.1083225)	2.44
DLnTrade	-	-	-	-	0.0209229 (0.0135609)	1.54
Constant	-42.68296*** (12.64309)	-3.88	-73.9903*** (12.53399)	-5.90	-38.32895*** (12.15516)	-3.15

Brazil						
	Model 1 (1,1,1,0,2,1,2)		Model 2 (2,1,1,0,0,0,2,1)		Model 3 (1,1,1,0,0,0,1,0,1)	
Variable	Coefficient	t-statisitc	Coefficient	t-statisitc	Coefficient	t-statisitc
ECT(-1)	-0.9160742*** (0.1001981)	-9.14	-0.9911566*** (0.1149028)	-8.63	-0.8885256*** (0.1089206)	-8.16
Long-run estimations						
LnGDPpc(-1)	-9.317779** (3.816529)	-2.44	-6.015536* (3.468424)	-1.73	-6.096905 (3.586267)	-1.70
LnGDPpc2(-1)	0.5297702** (0.2122999)	2.50	0.3473731* (0.1945302)	1.79	0.3495479* (0.1989248)	1.76
LnOCpc(-1)	0.8409074*** (0.0398518)	21.10	0.7787191*** (0.0580378)	13.42	0.8463142*** (0.0544476)	15.54
LnNGaspc(-1)	0.0761091*** (0.0097743)	7.79	0.0686745*** (0.0081382)	8.44	0.0654339*** (0.0173359)	3.77
LnHydropc(-1)	-0.1408244*** (0.0399231)	-3.53	-0.1411248*** (0.0357902)	-3.94	-0.1270753*** (0.0362592)	-3.50
LnRECpc(-1)	0.0120785 (0.0091891)	1.31	0.025626** (0.0123058)	2.08	0.022739 (0.0150212)	1.51
LnAgriland(-1)	-	-	-0.151479 (0.1863728)	-0.81	-0.022609 (0.2288408)	-0.10
LnTrade(-1)	-	-	-	-	0.0049995 (0.0337135)	0.15
Short-run estimations						
DLnGDPpc	-1.52678 (5.75949)	-0.27	2.602079 (5.900016)	0.44	-1.699185 (6.849454)	-0.25
DLnGDPpc2	0.0982585 (0.3279211)	0.30	-0.1372083 (0.3364654)	-0.41	0.1072338 (0.3896308)	0.28
DLnOCpc	0.7703335*** (0.0749801)	10.27	0.7718326*** (0.0719638)	10.73	0.7519719*** (0.0838268)	8.97
DLnNGaspc	0.05342* (0.0262725)	2.03	0.0680672*** (0.0123154)	5.53	0.0581397*** (0.0134327)	4.33
DlnNGaspc(-1)	-0.0240029 (0.0208392)	-1.15	-	-	-	-
DLnHydropc	-0.1221059** (0.0566155)	-2.16	-0.1398767*** (0.041813)	-3.35	-0.1129096*** (0.0353368)	-3.20
DLnRECpc	-0.0071283 (0.0261782)	-0.27	-0.0026785 (0.0230384)	-0.12	0.0191331 (0.0187674)	1.02
DLnRECpc(-1)	-0.0052399 (0.0162018)	-0.32	-0.0197791 (0.0174509)	-1.13	-	-
DLnAgriland	-	-	0.7964744 (0.8968569)	0.89	-0.0200886 (0.2039579)	-0.10
DLnTrade	-	-	-	-	0.0005463 (0.0264114)	0.02

Constant	19.28221 (14.75453)	1.31	7.048558 (14.80404)	0.48	5.823078 (13.57771)	0.43

Chile						
	Model 1 (1,2,2,1,2,2,2)		Model 2 (2,2,2,1,1,2,0,1)		Model 3 (1,1,0,1,1,0,0,1,0)	
Variable	Coefficient	t-statisitc	Coefficient	t-statisitc	Coefficient	t-statisitc
ECT(-1)	-0.4256209*** (0.1273113)	-3.34	-0.707453*** (0.1442373)	-4.90	-0.7178329*** (0.1033298)	-6.95
Long-run estimations						
LnGDPpc(-1)	-3.172742 (2.941803)	-1.08	-5.947781*** (1.754796)	-3.39	-3.997114** (1.490585)	-2.68
LnGDPpc2(-1)	0.1994798 (0.1570183)	1.27	0.365072*** (0.0960864)	3.80	0.2618448*** (0.0825639)	3.17
LnOCpc(-1)	0.4714033*** (0.1185206)	3.98	0.404169*** (0.0574632)	7.03	0.3781112*** (0.0684468)	5.52
LnNGaspc(-1)	0.0166914 (0.040481)	0.41	0.0230268 (0.0180607)	1.27	-0.0013846 (0.0202744)	-0.07
LnHydropc(-1)	0.0068622 (0.1173394)	0.06	-0.093132* (0.047123)	-1.98	-0.2521945*** (0.0396949)	-6.35
LnRECpc(-1)	0.0344374 (0.0255483)	1.35	-0.023153* (0.0121484)	-1.91	-0.0378944** (0.0158016)	-2.40
LnAgriland(-1)	-	-	-2.009403*** (0.4417916)	-4.55	-2.616017*** (0.5344704)	-4.89
LnTrade(-1)	-	-	-	-	0.1742773*** (0.0572525)	3.04
Short-run estimations						
DLnGDPpc	1.665535 (3.161661)	0.53	-0.4958624 (2.467914)	-0.20	-2.585739** (1.073513)	-2.41
DLnGDPpc(-1)	-9.483017*** (2.887545)	-3.28	-6.769085*** (2.245582)	-3.01	-	-
DLnGDPpc2	-0.0620437 (0.1806148)	-0.34	0.0623216 (0.1417502)	0.44	0.1879608*** (0.0610787)	3.08
DLnGDPpc2(-1)	0.5490947*** (0.1690161)	3.25	0.3978518*** (0.1316831)	3.02	-	-
DLnOCpc	0.5597824*** (0.0839201)	6.67	0.5756713*** (0.0686688)	8.38	0.5590349*** (0.0797917)	7.01
DLnNGaspc	0.1007175*** (0.0309688)	3.25	0.1051515*** (0.0233582)	4.50	0.0482629** (0.0235089)	2.05
DLnNGaspc(-1)	0.0028841 (0.0261624)	0.11	-	-	-	-
DLnHydropc	-0.0869725* (0.04503)	-1.93	-0.1149218*** (0.0294118)	-3.91	-0.1810336*** (0.0354578)	-5.11
DlnHydropc(-1)	-0.1318324*** (0.0313572)	-4.20	-0.0931326*** (0.0328675)	-2.83	-	-
DLnRECpc	-0.0032152 (0.0168113)	-0.19	-0.0163797* (0.0087685)	-1.87	-0.0272019** (0.0109596)	-2.48
DLnRECpc(-1)	-0.040201** (0.0187582)	-2.14	-	-	-	-
DLnAgriland	-	-	-0.1540564 (0.4099375)	-0.38	-0.680673 (0.4794734)	-1.42
DLnTrade	-	-	-	-	0.125102*** (0.0383563)	3.26
Constant	-2.098415 (5.553907)	-0.38	10.20475* (5.602151)	1.82	5.874184 (5.428679)	1.08

Note: *,** ,and *** denote 10%,5%, and 1% statistical significance level respectively; ECT denotes Error Correction Term; the prefix D denotes first difference and (-1) indicates 1 lag.

- Postestimation tests

After the estimation of our models by using ARDL-ECM technique, we carried out postestimation tests to see whether the models estimated are well-behaved or not (Menegaki,2020). We used the Jarque-Bera test to check the normal distribution, the Breusch-Pagan test and the White test to check heteroskedasticity, the Breusch-Godfrey serial correlation LM test and the Durbin-Watson test to check autocorrelation and lastly the Ramsey RESET test to see whether functional forms of our regression models are well-specified or not (Menegaki,2020; Shahbaz and Shabbir,2012). The results of postestimation test of three models are summarized by country name in Table 5.

Table 5. Postestimation tests results

Argentina						
Test type	Model 1		Model 2		Model 3	
	χ^2	Probability	χ^2	Probability	χ^2	Probability
Jarque-Bera test	7.22	0.0271	23.58	0.0000	12.27	0.0022
Breusch-Pagan test	0.22	0.6383	0.04	0.8374	0.40	0.5267
White test	43.00	0.4282	43.00	0.4282	43.00	0.4282
ARCH test	0.185	0.6672	0.451	0.5017	0.238	0.6256
Breusch-Godfrey LM test	0.551	0.4578	0.640	0.4238	0.708	0.4001
Durbin-Watson	0.364	0.5465	0.393	0.5309	0.402	0.5262
Ramsey reset test	1.12	0.3581	0.66	0.5821	0.86	0.4757
Brazil						
Test type	Model 1		Model 2		Model 3	
	χ^2	Probability	χ^2	Probability	χ^2	Probability
Jarque-Bera test	4.78	0.0917	6.91	0.0316	7.51	0.0234
Breusch-Pagan test	3.88	0.0489	4.88	0.0272	4.90	0.0269
White test	43.00	0.4282	43.00	0.4282	43.00	0.4282
ARCH test	1,157	0.2822	1.057	0.3040	0.763	0.3825

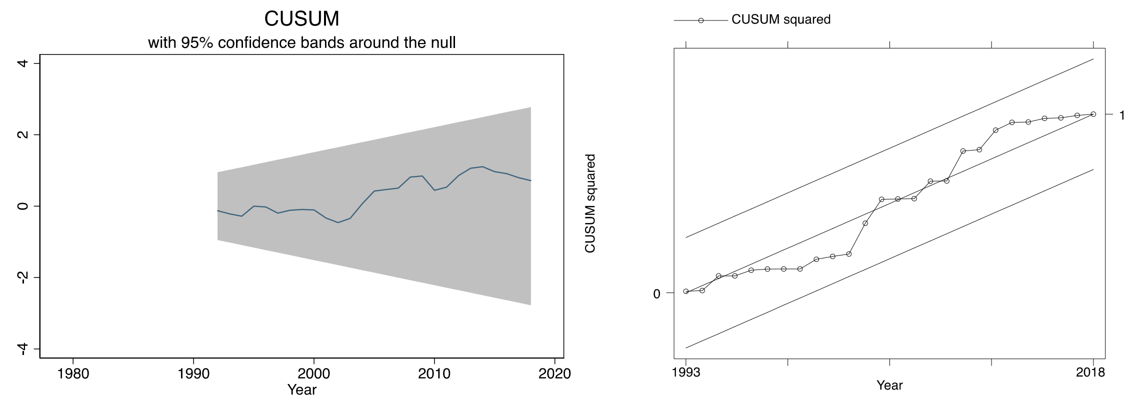
Breusch-Godfrey LM test	2.116	0.1458	2.229	0.1354	1.550	0.2131
Durbin-Watson	1.499	0.2287	1.422	0.2331	0.898	0.3434
Ramsey reset test	1.74	0.1834	1.422	0.2331	1.91	0.1574
Chile						
Test type	Model 1		Model 2		Model 3	
	χ^2	Probability	χ^2	Probability	χ^2	Probability
Jarque-Bera test	6.56	0.0377	71.28	0.0000	-	0.0000
Breusch-Pagan test	0.91	0.3409	0.83	0.3612	0.54	0.4630
White test	43.00	0.4282	43.00	0.4282	43.00	0.4282
ARCH test	2.320	0.1277	0.223	0.6368	0.018	0.8935
Breusch-Godfrey LM test	0.103	0.7484	0.026	0.8726	0.878	0.3488
Durbin-Watson	0.067	0.7956	0.016	0.9008	0.500	0.4794
Ramsey reset test	4.78	0.0088	3.88	0.0216	1.12	0.3635

NOTE: Jarque-Bera test H_0: normal distribution of the residuals; Breusch-Pagan test: H_0 :homokedasticity; White test: H_0 :homokedasticity; ARCH test: H_0 : no ARCH effects ; Breusch-Godfrey test: H_0 : no serial correlation; Durbin-Watson test: H_0 :no serial correlation; Ramsey RESET test: model has no omitted variables

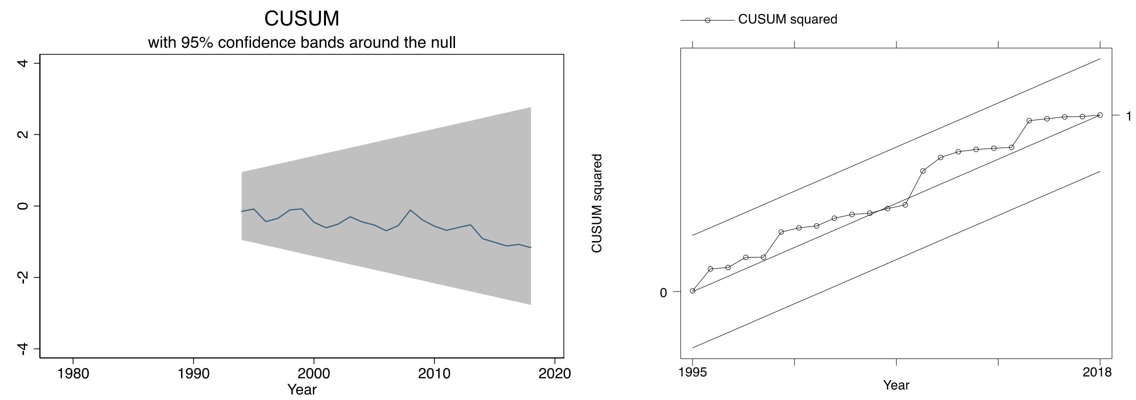
- CUSUM and CUSUMSQ tests

After postestimation tests, we examined the stability of our models by using CUSUM and CUSUMSQ tests. These tests are used to support the estimations results obtained previously in ARDL-ECM by predicting the stability of the long-run relationship among the variables and to detect structural breaks in our regression models (Menegaki,2020). For each country and model, the CUSUM tests are presented on the left-hand side while on the right-hand side, the CUSUMSQ tests are presented. The results of CUSUM and CUSUMSQ tests of three countries are depicted in separate graphs according to each country in Figure 2.

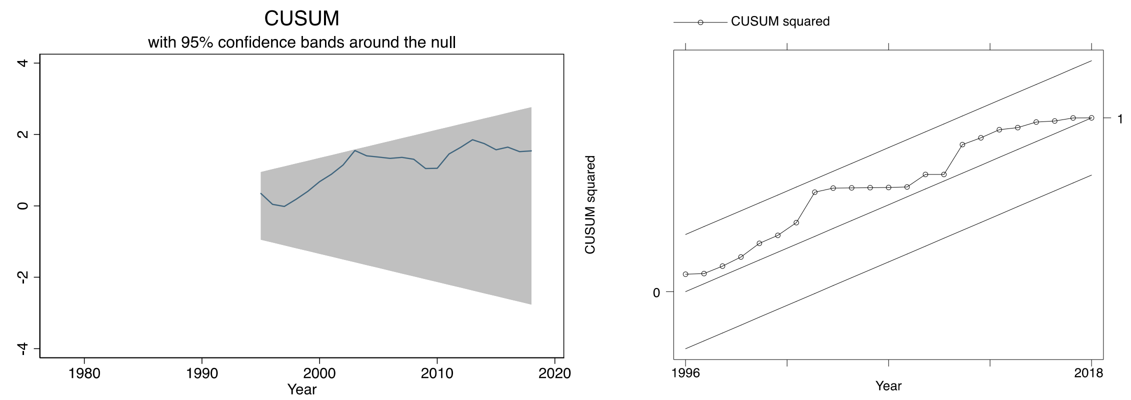
Argentina



Model 1

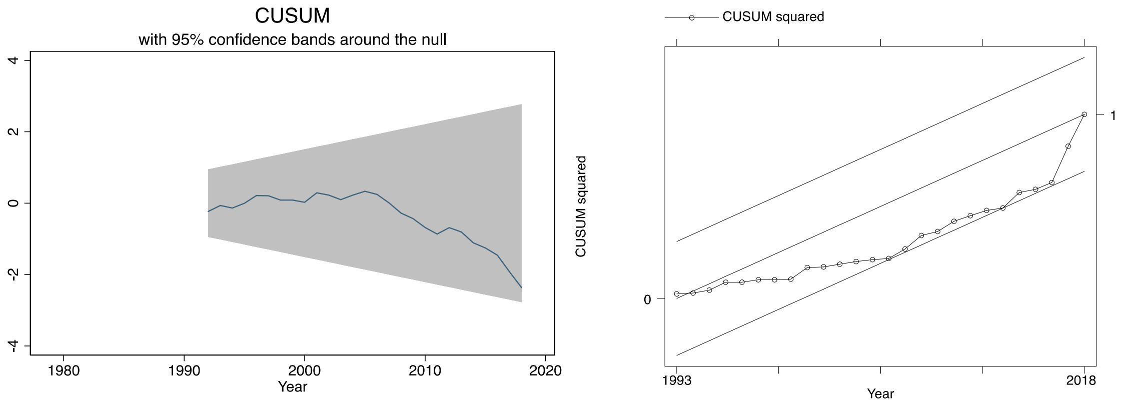


Model 2

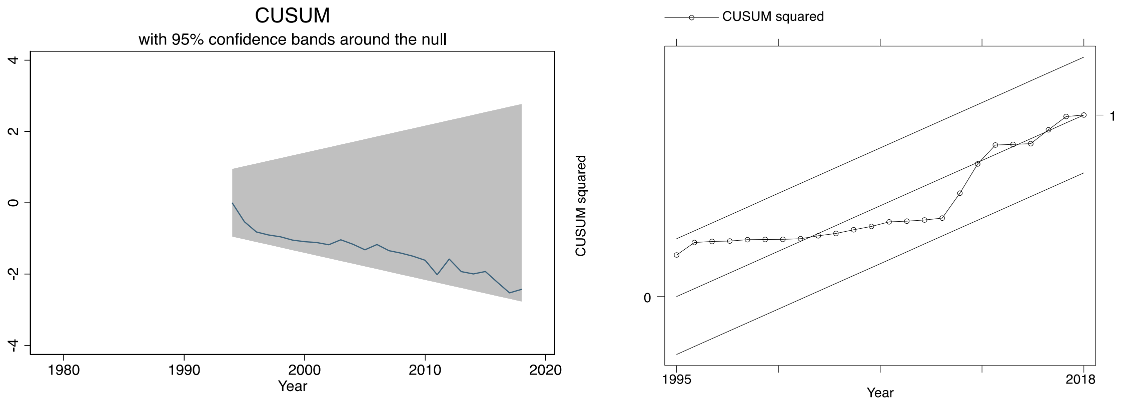


Model 3

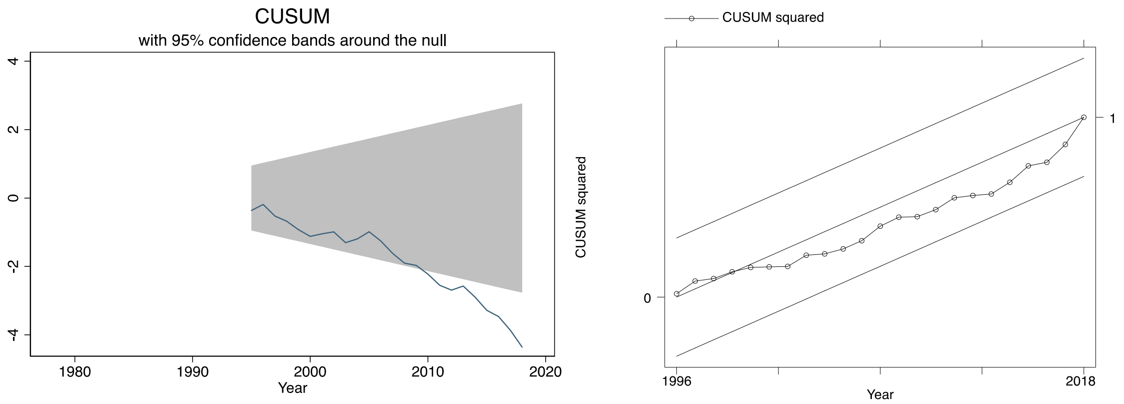
Brazil



Model 1

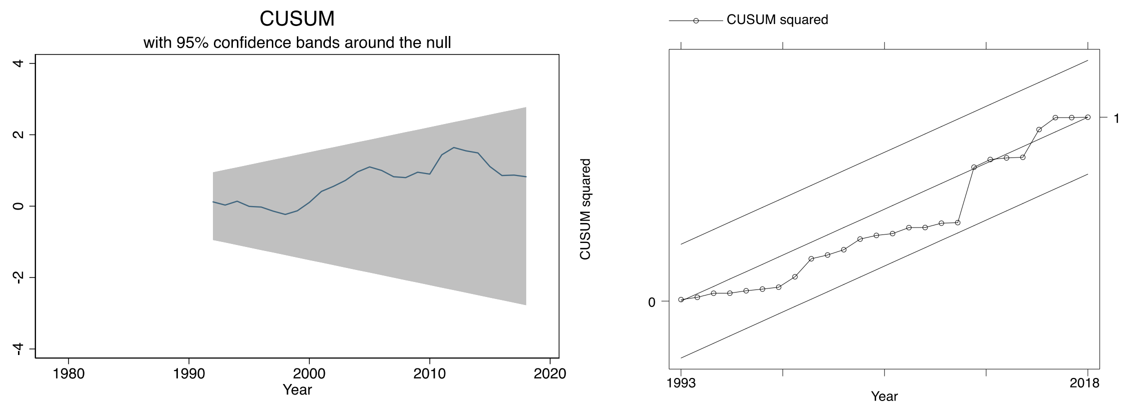


Model 2

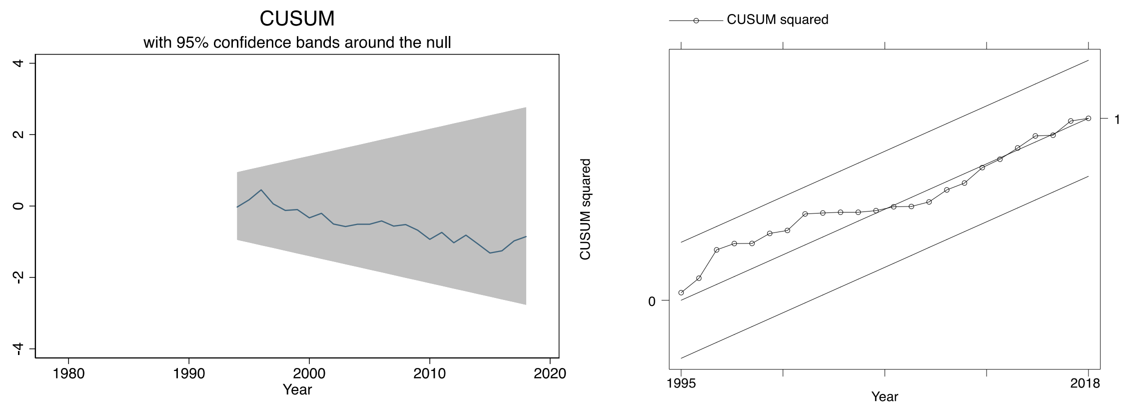


Model 3

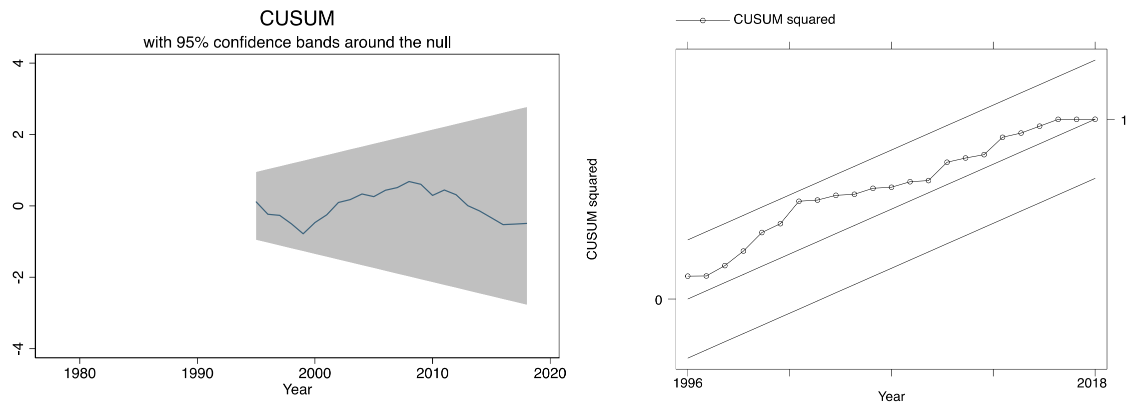
Chile



Model 1



Model 2



Model 3

Figure 2. CUSUM and CUSUMSQ tests for 3 estimated models for Argentina, Brazil, and Chile

- Toda-Yamamoto Granger causality test

After confirmation on the cointegration relationships among the variables by means of cointegration bounds test and estimation of the short- and the long-run effects by using ARDL-ECM method, the step of our analysis finalizing was continued to determine the direction of causality between the variables with the help of the Toda-Yamamoto Granger causality test. The advantage of using this test is that it can be used regardless of stationarity of the variables, so we do not need to transform variables into the first differences in case the variables are not stationary at levels. In the Toda-Yamamoto Granger causality test, we exclusively centered our attentions on two different directions of causality relationships: on the one hand, the direction of causality between $LnCO_2$ and independent variables to see whether it supports our previous ARDL-ECM estimation results obtained in previous stage. Otherwise, the direction of causality between economic growth and four different sources of energy consumption (oil, natural gas, hydro, and renewable energy) was examined[7].Furthermore, for the sake of simplicity and avoidance of redundancy, we excluded the variable LnGDPpc2 in our test shown in Table 6.

Table 6. Toda-Yamamoto Granger causality tests

Argentina								
Dependent Variables	Independent variables							
	LnCO2pc	LnGDPpc	LnOCpc	LnNGaspc	LnHydropc	LnRECpc	LnAgriland	LnTrade
LnCO2pc		9.0255***	3.6549*	5.8967**	7.7752***	0.04759	17.966***	2.4681
LnGDPpc	0.49322		2.1916	1.2297	3.1693*	1.8638	12.198***	3.2532*
LnOCpc	2.4295	8.2442***		12.793***	15.419	1.8228	21.308***	0.63087
LnNGaspc	1.0587	0.81457	0.03135		6.8343**	0.56967	3.9323*	0.27651
LnHydropc	0.20433	0.09403	0.50393	1.3784		0.01103	5.3906**	1.2688
LnRECpc	0.32114	13.601***	0.00244	0.23852	0.07888		0.15352	3.8933*
LnAgriland	3.0584*	0.05929	5.459**	9.1268***	0.01234	5.6169**		11.76***
LnTrade	2.424	6.1043**	5.5735**	4.125*	0.02524	6.8397**	9.8483***	
Brazil								
Dependent Variables	Independent variables							
	LnCO2pc	LnGDPpc	LnOCpc	LnNGaspc	LnHydropc	LnRECpc	LnAgriland	LnTrade
LnCO2pc		18.499***	0.01127	0.53143	0.98882	5.266**	36.772***	6.7633**
LnGDPpc	0.06972		0.22684	1.3039	0.9964	1.1995	3.2628*	2.7609
LnOCpc	0.36875	17.48***		1.3186	0.36437	11.754***	66.063***	5.3085**
LnNGaspc	1.8212	0.20243	4.1783**		12.411***	0.5267	0.09322	7.2561**
LnHydropc	0.4398	0.41541	0.00459	2.247		0.15674	2.1722	1.459
LnRECpc	0.34255	11.989***	1.1815	0.07135	0.05804		0.03668	4.2289**

[7] Regarding the nexus between energy consumption and economic growth, there are 4 well-known types of hypotheses, namely Growth hypothesis, Conservation hypothesis, Neutrality hypothesis, and Feedback hypothesis: In Growth hypothesis, there is a unidirectional causality from energy consumption to economic growth while in Conservation hypothesis, the causality is reversed. Neutrality hypothesis refers to the absence of relationship between energy consumption and economic growth while in Feedback hypothesis, there is a bidirectional causality relationship between energy consumption and economic growth (Fuinhas et al.2021).

LnAgriland	0.54536	25.665***	1.7789	2.7164	0.27466	6.7923**		7.0572**
LnTrade	0.04238	0.39973	1.6137	0.00987	5.6364**	3.632*	0.95133	

Chile								
Dependent Variables	Independent variables							
	LnCO2pc	LnGDPpc	LnOCpc	LnNGaspc	LnHydropc	LnRECpc	LnAgriland	LnTrade
LnCO2pc		2.117	0.00055	0.0378	8.8533***	10.019***	2.2279	1.8717
LnGDPpc	6.8241**		0.25374	3.3233*	6.8472**	22.732***	10.022***	2.9824*
LnOCpc	2.4088	7.693***		4.7518**	7.0404**	11.496***	6.5963**	5.1975**
LnNGaspc	4.675**	0.64943	2.1656		1.0267	1.7761	18.48***	0.04457
LnHydropc	0.10475	0.23825	0.00223	17.499***		1.4058	1.6161	0.40972
LnRECpc	0.19343	5.6058**	9.7184***	7.3274**	1.1283		1.3165	14.764***
LnAgriland	1.4726	2.1529	1.6711	3.4541*	1.5467	7.6397***		0.11461
LnTrade	0.14316	0.00192	0.97562	1.6967	6.7398**	0.93991	0.01029	

Note: *,** ,and *** denote 10%,5%, and 1% statistical significance level respectively; Before we proceed to examine Toda-Yamamoto Granger causality test, we determined optimal lags and estimated VAR regression by using "varsoc" and "var" command respectively in Stata. The optimal lags chosen for Argentina, Brazil, and Chile were 3,4 and 3 respectively.

5.Concluding remarks

Under the recognition that the importance of decoupling economic growth from environmental degradation and the critical role energy consumption patterns play in the evolution of carbon dioxide emissions in the economy, we examined the impacts of economic growth, consumption of four different types of energy sources, namely, Oil, natural gas, hydroelectricity, and unconventional renewable energy (solar, wind, geothermal, bioenergy), in addition to agricultural land and trade openness as control variables relevant to environmental quality in the framework of the EKC for a set of 41-year time series data (1975-2018) of 3 LAC countries: Argentina, Brazil, and Chile

According to the estimation results of ARDL-ECM, we could verify the EKC hypothesis (inverted U-shaped curve) only in Argentina in the long run but not in two other countries, Brazil and Chile, where the U-shaped curve relationship between economic growth and CO_2 emissions was found. This result suggests that the evidence of the EKC is not robust in these three economies and especially in case of Brazil and Chile, attentions should be paid carefully to monitoring evolution of CO_2 emissions in the long run since it shows an increasing trend as the economy grows after having reached a certain threshold level of income. In relation to the impacts of consumption of four different types of energy on environmental degradation, fossil fuel source, especially oil, was found to have a strong positive impact on CO_2 emissions in Argentina, Brazil, and Chile in both the short and the long run. As for natural gas, its consumption leads to an increase in CO_2 emissions in three countries (in Chile, the consumption of natural gas has a significant impact on CO_2 emissions only in the short run) but it has a significantly lower impact on environmental degradation than oil consumption as both the short and the long-term elasticities of consumption of natural gas with respect to CO_2 emissions in absolute values are quite lower than those of oil. This finding suggests that natural gas might be serve as a good intermediate backup energy source in the short and medium term when these 3 economies carry out the low-carbon energy transition (shift from dirty energy sources to clean renewable energy sources) which ultimately aims for reaching net zero carbon emissions target by 2050 according to the Paris Agreement in 2015 because natural gas emits significantly less amounts of CO_2 in comparison with another fossil fuels such as coal and oil and it can support and complement renewable energy sources as backup energy when intermittence issue is emerged. Regarding to hydroelectricity consumption, it contributes to reducing CO_2 emissions in Brazil and Chile in both the short and the long run while in Argentina, it has no meaningful impact anymore (in Chile, the hydroelectricity consumption has a significant negative impact on CO_2 emissions in the long run only for model 2 and 3, namely when two control variables were added in our regression analysis).This finding suggests that hydropower will continue to play an important role in reducing CO_2 emissions in Brazil and Chile in the future and it´s combination with another clean energy sources such as renewables might help to achieve a successful low-carbon energy transition in these two economies. With respect to renewable energy consumption, only in Chile, we could verify a significant negative impact on CO_2 emissions in model 2 and 3 in the short and the long run (although the elasticities in absolute value were significantly lower than that of oil or natural gas which means that consumption from renewable energy sources were shown to be not sufficient to compensate the negative impact on environmental quality driven by fossil fuels) while in other two countries, Argentina and Brazil, renewable energy consumption had a significant impact only in the long run (in model 1 for Argentina and in model 2 for Brazil respectively) but contrary to what we expected, it had a positive sign, so in this regard, significant efforts should be made by governments to increase the share of renewables in the primary energy consumption in their economies.

Regarding to the direction of causalities between economic growth and energy consumption, the Toda-Yamamoto Granger Causality test tells us that there is a unidirectional causality running from LnHydropc to LnGDPpc (growth hypothesis) while the opposite direction, namely a unidirectional causality running from economic growth to energy consumption was found in LnOCpc and LnRECpc respectively (conservation hypothesis) in Argentina. In Brazil, we could verify the conservation hypothesis in LnOCpc and LnRECpc. In Chile, we found that conservation hypothesis held for LnOCpc while the growth hypothesis was found to be valid for LnNGaspc, LnHydropc, and LnRECpc. These findings suggest that oil consumption can be drastically reduced and replaced by other clean energy sources which emit significantly less amounts of CO_2 emissions in accordance with economic growth in Argentina, Brazil, and Chile since the conservation hypothesis tells us that the reduction in oil consumption does not hinder economic growth in these countries. Furthermore, our findings suggest that energy consumption from natural gas, hydropower, and renewables leads to economic growth in Argentina and Chile (these 3 types of energy all granger caused economic growth in Chile while only hydropower did in case of Argentina), thus increased energy consumption of these 3 energy sources might help to boost economic growth along with achieving environmental protection goal in Argentina and Chile.

In our study, we considered renewable energy consumption in its entirety without considerations on specific types of energy sources in separate: solar, wind, geothermal, bioenergy. For further investigation, more specific and sophisticated approaches are requested for more clarification of the effects of specific renewable energy sources on carbon emissions and their nexus with economic growth in LAC countries.

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