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RESEARCH ARTICLE

Retesting the EKC hypothesis through transmission of the ARMEY curve model: an alternative composite model approach with theory and policy implications for NAFTA countries

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Abstract
We investigate the validity of the environmental Kuznets curve (EKC) hypothesis for the NAFTA countries. In this investigation, we approach this hypothesis from a different methodology and propose employing the ARMEY curve hypothesis since the mathematical-functional propositions of both hypotheses were constructed on the same inverted U-shaped relationships. Thus, for the first time, it can be interpreted that the EKC hypothesis is empirically tested through a transmission mechanism of the ARMEY curve hypothesis in a single composite model. Therefore, this approach makes our study different from all empirical studies in the relevant literature. We apply the Augmented Mean Group (AMG) estimator to this aim. Empirical findings indicate that the ARMEY curve hypothesis was verified only for the USA. However, this new approach proposed in this study cannot test the EKC hypothesis through the ARMEY curve model for any NAFTA country since this approach requires verification of the ARMEY curve hypothesis and a significant composite model for the same NAFTA country. If our composite model was significant, it might make it possible to numerically determine a maximum real GDP per capita level that would minimize or maximize CO_2 emission levels for the USA. Therefore, this study introduces-proposes this new methodology as an alternative way of testing the EKC hypothesis in the relevant literature for future empirical studies.

Keywords ARMEY curve hypothesis · EKC hypothesis · Transmission mechanism · NAFTA countries

JEL Classification E62 · Q50

Introduction

The answer to the historical question "should governments intervene in the economies?" is still unclear and has been under discussion for a long time. For instance, considering the two mainstream economic schools of thought, while the classical model does not rely on government interventions with its famous doctrine of "laissez-faire," the Keynesian model relies on these interventions through government spending, taxes, etc. Another question is that if governments intervene in the economies, "what should the sizes of the governments be?" This question implicitly seeks the answer to "what level of government spending can maximize the GDP?" According to Armey (1995), this question is crucially important for governments and economies. The author claims an inverted U-shaped (nonlinear) relationship between the level of government spending and GDP per capita. According to this postulation, raises in productive government spending initially increase GDP by fostering private investments and, eventually, decrease it after a certain point due to crowding-out private investments, taxation, and the laws of diminishing returns (Barro, 1990; Scully 1996; Karras 1997; Chao and Grubel 1998; Colombier 2009). Hence, this critical certain point (optimal government size) shows the governments the maximum spending they can increase without resulting in a reduction of economic growth. This postulation, known as "the ARMEY curve," resembles another one, namely the environmental Kuznets curve (EKC), which was hypothesized by Grossman and Krueger (1991). This hypothesis was constructed on the same mathematical-functional proposition as the ARMEY curve and also postulates an inverted

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U-shaped relation between GDP per capita and environmental degradation. Rises in real GDP per capita initially increase CO2 emissions in the first stages of economic growth due to consumption of fossil fuels (for instance) and, eventually, decrease them, after a certain point, due to environmentally friendly technologies-policies and cleaner energy demand (Dinda, 2004; Soytas and Sari 2009; Akan et al. 2010, 2007; Bilgili et al. 2016; Ongan et al. 2018; Erdogan and Acaravci 2019; Khan et al. 2020, 2021; Kisswani et al. 2019; Ioan et al. 2020; Işık et al. 2019a, b; Dogan et al. 2020; Dogru et al. 2020; Ongan et al. 2017; Ongan et al. 2018; Ongan et al. 2020; Wang and Zhang 2020; Abbasi et al. 2021a, b; Ahmad et al. 2021a, b, c; Alvarado et al. 2021a, b; Balsalobre-Lorente et al. 2021; Bashir et al. 2021; Bulut 2021; Hussain et al. 2021; Işık et al. 2020a, b, 2021a, b, 2022; Li et al. 2021a, b; Murshed et al. 2021; Nathaniel et al. 2021; Pata and Işık 2021; Rehman et al. 2021a, b, c, d; Shahzad et al. 2021; Wang and Zang 2020; Yuping et al. 2021; Ali et al. 2021; Jiang et al. 2022; Wan et al. 2022; Wang and Wang 2022; Yasir et al. 2022).

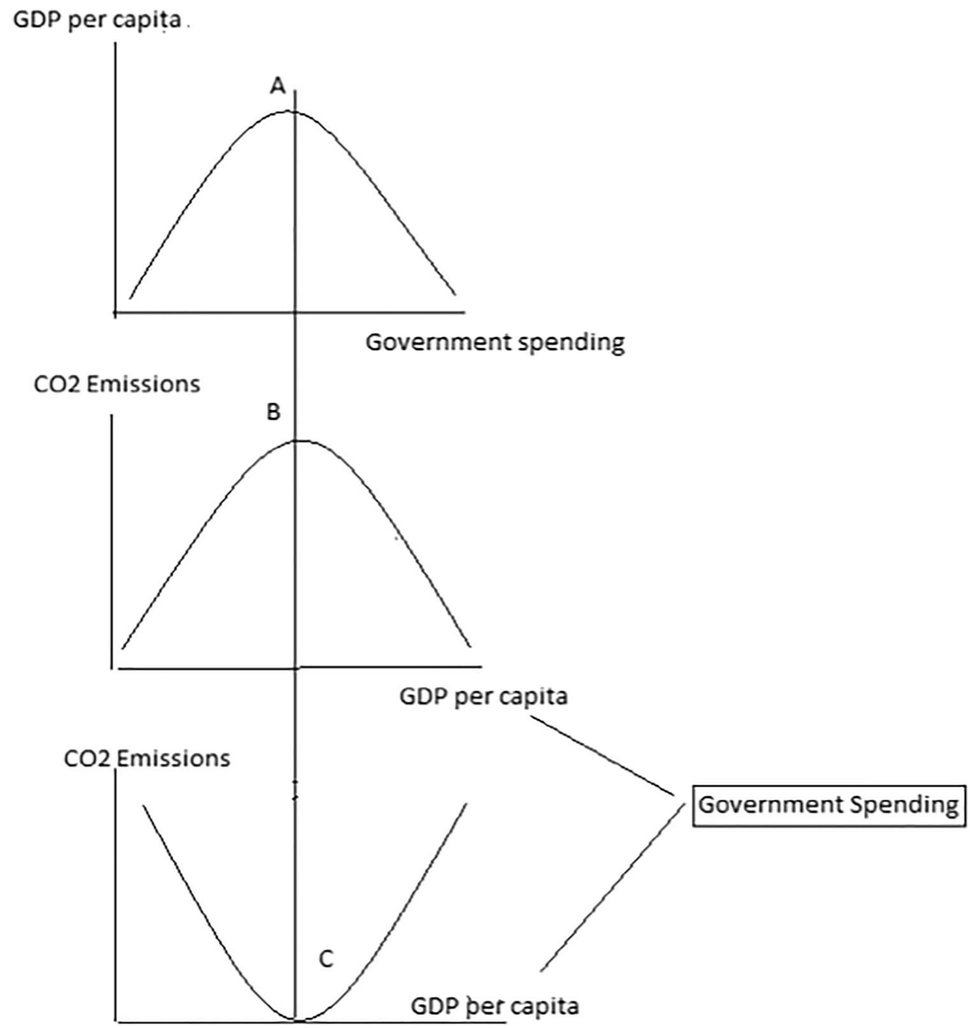
At this point, it should be noted that the Paris Agreement can play a crucial role in environmentally friendly policies. Therefore, 177 out of 193 countries have signed the Paris Agreement, which will enter into force in 2020, to reduce greenhouse gas emissions, adapt to the changing climate, and provide the appropriate financing to develop alternative energy sources (Sutter et al. 2015; Isik et al. 2018; 2020b). However, considering that energy is an important sector for the economy of many of these countries, low-income countries try to strengthen their economies by expanding energy, but their small share in world energy activities causes them to give less importance to sustainable energy than the developed countries (Isik 2010; Organization for Economic Cooperation and Development & United Nations Environment Programme 2011; www.oecd.org, www.unep.org; Isik et al. 2017; Dogru et al. 2019; Ahmad et al. 2021d; Aimer 2021; Irfan et al. 2021; Kunu and Duran 2021; Nuhanovic 2021)

After this little reminder, if we turn to the methodology of our study, the difference between these two inverted U-shaped curves is that, while the EKC hypothesis examines the impact of real GDP per capita on CO2 emissions, the ARMEY curve hypothesis examines the impact of government spending on GDP growth. At first glance, this dissimilarity indicates that these are two issues different from each other since these two models' dependent and independent variables are not the same. However, from a closer perspective, all these variables in both models exhibit directionally causal (interrelated) relationships. This means that rises in government spending lead to increases in real GDP per capita and, thereby, rises in real GDP per capita lead to increases in environmental degradation (CO2 emissions). Moreover, the mathematical-functional propositions of both curves were constructed on the same nonlinear (inverted-U shaped) relationships expected.

Therefore, these similar, implicitly causal, and nonlinear relationships expected may enable us to empirically examine-test the EKC hypothesis through the ARMEY curve hypothesis simultaneously, in a single composite model. So, as a first and the main contribution of this study, it can be interpreted that our proposed and constructed composite model combines two seemingly different but strongly interrelated models into an interconnected economic model. Therefore, from this methodological approach, the advantage of this methodological approach is that such a composite model may enable us to numerically determine a maximum (optimal) real GDP per capita level (through a maximum government spending level), which will minimize CO_2 emissions if the curve of this composite model is a U-shaped one, as shown in Fig. 1C. The lowest point of the letter "U" corresponds to the lowest level of CO_2 emissions. The same composite model may also enable us to numerically determine a maximum GDP per capita level (through a maximum government spending level), which will maximize CO_2 emissions if this curve is an inverted U-shaped one, as shown in Figure B. The highest point of the inverted letter U (∩) corresponds to the highest level of CO_2 emissions. This means that this composite model can be through either a U-shaped (convex) or an inverted U-shaped (concave). Hence, based on these predetermined optimal levels, governments/policymakers may easily, and proactively effectively, manage their economic growth rates and environmental policies without causing environmental degradation. Furthermore, this proposed composite model may enable us to examine how real GDP per capita, government spending, and CO_2 emissions interact with one another. It should be noted that all these empirical results expected from our composite model will be conditionally possible if we can verify the validity of the ARMEY curve hypothesis (denoted through the inverted U-shaped curve) and have a significant composite model for the same sample country. The curve shapes of the ARMEY (Fig. 1A) and potential composite models (Fig. 1B and C) are shown in Fig. 1.

From the governments' policy perspectives, the graph above may also depict, to some degree, a kind of transmission mechanism from economic to energy policy (from Fig. 1A to B and C) since energy policies are subsets of economic policies. In this transmission mechanism, while we consider the Armey curve hypothesis (model) as an economic growth policy, based on government spending, we regard the EKC hypothesis (model) as an energy policy based on economic growth. Hence, in this context, we may be able to determine the maximum size of economic growth policy (denoting the maximum size of government spending) that will minimize the CO_2 emissions (sustainable energy policy). Therefore, through the

Fig. 1 The curve shapes of the ARMEY and potential composite models



composite model, our proposed approach may provide the governments with crucial information about whether their economic growth policies are compatible with their energy policies. If the curve of this composite model is a U-shaped one, as shown in Figure C, it can be interpreted that both policies are *simultaneously* compatible with each other. This means that CO_2 emissions fall during economic growth. If this curve is an inverted U-shaped one, as shown in Figure B, it can be interpreted that both policies are *gradually* compatible with each other. This means that CO_2 emissions fall after a turning point in economic growth. If we do not take the timing of these reductions in CO_2 emissions in these two potential cases (Fig. 1B and C) into consideration, we can say that economic growth and energy policies are both compatible with each other and eco-friendly (sustainable). De Bruyn et al. (1998) define "sustainable growth" as economic growth that does not lead to an increase in CO_2 emissions. Hence, in this context, another (secondary) contribution of this study is to introduce a new terminology "economic growth-based environment-policy" that synthesizes economic and energy policies, in one single model. The expected environmental benefits of this proposed methodology are to answer some questions such as "how much economic growth for a clean environment" or "either higher economic growth or a cleaner environment." This either-or situation, of course, may create a dilemma for the government policymakers between the environment and growth, but they may have a threshold growth for a cleaner environment.

Economic growth is used as an independent variable in the models in the existing literature. However, this study uses two different models and makes them a single model. The dependent variable of the first model (the ARMEY model), "economic growth," becomes the independent variable of the second model (the EKC model). This methodological approach is the first attempt on both separate models (hypotheses), melting these into one model in the literature. Therefore, the methodological approach and modeling used in this study do not allow us to compare the results of this study and other EKC studies in the literature. Because here, economic growth is defined as economic growth stemming from public expenditure.

In this study, we will test the EKC hypothesis through the transmission of the ARMEY curve model and also examine all these interactions between government spending, real GDP per capita, and CO_2 emissions for the NAFTA (The North American Free Trade Agreement) countries, namely the USA, Canada, and Mexico, between 1971 and 2016, which is the latest available data year. The reason for selecting the NAFTA countries is that the USA, Canada, and Mexico have different levels of government spending as a percentage of their GDPs (37%, 42%, and 24%, respectively), GDP per capita ($58,000, $46,000, and $9000, respectively), and CO_2 emissions in kt (5.006, 3; 544,8; 486, 4, respectively) (World Bank 2020). Hence, findings expected from this study may provide crucial information to the policymakers of these countries that will help them understand how government spending, real GDP per capita, and CO_2 emission levels interact with each other in this world's largest trading block.

The rest of this study is structured as follows: The "Literature review" section provides a summary literature review. The "Empirical model" section explains the empirical model. The "Estimation methodology" and "Findings" sections provide estimation methodology and findings, respectively. Finally, the "Conclusion with policy implications and limitations" section presents the conclusion with policy implications and the study's limitations.

Literature review

In this section, relevant literature will be examined in two groups. The empirical studies about the ARMEY curve model will be presented in the first group, while those concerning the EKC hypothesis model will be presented in the second group. Following ARMEY (1995), many scholars have tested the validity of the ARMEY curve hypothesis using different methodologies for different countries. However, their findings have been mixed. For instance, Karras (1997) used the neoclassical production function for 20 European countries and verified the validity of the ARMEY curve hypothesis for these countries. Chen and Lee (2005) applied the threshold regression approach for Taiwan and verified the hypothesis for this country. De Witte and Moesen (2010) applied the non-parametric data envelopment analysis (DEA) model and verified this hypothesis for 23 OECD countries. Mutaşcu and Miloş (2009) applied the nonlinear regression approach and obtained findings supporting the ARMEY curve hypothesis for 27 EU countries. Fallahi and Shoorkchali (2012) applied a smooth transition model and verified the ARMEY curve hypothesis for Greece. Mehrara (2012) used the two-sector production model and verified the ARMEY curve hypothesis for Iran. Fallahi and Shoorkchali (2012) used the smooth transition regression (STR) model and could not verify this hypothesis for Greece. Altunc and Aydin (2013) applied the autoregressive distributed lag (ARDL) bounds testing model and found evidence supporting this hypothesis for Turkey, Romania, and Bulgaria. Turan (2014) applied the models that suggested by Schully (1994) and by Vedder and Gallaway (1998) and verified the ARMEY curve hypothesis for Turkey. Mendonça and Cacicedo (2015) applied the generalized method of moments (GMM) and ordinary least squares (OLS) methods and verified this hypothesis for Brazil. Nuţă et al. (2015) applied the correlation validity analysis and verified this hypothesis for Romania. Mursed et al. (2018) used the regression analysis and found evidence supporting this hypothesis for 9 South Asian countries. Aydin and Esen (2019) used the threshold autoregressive (TAR) approach and verified the validity of the ARMEY curve for 26 transition economies. However, Afonso and Furceri (2010) applied the panel regression approach for OECD countries and could not verify the hypothesis for these countries. Ghose and Das (2013) applied the panel cointegration approach and could not verify this hypothesis for 19 emerging economies. Cetin (2017) used the panel data methodology including panel unit root, cointegration, and causality tests and verified this hypothesis for 12 developing countries. Rajput and Tariq (2019) used the GMM estimation technique and could not verify the ARMEY curve hypothesis for the OECD countries. García (2019) applied the cointegration and causality analyses and verified the ARMEY curve hypothesis for Greece. Husseiny (2019) used the "Scully" and "quadratic equation" models and found evidence supporting this hypothesis for Egypt. Kim et al. (2020) applied the Granger causality test and could not verify the ARMEY curve hypothesis for South Korea.

Concerning the EKC hypothesis, following Grossman and Krueger (1991), many scholars have tested this hypothesis with different methodologies for different countries. However, similar to the results of the ARMEY curve hypothesis, the results of these empirical studies are ambiguous for the EKC. For instance, Apergis and Payne (2009) applied the panel vector error-correction model and could not find evidence supporting the EKC hypothesis for 6 Central American countries. Acaravci and Ozturk (2010) applied the ARDL bounds test and could not verify the EKC hypothesis for 19 European countries. Arouri et al. (2012) applied the bootstrap panel unit root tests and cointegration techniques and found poor evidence supporting the EKC hypothesis for 12 Middle East and North African Countries. Shahbaz et al. (2014) applied the ARDL and error correction model (VECM) and verified this hypothesis for the United Arab Emirates. Farhani et al. (2014) applied the FMOLS, DOLS, and Granger causality analysis and verified the EKC hypothesis for 10 Middle East and

North African (MENA) countries. Heidari et al. (2015) used the panel smooth transition regression and could not find any evidence of the EKC hypothesis for 5 ASEAN countries. Sugiawan and Managi (2016) used the ARDL approach to cointegration and verified the EKC hypothesis for Indonesia. Antonakakis et al. (2017) applied the panel vector autoregression and impulse-response analysis for 106 countries. They could not find any evidence about the hypothesis for these countries. Hu et al. (2018) applied fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) estimators for 25 developing countries and could not verify the hypothesis for these countries. However, Ichinose et al. (2015) applied the OLS method for Japan and found evidence supporting the EKC hypothesis for this country. Oshin and Ogundipe (2014) applied the panel data approach and verified the EKC hypothesis for 15 West African countries. Kivyiro and Heli (2014) used the ARDL approach for 6 Sub-Saharan African countries: the Democratic Republic of the Congo (DRC), Kenya, the Republic of the Congo, Zambia, South Africa, and Zimbabwe. They verified the EKC hypothesis only for DRC, Kenya, and Zimbabwe. Onafowora and Owoye (2014) applied the ARDL bounds testing to cointegration for Brazil, China, Egypt, Japan, Mexico, Nigeria, South Korea, and South Africa. They verified this hypothesis only for Japan and South Korea. Lacheheb et al. (2015) used the ARDL approach and could not verify the EKC hypothesis for Algeria. Arbulú et al. (2015) applied the pooled OLS and found evidence supporting the EKC hypothesis for 25 European countries. Al-Mulali et al. (2015) applied the ARDL methodology and could not verify this hypothesis for Vietnam. Li et al. (2016) used the GMM method and ARDL approach and verified this hypothesis for China. Gokmenoglu and Taspinar (2016) used the Todo-Yamamoto model and verified the EKC hypothesis for Turkey. Kim et al. (2018) applied the geographically weighted regression and verified the EKC hypothesis for China. Su and Chen (2018) used the OLS and verified this hypothesis for Taiwan. Awad (2019) applied the OLS and FMOLS approaches and verified the EKC hypothesis for 46 African countries. Madden et al. (2019) applied the pooled OLS and geographically and temporally weighted regression (GTWR) models for Australia and found some evidence supporting the EKC hypothesis for this country. Beyene and Kotosz (2020) applied the pooled mean group (PMG) estimation technique and could not verify this hypothesis for 12 East African countries. Barnes (2019) used the OLS approach for 151 countries and found evidence supporting this hypothesis. Cheng et al. (2020) applied the difference-in-difference (DID) model and found evidence supporting this hypothesis for China. Zhai et al. (2020) applied the vector auto-regressive (VAR) model for China and could not find evidence supporting the hypothesis for this country. Gomez and Rodríguez applied the FMOLS model and verified this hypothesis for the NAFTA countries. Miranda et al. (2021) applied the OLS, vector autoregression, and Granger causality tests for the NAFTA countries and found evidence supporting the EKC hypothesis only for the USA and Mexico.

Empirical model

The empirical composite model of this study is derived from both the ARMEY curve and EKC models in the following steps in Eqs.1 and 2, respectively. The ARMEY curve model is constructed in the following natural logarithmic form:

$$lnY_{it} = \alpha + \beta lnGS_{it} + \gamma lnGS_{it}^2 + \zeta lnC_{it} + \varepsilon_{it} \tag{1}$$

where Y represents real GDP per capita (in local currencies); GS and GS^2 denote government spending and the squared term of government spending (local currencies), respectively; C, as a control variable, represents total energy consumption (million btu); ε represents white noise error terms. The sign expected for β is to be positive since rises in government spending will increase real GDP per capita. However, the sign expected for γ is to be negative since additional spending will decrease the real GDP per capita after a certain (maximum) point, as explained in the introduction. The ARMEY curve hypothesis will be verified if the signs for β and γ are to be positive and negative, respectively, for a country in our model. The sign expected for ζ is to be positive since rises in energy consumption will lead to increases in real GDP per capita. Data for all variables were obtained from the World Development Indicators (World Bank 2020). Following the ARMEY curve model in Eq. 1, the EKC model is constructed in the form below:

$$InCO2_{it} = a + blnY_{it} + clnY_{it}^2 + zlnC_{it} + \varepsilon_{it} \tag{2}$$

where CO_2 represents carbon emissions (metric million tons); Y and Y^2 are real GDP per capita and the squared term of real GDP per capita, respectively (in local currencies); C represents total energy consumption (million btu); ε represents white noise error terms. The signs expected for b and c are positive and negative, respectively. Because rises in real GDP per capita will initially increase CO_2 emissions and, eventually, decrease them after a certain (maximum) point. Similar to the ARMEY curve hypothesis model, the EKC hypothesis will be verified if the signs for b and c are to be positive and negative, respectively, for a country in our model. The sign expected for z is to be positive since rises in energy consumption will lead to increases in CO_2 emissions. Data for all variables were obtained from the World Development Indicators (2021).

From the models in Eqs. 1 and 2, we obtain the following composite model without total energy consumption (C) in Eq. 3:

$$lnCO2_{it} = a + b\underbrace{(\alpha + \beta lnGC_{it} + \gamma lnGS_{it}^2)}_{Y} + c\underbrace{(\alpha + \beta lnGS_{it} + \gamma lnGS_{it}^2)}_{Y^2} \cdots \varepsilon_{it} \tag{3}$$

In this model, the EKC hypothesis is tested through the ARMEY curve model since variables-values of the ARMEY curve model in parentheses will also correspond to independent variables of the EKC model (Y and Y^2). In the model above, at first, we do not display the independent variable total energy consumption (C) to clearly show this transmission mechanism from the ARMEY curve model to the EKC model. The signs expected for Y and Y^2 are to be positive and negative, respectively. Hence, we obtain the following expanded final composite model derived from Eq. 3 with total energy consumption (C):

$$CO2_{it} = a + b(\alpha + \beta lnGS_{it} + \gamma lnGS_{it}^2 + \zeta lnC) + c(a + \beta lnGS_{it} + \gamma lnGS_{it}^2 + \zeta lnC)^2 + zlnC + \varepsilon_{it} \tag{4}$$

In the composite model above, we will be able to verify the EKC hypothesis (through the ARMEY curve model) if the signs of b and c are to be positive (+) and negative (−), respectively (denotes an inverted U-shaped curve). However, such verification presupposes that the ARMEY curve hypothesis has been verified and that the composite model above is significant for the same NAFTA country. The shape of the curve plotted from this significant composite model can be in a U-shape (convex) or an inverted U-shape (concave), as explained and shown in Fig. 1 in the introduction.

Estimation methodology

In the estimation methodology of the study, we will proceed with the analyses under four sub-titles.

Cross-sectional dependence and heterogeneity tests

The first step in a panel data analysis is to test for cross-sectional dependence and slope heterogeneity since a shock in one cross-section unit may affect other units in the panel and cross-section units. To test for the null hypothesis of no cross-sectional dependence, we employ the Lagrange multiplier (LM) test propounded by Breusch and Pagan (1980), CD and CD_{LM} tests developed by Pesaran (2004), and the LM_{adj} test produced by Pesaran et al. (2008). To test for the null hypothesis of slope homogeneity, we perform the $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$ tests of Pesaran and Yamagata (2008).

Pesaran panel unit root test

To avoid any potential spurious regression problem, we examine the stationarity properties of the variables under consideration through a panel unit root test. For the null hypothesis of a unit root, we use the cross-sectionally augmented Dickey-Fuller (hereafter, CADF) panel unit root test suggested by Pesaran (2007). This test is capable of revealing efficient output in the presence of cross-sectional dependence and slope heterogeneity.

Westerlund panel cointegration test

Westerlund (2007) proposes four error correction-based panel cointegration tests considering cross-sectional dependence. While panel statistics, namely P_t and P_a, rely on pooling information about the error correction across cross-sectional units in the panel, group mean statistics, namely G_t and G_a, do not use this information. The null hypothesis of no cointegration is tested against the alternative hypothesis of cointegration for all tests. Westerlund (2007) considers the following panel regression model:

$$\Delta Y_{it} = \delta_i' d_t + \lambda_i' \Delta X_{it} + \gamma_i Y_{it-1} + \varphi_i X_{it-1} + \varepsilon_{it} \tag{5}$$

The null hypothesis of no cointegration, namely H_0: $p_i = 0$ for all i, is tested against the alternative hypothesis of cointegration, namely H_1: $p_i < 0$ for all i, which is tested for P_a and P_t tests. These test statistics are calculated in the following forms:

$$P_a = \left(\sum_{i=1}^{N} L_{i11}\right)^{-1} \sum_{i=1}^{N} L_{i12} \tag{6}$$

$$P_t = \hat{\sigma}^{-1}\left(\sum_{i=1}^{N} L_{i11}\right)^{-1/2} \sum_{i=1}^{N} L_{i12} \tag{7}$$

The null hypothesis of no cointegration, namely H_0: $p_i = 0$ for all i, is tested against the alternative hypothesis of cointegration, namely H_1: $p_i < 0$ for at least some i, which is tested for G_a and G_t tests. These test statistics are calculated in the following forms:

$$G_a = \sum_{i=1}^{N} L_{i11}^2 L_{i12} \tag{8}$$

$$G_t = \sum_{i=1}^{N} \hat{\sigma}_i^{-1} L_{i11}^{-1/2} L_{i12} \tag{9}$$

Augmented Mean Group estimator

To estimate the long-run coefficients, Eberhardt and Bond (2009) produce a two-stage estimator as described in following forms:

$$\text{(i)}\ \triangle y_{it} = b' \triangle x_{it} + \sum_{t=2}^{T} c_t D_t + e_{it} \rightarrow \hat{c}_t = \hat{\mu}_t^o \tag{10}$$

$$\text{(ii)}\ y_{it} = a_i + b_i' x_{it} + c_i t + d_i \hat{\mu}_t^o + e_{it} \rightarrow \hat{b}_{AMG} = N^{-1} \sum_{i=1}^{N} \hat{b}_i \tag{11}$$

First, a standard pooled first difference regression including T-1 dummies redescribed as $\hat{\mu}_t^o$ is estimated. Then, this variable is contained in N standard unit regressions. The long-term parameters of the variables are exhibited by $\widehat{b}_{AMG}$ for the panel.

Findings

The cross-sectional dependence and heterogeneity test results for the ARMEY curve, the EKC, and composite models are reported in Table 1.

According to test results in Table 1, we can reject the null hypothesis of no CD, which implies that a shock in one of the NAFTA countries can have impacts on the other two countries. In addition, the delta ($\tilde{\Delta}$) and adjusted delta ($\tilde{\Delta}_{adj}$) statistics, in this table, reveal the presence of slope heterogeneity across the countries. In the third step, we apply Pesaran's (2007) cross-sectionally augmented Dickey-Fuller (CADF) unit root test to reveal whether the variables are stationary. Test results of the CADF unit root test are reported in Table 2.

Table 1 Cross-sectional dependence and heterogeneity tests

	Test statistic	*p*-value
ARMEY curve model		
$lnY = F(lnGS, (lnGS)^2, C)$		
Cross-sectional dependence tests		
LM	26.883*	0.000
CD_{LM}	9.750*	0.000
CD	4.887*	0.000
LM_{adj}	7.027*	0.000
Heterogeneity tests		
$\tilde{\Delta}$	292.561*	0.000
$\tilde{\Delta}_{adj}$	7.797*	0.000
EKC model		
$lnCO_2 = F(lnY, (lnY)^2, EC)$		
Cross-sectional dependence tests		
LM	25.900*	0.000
CD_{LM}	9.349*	0.000
CD	3.885*	0.000
LM_{adj}	8.743*	0.000
Heterogeneity tests		
$\tilde{\Delta}$	4408.600*	0.000
$\tilde{\Delta}_{adj}$	7.653*	0.000
Composite model		
$lnCO_2 = F[(lnGS + (lnGS)^2), (lnGS + (lnGS)^2)^2, EC]$		
Cross-sectional dependence tests		
LM	31.833*	0.000
CD_{LM}	11.771*	0.000
CD	5.066*	0.000
LM_{adj}	11.873*	0.000
Heterogeneity tests		
$\tilde{\Delta}$	108.021*	0.000
$\tilde{\Delta}_{adj}$	11.664*	0.000

* indicates 1% statistical significance

The results of the CADF unit root test in Table 2 reveal that all series are stationary at first differences since the *t*-statistics values of all panel units are lower than the critical values. Hence, the next step is to examine whether cointegration exists in the models. Table 3 reports the results of the Westerlund (2007) panel cointegration test.

Test results in Table 3 indicate that G_t, P_t, and P_a test statistics are significant for different models, which indicates some evidence of cointegration with the rejection of the null hypothesis of no cointegration. After the Westerlund (2007) panel cointegration test, we apply the Augmented Mean Group (AMG) estimator, developed by Eberhardt and Bond (2009), which considers cross-sectional dependence and heterogeneity. Country-specific coefficient estimations of the AMG estimators for the three models are reported in Table 4.

Test results in Table 4 indicate that the ARMEY curve hypothesis is verified only for the USA with an inverted U-shape curve. The EKC hypothesis could not be verified for any country since coefficients *lnY* and $(ln\,Y)^2$ are insignificant for Mexico or only U-shaped for Canada and the USA. In addition, although the coefficients of the composite model verify the EKC hypothesis for Mexico, this model is not capable of testing the EKC hypothesis through the transmission mechanism of the ARMEY curve model for any NAFTA country. This is because our constructed composite model proposed requires that the ARMEY curve hypothesis (denotes inverted U-shaped curve) has been verified and the composite model is significant for the same NAFTA country. It does not mean that this proposed composite model cannot be used as an alternative testing approach for any sample country. The incapability of our composite model in this study is limited only to the sample NAFTA countries. This means that future empirical studies with our proposed approach can test the EKC hypothesis for any sample country. Furthermore, rises in energy consumption (*lnC*), as a

Table 2 CADF unit root test results

Variable	Test statistic	
	Level	First difference
lnY	−1.732	−3.322*
lnGS	−1.644	−2.981*
$(lnGS)^2$	−1.692	−2.946*
$lnCO_2$	−2.187	−2.647*
$(lnY)^2$	−1.697	−3.252*
$(lnGS + (lnGS)^2)$	−1.691	−2.946*
$(lnGS + (lnGS)^2)^2$	−1.759	−2.884*
lnC	−1.998	−3.374*

* indicates 1% statistical significance

Table 3 Westerlund panel cointegration test results

	G_t	G_a	P_t	P_a
ARMEY *curve model* $lnY = F(lnGS, (lnGS)^2, EC)$	−3.179**	−4.240	−4.110	−4.192
EKC model $lnCO_2 = F(lnY, (lnY)^2, C)$	−3.083***	−13.963	−6.288*	−17.071*
Composite model $lnCO_2 = F[(lnGS + (lnGS)^2), (lnGS + (lnGS)^2)^2, C]$	−3.077***	−15.845	−6.863*	−20.186*

*, **, and *** indicate 1%, 5%, and 10% statistical significances, respectively. G_t and G_a denote group mean statistics; P_t and P_a denote panel statistics

control variable, lead to increases in both income (*lnY*) and lnCO_2 in all countries and all models, as expected. However, the most positive impact of rising energy consumption on income (*lnY*) concerns Mexico (0.520 in the ARMEY curve model). So, it can be interpreted that energy is an important input for economic growth in this emerging country more than for the USA and Canada. The most negative impact of rising energy consumption on CO_2 concerns the USA (1.183 and 1.145 in the EKC and composite models, respectively). Therefore, it can be interpreted that US energy policy may be less sustainable than the Canadian and Mexican energy policies. Table 5 clearly shows the curve shapes of the ARMEY, the EKC, and composite models obtained from Table 4.

Conclusion with policy implications and limitations

This study revisits the EKC hypothesis testing from a different methodological perspective, which has never been used before in relevant literature. In doing so, the study introduces and employs the ARMEY curve hypothesis. In other words, for the first time, the EKC hypothesis is empirically tested through a transmission mechanism of the ARMEY curve model. The rationale for using the ARMEY curve model in testing the EKC hypothesis is twofold. First, these two hypotheses (models) were constructed on the same nonlinear relationships with inverted U-shaped curves, which indicates that their mathematical-functional propositions are the same. Second, although the dependent and independent variables of these two hypotheses (models) are not the same, both models exhibit directionally causal (interrelated) relationships. This means that rises in government spending lead to increases in real GDP per capita and, thereby, rises in real GDP per capita lead to increases in environmental degradation (CO_2 emissions). Hence, these interrelated causal relations reflected in the same mathematical-functional propositions may enable us to test the EKC hypothesis through the ARMEY curve model in a single composite model as constructed in this study. This composite model was obtained from both the ARMEY curve and the EKC models. The advantage of this approach (our proposed composite model) is that this model may enable us (governments) to numerically determine a maximum (optimal) real GDP per capita

Table 4 AMG estimator test results

Variable	Canada	Mexico	USA
ARMEY *Curve Model*			
$lnY = F(lnGS, (lnGS)^2, lnC)$			
lnGS	−10.109** (0.023)	−0.293 (0.913)	18.358* (0.000)
$(lnGS)^2$	0.203** (0.016)	0.005 (0.931)	−0.312* (0.000)
lnC	0.317* (0.005)	0.520* (0.000)	0.447* (0.000)
EKC Model			
$lnCO_2 = F(lnY, (lnY)^2, lnC)$			
lnY	−5.370** (0.011)	−0.176 (0.970)	−2.066** (0.018)
$(lnY)^2$	0.251** (0.012)	0.011 (0.965)	0.094** (0.023)
lnC	0.925* (0.000)	1.021* (0.000)	1.183* (0.000)
Composite Model			
$lnCO_2 = F[(lnGS + (lnGS)^2), (lnGS + (lnGS)^2)^2, lnC]$			
$(lnGS + (lnGS)^2)$	−0.53*** (0.064)	0.031*** (0.074)	−0.041 (0.118)
$(lnGS + (lnGS)^2)^2$	0.001*** (0.069)	−0.001*** (0.095)	0.001 (0.130)
lnC	0.864* (0.000)	0.775* (0.000)	1.145* (0.000)

*, **, and *** indicate 1%, 5%, and 10% statistical significances, respectively

Table 5 The curve shapes of the ARMEY, EKC, and composite models

	ARMEY curve model	EKC model	Composite model
Canada	U-shaped	U-shaped	U-shaped
Mexico	Insignificant	Insignificant	Inverted U-shaped
USA	Inverted U-shaped	U-shaped	Insignificant

level (through the maximum government spending level) that will minimize CO_2 emissions if this model's curve is expressed in a U-shape (convex). The lowest point of the letter "U" corresponds to the lowest CO_2 emissions. The same composite model may also enable us (governments) to numerically determine a maximum real GDP per capita level (through the maximum government spending level) that will maximize CO_2 emissions if this model's curve is expressed in an inverted U-shape (concave). The highest point of the inverted letter U "∩" corresponds to the highest CO_2 emission level. Predeterminations of these maximum (optimal) levels may provide crucial information for the governments to manage both their economic and environmental policies proactively and effectively without causing environmental degradation. This approach (composite model) proposed will also show us how the causally interrelated independent and dependent variables, i.e., *government spending*, *real GDP per capita*, and *CO_2 emissions*, interact with one another in the ARMEY, EKC, and composite models. However, it should be noted that testing the EKC hypothesis with the approach proposed requires verified ARMEY curve hypothesis and a significant composite model for the same NAFTA country.

Empirical findings of this study indicate that this composite model is not capable of testing the EKC hypothesis through the ARMEY curve model for any NAFTA country since we could not verify the ARMEY curve hypothesis and have a significant composite model for the same NAFTA country. One may think that this approach (composite model) is not applicable for any country, but this cannot be true since our findings from this model are valid only for our sample NAFTA countries. This means that this approach can be effectively applicable for other countries. Therefore, we believe that this approach, as an alternative way, with the advantages described above, will offer a different perspective in EKC hypothesis testing of relevant literature. The main policy implication of this approach proposed is that governments/policymakers may be able to anticipate their maximum government spending and GDP per capita levels (their upper limits) to ensure more sustainable economic and environmental policies. This means that, to some extent, they may be able to slow down their government spending so as not to cause an increase in CO_2 emissions from another point of view, policymakers can decide whether to have a cleaner environment or higher economic growth with this methodology. This either-or situation can be a kind of dilemma for policymakers; however, they will know a threshold economic growth rate that will not cause environmental degradation.

Another policy implication of this approach is that our proposed composite model may provide policymakers with an idea about whether their economic growth and energy policies are compatible with each other. This means that they may know how their economic growth policies based on government spending (the Armey curve hypothesis) affect their energy policies. If additional government spending leads to continuous increases in CO_2 emissions, this, to some degree, may mean that such a type of economic growth policy (model) is not sustainable/eco-friendly or compatible with the energy policy. In this context, our composite model may bring a different point of view to the relevant literature when examining both economic and energy policies together since energy policies are subsets of economic policies and vice versa.

The limitation of this study is that this new approach was applied only to NAFTA countries, namely the USA, Canada, and Mexico. We believe that this approach, which combines the ARMEY curve and EKC hypotheses, will lead to successful results in future empirical studies that will use many more sample countries.

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Data availability The datasets generated and analyzed during the current study are available in the World Bank Indicator, Materialflows.net, World Intellectual Property Organization repository, http://data.worldbank.org.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

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