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RESEARCH ARTICLE

Reinvestigating the Environmental Kuznets Curve (EKC) hypothesis by a composite model constructed on the Armey curve hypothesis with government spending for the US States

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Abstract

This study reinvestigates the EKC hypothesis for US states with a new methodology that differs from all previous empirical studies using traditional EKC models. To this aim, this methodology, for the first time, unifies two seemingly different but strongly interrelated hypotheses (models), namely the Armey curve (AC) and traditional EKC models, into one single composite model. The rationale for creating this composite model is twofold. First, the functional propositions of these two hypotheses are depicted with inverted U-shaped curves. Second, they also have economically interrelated-causal relationships. This means that rising government spending (through the AC hypothesis) increases real GDP per capita (RGDPPC) and, consequently, increases in RGDPPC (through the EKC hypothesis) increase CO_2 emissions. The composite model created may also allow US state policymakers to determine a single maximum spending level that will maximize or minimize CO_2 emissions. Empirical findings indicate that the composite model is capable of testing the EKC hypothesis for 7 US states. Additionally, for 7 US states, maximum spending level was calculated to be around 15% of their RGDPPCs. Hence, with this calculated spending level, policymakers of these states may be able to determine-adjust their golden spending levels so as not to cause environmental degradation and declines in GDP.

Keywords The Armey curve hypothesis · the EKC hypothesis

Jel classification E62 · Q50

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Introduction

The roles of the governments in economic growth have been discussed for a long time. In the theoretical discussion, the neoclassical growth model, developed by Solow (1956), postulates that fiscal policies through taxation and government spending can affect the economic growth up to only a steady-state rate of growth, which is determined by the exogenous rate of technological progress. On the other hand, the endogenous growth model, pioneered by Romer (1986), Lucas (1988), and Barro (1990), postulates that a government can affect the economic growth since transition and steady-state growth rates and government is considered endogenous. This means that governments play a serious role in the economy. From a closer perspective, this discussion implicitly arises from a basic question about how much should a government be involved in the economy? According to Armey (1995), rises in government spending trigger economic growth only up to a threshold (turning) point. Further rises in spending lead to falls in growth and the initially linear relationship between growth and spending becomes nonlinear just after this threshold point (optimal government spending level). This nonlinear relationship postulated draws a parabolic inverted U-shaped curve, the so-called Armey curve shown in Figure 1. The rationale of this expectation is that real GDP per capita will initially increase by increasing productive government spending and eventually decrease after a threshold (turning) point due to different dynamics, such as the crowding-out effect, taxation, the law of diminishing returns, and bureaucratic costs (Bastiat 1983; Barro, 1990; Scully, 1994; Karras, 1997; Chao and Grubel, 1998; Sarte, 2001; Colombier, 2009).

The pattern of this curve gives government policymakers the maximum level of spending which could maximize their real GDP per capita. On the basis of causal interconnectivity among the macroeconomics variables in the economy, the Armey curve resembles another inverted U-shape curve, the so-called Environmental Kuznets Curve (EKC), developed by Grossman and Krueger (2019), shown in Figure 2. According to the EKC hypothesis, in the first stages of economic growth, rises in the real GDP per capita initially lead to increases in environmental degradation (CO_2 emissions) but further rises eventually lead to decreases in emissions after a certain turning point & In a way similar to the Armey curve hypothesis, this certain point gives government policymakers the maximum level of real GDP per capita, which will trigger declines in CO2 emissions.In a way similar to the Armey curve hypothesis, this certain point gives government policymakers the maximum level of real GDP per capita, which will trigger declines in CO2 emissions (Ahmad et al. 2021a, b, c; Alvarado et al. 2021a, b; An et al. 2021; Işık 2010, 2013; Işık et al. 2017, 2018, 2019a, b, 2020, 2021a, b; Ongan et al. 2017, 2018, 2021; Pata and Işık 2021; Rajput and Tariq 2019; Rehman et al. 2021a, b, c; Pablo-Romero et al. 2021; Roy 2009; Shahbaz et al. 2017; Shahzad et al. 2021; Sohag et al. 2021; Sun et al. 2021; Urban 2021; Vedder and Gallaway 1998; Verbič et al. 2021; Anser et al. 2020; Dogan et al. 2020; Dogru et al. 2019, 2020; Aslan et al. 2018; Apergis et al. 2017; Bekun et al. 2021; Bilgili et al. 2021; Bozma et al. 2019; Cheong-Fatt et al. 2020; Connolly and Li 2016; Dar and Khalkhali 2002; Data Planet 2021; Dogan and Inglesi-Lotz2020; Dogan and Ozturk 2017; Dogan and Turkekul 2016; EIA 2021; Go et al. 2021; Güngör et al. 2021; Gyamfi et al. 2021; Khan and Hou 2021; Knoop 1999; Minlah and Zhang 2021; Murshed et al. 2021; Naqvi et al. 2021; Nawaz et al. 2021).

When these two hypotheses (curves) are closely examined, a sequentially causal relationship can be clearly seen from the Armey curve hypothesis to the EKC hypothesis. This means that rises in government spending lead to increases in real GDP per capita in the Armey curve model and, thereby, rises in real GDP per capita lead to increases in CO_2 emissions in the EKC model. Moreover, this variable-level causal relationship between the two models was constructed on the same inverted U-shaped mathematical proposition. Therefore, an interesting question arises: Can these two hypotheses be jointly examined theoretically and mathematically? Does this mean that such similarity enables us to test the EKC

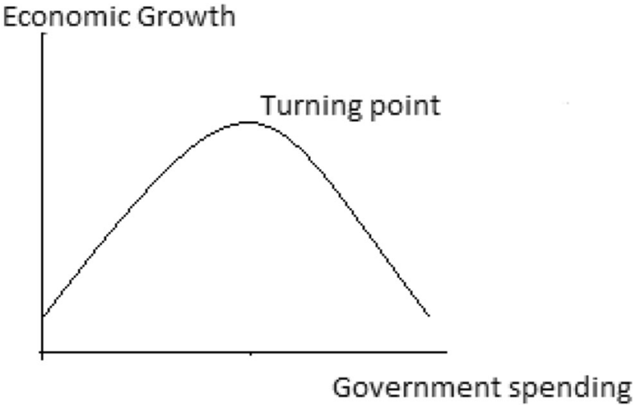


Fig. 1 Armey curve

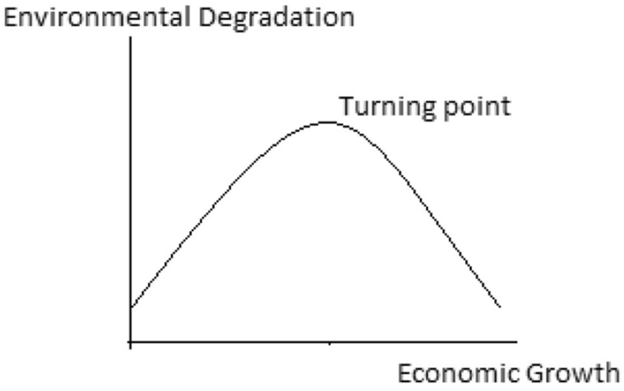


Fig. 2 Environmental Kuznets Curve

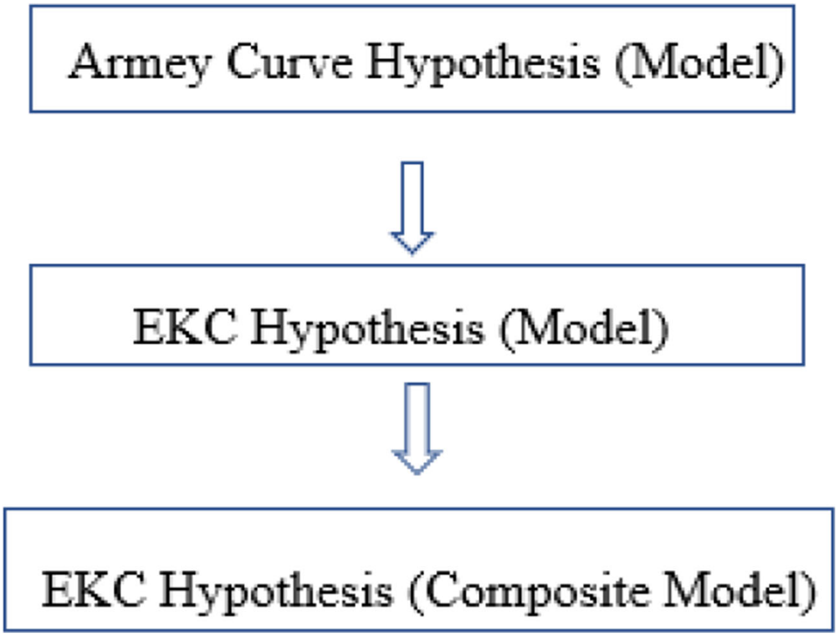


Fig. 3 EKC hypothesis testing through the Armey curve hypothesis

hypothesis through the Armey curve hypothesis (model)? If we can, this can be interpreted that the EKC hypothesis can be potentially tested by a kind of transmission mechanism of the Armey curve model. The answers to these questions will reveal clearly the objective and the empirical contribution of this study in the related literature.

In this context, a single composite model derived from these two hypotheses (models) can be set up. To the best of our knowledge, this new methodological approach proposed using a single composite model will be the only attempt used in testing the EKC hypothesis in relevant literature. This alternative approach of testing the EKC hypothesis and transmission mechanism can be shown in the following Figure 3:

Therefore, we will try to test the EKC hypothesis in this methodological context for 50 US states from 1990 to 2017 based on the latest available year data. The rationale of a state-level empirical study is that US states have different levels of real GDP per capita, spending, CO_2 emissions, and energy policies. These differences make the USA a unique sample country. Another advantage of sampling US states is that this country provides a wide range of data at the state level for more detailed empirical results. The necessary conditions for testing the EKC hypothesis through the Armey curve model are as follows: first, the Armey curve must be validated for a sample US state. Second, the composite model must be significant for the same US state. This means that the curve shape of the Armey model must be inverted U-shaped. However, significant composite model can be either U-shaped or inverted U-shaped. If the composite model's curve is also inverted U-shaped, this will imply that the EKC hypothesis is validated through the Armey curve hypothesis (Case 1 in Figure 4). Otherwise, significant but U-shaped curve will not validate this hypothesis through the Armey curve model (Case 2 in Figure 5). In the following Figures 4 and 5, we graphically depict these two potential curve cases of the composite EKC model with a validated Armey curve hypothesis.

This proposed alternative EKC hypothesis testing method may provide an important advantage to US state policymakers in these two different cases. Case 1 may enable them to determine a maximum (optimal) spending level (through a maximum real GDP per capita level: point (A) that maximizes CO_2 emission (point B). Hence, the policymakers may know that additional spending after point A will decrease real GDP per capita and CO_2 emission, implying a dilemma between

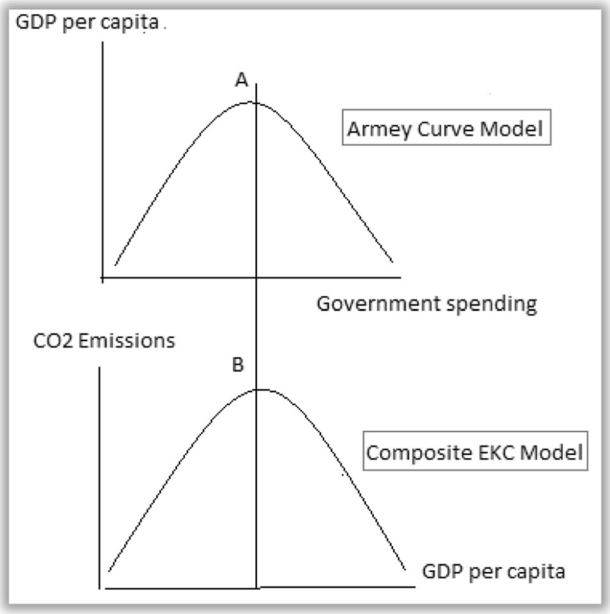


Fig. 4 Case 1

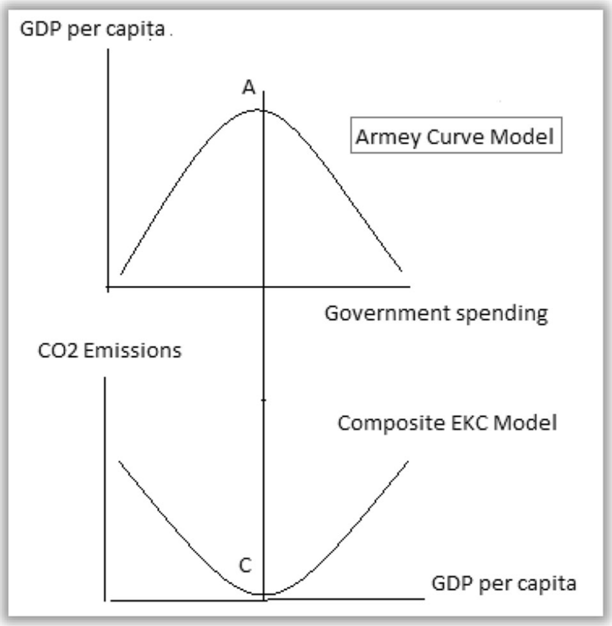


Fig. 5 Case 2

cleaner environment or lower real GDP per capita. From this point of view, they may determine a golden (optimal) ratio reckoning with the potential changes in real GDP per capita and CO_2 emission as a whole. Case 2 may enable them to determine a maximum (optimal) public spending level (through a maximum real GDP per capita level: point (A) that minimizes CO_2 emission (point C). Hence, policymakers may know that additional spending, after point A, will decrease real GDP per capita and increase CO_2 emission (point C), implying no more government spending is needed after point A. To some degree, this proposed methodological approach also enables US state policymakers to find out whether their economic growth and energy policies are compatible with each other and sustainable or how these two policies interact with each other. In this interpretation, while we regard economic growth policy with the Armey curve hypothesis (based on government spending), we regard energy policy with the EKC hypothesis (based on increases in real GDP per capita). Therefore, policymakers in cross-border states can develop some common economic and energy policies to ensure more sustainable environment. The following sections of the study are as follows: "Empirical model and estimation methodology" explains the empirical model and estimation methodology. "Empirical findings" and "Conclusion with policy implications" provide the empirical findings and the conclusion with policy implications, respectively. An updated comprehensive literature review that examines these two hypotheses individually for the US or in a group of countries is provided in Table 6 in Appendix 1.

Empirical model and estimation methodology

The empirical model of this study was theoretically constructed based on Figure 3 in the introduction section. Hence, to create our composite EKC model, we, first, write the following Armey curve model in the natural logarithmic form for the 50 US states:

$$lnDI_{it} = \alpha + \beta lnS_{it} + \gamma lnS_{it}^2 + \zeta lnEC_{it} + \varepsilon_{it} \tag{1}$$

where *DI* is state-level per capita real disposable personal income as the proxy of real GDP per capita. *S* and S^2 are state government spending and squared value of state government spending, respectively; *EC* is total energy consumption. According to the Armey curve hypothesis, the signs for β and γ are expected to be significantly positive and negative, respectively. If these two coefficients are characterized by these signs ($\beta > 0; \gamma < 0$), it is implied that the Armey curve hypothesis is valid for a US state. This means that rises in spending will initially lead to increases in real GDP per capita up to a threshold point (optimal state government spending level) and eventually lead to decreases in it. The dataset and definitions of the variables are provided before the references section.

Following the Armey curve model in Eq. (1), we present the EKC hypothesis model in the following form:

$$lnCO2_{it} = a + blnDI_{it} + clnDI_{it}^2 + zlnEC_{it} + \varepsilon_{it} \tag{2}$$

where CO_2 is state-level carbon emissions, and *DI* and DI^2 are state-level per capita real disposable personal income and squared value of per capita real disposable personal income, respectively. *EC* is total energy consumption. According to the EKC hypothesis, the signs for *b* and *c* are expected to be significantly positive and negative, respectively. If these two coefficients are characterized by these signs ($b > 0; c < 0$), it is implied that the EKC hypothesis is valid for a US state. This means that rises in income will initially lead to an increase in CO_2 emissions and eventually lead to a decrease in it after a maximum point of income.

From the models in Eqs. (1) and (2), we create-obtain the following composite model without *EC* in Eq. (3). To show the methodological approach of this study clearly, we have designed the model in the following form without *EC*:

$$lnCO2_{it} = a + b(\underbrace{\alpha + \beta lnS_{it} + \gamma lnS_{it}^2}_{DI}) + c(\underbrace{\alpha + \beta lnS_{it} + \gamma lnS_{it}^2}_{DI^2})^2 \dots\dots\dots\dots \varepsilon_{it} \tag{3}$$

Hence, with this model formula, we can test the EKC hypothesis through the Armey curve model mathematically since the independent variables of the EKC model (DI and DI^2) will be represented by the independent variables of the Armey curve model in parentheses (S and S^2). The EKC hypothesis is validated if the signs for ***b*** and ***c*** (corresponding to DI and DI^2) are positive and negative, respectively.

To determine the maximum (optimal) government spending level that will maximize (Case 1 in Figure 4) or minimize (Case 2 in Figure 5) CO_2 emissions, we have created and used the following steps and formulae:

From the first-order optimization condition $dlnDI/dlnS$ applied to Eq. (1), we obtain the state government spending level as,

$$lnS=-\frac{\beta}{2\gamma}$$

The sufficient condition for maximization is $d^2lnDI/dlnS^2 = 2\gamma < 0$,so γ is expected to be < 0. For data consisting of $S_i > 1$, lnS is positive, so β is expected to be > 0. Later, we obtain the optimal level for the composite model in Eq. (3), from the first-order condition dCO_2/dS:

$$lnS_1=-\frac{\beta}{2\gamma}$$

$$lnS_{2,3}=\frac{-\beta\pm\sqrt{\beta^2-2\left(\frac{b}{c}\right)\gamma-4\alpha\gamma}}{2\gamma}$$

The value of $lnS=-\frac{\beta}{2\gamma}$ in Eq. (4) will be the optimal CO_2 emissions level for Eq. (3). When we insert the value of $lnS=-\frac{\beta}{2\gamma}$ into $d^2CO2/dlnS^2=2b\gamma+2c\,(\beta+2\gamma lnS)^2+4c\gamma\,(\alpha+\beta lnS+\gamma lnS^2)$,we obtain the following formula:

$$\frac{d^2CO2}{dlnS^2}(lnS_1)=-c\beta^2+2b\gamma+4c\alpha\gamma$$

if $\gamma < 0$ and $-c\beta^2+2b\gamma+4c\alpha\gamma > 0$, it means that the Armey curve has an inverted U-shape and the composite EKC is U-shaped. If $\gamma < 0$ and $-c\beta^2+2b\gamma+4c\alpha\gamma < 0$, it means that the Armey curve and the composite EKC are both inverted U-shaped. Finally, to estimate the coefficients of the model in Eq. (3), we have followed several methodological steps in the following sub-titles.

Cross-sectional dependence and heterogeneity tests

The empirical analysis begins with testing cross-sectional dependence and slope heterogeneity in the panel data set. The paper performs the Lagrange Multiplier (LM), CD, CD_{LM}, and LM_{adj} tests to examine whether cross-sectional dependence exists. While the LM test was produced by Breusch and Pagan (1980), CD and CD_{LM} tests were suggested by Pesaran (2004). In addition, LM_{adj} test was propounded by Pesaran et al. (2008). The paper also employs $\widetilde{\Delta}$ and $\widetilde{\Delta}_{adj}$ tests to investigate the possible presence of slope heterogeneity. Both tests were developed by Pesaran and Yamagata (2008). While cross-sectional dependence tests search for the null hypothesis of no cross-sectional dependence, heterogeneity tests examine the null hypothesis of slope homogeneity.

Pesaran (2007) panel unit root test

This paper carries out the augmented Dickey-Fuller (henceforth, CADF) panel unit root test of Pesaran (2007) to examine whether there is a unit root in the variables under consideration. This panel unit root test considers the null hypothesis of a unit root and can reveal biased and efficient output in the existence of slope heterogeneity and cross-sectional dependence in the panel data model.

Westerlund (2007) panel cointegration test

To test cointegration in the presence of cross-sectional dependence, Westerlund (2007) produces panel cointegration tests based on the error correction model. Among these tests, P_t and P_a statistics are defined as panel statistics and they depend on pooling information on error correction across cross sections in the panel. Besides, G_t and G_a are called group mean statistics and they do not use the information utilized by

Table 1 Descriptive statistics for the variables in the models

	lnDI	lnS	$(lnS)^2$	$lnCO_2$	$(lnDI)^2$	$(lnS+(lnS)^2)$	$(lnS+(lnS)^2)^2$	lnEC
Descriptive statistics								
Mean	10.246	16.604	276.766	3.016	105.096	293.370	87336.03	5.842
Median	10.275	16.609	275.874	2.942	105.578	292.484	85546.89	5.797
Maximum	11.014	19.673	387.033	4.872	121.318	406.706	165409.8	7.087
Minimum	9.406	14.111	199.118	2.086	88.478	213.229	45466.74	5.159
Std. deviation	0.332	1.037	34.613	0.547	6.803	35.650	21331.43	0.364
Number of observations	1400	1400	1400	1400	1400	1400	1400	1400

Table 2 Cross-sectional dependence and heterogeneity tests results

Armey curve model *lnDI=F(lnS, (lnS)^2, lnEC)*	Test statistic	*p*-value
Cross-sectional dependence tests		
LM	7707.202*	0.000
CD_{LM}	190.960*	0.000
CD	74.337*	0.000
LM_{adj}	119.031*	0.000
Heterogeneity tests		
$\tilde{\Delta}$	144.166*	0.000
$\tilde{\Delta}_{adj}$	42.908*	0.000
Traditional EKC model	Test statistic	*p*-value
lnCO$_2$=F(lnDI, (lnDI)^2, lnEC)		
Cross-sectional dependence tests		
LM	7162.865*	0.000
CD_{LM}	119.963*	0.000
CD	52.835*	0.000
LM_{adj}	252.897*	0.000
Heterogeneity tests		
$\tilde{\Delta}$	1525.583*	0.000
$\tilde{\Delta}_{adj}$	44.414*	0.000
Composite EKC model	Test statistic	*p*-value
lnCO$_2$=F[(lnS+(lnS)^2), (lnS+(lnS)^2)^2, lnEC]		
Cross-sectional dependence tests		
LM	6429.641*	0.000
CD_{LM}	105.150*	0.000
CD	48.781*	0.000
LM_{adj}	216.052*	0.000
Heterogeneity tests		
$\tilde{\Delta}$	741.817*	0.000
$\tilde{\Delta}_{adj}$	56.913*	0.000

* indicates 1% statistical significance

panel statistics. The null hypothesis of no cointegration is tested for all tests. Westerlund (2007) uses the panel regression model defined as follows:

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

where d_t indicates deterministic components, λ_i shows long-run parameters, and α_{ij} and γ_{ij} stand for short-run parameters. For P_α and P_τ tests, the null hypothesis of cointegration (H0: $p_i = 0$ for all i) is tested against the alternative of cointegration (H1: $p_i < 0$ for all i). P_α and P_τ tests are computed as,

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

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

Additionally, for G_α and G_τ tests, the null hypothesis of no cointegration is defined as H0: $p_i = 0$ for all i, while the alternative hypothesis of cointegration is described as H1:$p_i < 0$ for at least some i. G_α and G_τ test statistics are computed as shown in the following:

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

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

Table 3 CADF unit root test

Variable	Test statistic	
	Level	First difference
lnDI	− 1.766	− 2.213**
lnS	− 2.026	− 2.174**
(lnS)^2	− 2.022	− 2.170**
lnCO$_2$	− 1.423	− 2.342*
(lnDI)^2	− 1.762	− 2.225**
(lnS+(lnS)^2)	− 2.023	− 2.170**
(lnS+(lnS)^2)^2	− 2.015	− 2.166**
lnEC	− 1.008	− 2.324**

* and ** respectively indicate 1% and 5% statistical significance

Augmented mean group estimator

After detecting the presence of cointegration in a panel data model, the next step is to estimate long-run coefficients. Eberhardt and Teal (2010) propound a two-stage panel data estimator. The regression equations for this estimator are shown as

Table 4 Westerlund (2007) panel cointegration test

	G_t	G_a	P_t	P_a
Armey *curve model* $\ln DI = F(\ln S, (\ln S)^2, EC)$	− 2.761*	− 0.937	− 4.075*	− 2.957
Traditional EKC model $\ln CO_2 = F(\ln DI, (\ln DI)^2, EC)$	− 2.221*	− 5.242	− 12.905*	− 4.625
Composite EKC model $\ln CO_2 = F[(\ln S + (\ln S)^2), (\ln S + (\ln S)^2)^2, EC]$	− 2.114*	− 6.396	− 13.408*	− 6.038**

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

$$\Delta y_{it} = b^{'}\Delta x_{it} + \sum_{t=2}^{T} c_t D_t + e_{it}\ \widehat{c}_t = \overset{\circ}{\widehat{\mu}_t}$$

$$y_{it} = a_i + b_i^{'} x_{it} + c_i t + d_i \overset{\circ}{\widehat{\mu}_t} + e_{it}\quad \widehat{b}_{AMG} = N^{-1}\sum_{i=1}^{N}\widehat{b}_i$$

In the first step, a standard pooled first difference regression that incorporates T-1 dummies, namely $\overset{\circ}{\widehat{\mu}_t}$, is estimated. In the second step, this variable is included in N standard unit regressions. The cointegration parameters of the variables in the empirical models are demonstrated by $\widehat{b}_{AMG}$ for the panel.

The obtained values of descriptive are given in Table 1 for the datasets of US States.

Empirical findings

Table 2 reports the cross-sectional dependence (CSD) and slope heterogeneity tests results for the Armey curve, the traditional EKC, and composite EKC economic models.

Test results in Table 2 indicate that the null hypothesis of CSD is rejected at the 1% level of significance. This means all series of the models contains CSD and a shock in one of the US states can impact other US states. Furthermore, the null hypothesis of slope homogeneity can be rejected by both tests for all models. This means that US states have specific characteristics in terms of the Armey and the EKC hypotheses. The results of the covariate-augmented Dickey-Fuller (*CADF*) unit root test are reported in Table 3.

Test results in Table 3 indicate that all variables are integrated of order one (I(1)). This means that series are stationary at first differences. Hence, cointegration relationships in the models can be examined via the Westerlund (2007) panel cointegration test. The results of this test are reported in Table 4.

As seen in Table 4, Gt test statistic indicates there is a cointegration relationship in the Armey curve model, while Gt and Pt test statistics explore whether cointegration exists in the EKC model. Besides, Gt, Pt, and Pa test statistics show there is cointegration in the composite model. Hence, the Westerlund (2007) panel cointegration test implies there is a cointegration relationship in all models and the long-run coefficients of the independent variables in the models can be estimated via the augmented mean group (AMG) estimator. Test results of the AMG estimator test results are reported in Table 7 in Appendix 2.

Test results in Table 7 indicate that the Armey curve hypothesis is validated only for 15 US states out of the 50, namely, Colorado, Connecticut, Georgia, Idaho, Illinois, Indiana, Kentucky, Maine, Minnesota, Mississippi, Missouri, New Jersey, South Dakota, Tennessee, and Wisconsin. However, the composite EKC model is significant for only 7 of them, namely, Colorado, Georgia, Indiana, Kentucky, Maine, South Dakota, and Tennessee. This means that it is possible to test the EKC hypothesis with the proposed methodological approach of this study only for these 7 US states since the Armey curve hypothesis has been validated and the composite model is significant for these states. Furthermore, the composite EKC model hypothesis is validated only for Kentucky, Maine, South Dakota, and Tennessee since $\gamma < 0$ and $-c\beta^2 + 2b\gamma + 4c\alpha\gamma < 0$ (two inverted U-shaped curves: Case 1 in Figure 4). However, the composite EKC hypothesis is not validated for Colorado, Georgia, and Indiana since $\gamma < 0$ and $-c\beta^2 + 2b\gamma + 4c\alpha\gamma > 0$ (inverted U-shaped Armey curve and U-shaped composite EKC model in Case 2 in Figure 5). Furthermore, the maximum (optimal) state government spending levels that will maximize CO_2 emissions for Kentucky, Maine, South Dakota, and Tennessee were calculated as 17.5%, 16.4%, 15.2%, and 16.6% of real GDP per capita of these states, respectively. This can be depicted in Case 1 in Figure 4. Similarly, the maximum (optimal) state government spending levels that will minimize CO_2 emissions for Colorado, Georgia, and Indiana were calculated as 16.40%, 16.45, and 16.7% of real GDP per capita of these states, respectively. This can be depicted in Case 2 in Figure 5. Apart from the methodological approach of this study, the traditional EKC hypothesis is validated for only 7 US states out of the 50 since the signs for *b* and *c* in Eq. (2) are positive and negative, respectively (inverted U-shaped curves).

Additionally, rises in energy consumption (*EC*) increase CO_2 emissions in 41 US states out of the 50 since the signs of this variable are significantly positive. Table 5 shows the curve shapes of the Armey, traditional EKC, and composite EKC models. We also created US state-level maps (in Figures 6, 7, and 8) to show the validations of the Armey curve, the

Table 5 Curve shapes of the Armey, EKC, and composite models

State		Traditional EKC model	Armey curve model	Composite EKC model
Number	Name			
1	Alabama	–	–	–
2	Alaska	–	–	–
3	Arizona	U	U	U
4	Arkansas	–	–	–
5	California	U	U	U
6	Colorado	U	∩	U
7	Connecticut	–	∩	–
8	Delaware	U	–	U
9	Florida	–	U	–
10	Georgia	U	∩	U
11	Hawaii	∩	U	–
12	Idaho	U	∩	–
13	Illinois	∩	∩	–
14	Indiana	–	∩	U
15	Iowa	–	–	–
16	Kansas	–	U	–
17	Kentucky	∩	∩	∩
18	Louisiana	U	–	U
19	Maine	–	∩	∩
20	Maryland		–	U
21	Massachusetts	U	–	–
22	Michigan	∩	–	∩
23	Minnesota	–	∩	–
24	Mississippi	–	∩	–
25	Missouri		∩	–
26	Montana	U	U	U
27	Nebraska	–	–	∩
28	Nevada	–	–	–
29	New Hampshire	U	–	U
30	New Jersey	–	∩	–
31	New Mexico	–		–
32	New York	U	U	U
33	North Carolina	–	–	–
34	North Dakota	–	–	∩
35	Ohio	–	–	U
36	Oklahoma	–	U	–
37	Oregon	–	U	–
38	Pennsylvania	–	U	–
39	Rhode Island	∩	–	∩
40	South Carolina	–	–	U
41	South Dakota	∩	∩	∩
42	Tennessee	∩	∩	∩
43	Texas	U	–	–
44	Utah	–	–	–
45	Vermont	–	–	–
46	Virginia	–	U	–
47	Washington	–	–	–
48	West Virginia	–	–	–
49	Wisconsin	–	∩	–
50	Wyoming	–	–	∩

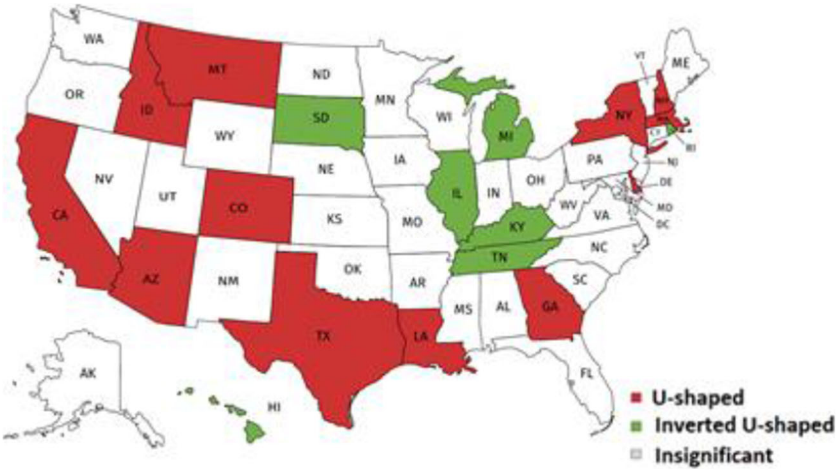
Curve shapes were obtained from Table 4. (U), U-shaped curve; (∩), inverted U-shaped curve; (–), insignificant model (curve)

traditional EKC, and composite EKC hypotheses. We believe that these maps will help state policymakers to re-review the results of their economic and energy polices in terms of these models. The Federal Government will also be enabled to re-review the states' positions based on a holistic picture from these maps since the impact of the states' economics-energy policies on CO_2 emissions varies from one another.

Conclusion with policy implications

The testing methodology of this study's EKC hypothesis differs from all previous empirical studies, in relevant literature, that have used traditional EKC models. This methodology unifies two seemingly different but strongly interrelated hypotheses (models) into one single composite model. These are

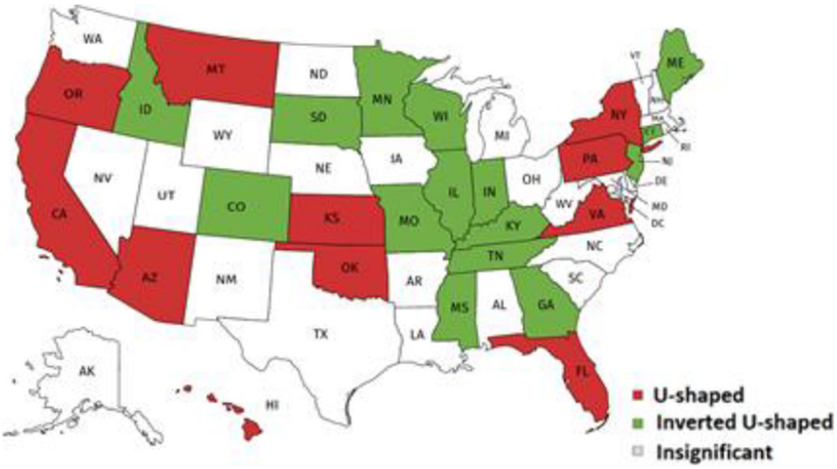
Fig. 6 Traditional EKC Hypothesis



the Armey curve and EKC hypotheses, which were constructed on the same nonlinear mathematical propositions with inverted U-shaped curves. These two hypotheses (models) also have economically interrelated-causal relationships between their independent and dependent variables. This can be explained because rising government spending (based on the Armey curve hypothesis) increases real GDP per capita and, consequently, the increases in real GDP per capita increase environmental degradation (CO_2 emissions). In other words, the Armey curve model's dependent variable is the independent variable of the EKC model. Therefore, both mathematically and economically, we can create a single composite model, which will be derived from the individual Armey and EKC models, to test the EKC hypothesis through the Armey curve hypothesis (model) for US states. This methodology proposed may also allow US state policymakers to determine a single maximum (optimal) spending level that will maximize or minimize CO_2 emissions depending on the composite model's curve shape. With this methodology, both economic policies through the Armey curve, based on government spending, and energy policies through the EKC hypothesis, based on real GDP per capita, can be jointly examined to a certain extent. This examination may also provide state policymakers to re-consider whether their economic and energy policies are compatible with each other.

Empirical findings indicate that the methodology proposed in this study, with its composite EKC model constructed based on the Armey curve model, is capable of testing the EKC hypothesis for 7 states namely, Colorado, Georgia, Indiana, Kentucky, Maine, South Dakota, and Tennessee. For 4 of the 7 states, namely, Kentucky, Maine, South Dakota, and Tennessee, the EKC hypothesis is validated but not for the other 3 states. But, more importantly, regardless of the verification of the EKC hypothesis, with the model proposed by this study, these 4 US states' policymakers will be able to determine the maximum spending levels that will maximize the real GDP per capita and CO_2 emissions. Hence, they will know that additional spending after this maximum threshold points will decrease environmental degradation as well as real GPD per capita. This outcome, of course, may create a dilemma for the policymakers who will have to choose between lower economic growth and cleaner environment. However, they can determine a golden ratio that will ensure them sustainable-compatible economic

Fig. 7 Armey Curve Hypothesis



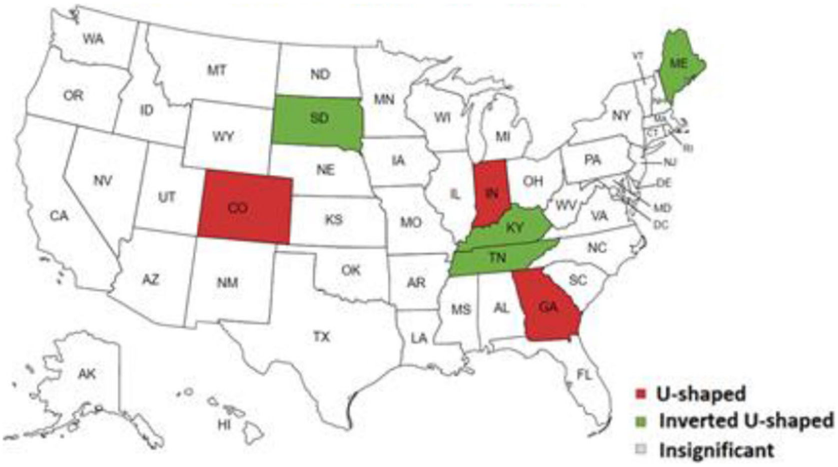


Fig. 8 The Composite EKC Model

and energy policies at a lower cost. From the same methodological context, the policymakers of Colorado, Georgia, and Indiana will be able to determine their maximum spending levels that will maximize the real GDP per capita and minimize CO_2 emissions. Hence, they will know that additional spending after this maximum threshold points will decrease real GDP per capita and increase CO_2 emissions. This outcome may give them an ideal (optimal) maximum spending level rather than creating a dilemma, as was the case with Kentucky, Maine, South Dakota, and Tennessee. Therefore, policymakers may slow down their economies with no more spending for compatible-sustainable economic and energy policies. Empirical findings of the models reveal that the maximum spending levels that will maximize or minimize real GDP per capita and CO_2 emissions are between 15.2 and 17.5% of the states' real GDP per capita. Additionally, the map created in Figure 7 clearly shows that the Armey curve hypothesis is validated in the states mostly located in the inner agricultural areas of the USA. Additional spending in these states initially increases real GDP per capita until a certain point and eventually decreases it.

All these outcomes and interactions expected between the variables should be considered based only on the proposed methodology of the study incorporating the Armey curve and the traditional EKC models and not on other macroeconomic variables of the economy. The findings of this study show the need for further empirical studies that will re-approach and re-test the old and recent hypotheses-theories based on multi-dimensional-functional perspectives as we did for the EKC hypothesis. These types of approaches may enable examining economic issues from a holistic point of view since macroeconomic variables dynamically and causally interact with one another.

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Data availability *DI* and *S* are in USD; *C* is million btu. Data of state government spending were obtained from the Urban Institute (Urban). Data of state-level total energy consumption-CO_2 emissions (metric million tons) and real *DI* were obtained from the U.S. Energy Information Administration (EIA) and Data Planet, respectively.

Declarations

Ethics approval and consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

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