The Armey Curve Hypothesis-based Environmental Kuznets Curve (EKC) Hypothesis Testing Across the US States with Government Spending

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Abstract: This study re-tests 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 CO₂ emissions. The composite model created may also allow US state policymakers to determine a single maximum spending level that will maximize or minimize CO₂ 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, New version of the EKC hypothesis testing.

Jel Classification: E62, Q50.
1. 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, 1996; 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 (1991), 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 CO$_2$ emissions.
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, we believe that these two hypotheses can be jointly examined, both theoretically and mathematically. This means that such similarity may enable us to test the EKC hypothesis through the Armey curve hypothesis (model). Therefore, it can be interpreted that the EKC hypothesis can be potentially tested by a kind of transmission mechanism of the Armey curve model. 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 1990-2017 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, CO₂ 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\textsubscript{2} emission (point B). Hence, the policymakers may know that additional spending after point A will decrease real GDP per capita and CO\textsubscript{2} emission, implying a dilemma between 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\textsubscript{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: Section 2 provides a summary literature review. Section 3 explains the empirical model and estimation methodology. Sections 4 and 5 provide the empirical findings and the conclusion with policy implications, respectively.

**2. Literature Review**

In this section, we provide the empirical studies which have tested the Armey and the EKC curves hypotheses individually for the US or in a group of countries such as those of the OECD and the G-7 group. Table 1 reports these studies with the empirical methodologies used and their findings.

| Table 1: Empirical Studies in the Armey Curve and EKC Hypotheses | Armey Curve Hypothesis |
|---------------------------------------------------------------|------------------------|
| Methodology | Findings |
|-------------|----------|
| Vedder and Gallaway (1998) | OLS Regression | Valid |
| Knoop (1999) | OLS Time Series | Not Valid |
| Dar and Amir Khalkhali (2002) | random coefficients model | Not Valid |
| Roy (2009) | Simultaneous Equations | Not Valid |
| Connolly and Li (2016) | GMM | Not Valid |
| Bozma, Başar, and Eren (2019) | ARDL Cointegration | Valid |
| Rajput and Tariq (2019) | GMM | Not Valid |

**EKC Hypothesis**

| Methodology | Findings |
|-------------|----------|
| Dogan and Turkekul (2016) | Bounds Testing | Not Valid |
| Dogan and Ozturk (2017) | Bounds Testing and Gregory-Hansen Cointegration | Not Valid |
| Shahbaz et al. (2017) | Bounds Testing with Structural Break | Not Valid |
| Apergis et al. (2017) | Panel Estimators | Valid in 10 out of 48 US States |
| Aslan et al. (2018) | Bootstrap window estimation | Valid |
| Isık et al. (2019) | CCE | Valid in 5 out of 10 US States |
| Ongan et al. (2021) | Decomposition | Valid by Decomposed model |
Empirical studies in Table 1 clearly reveal mixed results about the validity of the Armey curve and EKC hypotheses. This may stem from the different methodologies applied, time frames examined, and different variables used in the models.

3. 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:

\[
\ln DI_{it} = \alpha + \beta \ln S_{it} + \gamma \ln S_{it}^2 + \zeta \ln EC_{it} + \varepsilon_{it}
\]  

(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 \(\beta\) and \(\gamma\) 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 Eqn. 1, we present the EKC hypothesis model in the following form:

\[ \ln CO2_{it} = a + b\ln DI_{it} + c\ln DI^2_{it} + z\ln EC_{it} + \epsilon_{it} \]  \hspace{1cm} (2)

where \( CO_2 \) is state-level carbon emissions, \( DI \) 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 Eqns. 1 and 2, we create-obtain the following composite model without \( EC \) in Eqn. 3. To show the methodological approach of this study clearly, we have designed the model in the following form without \( EC \):

\[ \ln CO2_{it} = a + b(\alpha + \beta \ln S_{it} + \gamma \ln S^2_{it}) + c(\alpha + \beta \ln S_{it} + \gamma \ln S^2_{it})^2 + \epsilon_{it} \]  \hspace{1cm} (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 \(d\ln DI/d\ln S\) applied to Eqn. 1, we obtain the state government spending level as,

\[
\ln S = -\frac{\beta}{2\gamma}
\]

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

\[
\ln S_1 = -\frac{\beta}{2\gamma}
\]

\[
\ln S_{2,3} = \frac{-\beta \pm \sqrt{\beta^2 - 2\left(\frac{b}{c}\right)\gamma - 4\alpha\gamma}}{2\gamma}
\]
The value of $lnS = -\frac{\beta}{2\gamma}$ in Eqn.4 will be the optimal CO$_2$ emissions level for Eqn. (3).

When we insert the value of $lnS = -\frac{\beta}{2\gamma}$ into $d^2CO2/dlnS^2 = 2\beta\gamma + 2c (\beta + 2\gamma lnS)^2 + 4\gamma(\alpha + \beta lnS + \gamma lnS^2)$, we obtain the following formula:

$$d^2CO2_{}\left<(lnS)\right> = -c\beta^2 + 2\beta\gamma + 4c\gamma$$

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

### 3.1. 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 $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$ 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.

3.2. 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.

3.3. 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 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, $\lambda_i$ shows long-run parameters, and $\alpha_{ij}$ and $\gamma_{ij}$ stand for short-run parameters. For $P_a$ and $P_t$ 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 $i$). $P_a$ and $P_t$ tests are computed as,

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

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

Additionally, for $G_a$ and $G_t$ 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 $i$. $G_a$ and $G_t$ test statistics are computed as shown below:

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

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

### 3.4. Augmented Mean Group (AMG) Estimator

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

(i) $\Delta y_{it} = b' \Delta x_{it} + \sum_{\tau=2}^{T} c_{\tau} D_{\tau} + e_{it} \quad \rightarrow \quad \hat{c}_t = \hat{\mu}_t$

(ii) $y_{it} = a_i + b_i' x_{it} + c_i t + d_i \hat{\mu}_t + e_{it} \quad \rightarrow \quad \hat{b}_{AMG} = N^{-1} \sum_{i=1}^{N} \hat{b}_i$
In the first step, a standard pooled first difference regression that incorporates T-1 dummies, namely $\hat{\mu}_t$, 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 $\tilde{b}_{AMG}$ for the panel.

4. 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 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   |                |         |
| $\Delta$              | 144.166*       | 0.000   |
| $\Delta_{adj}$        | 42.908*        | 0.000   |

|                      | Test statistic | p-value |
|----------------------|----------------|---------|
| Cross-sectional dependence tests |                |         |
| Test                  | LM        | CD        | CDLM      | LMadj     |
|----------------------|-----------|-----------|-----------|-----------|
|                      | 7162.865* | 0.000     | 119.963*  | 0.000     |
|                      | 52.835*   | 0.000     |           |           |
|                      | 252.897*  | 0.000     |           |           |

Heterogeneity tests

|                | 1525.583* | 0.000     |
|----------------|-----------|-----------|
| Δ              | 44.414*   | 0.000     |

Composite EKC Model

\[
\ln CO_2 = F[\ln S + (\ln S)^2], \\
(\ln S + (\ln S)^2)^2, \ln EC
\]

Cross-sectional dependence tests

| Test                  | LM        | CD        | CDLM      | LMadj     |
|----------------------|-----------|-----------|-----------|-----------|
|                      | 6429.641* | 0.000     | 105.150*  | 0.000     |
|                      | 48.781*   | 0.000     |           |           |
|                      | 216.052*  | 0.000     |           |           |

Heterogeneity tests

|                | 741.817*  | 0.000     |
|----------------|-----------|-----------|
| Δ              | 56.913*   | 0.000     |

Note: * indicates 1% statistical significance.

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.

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**         |

Note: * and ** respectively indicate 1% and 5% Statistical significance.

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 AMG estimator. Test results of the AMG estimator test results are reported in Table 5.
Table 5: AMG Estimator Results

| State      | Armey Curve Model | Traditional EKC Model | Composite EKC Model |
|------------|-------------------|-----------------------|---------------------|
|            | lnS | (lnS)^2 | lnEC | lnDI | (lnDI)^2 | lnEC | lnS+(lnS)^2 | (lnS+(lnS)^2)^2 | lnEC |
| Alabama    | 1.111 | -0.031 | 0.037 | 2.494 | -0.123 | 0.580* | -0.002 | 0.001 | 0.638* |
|            | [1.39] | [-1.28] | [0.52] | [0.85] | [-0.84] | [4.25] | [-0.07] | [0.11] | [4.25] |
| Alaska     | -1.566 | 0.053 | -0.225** | -2.477 | 0.122 | 0.977* | 0.003 | -0.001 | 0.948* |
|            | [-0.44] | [0.48] | [-2.26] | [-1.57] | [1.60] | [20.34] | [0.11] | [-0.06] | [16.52] |
| Arizona    | -1.432*** | 0.046** | 0.635* | -13.361* | 0.659* | -0.839** | -0.097* | 0.001* | -0.409 |
|            | [-1.89] | [2.07] | [5.49] | [-4.14] | [4.11] | [-2.53] | [-3.64] | [3.62] | [-1.12] |
| Arkansas   | -0.542 | 0.020 | -0.048 | 1.700 | -0.085 | 0.752* | -0.011 | 0.001 | 0.874* |
|            | [-0.62] | [0.74] | [-0.44] | [0.43] | [-0.43] | [3.37] | [-0.30] | [0.29] | [3.83] |
| California | -4.548* | 0.123* | 0.298* | -6.002* | 0.290* | 0.629* | -0.055** | 0.001** | 0.645* |
|            | [-6.67] | [6.79] | [3.57] | [-2.99] | [2.98] | [3.36] | [-2.03] | [2.02] | [2.74] |
| Colorado   | 3.986* | -0.121* | -0.422* | -3.059* | 0.146* | 1.030* | -0.022** | 0.001** | 1.086* |
|            | [4.30] | [-4.21] | [-2.90] | [-3.59] | [3.50] | [13.46] | [-2.10] | [1.97] | [11.38] |
| Connecticut | 5.369** | -0.158** | -0.301*** | -2.071 | 0.096 | 0.843* | -0.036 | 0.001 | 0.866* |
|            | [2.13] | [-2.12] | [-1.94] | [-0.60] | [0.58] | [3.98] | [-1.00] | [0.96] | [4.59] |
| Delaware   | 2.431 | -0.080 | 0.482 | -25.291* | 1.221* | 1.071* | -0.212* | 0.001* | 1.248* |
| State       | Value 1  | Value 2  | Value 3  | Value 4  | Value 5  | Value 6  | Value 7  | Value 8  | Value 9  | Value 10 |
|-------------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|
| Florida     | -2.779* | 0.081* | 0.419* | 0.501   | -0.025  | 1.127*  | 0.184   | -0.001  | 1.097*  |
| Georgia     | 4.507*  | -0.137* | 0.325** | -7.821**| 0.385** | 1.022*  | -0.124* | 0.001*  | 1.250*  |
| Hawaii      | -6.899* | 0.230* | 0.243* | 6.759*  | -0.326* | 1.075*  | -0.014  | 0.001   | 1.023*  |
| Idaho       | 1.281***| -0.046**| 0.082  | -5.724***| 0.294***| 0.910*  | 0.032   | -0.001  | 0.676*  |
| Illinois    | 2.142*  | -0.063* | 0.106  | 5.492**  | -0.261**| 1.068*  | -0.020  | 0.001   | 1.129*  |
| Indiana     | 3.088** | -0.092**| -0.204 | 0.785   | -0.042  | 0.786*  | -0.040***| 0.001***| 0.725*  |
| Iowa        | 0.334   | -0.011  | 0.242** | 1.679   | -0.091  | 1.181*  | 0.145   | -0.001  | 1.108*  |
| Kansas      | -2.797**| 0.089** | 0.008  | 3.659   | -0.176  | 1.404*  | 0.027   | -0.001  | 1.359*  |
| Kentucky    | 2.105*  | -0.060* | -0.071*| 6.381** | -0.323**| 0.671*  | 0.054***| -0.001***| 0.728*  |
|        | [6.68] | [-6.31] | [-2.94] | [2.11] | [-2.13] | [4.06] | [1.69] | [-1.72] | [4.22] |
|--------|--------|---------|---------|--------|---------|--------|--------|---------|--------|
| Louisiana | -0.154 | 0.012 | -0.065 | -3.901* | 0.197* | 0.878* | -0.044* | 0.001* | 0.814* |
|         | [-0.17] | [0.46] | [-0.82] | [-2.62] | [2.65] | [10.61] | [-3.56] | [3.69] | [12.81] |
| Maine  | 3.091*  | -0.094* | -0.205** | 0.257 | -0.011 | 0.781 | 0.133** | -0.001** | -0.205 |
|         | [3.11]  | [-2.93] | [-2.54] | [0.05] | [-0.04] | [0.23] | [1.98] | [-1.96] | [-0.65] |
| Maryland | -1.604 | 0.053 | 0.379* | -2.522 | 0.117 | 0.604* | -0.051*** | 0.001*** | 0.570* |
|         | [-1.05] | [1.21] | [3.36] | [-1.04] | [1.00] | [2.77] | [-1.74] | [1.70] | [2.68] |
| Massachusetts | -0.006 | -0.001 | -0.061 | -7.010* | 0.331* | 0.422*** | -0.023 | 0.001 | 0.285 |
|         | [-0.0019] | [-0.004] | [-0.46] | [-3.10] | [3.02] | [1.79] | [-0.61] | [0.50] | [1.11] |
| Michigan | -0.248 | 0.012 | 0.363** | 4.175** | -0.213** | 0.769* | 0.071* | -0.001* | 0.608* |
|         | [-0.10] | [0.17] | [2.53] | [2.31] | [-2.38] | [7.51] | [2.76] | [-2.84] | [5.66] |
| Minnesota | 1.840*** | -0.053* | 0.060 | 0.154 | -0.011 | 0.859* | 0.001 | -0.001 | 0.848* |
|         | [1.81]  | [-1.75] | [0.54] | [0.08] | [-0.13] | [5.44] | [0.03] | [-0.08] | [5.13] |
| Mississippi | 1.944* | -0.054* | -0.228** | -2.903 | 0.160 | 0.613*** | 0.001 | 0.001 | 0.542 |
|         | [3.05]  | [-2.66] | [-2.49] | [-0.70] | [0.76] | [1.79] | [0.04] | [0.09] | [1.51] |
| Missouri | 2.154*  | -0.062* | -0.096*** | 4.494 | -0.215 | 0.597** | 0.007 | -0.001 | 0.714* |
|         | [3.71]  | [-3.49] | [-1.96] | [1.09] | [-1.05] | [2.18] | [0.19] | [-0.11] | [2.72] |
| Montana  | -5.657* | 0.189* | 0.077 | -12.478* | 0.629* | 0.156 | -0.120* | 0.001* | 0.234 |
| State         | [1.39] | [1.00] | [-3.49] | [3.51] | [1.06] | [-2.81] | [2.87] | [1.51] |
|--------------|--------|--------|---------|--------|--------|---------|--------|-------|
| Nebraska     | -1.397 | 0.047  | 0.302*  | 3.030  | -0.149 | 0.857*  | 0.061***| -0.001***| 0.899* |
|              | [-1.38]| [1.39] | [2.98]  | [1.04] | [-1.05]| [4.96]  | [1.76] | [-1.77]| [6.17] |
| Nevada       | 0.669  | -0.018 | 0.701*  | -1.554 | 0.057  | 0.976*  | 0.020  | -0.001| 0.506***|
|              | [1.07] | [-0.90]| [7.87]  | [-0.28]| [0.21] | [4.02]  | [0.51] | [-0.71] | [1.88] |
| New Hampshire| 1.204  | -0.038 | 0.297*  | -7.791***| 0.385***| 0.258   | -0.096**| 0.001*| 0.356   |
|              | [1.30] | [-1.22]| [2.61]  | [-1.78]| [1.80] | [0.97]  | [-2.49]| [2.61] | [1.49] |
| New Jersey   | 1.861* | -0.054*| -0.090***| -2.918 | 0.140  | 1.154*  | 0.013  | -0.001| 1.144*  |
|              | [2.70] | [-2.76]| [-1.76]| [-1.25]| [1.24] | [7.78]  | [0.43] | [-0.45]| [7.73] |
| New Mexico   | 0.314  | -0.003 | -0.004  | -3.069 | 0.147  | 0.300   | -0.028 | 0.001 | 0.312   |
|              | [0.79] | [-0.23]| [-0.05]| [-0.82]| [0.79]| [1.31]  | [-1.19]| [1.12]| [1.53] |
| New York     | -5.228*| 0.138* | -0.048  | -5.999*| 0.284* | 0.940*  | -0.081*| 0.001*| 1.010*  |
|              | [-3.61]| [3.49]| [-0.47]| [-3.40]| [3.31]| [8.58]  | [-3.98]| [3.85]| [11.09]|
| North Carolina| 1.376 | -0.042 | 0.187   | -0.281 | 0.015  | 1.404*  | 0.003  | -0.001| 1.318*  |
|              | [0.81]| [-0.85]| [1.08]| [-0.14]| [0.15]| [7.47]  | [0.14]| [-0.10]| [6.12] |
| North Dakota | 2.954  | -0.088 | 0.586** | -0.487 | 0.026  | 0.260** | 0.037* | -0.001| 0.440*  |
|              | [0.99]| [-0.93]| [2.19]| [-0.40]| [0.42]| [2.34]  | [2.68]| [-2.77]| [4.86] |
| Ohio         | 1.775  | -0.056 | -0.044  | -0.632 | 0.030  | 0.319***| -0.080**| 0.001**| 0.516*  |
| State       | Coefficient 1 | Coefficient 2 | Coefficient 3 | Coefficient 4 | Coefficient 5 | Coefficient 6 | Coefficient 7 | Coefficient 8 | Coefficient 9 |
|-------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| Oklahoma    | -2.579***     | 0.088***      | 0.845**       | -4.089        | 0.206         | -0.097        | -0.037        | 0.001         | 0.175         |
|             | [-1.72]       | [1.94]        | [2.52]        | [-1.51]       | [1.52]        | [-0.29]       | [-0.84]       | [0.87]        | [0.58]        |
| Oregon      | -0.981**      | 0.034**       | 0.381*        | -0.746        | 0.043         | 0.446**       | -0.009        | 0.001         | 0.453***      |
|             | [-2.07]       | [2.36]        | [3.66]        | [-0.21]       | [0.24]        | [2.24]        | [-0.25]       | [0.31]        | [1.82]        |
| Pennsylvania| -1.169*       | 0.034*        | 0.050         | 0.549         | -0.030        | 0.432**       | -0.016        | 0.001         | 0.437**       |
|             | [-3.23]       | [3.28]        | [0.99]        | [0.22]        | [-0.25]       | [2.58]        | [-0.61]       | [0.59]        | [2.53]        |
| Rhode Island| 0.307         | -0.006        | -0.089***     | 36.391*       | -1.784*       | 0.908*        | 0.536*        | -0.001*       | 0.672*        |
|             | [0.35]        | [-0.22]       | [-1.67]       | [5.15]        | [-5.14]       | [3.76]        | [4.11]        | [-4.09]       | [2.59]        |
| South Carolina| 1.293       | -0.041        | 0.087         | 1.538         | -0.071        | 0.236         | -0.050***     | 0.001**       | 0.641*        |
|             | [1.49]        | [-1.57]       | [1.15]        | [0.56]        | [-0.52]       | [1.03]        | [-1.85]       | [1.97]        | [2.86]        |
| South Dakota| 1.338***      | -0.044***     | 0.439*        | 7.187*        | -0.361*       | 0.455*        | 0.115**       | -0.001**      | 0.395*        |
|             | [1.81]        | [-1.71]       | [5.27]        | [2.93]        | [-2.94]       | [3.04]        | [2.49]        | [-2.49]       | [2.69]        |
| Tennessee   | 5.038*        | -0.151*       | -0.249*       | 6.215**       | -0.319**      | 1.481*        | 0.081*        | -0.001*       | 1.061*        |
|             | [5.11]        | [-5.00]       | [-3.23]       | [2.19]        | [-2.26]       | [5.03]        | [2.87]        | [-2.99]       | [3.96]        |
| Texas       | -0.029        | 0.002         | 0.050         | -1.553**      | 0.074**       | 0.908*        | -0.003        | 0.001         | 0.877*        |
|             | [-0.05]       | [0.13]        | [0.71]        | [-2.10]       | [2.01]        | [31.22]       | [-0.52]       | [0.38]        | [26.30]       |
| Utah        | -0.659        | 0.019         | 0.251***      | -3.442        | 0.162         | 0.362**       | -0.042        | 0.001         | 0.358***      |
|            | [-0.77] | [0.69] | [1.79] | [-1.61] | [1.51] | [2.22] | [-1.43] | [1.31] | [1.88] |
|------------|---------|--------|--------|---------|--------|--------|---------|--------|--------|
| Vermont    | 0.833***| -0.022 | -0.038 | 4.431   | -0.220 | 0.346***| 0.085   | -0.001 | 0.433**|
|            | [1.92]  | [-1.58]| [-0.76]| [1.10]  | [-1.11]| [1.66]  | [1.64]  | [-1.65]| [2.03] |
| Virginia   | -2.693* | 0.084* | 0.390* | 2.021   | -0.100 | 0.517   | 0.053   | -0.001 | 0.592***|
|            | [-3.56] | [3.71] | [5.72] | [0.60]  | [-0.61]| [1.36]  | [1.36]  | [1.36] | [1.66] |
| Washington | -0.287  | 0.006  | 0.047  | -5.137  | 0.246  | 0.391** | 0.028   | -0.001 | 0.275  |
|            | [-0.43] | [0.33] | [0.61] | [-1.51]| [1.47] | [2.18]  | [0.53]  | [-0.58]| [1.25] |
| West Virginia | -0.691 | 0.021  | 0.188***| 3.777   | -0.186 | 1.230*  | -0.004  | 0.001  | 1.073* |
|            | [-0.93] | [0.90] | [1.71] | [1.06]  | [-1.07]| [4.15]  | [-0.07] | [0.09] | [4.14] |
| Wisconsin  | 1.887** | -0.053**| 0.039  | -0.628  | 0.026  | 1.303*  | -0.002  | 0.001  | 1.257* |
|            | [2.33]  | [-2.18]| [0.57] | [-0.43]| [0.36] | [12.48] | [-0.013]| [0.04] | [11.20]|
| Wyoming    | 0.226   | -0.002 | 0.400**| -0.144  | 0.004  | 0.284** | 0.064** | -0.001**| 0.458* |
|            | [0.16]  | [-0.005]| [2.44] | [-0.08] | [0.05] | [2.04]  | [2.16]  | [-2.21]| [3.66] |
Test results in Table 5 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 Eqn. 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 6 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 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 vary from one another.

Table 6: Curve Shapes of the Armey, EKC, and Composite Models

| Number | State | Traditional EKC Model | Armey Curve Model | Composite EKC Model |
|--------|-------|-----------------------|-------------------|---------------------|
| 1      | Alabama | -                     | -                 | -                   |
| 2      | Alaska  | -                     | -                 | -                   |
| 3      | Arizona | U                     | U                 | U                   |
| 4      | Arkansas| -                     | -                 | -                   |
| 5      | California | U                  | U                 | U                   |
| 6      | Colorado| U                     | \(\cap\)          | U                   |
| 7      | Connecticut | -               | \(\cap\)          | -                   |
| 8      | Delaware | U                     | -                 | U                   |
| 9      | Florida | -                     | U                 | -                   |
| 10     | Georgia | U                     | \(\cap\)          | U                   |
| 11     | Hawaii  | \(\cap\)               | U                 | -                   |
|   | State      | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 |
|---|------------|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 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  | -  |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |    |
Note: Curve Shapes were obtained from Table 4. (U): U-shaped curve, (∩): Inverted U-shaped curve, (-): insignificant model (curve).

|    | 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 | - | - | ∩ |

Figures 6, 7, and 8: US state-level Maps
Note: States in green and red mean that the Armey curve, traditional EKC, and composite EKC hypotheses (models) were validated and not verified, respectively. The states in white mean that these three models were insignificant. Maps were created from empirical findings of the study.

5. 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 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 GDP 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 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 CO₂
emissions. Hence, they will know that additional spending after this maximum threshold
points will decrease real GDP per capita and increase CO₂ 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 CO₂ emissions are between 15.2% -
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.

**Dataset:** $DI$ 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.

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**Compliance with ethical standards**

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