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*Published in:*
Energy

*DOI:*
10.1016/j.energy.2018.01.172

*Publication date:*
2018

*Citation for published version (APA):*
Kourtzidis, S., Tzeremes, P., & Tzeremes, N. (2018). Re-evaluating the energy consumption-economic growth nexus for the United States: An asymmetric threshold cointegration analysis. *Energy*, *148*, 537-545. https://doi.org/10.1016/j.energy.2018.01.172

# Re-evaluating the energy consumption-economic growth nexus for the United States: An asymmetric threshold cointegration analysis

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## Abstract

This paper examines the relationship between energy consumption and economic growth for the United States both at a country and at a sectoral level (Industry, Residential, Electric Power and Transportation) using an asymmetric threshold cointegration approach and monthly data from January 1991 to May 2016. Granger causality tests support a neutrality hypothesis for all sectors, except for the case of total consumption at the country level where a unidirectional causality is running from energy consumption to economic growth.

**Keywords**: Energy consumption; Economic growth; Threshold cointegration; Asymmetric error correction; United States.

## 1. Introduction

Over the last decades, a substantial bulk of econometric frameworks have been the inciter in determining the relationship between economic growth and energy consumption.[1] Currently, many authors embark on review and classification of the existing literature (e.g. Ozturk, 2010; Payne, 2010; Smyth and Narayan, 2015). There is a debate across the literature about the contribution of each approach. Specifically, researchers employing the prevalent models with the ordinary variables, by modifying solely the reckoned period (Karanfil, 2009; Stern, 2011). Intrinsically, a large amount of studies that estimate the interrelated functionality between energy consumption and economic growth[2], apply annual data (Tzeremes, 2017); whereas, only a fraction of studies implement higher frequency sample such as quarterly or monthly samples (Lean and Smyth, 2009, 2013). Therefore, this inquiry contributes to the relative literature by tendering a better understanding of how economic growth and energy consumption are interrelated by using the threshold cointegration and an asymmetric error correction model for the first time in the relevant literature.

It must be highlighted that a common feature in the applied econometric models is the hypothesis of linear relationships over the time period (Smyth and Narayan, 2015). Hiemstra and Jones,(1994) asserted the existence of nonlinearity which is underlined below the linear causality tests. Given the amount of studies examined the phenomenon, only a slight number of them evaluated nonlinear causality among economic growth and energy consumption (Chiou-Wei et al., 2008; Dergiades et al., 2013; Fallahi, 2011; Huang et al., 2008; Lee and Chang, 2007; Omay et al., 2012;

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[1] The relative literature provides a vast amount of recent empirical findings on the matter subject from different regions and countries applying different methodological frameworks (among others, Naser, 2015; Chiou-Wei et al. 2016; Destek, 2016; Esso and Keho, 2016; Kahia et al., 2016; Ahmad and Du, 2017; Adewuyi and Awoduni, 2017; Ge et al., 2017).

[2] Burns et al., (2014), were the first who used meta-analysis in 72 studies selected from this literature in order to determine if exist a genuine effect in this literature.

Salamaliki and Venetis, 2013; Yang et al., 2010; Yildirim et al., 2014). Moreover, Stern and Kander (2012) implement a static nonlinear production function providing evidence about the long-run relationship among the variables which is in fact nonlinear suggesting a small elasticity of substitution between the covariates[3]. Considering the aforementioned investigation, our inquiry contributes to the relevant literature by investigating the existence of a nonlinear relationship through the application of a threshold cointegration and an asymmetric error correction model.

Drawing evidence from a widespread dataset of US sectors (total primary energy consumption at a national level and at a sectoral level for four sectors), our analysis divulges pronounced nonlinearities (i.e. asymmetries effects) of the examined relationship. The present study diverges from the majority of the previous ones which report only cointegration estimates (Apergis and Payne, 2009a; Apergis and Payne, 2009b; Apergis and Payne, 2010a; Apergis and Payne, 2010b; Baranzini et al., 2013; Chandran et al., 2010; Fuinhas and Marques, 2012; Odhiambo, 2009; Sari et al., 2008; Shahbaz et al., 2012; Tang, 2008; Wolde-Rufael, 2010) and the single one which applies a threshold cointegration analysis (Esso, 2010). Specifically, the present study is the first to examine the existence of an asymmetric behavior of the economic growth-energy consumption relationship at a sectoral level.

In this context, the contribution of this paper is twofold. Firstly, we investigate the asymmetric relationship between economic growth and energy consumption using a threshold cointegration approach, while examining the adjustment in the short term via asymmetric error correction model with threshold cointegration. This econometric approach has previously been used for the examination of asymmetric price

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[3] Stern and Enflo (2013), estimated linear cointegration in order to collate the results with Stern and Kander's (2012).

transmission (Al-Gudhea et al., 2007; Asane-Otoo and Schneider, 2015; Chen et al., 2005; Chen and Zhu, 2015; Kollias et al., 2016; Mighri and Mansouri, 2015; Sun, 2011; Tsai et al., 2012). In this paper, we apply this framework at economic growth-energy consumption context in order to investigate for nonlinearities.

Secondly, we investigate the underlying relationship not only at a national level but also at a sectoral level (Industry, Residential, Electric Power and Transportation) for the first time. The comparison of the results among national and sectoral level is of extreme importance and reveals a dissimilar outcome between national and sectoral level. Specifically, Granger causality tests reflect a neutrality hypothesis for all sectors, except for the case of total consumption where a unidirectional causality is running from energy consumption to economic growth. This difference in results is not unexpected. Although we refer to the same countries and time periods, we apply different asymmetric models. Our results are in line with Zachariadis (2007), who found that different estimation methods such as bivariate/multivariate models or different causality techniques could lead to different results for the same dataset. However, it is important to note the implications for energy policy that emerge from the Granger causality test. On the one hand, when no causality exists between the energy and real gross domestic product (GDP) then energy conservation policies do not affect the economy. This is known as the “neutrality hypothesis”. On the other hand, when a unidirectional causality exists then energy conservation policies affect economic growth.

The paper is organized as follows. The next section introduces the data, variable definition, and methods to be used in the estimations. Section 3 presents the results of our analysis, and Section 4 concludes.

## 2. Methodology

### *2.1. Threshold cointegration analysis*

We investigate monthly data for United State's total primary energy consumption at a national and at a sectoral level. Our sample covers the period from January 1992 through May 2016 (293 observations). Furthermore, the data for energy consumption both at the national and at the sectoral level are measured in trillion of British thermal units (BTUs). Specifically the energy data are referred to the: Total primary energy consumption (TPC), Industry primary energy consumption (IPC), Residential primary energy consumption (RPC), Electric Power primary energy consumption (EPPC)[4] and Transportation primary energy consumption (TRPC). We have collected our data from the Energy Information Agency (EIA)[5], and the real gross domestic product (GDP) Index was derived from Macroeconomic Adviser[6]. Finally, we follow the relative literature and we use the natural logarithms of the variables[7].

We begin our analysis by pretesting the variables for unit roots and stationarity using Augmented Dickey-Fuller (ADF) tests (Dickey and Fuller, 1979). Moreover, as a robustness check we implement the Zivot and Andrews test (ZA) for possible structural breaks. Regarding the cointegration analysis we apply the Johansen approach (Johansen, 1988; Johansen & Juselius, 1990) and the Engle-Granger two-step

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[4] According to the EIA, in 2016 the US electric power sector primary energy consumption totalled 37783.781 trillion Btu of which fossil fuels comprised roughly 62.7%, nuclear 22.4%, and renewable 14.9%. Furthermore, the electric power sector is crucial for the generation of primary energy for other sectors (Gil-Alana et al., 2010). Evidently, a shock related to the use of energy sources by the electric power sector such as a cap and trade legislation and the depletion of fossil fuels would seriously affect both the electric power sector and the other sectors of the economy.

[5] http://www.eia.gov/

[6] According to Macroeconomic Advisers the index of Monthly GDP (MGDP) is a monthly indicator of real aggregate output that is conceptually consistent with real Gross Domestic Product (GDP) of the national income and product accounts. Moreover, MGDP is calculated using the same underlying monthly source data that is used in the calculation of GDP. Finally, the method of aggregation of MGDP is similar to that for the official GDP.
http://www.macroadvisers.com/

[7] The software R (https://www.r-project.org/) is used to conduct all statistical analyses, while the package of "apt" (https://cran.r-project.org/web/packages/apt/index.html) is used for the threshold cointegration analysis and asymmetric error correction model.

procedure (Engle and Granger, 1987)[8]. Likewise, Enders and Siklos (2001) proposed a two-regime threshold cointegration which extends the Engle–Granger two-step cointegration test by allowing the possible asymmetric adjustment to disequilibrium. Suppose $E_t$ is the energy consumption and $Y_t$ is the GDP (both are integrated in order one). Then the cointegration relationship can be stipulated as:

$$E_t = \zeta_0 + \zeta_1 Y_t + \xi_{t,} \tag{1}$$

where $\zeta_0$ and $\zeta_1$ are coefficients and $\xi_t$ is the disturbance term, which should be stationary in the existence of a long-run relationship among the two integrated series. The asymmetric adjustment towards the long-run equilibrium of estimated residual $\xi_t$ is given by:

$$\Delta \hat{\xi} = I_t \rho_1 \hat{\xi}_{t-1} + \left(1 - I_t\right) \rho_2 \hat{\xi}_{t-1} + \sum_{k=1}^{\theta} \phi_k \Delta \hat{\xi}_{t-k} + u_t, \tag{2}$$

where $I_t$ is an indicator function taking the following values:

$$I_t \begin{cases} 1 \ \ if \ \ \hat{\xi}_{\,t-1} \geq \tau, \ \ 0 \ otherwise; or & (3a) \\ 1 \ \ if \ \ \Delta\hat{\xi}_{\,t-1} < \tau, \ \ 0 \ otherwise & (3b) \end{cases}$$

In Eq. (2) $\theta$ represents the number of lags which have been selected using the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC). Furthermore, $\rho_1, \ \rho_2 \ and \ \phi_\kappa$ represent the coefficients, whereas the term $\tau$ represents the threshold value and $\Delta$ the difference operator. Finally, $u_t$ is assumed to be white noise.

According to Enders and Granger (1998) and Enders and Siklos (2001) the estimated model (defined as the level of residuals) using the Eqs. (1), (2) and (3a) is

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[8] Balke and Fomby (1997) modified the test and suggested a two-step approach for examining threshold cointegration.

referred to as the Threshold Autoregressive models (TAR)[9], whereas, the estimated model (defined as the change in residuals) using the Eqs. (1), (2) and (3b) is referred to as the Momentum Threshold Autoregressive models (MTAR). Furthermore, the consistent estimate of the threshold $\tau$ can be adopted by utilizing Chan's (1993) approach by minimizing the sum of squares errors from the fitted model.

Considering all the possible methodological settings, four models are estimated in this study, namely: the TAR in Eq.(3a) with $\tau$=0 ; the consistent TAR in Eq.(3a) with $\tau$ estimated; the MTAR in Eq.(3b) with $\tau$=0 ; and the consistent MTAR in Eq.(3b) with $\tau$ estimated. Accordingly, there is no presumption for the appropriate adjustment mechanism (TAR or MTAR), therefore the choice of the model is based on the smallest AIC and BIC values. Finally, we test two hypothesis in order to examine the log-term cointegration relation for the asymmetric adjustment. On the one hand, the null hypothesis of no cointegration i.e. $H_0\colon \rho_1 = \rho_2 = 0$, and on the other hand the null hypothesis of the symmetry i.e. $H_0\colon \rho_1 = \rho_2$ (Enders and Granger, 1998; Enders and Siklos, 2001).

### *2.2. Asymmetric error correction model with threshold cointegration*

According to Engle and Granger (1987), if all variables are cointegrated, then there will be a corresponding error correction model (ECM). According to the relative literature two extensions has been proposed for this model. Firstly, an extension by Granger and Lee (1989), where the error correction terms and first differences on the variables are decomposed into positive and negative variables, and secondly, the one which is enhancing the Granger and Lee (1989) model via the threshold cointegration mechanism (Balke and Fomby, 1997; Enders and Granger, 1998).

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[9] The basic TAR model have been developed by Tong (1983).

In this study, the asymmetric error correction model with threshold cointegration is described as follows:

$$\begin{aligned}\Delta E_t = {} & \gamma_E + \delta_E^+ T_{t-1}^+ + \delta_E^- T_{t-1}^- \\ & + \sum_{j=1}^{P} a_{E_j}^+ \Delta E_{t-j}^+ + \sum_{j=1}^{P} a_{E_j}^- \Delta E_{t-j}^- + \sum_{j=1}^{P} \beta_{E_j}^+ \Delta Y_{t-j}^+ + \sum_{j=1}^{P} \beta_{E_j}^- \Delta Y_{t-j}^- + \mu_{Et}\end{aligned} \tag{4a}$$

and

$$\begin{aligned}\Delta Y_t = {} & \gamma_Y + \delta_Y^+ T_{t-1}^+ + \delta_Y^- T_{t-1}^- \\ & + \sum_{j=1}^{P} a_{Y_j}^+ \Delta E_{t-j}^+ + \sum_{j=1}^{P} a_{Y_j}^- \Delta E_{t-j}^- + \sum_{j=1}^{P} \beta_{Y_j}^+ \Delta Y_{t-j}^+ + \sum_{j=1}^{P} \beta_{Y_j}^- \Delta Y_{t-j}^- + \mu_{Yt}\end{aligned} \tag{4b}$$

where

$$\Delta E_{t-j}^+ = \begin{cases} E_{t-j} - E_{t-j-1}, & E_{t-j} \geq E_{t-j-1} \\ 0, & E_{t-j} < E_{t-j-1} \end{cases} ,$$

$$\Delta E_{t-j}^- = \begin{cases} E_{t-j} - E_{t-j-1}, & E_{t-j} < E_{t-j-1} \\ 0, & E_{t-j} \geq E_{t-j-1} \end{cases}$$

$$\Delta Y_{t-j}^+ = \begin{cases} Y_{t-j} - Y_{t-j-1}, & Y_{t-j} \geq Y_{t-j-1} \\ 0, & Y_{t-j} < Y_{t-j-1} \end{cases} ,$$

$$\Delta Y_{t-j}^- = \begin{cases} Y_{t-j} - Y_{t-j-1}, & Y_{t-j} < Y_{t-j-1} \\ 0, & Y_{t-j} \geq Y_{t-j-1} \end{cases}$$

where $\Delta E_t$ $(Eq.4_a)$ and $\Delta Y_t (Eq.4_b)$ are the quantities of energy consumption and economic growth in the first differences. Moreover, $\gamma, \delta, \alpha$ and $\beta$ are the coefficients, whereas, $p$ is the number of lag (the maximum lag is chosen with the AIC statistic) and μ represents the error term. The subscripts $E$ and $Y$ denote the coefficients by country and $t$ is the time. Finally, the superscripts "+" and "–" imply which variables are split into positive and negative components.

Following the relative literature we can examine four different methodological hypothesis (Meyer and Von Cramon-Taubade 2004; Frey and Manera 2007; Sun 2011; Mighri and Mansouri 2015). Firstly, the equilibrium adjustment path of asymmetry can be tested through the following hypothesis of $H_0\colon \delta^+ = \delta^-$. Secondly, the cumulative asymmetric effect for the energy consumption and economic growth can examined through the hypothesis $H_0\colon \sum_{i=1}^{j} a_i^+ = \sum_{i=1}^{j} a_i^-$ and $H_0\colon \sum_{i=1}^{j} \beta_i^+ = \sum_{i=1}^{j} \beta_i^-$, respectively. Thirdly, the Granger causality test can be examined by employing the F-test with the null hypothesis of $H_0\colon a_i^+ = a_i^- = 0$ for all lags $i$ simultaneously. Lastly, the distributed lag asymmetric effect can be investigated through the effects of energy consumption on its own quantities or on the economic growth quantities. This can be tested through the hypothesis of $H_0\colon a_1^+ = a_1^-$ and can be repeated for each lag and both variables $H_0\colon \beta_1^+ = \beta_1^-$.

## 3. Empirical results

The descriptive statistics for all the variables used in our models are presented in Table 1. In addition, ADF unit root tests were undertaken to infer the maximum order of integration among the variables[10]. The tests were employed to the drift and trend, whereas the lag length of the test was determined by the AIC statistic. Plausibly, the results from the ADF statistics suggest that the variables of primary energy consumption (TPC, RPC, EPPC, IPC and TRPC) are integrated of order zero I(0). Additionally, the ZA unit root test was employed to the full sample of all the monthly

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[10] The critical values are −4.04, -3.45, and−3.15 for ADF test with trend, and−3.51, -2.89, -2.58 for ADF test with a drift at the 1%, 5%, and 10% level, respectively (Enders, 2004). The numbers in the bracket are lags used in the test.

series and the results proved the unit root hypothesis as well as the existence of a structural break. Consequently, all variables are integrated of order one I(1).

The linear cointegration analysis was applied by using the Johansen and Engle-Granger approach. For the case of Johansen cointegration, four lags have been considered. Moreover, the determination of a lag length was based on the lowest AIC and BIC values. As illustrated in Table 2[11], the Johansen maximum eigenvalue statistic ($\lambda_{max}$) and trace ($\lambda_{trace}$) implies that the variables are cointegrated between the quantities of primary energy consumption and GDP[12] for all the cases. On the other hand, when testing the null hypothesis of one cointegrating vector, the Johansen maximum eigenvalue statistic suggests that the variables are cointegrated but only for the cases of ‘constant’ and ‘none’.

The Engle–Granger two-step cointegration (see Eq. 1) probes the long-term relationship between the primary energy consumption and GDP. The estimation of the coefficient for TPC-GDP (i.e. $\zeta_1$) is 0.186, for RPC-GDP is -0.64, for EPPC-GDP is 0.381, for IPC-GDP is -0.175 and for TRPC-GDP is 0.358. Note that all the coefficients are statistically significant at 1%. Furthermore, Table 3 reports the statistics from the unit root tests which are -0.291, -0.64, -0.615, -0.21 and -0.395 for the RPC-GDP, TPC-GDP, EPPC-GDP, IPC-GDP and TRPC-GDP respectively. The results from both tests (Johansen and Engle-Granger approach) confirm that the quantities of primary energy consumption and GDP are cointegrated[13].

*Table 1 and Table 2 about here*

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[11] The critical values are from Enders (2004) and “r” is the number of cointegrating vectors.

[12] Gross domestic product is measured at billion dollars.

[13] Our findings confirm the remark raised by Smyth and Narayan (2015), suggesting that most of the time the literature signifies that energy variables share a long-run relationship with non-energy variables.

*3.1 Empirical findings of the threshold cointegration analysis*

In our analysis the threshold autoregression model is applied in order to determine the long-run relationship between primary energy consumption and GDP. Furthermore, we apply four asymmetry models (i.e., TAR, MTAR, consistent TAR, consistent MTAR). In Table 3[14] the reported results are derived from the diagnostic analysis on the residuals using the AIC and BIC (maximum lag is 12) criteria. Moreover, we employ the Chan's (1993) method to evaluate the threshold values for the consistency of the TAR and MTAR models. Note that ρ1 and ρ2 refers to Eq. (2) and Φ is the threshold cointegration test[15]. F is a standard F-test on the asymmetry of the price and the numbers in the brackets are p-values. Presumably, the Φ statistics rejects the null hypothesis about no cointegration ($H_0: \rho_1 = \rho_2 = 0$) at the 1% significance level in all cases. This, in turn, signifies the existence of a cointegrating relationship between primary energy consumption and GDP. On the other hand, when we test for an asymmetric cointegration (the null assumption of $\rho_1 = \rho_2$), the best model for each case respectively is deemed to be the consistent TAR for RPC-GDP and TPC-GDP, the consistent MTAR for EPPC-GDP, the TAR for IPC-GDP and the consistent MTAR for TRPC-GDP.

Furthermore, we focus on the empirical findings derived from the consistent MTAR model for the case of EPPC-GDP and TRPC-GDP series. The results signify that the best threshold values are 0.086 (EPPC-GDP) and 0.036 (TRPC-GDP) respectively. The Φ-test for the null hypothesis of no cointegration is 47.863 for EPPC-GDP and 15.01 for TRPC-GDP and both are significant at the 1%. In addition, the F

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[14] For the Engle-Granger cointegration test, the critical value is −3.087, -3.398, and −4.008 at the 10%, 5%, and 1% level, respectively (Enders,2004).

[15] The critical values are from Enders and Siklos (2001).

statistic for the null hypothesis of symmetry has a value of 26.508 for EPPC-GDP and 3.369 for TRPC-GDP and in both cases they are significant at the 1% level. This latter finding suggests the existence of an asymmetric threshold cointegration relationship between the series (EPPC-GDP and TRPC-GDP).

Noteworthy is the fact that the evaluated quantities of adjustment are -0.192 for positive shocks and -0.668 for negative shocks for the case of EPPC-GDP, and also -0.178 for positive shocks and -0.403 for negative shocks for the case of TRPC-GDP. This means that positive shocks from the long-term equilibrium resulting from an increase in the EPPC or a decrease of the GDP $\left(\Delta\hat{\xi}_{t-1} \geq 0.086\right)$ will vanish at a rate of 19.2% per month. Furthermore, the negative shocks resulting from a decrease in the EPPC or an increase in the GDP $\left(\Delta\hat{\xi}_{t-1} < 0.086\right)$ are fully integrated at a rate of 66.8% per month. Accordingly, positive shocks from the long-term equilibrium resulting from an increase in the TRPC or a decrease in the GDP $\left(\Delta\hat{\xi}_{t-1} \geq 0.036\right)$ are vanished at 17.8% per month and the negative shocks resulting from a decrease in the TRPC or an increase in the GDP $\left(\Delta\hat{\xi}_{t-1} < 0.036\right)$ are fully integrated at 40.3% per month. Essentially, in the case of EPPC-GDP the positive shocks take about 5.2 months (1/0.192=5.2 months) to be fully digested while the negative deviation takes about 1.5 months (1/0.668=1.49 months) only. For TRPC-GDP, the positive shocks take about 5.5 months (1/0.178=5.6 months) to be fully digested while the negative shocks take about only 2.5 months (1/0.403=4.48 months). Our empirical findings suggest that in positive shocks there is a substantially slower convergence for the long-term equilibrium than for negative shocks both for EPPC-GDP and TRPC-GDP.

*Table 3 about here*

*3.2 Empirical findings of the asymmetric error correction model*

The threshold cointegration analysis disclosed the asymmetric error correction model among the series. As above, our interpretation is focused on the results from the consistent MTAR model (EPPC-GDP and TRPC-GDP). Table 4 reports and Figure 1 depicts the empirical findings of the asymmetric error correction model. The results from the AIC and BIC criteria suggest that five lags are appropriate for our models. Note that numbers in brackets are p-values. Regarding the equation for primary energy consumption (EPPC and TRPC), there are nine coefficients which are statistically significant for EPPC (i.e., $a_1^+, a_2^+$, $a_4^+,\ a_2^-, a_3^-, \beta_3^+, \beta_5^+,\ \beta_1^-, \delta^-$ ) and four for TRPC (i.e., $\gamma,\ a_1^+, a_2^+,\ a_3^-$). From the perspective of GDP, there are eight statistically significant coefficients for GDP (EPPC) (i.e., $a_2^-$, $\beta_1^+, \beta_4^+,\ \beta_3^-,\ \beta_4^-,\ \beta_5^-, \delta^+, \delta^-$) and twelve for GDP (TRPC) (i.e., $\gamma, \alpha_1^-, a_2^-$, $\beta_1^+, \beta_3^+, \beta_4^+,\ \beta_5^+, \beta_1^-,\ \beta_2^-,\ \beta_5^-, \delta^+, \delta^-$). Furthermore, the estimated value of $R^2$ is much lower for the EPPC and TRPC (0.17 and 0.15) than the GDPs (0.69 and 0.61). To recapitulate, the model specification is more appropriate fit on GDPs than on EPPC and TRPC.

Moreover, the hypotheses of Granger causality between the series, is evaluated with F-tests ($H_0\colon a_i^+ = a_i^-$ and $H_0\colon \beta_i^+ = \beta_i^-$). The F-statistic for EPPC is 1.037 and for GDP is 0.853 which reveals that in the short term both variables do not affect each other. However, the F-statistics for EPPC (4.469) and GDP (27.212) reveal that the lagged variables have significant impact on their own quantities. Regarding the TRPC the F-statistic is 0.458 and for GDP is 0.946 which indicates that the quantity of TRPC does not Grange cause the quantity of GDP, and vice versa. Also, both covariates have significant impact on their own quantities.

Finally, the distributed lag asymmetric effect ($H_0\colon \alpha\beta_{1-5}^+ = \alpha\beta_{1-5}^-$) is applied. Since we have five lags, there are ten F-tests for this hypothesis. We found only one F-test that is significant at the 5% level for the case of EPPC and TRPC. Furthermore, a positive coefficient at the second lag has been found when we consider the distributed lag asymmetric effect. From the GDP side, we found four cases in which the F-test are significant. An asymmetric effect has been found on GDP (EPPC) quantities specifically between the first and the fourth lag (one positive and three negative coefficients), and similarly for the case of GDP (TRPC) (all of them have negative coefficients). Moreover, the cumulative asymmetric effects ($H_0 = \sum_{i=1}^{5} a\,\beta_i^+ = \sum_{i=1}^{5} a\,\beta_i^-$) are also estimated. Regarding the first model (EPPC-GDP) the results signify that only one F-test is significant; the one of EPPC with the largest quantity. When looking for the TRPC-GDP model two F-test values are reported to be statistical significant. The results signify a positive coefficient with an F-statistic of 2.727 (significant at 10% level) and a negative coefficient with an F-statistic of 47.812 (significant at 1%). Finally, we evaluate the momentum equilibrium adjustment path asymmetries ($H_0$: $\delta^+ = \delta^-$). The F-statistics in all cases is non-significant which disclose the absence of momentum equilibrium adjustment asymmetry.

*Table 4 about here*

*Figure 1 about here*

## 4. Concluding remarks and policy implications

Indicating a vast number of authors who have investigated the connection between the energy use and GDP. The results are diverse relative to the variables, the period or the methodological patterns chosen. Based on this framework this study further investigates the relationship among energy consumption and GDP for the United States at a national and at a sectoral level for four sectors. In light of methodological part, the contribution depends on the information that for the first time this connection has been probed with econometric tools which are normally applied on prices (Meyer and Cramon- Taubadel, 2004; Frey and Manera, 2007; Sun, 2011; Mighri and Mansouri, 2015). Specifically, we apply a threshold cointegration approach by implementing monthly data. Furthermore, we examine the adjustment in the short term via asymmetric error correction model with threshold cointegration incorporated. Most importantly, the results reveal an asymmetric relationship signifying non-linearity.

In detail, we apply the threshold autoregression model in order to contend the long-run relationship among primary energy consumption and GDP. We focused on the consistent MTAR model and we found that in the case of EPPC-GDP the positive shocks take about 5.2 months to be fully digested while the negative deviation take about 1.5 months only. Furthermore, in the case of TRPC-GDP, the positive shocks take about 5.5 months to be fully digested while the negative shocks take about 2.5 months only. Moreover, the adjustment speed in both cases (EPPC-GDP and TRPC-GDP) is faster in the presence of negative deviation from the long-run equilibrium. The unanticipated outcomes for each sector are proved by the sectoral differences, inter alia; the fuel combination (such as oil, gas, renewable energy), the arrangement of GDP for each sector over the period and the ratio of technical advancement (Judson et al., 1999).

Furthermore, the results from the Granger causality tests reflect a neutrality hypothesis for all sectors, except for the case of total consumption, where a unidirectional causality running from energy consumption to GDP has been reported. This finding is in line with i) Soytas and Sari (2006) and Bowden and Payne (2009) for the TPC (at aggregated levels) and ii) Zachariadis (2007) for the cases of IPC, RPC (at disaggregated levels). Lastly, the results of the momentum equilibrium adjustment asymmetry, suggest that there are not any differences in the responding speed in the short-term quantities of EPPC-GDP and TRPC-GDP. For the sake of completeness, we performed correlation analysis using Spearman’s correlation coefficient among GDP and energy consumption. The results indicate a positive correlation among total energy consumption and GDP (0.445) while they are mixed for the sectors. Specifically, there is a positive correlation among GDP and energy consumption for Electric Power (0.555) and Transport (0.781) sectors, a negative relationship for Industry (-0.475) and no correlation for Residential (-0.027) sector.

Our findings suggest that increases in energy consumption at a national level provoke increases in economic growth. Yet, this outcome assert that diminish economic growth may not have an adverse consequence on energy consumption. Evidently, our findings endorse that USA should pass legislation to restrict GHGs and handling environmental degradation. It can easily be derived that by decreasing energy intensity, increasing energy efficiency and changing the fuel mix in the direction of renewable energy sources. Moreover, decision makers have to consider the asymmetric causality between energy consumption and GDP growth.

Lastly, the outcomes signified that a causal relationship on aggregate level is not the same in a sectoral level, thus, initiating a research agenda towards this direction. Moreover, future research extending the two-regime threshold cointegration model to three and more regimes and/or an error correction model within a threshold cointegration via component GARCH errors framework could be considered. Another intriguing research theme is asymmetric Granger causality that is proposed by Hatemi-j (2012) and could be very useful in order to better comprehend the idiosyncratic characteristics of US sectoral level.

## Acknowledgements

We would like to thank the subject editor Isabel Soares and the reviewers for their constructive comments on an earlier version of our manuscript. Any remaining errors are solely the authors’ responsibility.

## Appendix

Nomenclature

| | | | |
|---|---|---|---|
| GDP | Gross domestic product | $E_t$ | Energy consumption |
| BTUs | British thermal units | $Y_t$ | GDP |
| TPC | Total primary energy consumption | $\zeta_0, \zeta_1$ | Coefficients |
| IPC | Industry primary energy consumption | $\xi_t$ | Disturbance term |
| RPC | Residential primary energy consumption | $I_t$ | Indicator function |
| EPPC | Electric Power primary energy consumption | $\theta, p$ | Number of lags |
| TRPC | Transportation primary energy consumption | $\rho_1, \rho_2, \phi_\kappa$ | Coefficients |
| EIA | Energy Information Agency | $\tau$ | Threshold value |
| MGDP | Monthly GDP | $\Delta$ | Difference operator |
| ADF | Augmented Dickey-Fuller | $u_t$ | White noise |
| ZA | Zivot and Andrews | $\gamma, \delta, \alpha, \beta$ | Coefficients |
| AIC | Akaike Information Criterion | $\mu$ | Error term |
| BIC | Bayesian Information Criterion | $t$ | Time |
| TAR | Threshold Autoregressive models | $\lambda_{max}$ | Maximum eigenvalue statistic |
| MTAR | Momentum Threshold Autoregressive models | $\lambda_{trace}$ | Trace eigenvalue statistic |
| ECM | Error correction model | “+”, “–“ | Positive, negative |

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**Table 1.** Descriptive statistics and unit root test results for the prices of primary energy consumption and GDP.

| Statistic | Level | | | | | |
|---|---|---|---|---|---|---|
| | RPC | TPC | EPPC | IPC | TRPC | GDP |
| Mean | 341.718 | 7985.889 | 3089.548 | 1808.549 | 2179.472 | 13198.625 |
| Std. Dev. | 143.121 | 582.141 | 371.035 | 114.656 | 169.381 | 2175.836 |
| Minimum | 179.888 | 6654.008 | 2306.77 | 1474.453 | 1716.886 | 9066.389 |
| Maximum | 670.968 | 9597.777 | 4084.462 | 2098.731 | 2533.996 | 16652.319 |
| Total obs. | 293 | 293 | 293 | 293 | 293 | 293 |
| ADF with trend | -17.31[1]*** | -10.06[1]*** | -11.7[1]*** | -4.88[1]*** | -5.24[1]*** | -1.26[1] |
| ADF with drift | -17.32[1]*** | -9.04[1]*** | -9.56[1]*** | -3.81[1]*** | -3.91[1]*** | -3.18[1] |
| ZA tests value | -5.061* | -10.810*** | -9.221*** | -10.296*** | -15.284*** | -3.973 |
| ZA tests break | 2015M03 | 2015M03 | 2008M08 | 2008M03 | 2007M12 | 2008M06 |

| Statistic | 1st diff | | | | | |
|---|---|---|---|---|---|---|
| | RPC | TPC | EPPC | IPC | TRPC | GDP |
| Mean | — | — | — | — | — | — |
| Std. Dev. | — | — | — | — | — | — |
| Minimum | — | — | — | — | — | — |
| Maximum | — | — | — | — | — | — |
| Total obs. | — | — | — | — | — | — |
| ADF with trend | -8.97[1]*** | -14.23[1]*** | -13.93[1]*** | -17.42[1]*** | -19.80[1]*** | -15.06[1]*** |
| ADF with drift | -8.99[1]*** | -14.25[1]*** | -13.9[1]*** | -17.45[1]*** | -19.82[1]*** | -9.87[2]*** |
| ZA test value | -6.942*** | -18.427*** | -14.529*** | -30.750*** | -31.732*** | -23.381*** |
| ZA test break | 2015M12 | 2015M12 | 2015M06 | 2015M12 | 2016M01 | 2009M09 |

***, **, *, indicates significant at the 1% 5% and 10% level respectively

**Table 2.** Results of the Johansen cointegration tests on the prices of primary energy consumption and GDP.

| Test | Specification | Statistic | | | | |
|---|---|---|---|---|---|---|
| | | RPC-GDP | TPC-GDP | EPPC-GDP | IPC-GDP | TRPC-GDP |
| Johansen $\lambda_{max}$ | | | | | | |
| r=1 | Trend | 9.5 | 9.48 | 9.19 | 8.36 | 9.16 |
| r=0 | Trend | 194.58*** | 103.39*** | 80.50*** | 38.06*** | 67.89*** |
| r=1 | Constant | 46.84*** | 43.48*** | 44.62*** | 21.78*** | 25.64*** |
| r=0 | Constant | 194.48*** | 66.16*** | 60.34*** | 57.65*** | 47.04*** |
| r=1 | None | 9.34** | 9.34** | 8.98** | 8.15* | 9.04** |
| r=0 | None | 194.45*** | 63.77*** | 59.41*** | 34.21*** | 26.36*** |
| Johansen $\lambda_{trace}$ | | | | | | |
| r≤1 | Trend | 9.5 | 9.48 | 9.19 | 8.36 | 9.16 |
| r=0 | Trend | 204.08*** | 112.87*** | 89.69*** | 46.42*** | 77.05*** |
| r≤1 | Constant | 46.84*** | 43.48*** | 44.62*** | 21.78*** | 25.64*** |
| r=0 | Constant | 241.32*** | 109.65*** | 104.97*** | 79.44*** | 72.69*** |
| r≤1 | None | 9.34** | 9.34** | 8.93** | 8.15* | 9.04** |
| r=0 | None | 203.80*** | 73.12*** | 68.35*** | 42.37*** | 35.41*** |

***, **, *, indicate significant at the 1% 5% and 10% level respectively.

**Table 3.** Results of the Engle-Granger and threshold cointegration tests.

| Item | Engle-Granger | | | | | TAR | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | RPC-GDP | TPC-GDP | EPPC-GDP | IPC-GDP | TRPC-GDP | RPC-GDP | TPC-GDP | EPPC-GDP | IPC-GDP | TRPC-GDP |
| *Estimate* | | | | | | | | | | |
| Threshold | — | — | — | — | — | 0 | 0 | 0 | 0 | 0 |
| $\rho_1$ | -0.291***<br>(-53.839) | -0.64***<br>(-38.373) | -0.615***<br>(-44.66) | -0.21***<br>(-16.125) | -0.395***<br>(-22.603) | -0.557***<br>(-16.476) | -0.767***<br>(-8.229) | -0.552***<br>(-6.847) | -0.313***<br>(-4.669) | -0.305***<br>(-3.582) |
| $\rho_2$ | — | — | — | — | — | -0.458***<br>(-14.038) | -0.594***<br>(-6.181) | -0.621***<br>(-7.087) | -0.182***<br>(-3.194) | -0.383***<br>(-4.565) |
| AIC | -4598.34 | -10356.91 | -8535.456 | -12716.26 | -12137.591 | -515.633 | -868.17 | -726.882 | -1060.968 | -1000.86 |
| BIC | -4579.854 | -10338.425 | -8516.971 | -12697.775 | -12119.105 | -493.634 | -846.171 | -704.883 | -1038.97 | -978.862 |
| *Hypotheses* | | | | | | | | | | |
| $\Phi(H_0{:}\rho_1=\rho_2=0)$ | — | — | — | — | — | 146.485*** | 37.362*** | 32.084*** | 13.987*** | 13.485*** |
| $F(H_0{:}\rho_1=\rho_2)$ | — | — | — | — | — | 12.108***<br>[0.001] | 3.152*<br>[0.077] | 0.703<br>[0.402] | 2.635***<br>[0.106] | 0.579<br>[0.447] |

**Table 3.** continued

| Consistent TAR | | | | | MTAR | | | | | Consistent MTAR | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| RPC-GDP | TPC-GDP | EPPC-GDP | IPC-GDP | TRPC-GDP | RPC-GDP | TPC-GDP | EPPC-GDP | IPC-GDP | TRPC-GDP | RPC-GDP | TPC-GDP | EPPC-GDP | IPC-GDP | TRPC-GDP |
| 0.292 | -0.062 | -0.059 | 0.041 | -0.046 | 0 | 0 | 0 | 0 | 0 | 0.276 | -0.071 | 0.086 | 0.052 | 0.036 |
| -0.58***<br>(-16.984) | -0.82***<br>(-9.102) | -0.532***<br>(-6.558) | -0.356***<br>(-5.116) | -0.288***<br>(-3.625) | -0.502***<br>(-15.742) | -0.772***<br>(-8.709) | -0.461***<br>(-5.484) | -0.273***<br>(-4.685) | -0.281***<br>(-3.229) | -0.53***<br>(-10.868) | -0.723***<br>(-8.867) | -0.192*<br>(-1.868) | -0.14<br>(-1.129) | -0.178*<br>(-1.589) |
| -0.453***<br>(-14.342) | -0.49***<br>(-4.901) | -0.649***<br>(-7.333) | -0.165***<br>(-3) | -0.424***<br>(-4.692) | -0.505***<br>(-13.36) | -0.531***<br>(-5.109) | -0.689***<br>(-8.406) | -0.185***<br>(-2.801) | -0.401***<br>(-4.812) | -0.495***<br>(-15.293) | -0.342**<br>(-2.314) | -0.668***<br>(-9.304) | -0.246***<br>(-5.059) | -0.403***<br>(-5.45) |
| -523.758 | -875.504 | -728.049 | -1063.806 | -1002.014 | -503.575 | -870.598 | -733.849 | -1059.501 | -1001.595 | -504.101 | -872.676 | -751.956 | -1059.001 | -1003.68 |
| -501.76 | -853.506 | -706.05 | -1041.808 | -980.015 | -481.577 | -848.6 | -711.851 | -1037.503 | -979.596 | -482.102 | -850.678 | -729.958 | -1037.002 | -981.682 |
| 154.711*** | 41.972*** | 32.788*** | 15.527*** | 14.107*** | 134.697*** | 38.875*** | 36.332*** | 13.198*** | 13.881*** | 135.201*** | 40.18*** | 47.863*** | 12.929*** | 15.01*** |
| 20.552***<br>[0.00] | 10.533***<br>[0.001] | 1.855<br>[0.174] | 5.464<br>[0.02] | 1.717<br>[0.191] | 0.008<br>[0.928] | 5.575**<br>[0.019] | 7.651***<br>[0.006] | 1.184<br>[0.277] | 1.303<br>[0.255] | 0.525<br>[0.469] | 7.664***<br>[0.006] | 26.508***<br>[0] | 0.69<br>[0.407] | 3.369*<br>[0.067] |

***, **, *, indicates significant at the 1% 5% and 10% level respectively.

**Table 4.** Results of the asymmetric error correction model with threshold cointegration.

| Item | RPC | | GDP | | TPC | | GDP | |
|---|---|---|---|---|---|---|---|---|
| | Estimate | t-ratio | Estimate | t-ratio | Estimate | t-ratio | Estimate | t-ratio |
| $\Gamma$ | 0.007** | 2.267 | 0.053 | 1.198 | 0.006*** | 2.971 | 0.049*** | 3.888 |
| $\alpha^+_1$ | -0.429*** | -4.515 | -0.543 | -0.394 | -0.46*** | -4.822 | -0.057 | -0.09 |
| $\alpha^+_2$ | -0.229** | -2.31 | -0.217 | -0.151 | -0.212** | -2.155 | -0.575 | -0.873 |
| $\alpha^+_3$ | 0.037 | 0.368 | 0.695 | 0.479 | 0.084 | 0.842 | -0.529 | -0.793 |
| $\alpha^+_4$ | 0.15* | 1.49 | 1.441 | 0.987 | 0.184* | 1.872 | 0.171 | 0.26 |
| $\alpha^+_5$ | 0.044 | 0.447 | 0.797 | 0.565 | 0.081 | 0.85 | 0.409 | 0.644 |
| $\alpha^-_1$ | -0.158 | -1.211 | -0.683 | -0.361 | -0.149 | -1.153 | -0.75 | -0.866 |
| $\alpha^-_2$ | 0.202* | 1.544 | 3.444* | 1.812 | 0.211* | 1.639 | 0.803 | 0.93 |
| $\alpha^-_3$ | 0.237* | 1.801 | 0.889 | 0.466 | 0.216* | 1.663 | 0.806 | 0.925 |
| $\alpha^-_4$ | -0.08 | -0.608 | 1.871 | 0.986 | -0.106 | -0.811 | 0.191 | 0.218 |
| $\alpha^-_5$ | 0.199* | 1.51 | -0.51 | -0.267 | 0.129 | 0.991 | 0.373 | 0.427 |
| $\beta^+_1$ | -0.004 | -0.56 | 0.762*** | 7.98 | -0.041*** | -2.618 | 0.194* | 1.855 |
| $\beta^+_2$ | -0.008 | -1.22 | 0.583*** | 6.346 | -0.035** | -2.237 | -0.423*** | -4.089 |
| $\beta^+_3$ | -0.001 | -0.153 | 0.506*** | 5.91 | 0 | 0.025 | 0.063 | 0.551 |
| $\beta^+_4$ | -0.006 | -0.984 | 0.191** | 2.03 | 0.019 | 1.295 | -0.723*** | -7.206 |
| $\beta^+_5$ | 0.001 | 0.214 | 0.012 | 0.138 | 0.024* | 1.494 | -0.511*** | -4.771 |
| $\beta^-_1$ | 0.003 | 0.484 | 0.636*** | 7.883 | 0.015 | 0.854 | 0.036 | 0.312 |
| $\beta^-_2$ | 0.001 | 0.263 | 0.477*** | 6.222 | 0.02* | 1.461 | 0.228** | 2.519 |
| $\beta^-_3$ | 0.003 | 0.691 | 0.391*** | 5.637 | 0.024* | 1.849 | -0.851*** | -9.888 |
| $\beta^-_4$ | 0 | 0.058 | 0.622*** | 8.335 | -0.005 | -0.414 | 0.095 | 1.173 |
| $\beta^-_5$ | 0.004 | 0.738 | 0.541*** | 6.232 | -0.002 | -0.172 | 0.698*** | 8.53 |
| $\delta^+$ | -0.003 | -0.588 | -1.009*** | -12.187 | 0.007 | 0.693 | -0.321*** | -4.616 |
| $\delta^-$ | 0.002 | 0.403 | -0.989*** | -12.894 | 0.004 | 0.224 | 0.073 | 0.585 |
| $R^2$ | 0.181 | _ | 0.901 | _ | 0.203 | _ | 0.752 | _ |
| AIC | -2185.839 | _ | -650.62 | _ | -2193.444 | _ | -1101.647 | _ |
| BIC | -2098.011 | _ | -562.792 | _ | -2105.616 | _ | -1013.82 | _ |
| $H_0=\alpha^+_i=\alpha^-_i=0$ for all lags | 4.506*** | [0] | 0.755 | [0.67] | 4.85*** | [0] | 0.409 | [0.94] |
| $H_0=\beta^+_i=\beta^-_i=0$ for all lags | 0.571 | [0.84] | 186.018*** | [0] | 2.052** | [0.03] | 47.398*** | [0] |
| $H_0=\alpha^+_1=\alpha^-_1$ | 2.059 | [0.15] | 0.003 | [0.96] | 2.753* | [0.1] | 0.303 | [0.58] |
| $H_0=\alpha^+_2=\alpha^-_2$ | 5.154** | [0.02] | 1.767 | [0.18] | 5.123** | [0.02] | 1.21 | [0.27] |
| $H_0=\alpha^+_4=\alpha^-_4$ | 1.448 | [0.23] | 0.024 | [0.88] | 2.34* | [0.13] | 0 | [0.99] |
| $H_0=\beta^+_1=\beta^-_1$ | 0.437 | [0.51] | 0.817 | [0.37] | 5.427** | [0.02] | 0.966 | [0.33] |
| $H_0=\beta^+_2=\beta^-_2$ | 1.042 | [0.31] | 0.67 | [0.41] | 6.606** | [0.01] | 21.165*** | [0] |
| $H_0=\beta^+_3=\beta^-_3$ | 0.315 | [0.57] | 1.122 | [0.29] | 1.008 | [0.32] | 34.455*** | [0] |
| $H_0=\beta^+_4=\beta^-_4$ | 0.638 | [0.42] | 12.627*** | [0] | 1.081 | [0.3] | 27.072*** | [0] |
| $H_0=\beta^+_5=\beta^-_5$ | 0.121 | [0.73] | 16.721*** | [0] | 1.148 | [0.28] | 55.39*** | [0] |
| $H_0=\Sigma^5_{i=1}\alpha^+_i=\Sigma^5_{i=1}\alpha^-_i$ | 4.22** | [0.04] | 0.236 | [0.63] | 2.475* | [0.12] | 0.566 | [0.45] |
| $H_0=\Sigma^5_{i=1}\beta^+_i=\Sigma^5_{i=1}\beta^-_i$ | 0.998 | [0.32] | 2.048 | [0.15] | 2.119* | [0.15] | 17.722*** | [0] |
| $H_0=\delta^+=\delta^-$ | 2.705* | [0.1] | 0.167 | [0.68] | 0.029 | [0.86] | 10.763*** | [0] |

**Table 4.** continued

| EPPC | | GDP | | IPC | | GDP | | TRPC | | GDP | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Estimate | t-ratio | Estimate | t-ratio | Estimate | t-ratio | Estimate | t-ratio | Estimate | t-ratio | Estimate | t-ratio |
| 0.003 | 1.122 | -0.03 | -1.174 | 0.005*** | 3.485 | 0.008 | 0.778 | 0.004** | 2.436 | -0.056*** | -5.111 |
| -0.421*** | -4.365 | 0.82 | 0.834 | -0.423*** | -4.384 | 0.701 | 1.086 | -0.412*** | -4.194 | 0.683 | 1.018 |
| -0.219** | -2.21 | -1.12 | -1.107 | -0.24** | -2.396 | 0.622 | 0.929 | -0.213** | -2.099 | 0.276 | 0.398 |
| 0.072 | 0.723 | 0.767 | 0.754 | 0.019 | 0.183 | 0.664 | 0.98 | 0.062 | 0.612 | 0.554 | 0.797 |
| 0.172* | 1.737 | 0.61 | 0.606 | 0.107 | 1.059 | 1.039* | 1.542 | 0.146 | 1.44 | 0.194 | 0.279 |
| 0.072 | 0.744 | 0.787 | 0.799 | 0.041 | 0.415 | 1.545** | 2.367 | 0.068 | 0.684 | -0.069 | -0.103 |
| -0.181 | -1.353 | -0.916 | -0.673 | -0.167 | -1.224 | 0.175 | 0.192 | -0.148 | -1.088 | 1.535* | 1.651 |
| 0.222* | 1.682 | 2.77** | 2.055 | 0.192 | 1.419 | 0.087 | 0.096 | 0.189 | 1.385 | 1.581* | 1.697 |
| 0.194* | 1.458 | 1.179 | 0.868 | 0.164 | 1.197 | 0.477 | 0.522 | 0.201* | 1.469 | -0.311 | -0.333 |
| -0.09 | -0.682 | -1.004 | -0.745 | -0.139 | -1.037 | 1.093 | 1.218 | -0.098 | -0.721 | -0.318 | -0.342 |
| 0.176 | 1.324 | -0.464 | -0.343 | 0.156 | 1.155 | 0.784 | 0.871 | 0.193 | 1.42 | -0.716 | -0.77 |
| 0.004 | 0.336 | 1.061*** | 7.838 | -0.034* | -1.751 | -0.396*** | -3.077 | 0.015 | 0.816 | -0.217* | -1.72 |
| 0.002 | 0.146 | 0.016 | 0.12 | -0.025* | -1.456 | -0.478*** | -4.113 | -0.016 | -0.84 | 0.073 | 0.573 |
| 0.019* | 1.486 | 0.167 | 1.281 | -0.005 | -0.261 | 0.249** | 2.063 | 0 | 0.002 | 0.464*** | 3.615 |
| 0.006 | 0.561 | -0.616*** | -5.243 | 0.022 | 1.288 | -0.383*** | -3.388 | 0 | -0.008 | 0.635*** | 5.342 |
| 0.019* | 1.573 | 0.102 | 0.817 | 0.01 | 0.596 | 0.257** | 2.273 | 0.012 | 1.023 | 0.628*** | 7.741 |
| 0.017* | 1.502 | -0.068 | -0.578 | 0.007 | 0.441 | -0.309*** | -3.089 | 0.005 | 0.322 | -0.686*** | -6.167 |
| 0.002 | 0.143 | -0.005 | -0.05 | -0.007 | -0.509 | 0.331*** | 3.47 | 0.018 | 0.967 | -0.388*** | -3.013 |
| 0.011 | 1.095 | -0.54*** | -5.098 | 0.01 | 0.695 | -0.026 | -0.271 | -0.006 | -0.297 | -0.161 | -1.263 |
| 0.006 | 0.592 | 0.373*** | 3.517 | 0.005 | 0.313 | 0.231** | 2.272 | 0.004 | 0.208 | -0.028 | -0.219 |
| -0.004 | -0.36 | 0.288*** | 2.864 | 0.015 | 1.075 | 0.088 | 0.968 | -0.002 | -0.084 | 0.49*** | 3.809 |
| -0.009 | -0.782 | -0.474*** | -3.995 | 0.019 | 0.908 | -0.134 | -0.984 | -0.01 | -0.616 | -0.377*** | -3.471 |
| -0.011* | -1.493 | -0.473*** | -6.054 | 0.008 | 1.086 | -0.281*** | -5.549 | -0.004 | -0.375 | -0.296*** | -4.029 |
| 0.17 | _ | 0.688 | _ | 0.166 | _ | 0.513 | _ | 0.148 | _ | 0.611 | _ |
| -2181.842 | _ | -849.162 | _ | -2180.6 | _ | -1090.024 | _ | -2174.495 | _ | -1070.919 | _ |
| -2094.015 | _ | -761.334 | _ | -2092.772 | _ | -1002.197 | _ | -2086.667 | _ | -983.092 | _ |
| 4.469*** | [0] | 0.853 | [0.58] | 4.137*** | [0] | 1.419 | [0.17] | 4.087*** | [0] | 0.946 | [0.49] |
| 1.037 | [0.41] | 27.212*** | [0] | 0.921 | [0.51] | 13.33*** | [0] | 0.458 | [0.92] | 18.976*** | [0] |
| — | — | — | — | — | — | — | — | — | — | — | — |
| 5.303** | [0.02] | 3.954** | [0.05] | 4.945** | [0.03] | 0.169 | [0.68] | 4.181** | [0.04] | 0.945 | [0.33] |
| — | — | — | — | — | — | — | — | — | — | — | — |
| 0.518 | [0.47] | 38.052*** | [0] | 2.177. | [0.14] | 0.228 | [0.63] | 0.134 | [0.72] | 6.475** | [0.01] |
| — | — | — | — | — | — | — | — | 1.672 | [0.2] | 6.619** | [0.01] |
| 0.151 | [0.7] | 12.577*** | [0] | 0.362 | [0.55] | 2.797* | [0.1] | 0.045 | [0.83] | 12.237*** | [0] |
| 0 | [0.99] | 25.089*** | [0] | 0.487 | [0.49] | 14.146*** | [0] | 0.024 | [0.88] | 13.858*** | [0] |
| — | — | — | — | — | — | — | — | — | — | — | — |
| 2.542* | [0.11] | 0.005 | [0.94] | 2.882* | [0.09] | 0.499 | [0.48] | 2.727* | [0.1] | 0.002 | [0.96] |
| — | — | — | — | 1.107 | [0.29] | 7.665*** | [0.01] | 0.031 | [0.86] | 47.812*** | [0] |
| 0.056 | [0.81] | 0 | [0.99] | 0.251 | [0.62] | 1.121 | [0.29] | 0.1 | [0.75] | 0.429 | [0.51] |

***, **, *, indicates significant at the 1% 5% and 10% level respectively.

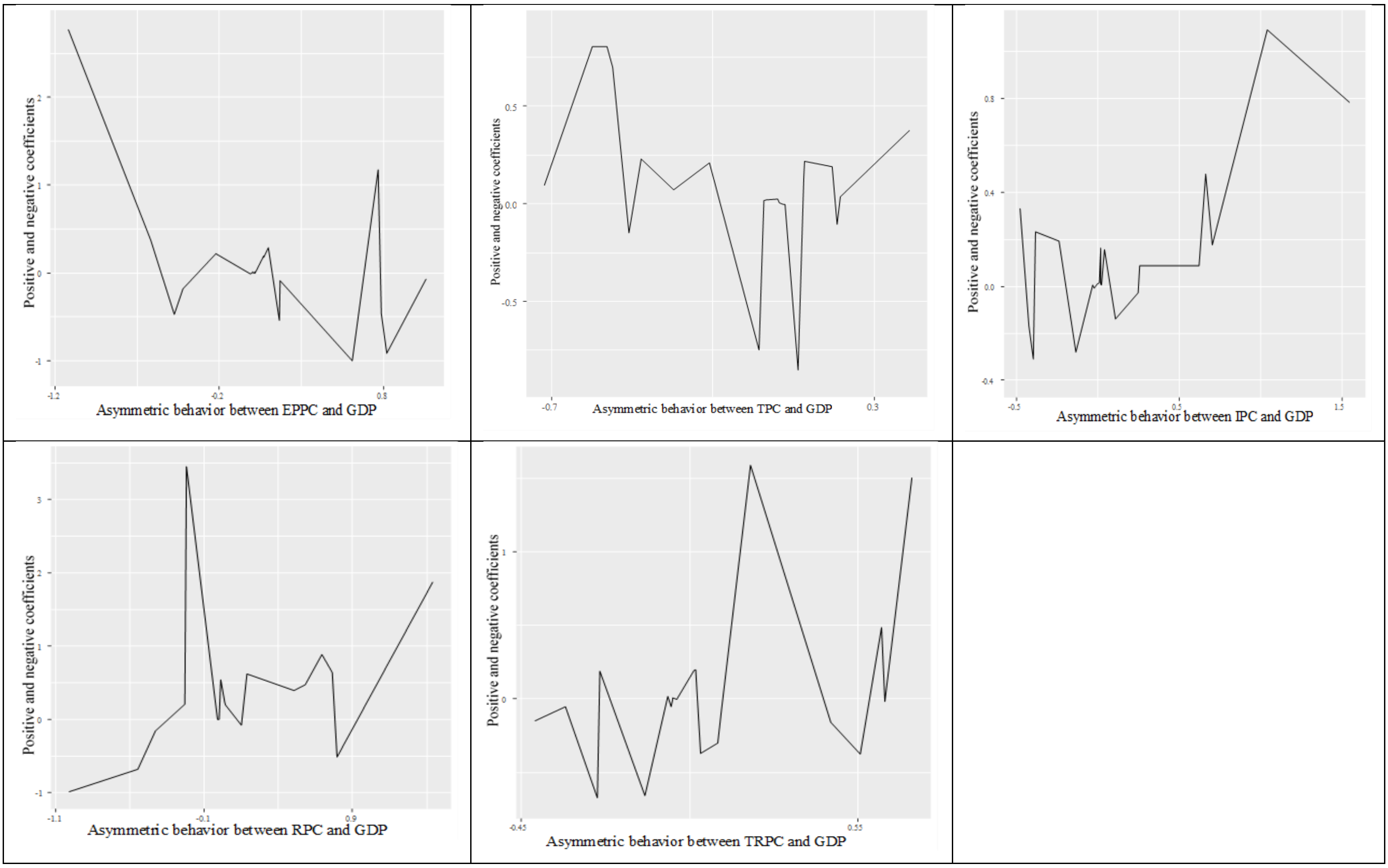

**Figure 1.** Asymmetric behavior among the variables.