The energy-growth nexus reconsidered: persistence and causality

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ABSTRACT

This communication applies a recent econometric framework to the analysis of the relationship between energy consumption and economic growth in the US, which allow a joint study of causality and persistence. We provide evidence suggesting a nonlinear relationship with two structural breaks. In the most recent regime we find that GDP causes energy consumption (and vice versa). Furthermore, both series show persistence, i.e. cyclical and natural components do not evolve independently. Thus, policies oriented to the reduction of energy consumption could constrain economic growth and policy shocks can have permanent effects.

Keywords:

Energy consumption

Economic Growth

Unobserved components model

Causality

Persistence

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1. Introduction

The relationship between energy consumption and economic growth has been at the heart of the debate on energy policy. In particular, the existence and direction of causality should be considered as a key element for the formulation of energy policies, whereas testing for persistence is a crucial key element for analysing the long-run effects of the energy policy.

For example, if causality does not exist in both directions or if causality is only in one direction such as from GDP to energy, then a policy of energy conservation may be appropriate since it will not have a negative effect on economic growth and will have a positive effect on the environment –conservation hypothesis-. By contrast, if there is a bi-directional causality or a causality relation from energy to GDP, the reduction in energy consumption may harm economic recovery or constrain economic growth –feedback hypothesis-.[2]

This causal relationship between energy consumption and economic growth has been extensively explored in different countries or groups of countries, time periods, and proxy variables using different strategies, as recently survey Ozturk [1] or Payne [2]. As it is well-known, the relation between energy consumption and economic growth has become a source of controversy in Energy Economics, since evidence has not provided unambiguous results. Leaving aside proxy and times periods, and as Ozturk [1] states one of the most likely reasons for explaining the lack of consensus on the causality relationship between energy consumption and economic growth may be arise due to different econometric approaches have been used. In this article we put the focus on the importance of the econometric approach undertaken, as one of the most important cause of this wide range of results.

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[2] The other two options are no causality or neutrality hypothesis the uni-directional causality from energy consumption to economic growth or growth hypothesis (see Ozturk[20]).

In country specific studies, the most popular approach has consisted of testing for Granger causality. As it is well-known, these tests should be undertaken with stationary time series. For this reason unit roots tests with or without structural breaks are used before looking for Granger causality in order to yield valid inferences. However, when time series are non-stationary, the alternative way for analyzing the causality relationship is the cointegration approach, procedures valid irrespective whether time series are stationary or not.. In that case, either by using the Johansen-Juselius [3] cointegration approach (for cointegrated time series) or procedures such as Pesaran Shin [4], Pesaran et al. [5] Toda Yamamoto [6] and Dolado and Lütkepol [7] (when the time series are not cointegrated), researchers avoid the potential biases of pre-testing when undertaking causality tests. (Payne [2], p. 729)

However, there is another way to avoid the pre-testing. In this article, we propose the use of a multivariate unobserved component model, recently developed by Sinclair [8] to decompose energy consumption and the real GDP into the sum of its two (unobservable) components: the non-stationary natural component, and the stationary cyclical components. In doing so, and given that a cyclical component is stationary, we can test directly the causality by using this component. To the best of our knowledge its application to Energy Economics is novel.

We also ask whether energy consumption exhibits persistence[3], defined as a macro dynamic structure in which the cyclical component of energy consumption has persistent effects on its natural rate, as Jaeger & Parkinson suggests [9] [10]. Persistence can be defined and measured in various ways. The most popular approach in the empirical literature simply equates persistence with the existence of a unit root in a

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[3] Persistence is another important topic in Energy Economics, since it concerns to the long-term effects of energy policies: if energy consumption is non-stationary, policy shocks can be regarded as permanent; by contrast, if energy consumption is trend-stationary, economic and policy shocks can be regarded as transitory: the level eventually reverts to its trend. Therefore, at the heart of this question is whether energy consumption evolves as a trend-stationary or as a non-stationary time-series process.

variable[4]. The available evidence on persistence in energy consumption, is also mixed. Some authors suggests that energy consumption is integrated of order zero in which case policies only have short-term effects (Chen & Lee [11]; Narayan & Smith, [12]; Apergis et al., [13],[14] while others as Hsu et al. [15] or Mishra et al [16]provides evidence on the contrary[5].

Furthermore a number of papers have studied methods for checking for presence of hysteresis (persistence and remanence[6]) in a nonlinear framework, testing for structural breaks (see Ozturk, [1]). However, though these models incorporate nonlinearities they have the same weak point as the linear models described above: natural and cyclical shocks are summarized in the innovation with no distinction.

However, persistence in a time series arises when a change in the cyclical component induces a permanent change in the natural component. Therefore, the presence of a unit root in the time series is a necessary condition for the existence of persistence but not a sufficient one since the unit root could be generated by accumulation of natural shocks and be completely independent of whether there is persistence (Pérez and di Sanzo [17] or Congregado et al. [18]).

Hence, separating the respective effects of transitory and permanent shocks on the natural component is the only way to assess if changes in it are due to cyclical (this is the case of persistence) or natural shocks or both. For this reason, we adopt an unobserved components model in order to put this idea in perspective and for testing the validity of the persistence hypothesis for energy consumption. In particular, we use the unobserved component model recently proposed by Sinclair [8] which decomposed the

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[4] See, Røed [19], for a survey.

[5] See Payne [2] for a survey.

[6] We prevent the use of persistence and hysteresis as synonymous. A formal definition of a hysteretic process requires the properties of persistence and **remanence**, and this last one is lacking in a linear model (Amable et al., [20]). At this point, we want to thank an anonymous referee suggestion about the use of this term.

actual values of a series into two components, a natural and cyclical component. This framework allows: i) on the one hand, to check the presence of hysteresis in energy consumption from an analysis of the cross correlation between the natural and cyclical component of the energy consumption series; and, ii) an analysis of causality between energy consumption and GDP using the cyclical components of both series, extracted by using this UC model, which allow to avoid problems related to the stationarity properties of our series in levels.

Hence, separating the respective effects of transitory and permanent shocks on the natural component of energy consumption the only way to assess if changes in it are due to cyclical (this is the case of persistence) or natural shocks or both.

For this reason, the second novelty of our approach is the study of the persistence by means of the analysis of the cross-correlation between the two unobserved components of each time series, described above, which allow us to know whether temporary shocks in energy consumption have permanent effects while the energy cycle does not evolve independently of the natural component.

In that sense, this paper explore a new empirical approach in order to understand and interpret the why and wherefore of the lack of uniformity shown by the previous empirical evidence on the relationship between energy consumption and growth and on the permanent or transitory character of shocks in energy consumption.

Leaving aside issues of data quality, the key question is to identify the correct model specification so as to ensure a consistent estimating procedure. In this context, this article provide the results of applying an unobserved component model, recently proposed by Sinclair [8] which allows for a simultaneous study of causality and persistence in a single framework.

In particular, the method consists of decomposing the two time-series in two unobservable components: a non-stationary “natural” component, and a stationary “cyclical” component. The use of these cyclical components would allow to avoid potential biases associated to the stationarity properties of time series necessary for the causality analysis. On the other hand, separating the respective effects of transitory and permanent shocks on the natural component is the only way to assess if changes in it are due to cyclical (this is the case of persistence) or natural shocks or both.

In sum, this article jointly estimates the permanent and transitory movements in U.S. output and energy consumption as well as the relationships between them. The estimated components, suggest that movements in their permanent components look similar to the series themselves. In addition, the innovations to the permanent component and the transitory component are highly correlated for both output and energy consumption. This suggests that it would be inappropriate to treat these components as independent. Finally, the positive correlation between the permanent and transitory innovations to real GDP and energy consumption indicates that real GDP and the energy consumption are strongly linked not only through their transitory movements but also through their permanent movements.

The rest of the article is organized as follows. The next section presents the econometric framework. The empirical results are discussed in section 3. Finally, section 4 presents the concluding remarks.

2. Econometric framework and data

The starting point of our estimation strategy call for, decompose the series X_t into the sum of its two (unobservable) components: the non-stationary natural component, x_t^N , and the stationary cyclical component, x_t^C

The relationship between output growth and energy consumption is analyzed estimating a bivariate correlated unobserved components model to investigate the interplay between output and energy consumption. We use Sinclair's [8] model which allows for possible correlation between the components of the covariance matrix. This model can be used to decompose the two series into their cyclical and natural components:

$$C_t = C_t^C + C_t^N \tag{1}$$

$$Y_t = Y_t^C + Y_t^N \tag{2}$$

Each cyclical component is modeled as an AR(2) process[7]:

$$\mathrm{C_t^C} = \varphi_{1c}\mathrm{C_{t-1}^C} + \varphi_{2c}\mathrm{C_{t-2}^C} + \varepsilon_{st} \qquad \varepsilon_{ct} \sim \mathrm{NID}\left(0, \sigma_{\varepsilon_c}^2\right) \tag{3}$$

$$\mathrm{Y_t^C} = \varphi_{1y}\mathrm{Y_{t-1}^C} + \varphi_{2y}\mathrm{Y_{t-2}^C} + \varepsilon_{yt} \qquad \varepsilon_{yt} \sim \mathrm{NID}\left(0, \sigma_{\varepsilon_y}^2\right) \tag{4}$$

Each natural component is assumed to be given by a random walk[8], although we also allow for a drift μ in the GDP equation:

$$C_t^N = \mu_{ct} + C_{t-1}^N + \eta_{ct} \quad \eta_{ct} \sim NID\left(0, \sigma_{\eta_c}^2\right) \tag{5}$$

$$Y_t^N = \mu_{yt} + Y_{t-1}^N + \eta_{yt} \quad \eta_{yt} \sim NID\left(0, \sigma_{\eta_y}^2\right) \tag{6}$$

The state-space form of this model can be estimated using the Kalman Filter with maximum likelihood estimation of the parameters and the cyclical and natural components.[9] We also estimate all the correlations between the unobserved components of the two series. The correlation coefficient between the cyclical components of the

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[7] We find that an AR(2) process for the cyclical component fits the data well for all the time series under study.

[8] Ng-Perron [21] tests cannot reject a unit root for either of the series used (see appendix). Zivot & Andrews [22] tests are also used for testing unit roots allowing for structural breaks (available upon request).

[9] As Sinclair [8] explains, this model is identified without the imposition of any restriction on the covariance matrix.

two series reveals pro- or counter-cyclical variation depending on whether the coefficient is positive or negative. At the same time, the correlation between the natural components of energy consumption and output reveals the nature of the relationship between these variables in the long-run. Once the previous strategy has been used as a way to separate cyclical and natural components in the two series, our next objective will be looking for Granger-causality in the relationship by using the estimates of the two cyclical components.

The data used are quarterly observations from 1973:1 to 2010:3. The energy consumption (measured in quadrillion Btu.) and GDP data (measured in billions of chained 2005 dollars) are extracted from the US Energy Information Administration (EIA) and the US Bureau of Economics Analysis (BEA), respectively. Before conducting the empirical analysis data were seasonally adjusted.

3. Results

The estimates are presented in Table 1. These estimates come from joint estimation produced using a Kalman filter. Figure 1 presents the estimated components of output and energy consumption, respectively along with the observed series.

INSERT FIGURE 1 AROUND HERE

The estimates in Table 1 and the estimated permanent component of energy consumption indicate that movements are highly variable. Second, innovations to the permanent component are significantly negatively correlated with innovations to the transitory component, rejecting the restriction of independent components.

The estimate of the permanent component, shown in Figure 1, looks very similar to the energy consumption series. The transitory movements are the difference between the series and the permanent component.

Let's focus now on the cross-series correlations, that is, on rhe relationship between the transitory components of output and energy consumption. As discussed in the previous section, the correlation between the transitory and natural components of GDP and energy consumption points to a pro-cyclical nature of this relationship .This correlation suggests that the transitory components of output and energy consumption are positively correlated. (see the last two rows in table 1).

Regarding to the relationship between the permanent components the estimates presented in Table 1 indicate a positive relationship, similar to that of transitory output and energy consumption.

Finally, the size of the correlation between the cyclical and natural component for either series suggests that a substantial amount of the transitory component arises from adjustment to permanent shocks (rows 1 and 5, in table 1).

Table 1. Estimates of the bivariate unobserved component model

	GDP ($\mathbf{Y_t}$)	
Correlation between GDP innovations	$\rho_{ny\varepsilon y}$	-0.983*** (0.007)
$\mathbf{Y_t}$ drift	μ_y	0.737*** (0.160)
$\mathbf{Y_t}$ 1st AR parameter	φ_{1y}	0.707*** (0.064)
$\mathbf{Y_t}$ 2nd AR parameter	φ_{2y}	-0.002 (0.031)
	Energy consumption ($\mathbf{C_t}$)	
Correlation between $\mathbf{C_t}$ innovations	$\rho_{nc\varepsilon c}$	-0.839*** (0.051)
$\mathbf{C_t}$ drift	μ_c	0.242 (0.174)
$\mathbf{C_t}$ 1st AR parameter	φ_{1c}	1.283*** (0.065)
$\mathbf{C_t}$ 2ND AR parameter	φ_{2c}	-0.615*** (0.061)
	Cross Series Correlations	
Natural $\mathbf{Y_t}$ /Natural $\mathbf{C_t}$	ρ_{nync}	0.915*** (0.033)
Cyclical $\mathbf{Y_t}$ / Cyclical $\mathbf{C_t}$	$\rho_{\varepsilon y\varepsilon c}$	0.953*** (0.046)

Notes: Standard errors are in parentheses. ***,**,*, rejects null hypothesis at 1%, 5% and 10% significance level, respectively.

Table 2 report the result of the Granger causality test, where the null is the hypothesis of no causation. The null hypothesis of no causation is rejected in both directions, implying then that the direction of causality is bilateral. The Granger causality tests show that there is bidirectional causality between energy consumption variation and output for U.S.

Therefore, the Granger-causality tests show that there is bidirectional causality between GDP and energy consumption.

Table 2. Granger Causality tests between GDP and Energy Consumption

Null hypothesis	**P-value**
$C_t^c \nrightarrow Y_t^c$	**0.006**
$Y_t^c \nrightarrow C_t^c$	**0.087**

Note: In bold p-values smaller than 10%.

Our results are in line with Lee [23] since we find a bi-directional causality at the 10% level of significance. However, if we establish a more demanding statistical criterion with regard the significance level, our results agrees well with the previous work of Stern [24] [25] using a multivariate VAR model and cointegration and Granger causality test, respectively, Soytas & Sari [26] and Bowden and Payne [27] using the Toda-Yamamoto approach, given that at the 5% only a causality running from C to GDP is found.

Finally, and since we are considering a long period of time (1973-2010), it is possible that the relationship under consideration underwent some structural shifts. Because the existence of structural shifts would bias our results, leading to incorrect inference about cyclicality, we checked for (possibly multiple) structural breaks in the relationship estimated, using a methodology proposed by Bai and Perron [28] [29] [30]. In the absence of structural breaks, the inferences made earlier remain valid. In presence of structural breaks, on the other hand, the causal relationships estimated in the previous subsection need to be re-estimated for each sub-period determined by the breaks. That way, we can avoid drawing spurious conclusions from an inappropriately conjoined set of sub-periods.

As Table A4 (in the appendix) shows, the energy-growth relationship is subject to structural breaks, with break points 1984(II) and 1990(III). This implies three sub-periods over which the causality relationship can exhibit different performance.

Given the existence of structural breaks, we reexamine the casuality relationships for each sub-period separately. The results are summarized in Table 3. Looking at table, it is clear that, different sub-periods exhibit different relationships − and that these differ from those reported for the full-sample analyses in Table 2. In particular, the first sub-period, does not exhibit causality running from output cycles to energy consumption cycles or vice-versa. In contrast, the second period exhibit causality running from energy consumption cycles to output cycles. However, the most recent regime, exhibits pro-cyclical bi-directional causality between energy consumption.

Table 3. Granger causality tests between self-employment and output in different sub-periods.

Null hypothesis	Sub-period 1 1973(I)-1984(I)	Sub-period 2 1984(II)-1990(II)	Sub-period 3 1990(III)-2010(IV)
$C_t^c \nrightarrow Y_t^c$	0.650	**0.057**	**0.087**
$Y_t^c \nrightarrow C_t^c$	0.695	0.249	**0.042**

Note: In bold p-values smaller than 10%.

4. Concluding remarks

Our results shed new light on the important issue of the relationship between energy consumption and economic growth. In particular, this paper applies a new approach in order to clarify in some extent the literature's puzzle on this relationship. In line with some previous results our findings point to, the existence of a bi-directional causality between energy consumption and economic growth or by applying a more demanding statistical significance level the existence of a unidirectional causality running from energy consumption to economic growth. However, and once the possibility of structural breaks has been taken into account, our findings suggest that the causality relationships have changed between periods. In particular, in the most recent regime, a bi-directional relationship is found. The Granger causality tests reveal that energy consumption cycles causes output cycles and vice versa. Therefore, energy conservative policies may harm economic recovery.

Second, this paper contributes to the debate about the variability in the natural rate of energy consumption. In that sense, our results show that movements in U.S. energy consumption are largely permanent.

We also provide estimates of the different relationships between the unobserved components of output and energy consumption. On the one hand we find negative and statistically significant correlations within-series, that is, those between the innovations to the permanent and transitory components of the same series. The innovations to the permanent and transitory components of the two series are negatively correlated.

Finally we also report cross-series correlations, that is, the correlation between the transitory components of output and energy consumption and, between their two permanent components being both of them negatives.

However, we cannot rule out the possibility that it might also simply reflect data limitations, including the possibility that self-employment is an unsatisfactory practical measure of entrepreneurship. Further research is needed to determine whether it is different national (e.g. institutional) and economic conditions, or merely different data definitions of self-employment, which explain the diverse findings. Future work could also fruitfully apply the methodology used in this article to a broader range of countries, and should seek to lengthen the length of the data series that are utilized. Future work might fruitfully apply the methodology used in this article to a broader range of countries, and should also seek to use alternative data series.

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APPENDIX

Unit roots

Table A1. Ng and Perron[a,b] tests for a unit root

I(1) vs. I(0)	Case: p = 1, $\bar{c}= -13.5$			
Variable	$\bar{M}Z_{\alpha}^{GLS}$	$\bar{M}Z_{t}^{GLS}$	$\bar{M}SB_{\alpha}^{GLS}$	$\bar{M}P_{T}^{GLS}$
lY	-9.206	-1.976	0.215	10.582
lC	-8.840	-2.043	0.231	10.535

[a] A *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively;

[b] The *MAIC* information criteria is used to select the autoregressive truncation lag, *k*. The critical values are taken from Ng and Perron [19], table 1.

Critical values:	Case: p = 1, $\bar{c}= -13.5$		
Variable	10%	5%	1%
$\bar{M}Z_{\alpha}^{GLS}$	-14.2	-17.3	-23.8
$\bar{M}SB_{\alpha}^{GLS}$	0.185	0.168	0.143
$\bar{M}Z_{t}^{GLS}$	-2.62	-2.91	-3.42
$\bar{M}P_{T}^{GLS}$	6.67	5.48	4.03

Testing for the lag length

Cointegration analysis requires the model to have a common lag length. To select the lag length of the VAR we have used the Akaike information criterion (AIC), the Schwarz information criterion (SC), and the Hannan-Quinn (HQ) criterion. Although the SC and HQ criteria suggest that $k=2$, the choice of k based on the Akaike information criterion suggests that $k=4$ is to be preferred. Hence, since the VECM variables are in first-differences, our estimates (see Tables 1 and 2 in the text) incorporate three lags.

Table A2. Results for choosing the lag length of the VAR model based on the AIC, SC and HQ criteria[a].

Lag	AIC	SC	HQ
0	-3.459403	-3.416775	-3.442080
1	-12.08295	-11.95507	-12.03098
2	-12.37244	-12.15930*	-12.28583*
3	-12.36564	-12.06725	-12.24438
4	-12.37357*	-11.98992	-12.21766

[a] Asterisk denotes rejection at the 5% significance level.

Testing for cointegration

The results obtained from applying the Johansen reduced rank regression approach to our model are given in table A3. The two hypothesis tested, from no cointegration r=0 (alternatively n-r=2) to the presence of one cointegration vector (r=1) are presented in the two first columns. The eigenvalues associated with the combinations of the $I(1)$ levels of x_t are in column 3. Next come the $\lambda_{\max}$ statistics that test whether r=0 against r=1. That is, a test of the significance of the largest λ_r is performed. The results suggest that the hypothesis of no cointegration (r=0) cannot be rejected at the 5% level (with the 5% critical value given in column 5).

Table A3. Johansen Cointegration test [a]

$H_o : r$	$n - r$	λ	$\lambda_{\max}$ test	$\lambda_{\max}$ (0,95)	λ_{trace} test	λ_{trace} (0,95)	Lags
0	2	0.037	5.314	14.265	6.142	15.495	3
1	1	0.006	0.829	3.841	0.829	3.841	

[a] Asterisk denotes rejection at the 5% significance level.

Bai-Perron tests of multiple structural changes in the relationship between the cyclical components of Energy Consumption and GDP

We give a brief description of the Bai-Perron methodology before reporting the results. The Bai-Perron methodology comprises a sequence of tests, of the following form. First, the null hypothesis of no structural breaks is tested against the alternative of an unknown number of breaks. If the null is rejected, one proceeds to the second step which contains a set of tests of no breaks against an integer number *l* of breaks. If these tests show evidence of at least one break, at the third step a further set of hypotheses of *l* breaks is tested against the alternative of *l* +1 breaks. This identifies the precise number of structural breaks, as well as break points, in the data. The energy-growth relationship is subject to two structural breaks, with break points 1984(II) and 1990(III). This implies three sub-periods over which the relationship can exhibit different patterns: 1973(I)−1984(I); 1982(II)−1990(II); and 1990(III)−2010(IV). As Table A4 shows, the energy-growth relationship is subject to structural breaks. This implies that the inferences made earlier are not valid.

Table A4. Bai-Perron tests of multiple structural changes in the relationship between the energy consumption and economic growth.[a]

Statistics						
y_t={Y_t^C}	z_t={C_t^C}	$q=1$	$p=0$	$h=15$	$M=5$	
UDmax	*WDmax*	$SupF_t(1)$	$SupF_t(2)$	$SupF_t(3)$	$SupF_t(4)$	$SupF_t(5)$
19.227^{***}	16.179^{***}	9.772	16.179^{***}	11.483^{**}	9.184^{**}	6.383^{***}
$SupF_t(2/1)$	$SupF_t(3/2)$	$SupF_t(4/3)$	$SupF_t(5/4)$		BIC	LWZ
18.479^{***}	2.108	2.094	0.000		1	0

[a] y_t,z_t,q,p,h, and M denote the dependent variable, the explanatory variable allowed to change, the number of regressors, the number of corrections included in the variance-covariance matrix, the minimum number of observations in each segment, and the maximum number of breaks, respectively.

*,**,and *** denote significance at the 10%,5% and 1% levels, respectively. The critical values are taken from Bai and Perron [28], Tables 1 and 2; and from Bai and Perron [29], Tables 1 and 2.

The number of breaks (in our case, one) has been determined according to the sequential procedure of Bai and Perron [28] ,at the 1% size for the sequential test $SupF_t(\ell+1/\ell)$.