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Energy Consumption and Economic Growth: Further Evidence from Taiwan

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Abstract

This paper investigates the nonlinear relationship between energy consumption and GDP in Taiwan. By applying the method of Gonzalo and Pitarakis (2006), we consider the possibility of significant threshold effects within the long-run relationship between the two variables, where the effect is trigged by changes in the phase of the business cycle. The Granger-causality test in a threshold model indicates the relationship between energy consumption and GDP is regime-dependent. A bidirectional relationship between these two variables is observed in the contractionary regime, implying that energy serves as an engine of economic growth and that reductions in energy use will have adverse effects on economic activities. On the other hand, a unidirectional causality running from GDP to energy consumption is detected in the expansionary regime. It indicates energy conservation is feasible in this regime with little or no detrimental effects on economic growth. The policy implications are that energy use and economic growth are jointly reinforcing each other during recessionary periods. However, in periods of high economic growth when energy consumption cannot bring about economic growth, energy conservation policies should be adopted with more aggressive thinking.

Keywords: energy consumption, economic growth, cointegration, asymmetry, threshold

1. Introduction

The pioneering work of Kraft and Kraft (1978) opened up debate on the causal relationship between energy consumption and economic growth. Extensive studies spanning different countries and various time frames have produced results supporting both directions of causality, thus giving rise to conflicting opinions on energy policies. Possible explanations for such diverse empirical results include such things as different data frequencies, alternative econometric methodologies, and different indigenous characteristics of the countries studied — characteristics such as energy supplies, political and economic histories, and energy policies (Ozturk, 2010). Another line of reasoning attributes these variant findings to the assumption of a stable relationship between energy consumption and economic growth over the period investigated. Constant parameters obtained from linear models fail to capture the nonlinear behavior of most macroeconomic variables as they adjust towards their long-run equilibrium (Note 1).

The aim of this paper is to investigate the nonlinear relationship between energy consumption and GDP in Taiwan. We consider the possibility of significant threshold effects within the long-run relationship between the two variables, where the effect is triggered by changes in the phase of the business cycle. This then is the innovative contribution of our paper to the existing literature. Although many studies using models with one or more structural breaks have demonstrated that relationships between energy consumption and production are subject to structural breaks arising from world economic events affecting energy markets, not much is known about whether or not the cointegrating relation between energy and macroeconomic variables is regime-dependent, i.e. driven by changes in observable economic conditions. Using the model of Gonzalo and Pitarakis (2006), which introduces nonlinearities within a single-equation cointegrating regression model, our evidence points to multiple cointegrating relationships between energy use and output in Taiwan. The long-run equilibrium between these two variables varies according to regimes dependent on the strength of real GDP growth. This threshold-type cointegrating relationship, and its attendant Granger-causality directions, convey policy implications distinct from those obtained from a linear specification. Our results lead to a new vantage point for thinking about the appropriate time to adopt energy conservation policy. Specifically, the Granger causality tests of a linear model suggest that energy consumption does not Granger-cause output in the short-run. Yet, the multiple long-run equilibria model shows that such an opinion is valid only when the economy is in an expansionary condition. During contractionary periods, energy use and GDP are mutually interdependent, which weighs heavily against the arguments for conserving use of energy during periods of slackness.

Being relatively less-endowed with natural resources, Taiwan has relied heavily on imported energy over the past 50 years. Imported energy currently accounts for over 97% of total energy consumed, and 48.52% of this comes from imported crude (measured by 2014 data). Access to a steady, dependable, and abundant energy supply has always been an essential factor in the success of Taiwan's economic development. Owing to the 1973-1974 and 1979-1981 oil crises and the subsequent supply induced recessions, Taiwan's authorities began an earnest effort to develop more energy-efficient technologies. Environmental concerns, coupled with awareness of global responsibilities embodied in the Kyoto Protocol of 2005, further encouraged the government to improve the efficient use of Taiwan's limited energy resources, despite the apparent inconsistency and variability at times of polices, targets, and regulations (Shyu, 2014). According to its projected framework for a sustainable energy policy, Taiwan must successfully enhance energy efficiency by more than 2% per annum; that is, energy intensity in 2015 is planned to be 20% lower than the level of 2005. Supplemented by further technological breakthroughs and proper administrative measures, energy intensity compared with the level in 2005 is set to be 50% lower by 2025 when the renewable energy accounts for 20% of total power generation. As a matter of record, the energy intensity of Taiwan dropped more than 20% during the period 2005-2014, from 9.41 LOE/NT$1,000 in 2005 to 7.44 LOE/NT$1,000 in 2014. This in turn implies that energy consumption has grown in Taiwan at a lower rate than that of real GDP.

The energy intensity coefficient is defined as a ratio of energy input (i.e. energy consumed) to real output. It shows how many units of energy are required on average for society to enjoy one unit of final output, and is usually taken as an indicator of the efficiency of energy usage, as well as the performance of energy conservation policies (Note 2). Most empirical studies show that change in energy consumption has a high correlation with economic growth. However, the economic growth of Taiwan has been decreasing along with the declining trend in energy intensity over the past 10 years, with economic growth falling from a remarkable 8% per annum growth in the past, down to roughly 4% in the 2000s, with levels falling below 3% since 2011. It follows that it is of paramount concern whether policies aimed at conserving energy consumption can be implemented in Taiwan with little adverse effect on economic activity. Unfortunately, the current body of literature leads to no clear consensus on this issue. Divergent opinions arise from the heterogeneous choice of sample period, measurement issues, data frequency, and/or the econometric approach chosen (e.g. Cheng & Lai, 1997; Yang, 2000; Chiou-Wei et al., 2008; Yang et al., 2010). As remarked in Ozturk (2010), and Smyth and Narayan (2015), this uncertainty is undoubtedly a stimulus to new studies using innovative methods and perspectives, thus providing a fuller understanding of the energy consumption-economic growth relationship.

The remaining sections of this paper are organized as follows: Section 2 reviews the literature related to the causal relationship between energy consumption and economic growth. In contrast to this literature, we focus our attention on evidence related to Taiwan, and in so doing derive our conjecture about the presence of a regime-switching, long-run relationship. Section 3 introduces our econometric method – the Gonzalo and Pitarakis (2006) model – used to test for threshold effects associated with long-run equilibria. Section 4 examines the data and reports the results. Section 5 provides conclusions and discussions.

2. Literature Review

There are different views on the causal relationship between energy consumption and economic growth in the literature to date. These different views can be categorized into four types, each of which conveys important implications for energy policy. Ozturk (2010) gives an in-depth survey of the recent progress made in the literature concerning the energy consumption-growth causality nexus. Proponents of the so-called 'neutrality hypothesis' argue that there is no causality between energy consumption and economic growth. Supported by the absence of causality between energy use and output, the neutrality hypothesis implies that neither conservative nor expansive policies in relation to energy consumption have any effect on the growth rate of output. A second view, which we may term the 'conservation hypothesis', asserts a unidirectional form of causality running from output growth to energy consumption, but not vice-versa. The conservation hypothesis contends that a policy of conserving energy consumption may be implemented without hampering employment and real GDP. The third view may be termed the 'growth hypothesis', and considers energy consumption as a key element for growth. This hypothesis takes energy as a complement to labor and capital in the production function. A decrease in energy use will adversely affect economic growth while increases in energy use may contribute to economic growth. Finally, there is a 'feedback hypothesis' that asserts simultaneous, bidirectional relationships between energy use and economic growth.

A large amount of researches has devoted to studying the interrelationship between energy consumption and economic growth in Taiwan, yet evidence is mixed and causality goes in both sides. For example, Cheng and Lai (1997) apply the Granger causality test to a sample period of 1955-1993. They find a unidirectional relation from real GDP to energy use, hence in favor of the conservation hypothesis. Yet, using a sample period over 1954-1997 and Granger's technique, Yang (2000) find bidirectional causality between Taiwan's energy consumption and economic growth, implying conserving energy use brings adverse effect to economic growth. Similar conflict arises from Hwang and Gum (1991) who uses the Granger causality test with Hsiao sequential procedure suggests a bidirectional relation between energy consumption and production activities.

With the notable advancement in nonlinear modelling techniques, recent studies have introduced the possibility of structural breaks and threshold effects to empirical models. Events such as the dual energy crises in the 1970s had enormous impact on the behavior of consumers with respect to their energy usage; due in large measure to the stupendous change in relative prices, but also in part to public policies aimed at greater energy conservation and to the development of more energy-efficient production. In addition, higher living standards attending the path of long-term economic growth may also change the extent of energy consumption (Pao, 2006). More and more empirical evidence argues for considering nonlinear interactions between energy use and macroeconomic variables in order to avoid the acceptance of spurious results.

Chiou-Wei et al. (2008) compare the evidence between linear and nonlinear Granger causality and find conflicting results within some Asian newly industrialized countries. For example, the linear Granger causality test of Taiwan supports the 'conservation hypothesis', but the nonlinear Granger causality test favors the 'growth hypothesis'. The subsequent energy policy implied for the government is totally opposite. The conflictive evidence between linear and nonlinear causality is also shown in Yang et al. (2010) with an analysis on the sectoral electricity consumption and economic growth in Taiwan. Using two kinds of Hansen (1992) and Gregory and Hansen (1996) structural break tests, Lee and Chang (2005) find the relationship between energy consumption and real GDP of Taiwan is unstable over the period of 1954-2003. Some critical events occurred in the past have strong impacts on energy consumption and expenditures. However, energy acts unanimously as an engine of economic growth in the long run. This implies energy conserving policies are not suitable for Taiwan. Lee and Chang (2007a) extend their study to a dataset of 22 developed and 18 developing countries. When multiple breaks in the series are taken into account, the causality between energy consumption and real GDP varies with the level of output. Specifically, bidirectional causality is found among members of the group of developed countries, but a unidirectional relation, running from real GDP to energy consumption, is found for developing countries.

Using a threshold cointegration setup, with the error-correction term serving as the threshold variable, Hu and Lin (2008) studied the relationship between energy and growth with respect to the disaggregated energy sector of Taiwan. They find that the adjustment speed towards long-run equilibrium displays asymmetry across regimes and varies among different kinds of fossil fuel, as well as with respect to electricity. In a different vein, Lee and Chang (2007b) use the energy consumption level as a threshold variable to investigate contributions of aggregated energy consumption to Taiwan's real output growth, while taking into consideration the impact of both capital stock and labor force. Their evidence suggests the relationship between energy use and economic growth in Taiwan is characterized by an inverse U-shape over the period of 1955-2003. That means previous assertions in the literature that energy consumption serves as an engine of economic growth exist only where there is an initially low level of energy consumption, and disappears when energy consumption is higher than the estimated threshold. Based on cross-sectional data covering 82 countries over the period of 1971-2002, an analogous conclusion is proposed by Huang et al. (2008). Employing various energy-related variables as threshold variables (Note 3), the key finding of Huang et al. (2008) indicates that expanding energy usage cannot bring any significant effect to enhancing output growth.

Omay et al. (2014) have investigated the significance of nonlinearity on the energy-output relation of G-7 countries. Four candidate transition variables (Note 4) are applied to a smooth transition specification for both output growth and energy equations. Test results suggest the null hypothesis of linearity is rejected for all transition variables for both equations. However, the null of linearity is most forcefully rejected when the lagged output growth rate is used as a transition variable. This suggests the nonlinearity on energy-output relation is very likely governed by the phases of business cycle. The panel smooth transition vector error correction model further corroborates systematic variation in causality between energy consumption and output levels depending on the phase of business cycle.

Mohammadi and Amin (2015) investigate 79 countries which are grouped into high-, low-, and negative-growth categories based on the growth rates of per capita output and conclude in all three groups of countries output and energy consumption are long run bidirectional Granger caused, while short run bidirectional causality is confirmed only for (i) a sample pooling all growth categories or (ii) a sample restricted to countries exclusively in the low-growth category. Karanfil and Li (2015) examine the long- and short-run dynamics between electricity consumption and economic activities for 160 countries and conclude that the electricity-growth nexus is highly sensitive to regional differences, urbanization rates, and countries' income levels. The results of their panel analyses indicate that the energy consumption-output relationship varies according to classifications of the sample and variations in living standards with output growth playing an important role in guiding this relationship.

In this article, we employ the method of Gonzalo and Pitarakis (2006) to investigate whether there are threshold effects in the cointegrating relationship between energy consumption and real GDP for the case of Taiwan over the period 1982-2014. The theoretical grounds for a nonlinear relationship between energy price shocks and macroeconomic variables is documented by Hamilton (1996, 2003), Mork et al. (1994), Balke et al. (2002), and Huang et al. (2005). Energy price changes bring about negative and asymmetric responses of aggregate measures (e.g. output level, unemployment, etc.). Because of the 'reallocation effect', capital and labor cannot move easily to a more productive sector in the case of an unexpected change of oil price (regardless of the direction of the oil price change). That leads to an asymmetric effect on output change: oil price increase is much more harmful than oil price decrease. On the other hand, oil price determines energy use in a negative way. In a convex demand curve, changes in energy-use is asymmetric in response to one unit rise /or down of energy price. We may predict that a rise in energy price will cause a relative large decrease in output but a small reduce in energy consumption. Yet an energy price slide will have an opposite result, negligible output increase accompanied with a relative large increasing amount of energy consumption. Relation between output and energy consumption is not linear. Hasanov and Telatar (2011) provide an analogous argument that fluctuations in energy prices may lead to nonlinear dynamics in the presence of adjustment costs. Changes in input prices affect the firms' input demands. Firms react to increases in energy prices by reducing energy use in the short run, and adopting energy saving production technologies in the long run. This implies that the nonlinear relation between energy consumption and output exists both in the short- and long-runs.

Arguing a linear long-run equilibrium relationship between variables may not always be justifiable (Note 5), Gonzalo and Pitarakis (2006) propose a test for assessing the presence of regime specific nonlinearities within cointegrating relationships. Unlike previous studies that solely discuss the nonlinear adjustment process toward a long-run equilibrium, while holding the equilibrium relationship itself to be represented by a linear regression model (Note 6), Gonzalo and Pitarakis (2006) allow nonlinearity in the long run equilibrium relationship, itself. In addition, this nonlinearity within the long-run equilibrium can be induced by observable factors (for example, the phases of business cycle, term structure of interest rates), the Gonzalo and Pitarakis's (2006) model (the G-P model, hereafter) is different from Markov-Switching type nonlinearities where an unobservable state governs regime switches. The G-P model provides a particularly informative statistical environment for modelling the potential for multiple long-run equilibria between energy consumption and output levels. As mentioned above, energy consumption displays nonlinear relation with the production activities in the short- and long-runs, inference is therefore that the cointegration relation between energy consumption and output level could have multiple equilibria with the threshold effect triggered by crossing a critical level of GDP growth.

3. Methodology

Gonzalo and Pitarakis (2006) propose a testing procedure for testing the null hypothesis of linear cointegration versus cointegration with threshold effects. The type of nonlinearity works within the long run equilibrium relationship itself. Therefore, the regime specific behavior displays not only in the short run (which is known as the "threshold cointegration" in the existing literature where the cointegrating relationship linking two or more variables is constant and linear while the adjustment process to the long run equilibrium contains threshold effects). The cointegration vector may also display threshold-type nonlinearity, as a function of the size of a stationary variable in the G-P model.

Goetz and von Grammon-Taubadel (2008) utilize G-P model and identify four price transmission regimes characterized by different long run and short run relationships between the daily apple price of Hamburg and Munich. Due to substantial seasonal variation in supply quantities, price and price differences between the two related markets are subject to threshold effects both in the equilibrium relationships and short run adjustment processes. Kleykamp and Wan (2014) investigate the relationship of unemployment and labour force participation in the United States, and indicate the long run relationships between these two variables varies with the phase of business cycle. Frictions in finding a job during periods when the economy is slack and tight are different, which considerably affects workers' decisions about whether to get into the labour market to find a new job. The literature on animal spirits (Howitt and McAffee, 1992) suggests instances where some extraneous random variable such as a confidence indicator may cause macroeconomic variables to switch across different paths. These examples support the possibility of multiple long-run equilibria when an observable variable moves across some unknown threshold values. The G-P model has the specification given by

$$y_t = \boldsymbol{\omega}'\mathbf{x_t} + \boldsymbol{\lambda}'\mathbf{x_t} I(q_{t-d} > \gamma) + u_t \tag{1}$$

with $\mathbf{x}_t = \mathbf{x}_{t-1} + \mathbf{v}_t$, and where u_t and $\mathbf{v}_t$ are scalar and p-vector-valued stationary disturbance terms, respectively; q_{t-d} with $d \geq 1$ acting as the stationary threshold variable lagged d periods; and with $I(q_{t-d} > \gamma)$ an indicator function taking the value one when $q_{t-d} > \gamma$ and zero otherwise.

A natural test of the hypothesis of linear cointegration vs. the alternative of threshold cointegration takes the form H_0: $\lambda = 0$ against H_1: $\lambda \neq 0$. Gonzalo and Pitarakis (2006) argue for the use of a supLM test based on the following statistic:

$$LM_T(\lambda) = \left(u'\mathbf{M}\mathbf{X}_\gamma(\mathbf{X}_\gamma'\mathbf{M}\mathbf{X}_\gamma)^{-1}\mathbf{X}_\gamma'\mathbf{M}u\right) \Big/ \tilde{\sigma}_0^2 \tag{2}$$

where $\mathbf{M} = \mathbf{I} - \mathbf{X}(\mathbf{X}'\mathbf{X})^{-1}\mathbf{X}'$, and $\mathbf{X}$ stacks all values of $\mathbf{x}_t$ in the linear model, while $\mathbf{X}_\gamma$ stacks the values of $\mathbf{x}_t I(q_{t-d} > \gamma)$. T is the length of full sample, u is the residual, and $\tilde{\sigma}_0^2$ denotes the residual variance estimated from the linear model given the null hypothesis.

The test statistic $LM_T(\lambda)$ is obtained for each possible threshold value γ. Inferences are then based on the quantity given by $\sup LM = \sup_{\gamma\in\Gamma} LM_T(\lambda)$. A trimming parameter is employed to ensure a sufficient number of observations are available on either side of the threshold value. Critical values for this test statistics are taken from Andrews (1993).

Rejecting the null hypothesis suggests a threshold effect in the cointegrating regression itself. An unrestricted, regime-specific error correction model, defined by the indicator function $I(q_{t-d} > \gamma)$ corresponding to the threshold γ determined by the supLM test can be written as:

$$\begin{aligned} \Delta Z_t = {} & \left(\delta_1 + \sum_{i=1}^{m} \Gamma_{1i}\Delta Z_{t-i} + \alpha_1\beta_1' Z_{t-1}\right)\left(1 - I_t(q_{t-d} > \gamma)\right) \\ & + \left(\delta_2 + \sum_{i=1}^{n} \Gamma_{2i}\Delta Z_{t-i} + \alpha_2\beta_2' Z_{t-1}\right) I_t(q_{t-d} > \gamma) + \varepsilon_t \end{aligned} \tag{3}$$

where $\boldsymbol{Z}' = [y_t, \mathbf{x_t}]$. Two long-run equilibria are represented by matricies β_1 and β_2 depending on the respective regime, and the adjustment speed matrix $\boldsymbol{\alpha}' \equiv [\alpha_1, \alpha_2]$ is composed of (p+1)-dimensional vectors associated with each specific regime.

4. Data and Empirical Results

Quarterly data covering the period 1982.Q1-2014.Q4 are employed in this paper. Time series data on real GDP and chain-weighted GDP are used alternatively in testing and the estimating process to check for robustness of results. In order to mitigate against the possible omission-of-variable bias involved in using a bivariate VAR framework (Note 7), we introduce an additional variable, viz. the consumer price index, into the energy-GDP analysis. Prices are included in the system since it has been argued that price responses may play a crucial role in affecting income and energy consumption in limited resource endowed economies (Dunkerly, 1982; Hoa, 1992, 1993). In addition, energy prices substantially contribute to the overall measure of the price level. Intuitively, for countries highly dependent on external supplies of energy, secularly rising energy prices reduces aggregate supply, driving up the general price level, reducing energy consumption, and, in the absence of monetary accommodation, causing recession. In this paper, inflation is measured by changes in the consumer price index (CPI) (Note 8). The CPI, real GDP, and chain-weighted GDP are obtained from the Directorate-General of Budget, Accounting and Statistics of Executive Yuan, Taiwan. The real GDP and chain-weighted GDP are seasonally adjusted with Census X-12 method. The energy consumption series (ec_t) is taken from the AREMOS economic statistics data bank, created by Taiwan Economic Data Center. All variables are log-transformed and are coded as $lgdp_t$ (real GDP), $lchgdp_t$ (chain-weighted GDP), $lcpi_t$ (consumer price index) and lec_t (energy consumptions).

4.1 Unit Root Tests

Table 1 shows results for standard unit root tests on all four variables. The hypothesis of a unit root for all series in levels cannot be rejected by DF-GLS tests, suggesting that these series are nonstationary. However, as is also shown in Table 1, the ADF and Phillips-Perron unit root tests are sensitive to the inclusion or exclusion of constants and trends in levels of series, except for $lcpi_t$. Rejecting the unit-root null hypothesis should be inferred with some caution. Although all series in first difference appear to be stationary at 1% level of significance, evidence in Table 1 does not overwhelmingly favor the unit root argument. We speculate that this estimate bias may be due to the presence of nonlinearity in time series.

Table 1. Unit root tests for energy consumption, GDP and CPI

in level		lec_t	$lcpi_t$	$lgdp_t$	$lchgdp_t$
ADF test	τ_u	-4.101***	-0.905	-3.301**	-3.302**
	τ_t	0.703	-1.149	-1.590	-1.590
DF-GLS	τ_u	1.027	0.015	1.582	0.365
	τ_t	0.417	1.176	-0.528	-0.207
Phillips-Perron	τ_u	-2.508	-1.263	-4.662***	-4.659***
	τ_t	-2.412	-1.029	-0.793	-0.793
in first difference		Δlec_t	$\Delta lcpi_t$	$\Delta lgdp_t$	$\Delta lchgdp_t$
ADF	τ_u	-6.603***	-4.046***	-7.997***	-6.082***
	τ_t	-8.417***	-4.085***	-8.793***	-7.482***
DF-GLS	τ_u	-3.516***	-3.409***	-3.212***	-7.956***
	τ_t	-4.407***	-3.878***	-4.232***	-9.159***
Phillips-Perron	τ_u	-15.547***	-11.408***	-7.952***	-7.956***
	τ_t	-20.111***	-11.430***	-9.152***	-9.159***

Note. τ_u is the statistic with a constant. τ_t is the statistic with a constant and trend. Δ denotes first difference. ***, ** and * indicate significance at 1%, 5% and 10% levels. Lag length in the ADF and ADF-GLS tests are chosen based on SIC under maximum lag 6.

To detect the influence of a possible shift in regime on the unit root tests, we employ a unit root test due to Zivot and Andrews (1992) that allows for an endogenous structural break, as well as the more traditional unit root testing allowing for a break in the trend function at some unknown time, as proposed by Perron (1997). As shown in Table 2, the results are consistently in favor of non-stationarity in levels for all series. Together with stationarity in the first differences, we therefore proceed to assume that all four variables can be modelled as *I(1)* series.

Table 2. Structural break unit root tests for energy consumption, GDP and CPI

in level		lec_t	$lcpi_t$	$lgdp_t$	$lchgdp_t$
ZA	t_u	-2.528	-3.761	-2.438	-2.439
	t_t	-2.801	-4.317*	-3.071	-3.071
	$t_{u\,t}$	-2.804	-4.374	-3.045	-3.044
Perron	t_u	-2.570	-3.705	-2.441	-2.441
	t_t	-2.968	-2.568	-3.138	-3.137
	$t_{u\,t}$	-2.864	-3.966	-3.187	-3.186
in first difference		$\Delta\ lec_t$	$\Delta\ lcpi_t$	$\Delta\ lgdp_t$	$\Delta\ lchgdp_t$
ZA	t_u	-8.985***	-5.391***	-7.832***	-7.833***
	t_t	-8.691***	-5.272***	-7.550***	-7.551***
	$t_{u\,t}$	-9.510***	-5.890***	-7.852***	-7.854***
Perron	t_u	-9.243***	-8.483***	-8.251***	-8.251***
	t_t	-8.094***	-8.308***	-7.512***	-7.513***
	$t_{u\,t}$	-9.376***	-8.980***	-7.852***	-7.993***

Note. Δ denotes first difference. ZA denotes Zivot - Andrews (1992) unit root test with an unknown structural break. Perron denotes Perron (1997) unit root test with a break in the trend function at an unknown time. $\mathrm{t_u}$ is the statistic with a break in the constant. $\mathrm{t_t}$ is the statistic with a break in the trend. $\mathrm{t_{u\,t}}$ is the statistic with a break in the constant and trend. ***, ** and * indicate significance at 1%, 5% and 10% levels.

4.2 Cointegration and Granger Causality Tests in a Linear Framework

We use Johansen's maximum likelihood approach to test for the cointegration relationships among GDP, energy consumption and price level. GDP is measured by two proxies, i.e. $lgdp_t$ and $lchgdp_t$ as a robustness check on the estimation results. The optimal lags in the tri-variate autocorrelation models are determined by the AIC. As shown in Table 3, both trace and max statistics strongly suggest a cointegration vector exists among the variables.

Table 3. Johansen cointegration test

Model	$\lambda_{\max}$			λ_{trace}		
	r = 0	r = 1	r = 2	r = 0	r = 1	r = 2
lec_t $lcpi_t$ $lgdp_t$	41.985***	13.374	1.584	56.943***	14.958	1.584
lec_t $lcpi_t$ $lchgdp_t$	41.973***	13.377	1.583	56.935***	14.961	1.583

Note. ***, ** and * indicate significance at 1%, 5% and 10% levels.

Having established a cointegration relationship, we estimate the associated error-correction model to test for Granger causality among energy consumption, real GDP and the price level. The three-variable error-correction model is a tri-variate VAR in first differences augmented by the one-period lagged residuals from the cointegrated variables, i.e. the error-correction terms:

$$\begin{aligned}\Delta lec_t &= a_{10} + \sum a_{11}(k)\Delta lec_{t-i} + \sum a_{12}(k)\Delta lcpi_{t-i} + \sum a_{13}(k)\Delta \lg dp_{t-i} + \alpha_1 \Xi_{t-1} + \varepsilon_{1t} \\ \Delta lcpi_t &= a_{20} + \sum a_{21}(k)\Delta lec_{t-i} + \sum a_{22}(k)\Delta lcpi_{t-i} + \sum a_{23}(k)\Delta \lg dp_{t-i} + \alpha_2 \Xi_{t-1} + \varepsilon_{2t} \\ \Delta lgdp_t &= a_{30} + \sum a_{31}(k)\Delta lec_{t-i} + \sum a_{32}(k)\Delta lcpi_{t-i} + \sum a_{33}(k)\Delta \lg dp_{t-i} + \alpha_3 \Xi_{t-1} + \varepsilon_{3t}\end{aligned} \tag{4}$$

where Ξ_{t-1} is the error-correction terms, α_1, α_2 and α_3 are the speed of adjustment parameters. Variable $lgdp_t$ is replaced by $lchgdp_t$ in Eq. (4) for evidence of robustness. To check for short-run causality, we test $H_0: a_{ij}(k)=0, \forall ij$ ($i \neq j$), or alternatively, to detect whether short-run causality runs from real GDP to energy consumption, we test $H_0: a_{13}(k)=0$. The underlying null hypothesis for testing whether short-run causality runs from energy consumption to real GDP, requires that we test $H_0: a_{31}(k)=0$. Next, long-run causality is detected by testing the significance of the speed of adjustment, i.e. we test $H_0: \alpha_i = 0$. Rejecting the null hypothesis means the left hand side variable is responsive to last period's equilibrium error. Finally, we test for strong causality by jointly testing for the significance of the error correction term and lagged explanatory variables (Note 9). Results are shown in Table 4 where the panel A shows results when $lgdp_t$ enters Eq. (4), and the panel B denotes results of variable $lchgdp_t$.

Table 4. The Granger causality of energy consumption and output in a linear system

Dependent Variable	Independent variables(Source of causation)						
	Short run			Long run	Strong causality		
Panel A	Δlec	$\Delta lcpi$	$\Delta lgdp$	ECT	Δlec ECT	$\Delta lcpi$ ECT	$\Delta lgdp$ ECT
Δlec	-	7.968*	28.218***	14.701***	-	24.549***	59.701***
$\Delta lcpi$	12.337**	-	8.763*	0.500	13.495**	-	9.015
$\Delta lgdp$	2.521	4.896	-	28.323***	46.427***	49.464***	-
Panel B	Δlec	$\Delta lcpi$	$\Delta lchgdp$	ECT	Δlec ECT	$\Delta lcpi$ ECT	$\Delta lchgdp$ ECT
Δlec	-	7.957*	28.211***	14.686***	-	24.527***	59.691***
$\Delta lcpi$	8.748*	-	12.327**	0.498	13.483**	-	9.000
$\Delta lchgdp$	2.518	4.904	-	28.309***	46.426***	49.479***	-

Note. ECT represents the error-correction terms. ***, **and * indicate that the null hypothesis of no causation is rejected at the 1%, 5% and 10% levels.

Clearly, these two models with different real GDP definitions give similar results on Granger causality. With this in mind, our focus remains centered on the relationship between output and energy consumption. In the short-run, energy consumption is Granger-caused by output, but not vice-versa. In the long-run, both variables are responsive to deviations of long-run equilibrium. The strong causality test favors the feedback hypothesis, which assumes a bilateral-interactive relation between energy consumption and real GDP. The results of the linear vector correction model indicate output growth will not be impaired by energy conservation policy within a recent future, but in the long run the action of energy conservation may indeed hamper economic growth.

Now suppose we consider the presence of threshold effect in Eq. (4). As the business cycle may exert influences on energy consumption, both in the short and long runs, the annual growth rate of real GDP is introduced into the system serving as a threshold variable. Following Eq. (3), the error-correction model with threshold effects both in the short- and long-run relations can be specified by Eq. (5). Differences between the results from linear and nonlinear models are elaborated in next section.

$$\left.\begin{aligned}
\Delta lec_t &= a_{10}^1 + \sum_{i=1}^{p} a_{11i}^1 \Delta lec_{t-i} + \sum_{i=1}^{p} a_{12i}^1 \Delta lcpi_{t-i} + \sum_{i=1}^{p} a_{13i}^1 \Delta lgdp_{t-i} + \alpha_1^1 \Xi_{t-1}^1 + \varepsilon_{1,t}^1 \\
\Delta lcpi_t &= a_{20}^1 + \sum_{i=1}^{p} a_{21i}^1 \Delta lec_{t-i} + \sum_{i=1}^{p} a_{22i}^1 \Delta lcpi_{t-i} + \sum_{i=1}^{p} a_{23i}^1 \Delta lgdp_{t-i} + \alpha_2^1 \Xi_{t-1}^1 + \varepsilon_{2,t}^1 \\
\Delta lgdp_t &= a_{30}^1 + \sum_{i=1}^{p} a_{31i}^1 \Delta lec_{t-i} + \sum_{i=1}^{p} a_{32i}^1 \Delta lcpi_{t-i} + \sum_{i=1}^{p} a_{33i}^1 \Delta lgdp_{t-i} + \alpha_3^1 \Xi_{t-1}^1 + \varepsilon_{3,t}^1
\end{aligned}\right\} \quad if \quad q_{t-d} > \gamma$$

$$\left.\begin{aligned}
\Delta lec_t &= a_{10}^2 + \sum_{i=1}^{p} a_{11i}^2 \Delta lec_{t-i} + \sum_{i=1}^{p} a_{12i}^2 \Delta lcpi_{t-i} + \sum_{i=1}^{p} a_{13i}^2 \Delta lgdp_{t-i} + \alpha_1^2 \Xi_{t-1}^2 + \varepsilon_{1,t}^2 \\
\Delta lcpi_t &= a_{20}^2 + \sum_{i=1}^{p} a_{21i}^2 \Delta lec_{t-i} + \sum_{i=1}^{p} a_{22i}^2 \Delta lcpi_{t-i} + \sum_{i=1}^{p} a_{23i}^2 \Delta lgdp_{t-i} + \alpha_2^2 \Xi_{t-1}^2 + \varepsilon_{2,t}^2 \\
\Delta lgdp_t &= a_{30}^2 + \sum_{i=1}^{p} a_{31i}^2 \Delta lec_{t-i} + \sum_{i=1}^{p} a_{32i}^2 \Delta lcpi_{t-i} + \sum_{i=1}^{p} a_{33i}^2 \Delta lgdp_{t-i} + \alpha_3^2 \Xi_{t-1}^2 + \varepsilon_{3,t}^2
\end{aligned}\right\} \quad if \quad q_{t-d} < \gamma \tag{5}$$

4.3 Cointegration and Granger Causality Tests with a Threshold Approach

First of all, to detect for threshold effects within the long-run equilibrium relationship, we use the LM statistics as suggested by Gonzalo and Pitarakis (2006), previously associated with Eq. (2). Yet, Andrews and Ploberger (1994) and Balke (2000) propose using two additional statistics simultaneously, i.e. the "avg" and "exp" versions of the LM test, to reconsider the robustness on test results. The sup-LM statistics is the maximum statistic over all possible threshold values; the avg-LM is the average statistic over all possible threshold values; and the exp-LM is a function of the sum of exponential LM statistics. Table 5 reports the test results. Clearly, all the LM-type statistics give strong evidence favoring the presence of a threshold effect within the long-run equilibrium relationship for our tri-variate system. Two models of different GDP definitions report close estimates on the threshold value (γ). This fixes the expansionary period as one defined when real GDP grows at an annual rate over 4.315% (or 4.320%), otherwise the economy is in a contractionary period.

Table 5. The sup-LM, avg-LM and exp-LM test with lagged annual growth rate of real GDP or chain-rule GDP as threshold variable

Model	sup-LM	avg-LM	exp-LM	γ
lec_t $lcpi_t$ $lgdp_t$	54.30***	27.90***	23.21***	4.315
lec_t $lcpi_t$ $lchgdp_t$	54.29***	27.90***	23.21***	4.320

Note. ***, ** and * indicate significance at 1%, 5% and 10% levels.

The Granger-causality test now proceeds using Eq. (5), where two separate macroeconomic regimes are defined by virtue of the estimated threshold value and the behavior of actual real GDP. The regime can be split into disjointed upper and lower regimes, where the lagged output growth is above and below the threshold value. Causality test results with different GDP definitions are reported in Table 6 and 7, respectively. Results are quite consistent in terms of short-run, long-run and strong causality tests for each specific regime. Focus is placed on the differences existing between individual regimes. First, Table 6 shows that in the lower regime the short-run Granger-causality tests report a mutually interactive relation between energy consumption and GDP. The coefficients reflect that the two hypotheses (1) $\Delta lgdp$ Granger-causes Δlec and (2) Δlec Granger-causes $\Delta lgdp$ are both significant at the usual size for such tests. However in the long-run, the appearance of a nonsignificant estimate for Δlec on the relevant ECT, implies energy consumption does not respond to a departure from long-run equilibrium. The strong causality test in the lower regime supports a feedback relationship between energy consumption and GDP, which is similar to the result from the linear model. Results from Table 7 governing behavior in the lower regime agrees with this argument.

Table 6: The Granger causality of energy consumption and output ($lgdp_t$) under regime specific error correction model

Dependent Variable	Independent variables (Source of causation)						
	Short run			Long run	Strong causality		
	Δlec	$\Delta lcpi$	$\Delta lgdp$	ECT	Δlec ECT	$\Delta lcpi$ ECT	$\Delta lgdp$ ECT
In upper regime / expansionary period							
Δlec	-	6.216	26.238***	0.529	-	6.471	26.286***
$\Delta lcpi$	10.886**	-	1.912	7.861***	20.169***	-	11.729**
$\Delta lgdp$	7.354	14.818***	-	0.761	7.562	15.100***	-
In lower regime/ contractionary period							
Δlec	-	16.102***	21.140***	0.006	-	17.453***	21.345***
$\Delta lcpi$	11.882**	-	32.798***	16.511***	23.929***	-	72.274***
$\Delta lgdp$	11.239**	5.080	-	11.427***	27.436***	21.321***	-

Note. ECT represents the error-correction terms. ***, **and * indicate that the null hypothesis of no causation is rejected at the 1%, 5% and 10% levels.

Next, we turn our attention to the upper regime. The Granger-causality test of the upper regime gives a rather distinct conclusion from that of the lower regime. The short-run test result indicates a unidirectional relation running from $\Delta lgdp$ to Δlec, while the long-run relationship between the two variables is weak. The strong causality test validates a unidirectional relation between energy consumption and GDP, and concludes that economic growth bolsters energy consumption, but not vice-versa. The real GDP is not Granger-caused by energy consumption both in the short- and long-runs. Results in Table 7 for the upper regime also accepts the conservation hypothesis. This concludes the implication that a policy of conserving energy consumption may have little or no adverse effect on economic growth when the economy is in an expansionary condition.

Table 7. The Granger causality of energy consumption and output ($lchgdp_t$) under regime specific error correction model

Dependent Variable	Independent variables (Source of causation)						
	Short run			Long run	Strong causality		
	Δlec	$\Delta lcpi$	$\Delta lchgdp_t$	ECT	Δlec ECT	$\Delta lcpi$ ECT	$\Delta lchgdp_t$ ECT
In upper regime/ expansionary period							
Δlec	-	6.212	26.221***	0.529	-	6.467	26.268***
$\Delta lcpi$	10.891**	-	1.899	7.868***	20.172***	-	11.719**
$\Delta lchgdp_t$	7.374	14.881***	-	0.759	7.582	15.166***	-
In lower regime/ contractionary period							
Δlec	-	16.095***	21.065***	0.006	-	17.456***	21.288***
$\Delta lcpi$	11.821**	-	32.528***	16.401***	23.811***	-	71.754***
$\Delta lchgdp_t$	11.226**	5.042	-	11.504***	27.491***	21.369***	-

Note. ECT represents the error-correction terms. ***, **and * indicate that the null hypothesis of no causation is rejected at the 1%, 5% and 10% levels.

In summary, the Granger-causality test in a threshold model defined by the phase of the business cycle indicates the relationship between energy consumption and GDP is regime-dependent. When the economy is in a recessionary state, restricting energy use may adversely affect economic performance, while increasing the use of energy may accelerate economic growth. Thus, energy consumption plays an important role in stimulating output and productions during the period of contraction. Yet in an expansionary period, energy consumption appears to be less crucial to output growth.

5. Conclusions and Discussion

If it is possible to conserve energy use while reporting a satisfactory record on output growth? This issue has received extensive debates among policy makers and academic researchers. Controversial opinions can be attributed to different countries' characteristics, investigating periods, data frequencies, proxy variables and alternative econometric methodologies. Opposite results on the causal relationship between energy consumption and GDP leads to conflicting implications on energy policies. A uni-directional causality running from energy consumption to economic growth, which supports the 'growth hypothesis', indicates the energy consumption serves as a complement to labor and capital, thus plays an important role in production process. If the uni-directional causality running from economic growth to energy consumption, the 'conservation hypothesis' is confirmed, indicating the economy is less energy-dependent. Conserving energy use brings little or no adverse effects to economic activities. There are also empirical results favoring the 'feedback hypothesis' (i.e. bi-directional relations are found) and the 'neutrality hypothesis' (when energy consumption is not correlated with output level) in the existing literature.

Armed with advanced econometric methodologies, such as multivariate systems and nonlinear modelling techniques, recent studies have the ability to cope with the effects of policy changes, impacts from energy/ or economic crises, and allow for the evolution of energy consumption behavior which is considered to change with income levels. However, the energy-growth nexus remains an open issue with no solid conclusion provided. Basing on the conjecture that the short- and long-run relationship between energy use and output may be nonlinear and asymmetric depending on the phase of business cycle, this study uses the Gonzalo and Pitarakis (2006) model to test for the presence of multiple long-run equilibria between energy consumption and economic activity.

A tri-variate system consisting of Taiwan's energy consumption, CPI and GDP data is studied over the period 1982.Q1 - 2014.Q4. The lagged annual growth rate of real GDP serves as the threshold variable. Evidence from two alternative measures of GDP and three LM-type statistics strongly suggest the acceptance of the hypothesis of a threshold effect within the cointegration relationship. The estimated threshold value that defines the upper and lower regimes is around 4.3%. Granger causality tests with threshold effects show the relationship between energy consumption and output of Taiwan varies with business cycle. It suggest that the energy policy of Taiwan with a GDP growth rate over and below 4.3% will be of much diverse consideration. Explicitly, when the economy is in a gloomy situation (i.e. the economic growth rate is less than 4.3%), evidence from the strong causality test reveals a positive feedback relationship. This means an increase (decrease) in energy consumption may bring about economic growth (slow-down), and an increase (decrease) in economic growth may also bring about further increase (decrease) in energy consumption. This positive feedback relationship exists both in the short- and long-runs. Energy consumption and economic growth are jointly determined and affected at the same time. Conserving energy use will adversely affect economic activities during the recessionary periods.

However when the economy is in a prosperous regime (output grows at a rate higher than 4.3%), a uni-directional causality running from output to energy consumption demonstrates that GDP growth reinforces a further use of energy, but not vice versa. The economic activity is not constrained by energy consumption in the short-run, nor bound by the long run deviations from equilibrium. This result is compliant with the conservation hypothesis, which implies energy conservation policy is feasible with no or few harmful effects to GDP.

Our evidence that the relationship between GDP and energy consumption is regime-dependent suggests a conditional use of energy conservation policy in Taiwan. Suppressing the energy use brings unfavorable effect on GDP growth both in the short-and long-runs when the economy is in a contractionary period, while energy conservation may not be harmful in an expansionary period. As a matter of fact, Taiwan's economy has continuously grown at a rate less than 4.3% (i.e. the threshold value estimated by our study) since 2011. That leads policy makers into a dilemmatic situation of preserving an energy-efficient environment or promoting productions and employments. Despite it has been designated by several consecutive authorities to protect Taiwan's environment, strategies implemented by imposing more energy taxes, new subsidies to explore green energies, directly or indirectly (by raising the price) restricting the quantity of energy consumed, and encouraging firms to install co-generation systems encounter with procrastinations. It could be partially due to the budget constraints of the public and private sectors. Yet, not to imperil the current economic condition could be of the major concern among governors at the circumstances.

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Notes

Note 1. The nonlinear adjustment process of macroeconomic variables has been evidenced by many recent literatures. For example, Taylor et al. (2001) show the real dollar exchange rate is nonlinearly mean reverting over the post-Bretton Woods period, consistent with a theoretical literature on transactions costs in international arbitrage. Enders and Granger (1998) show the movements of the term structure of interest rates toward the long-run equilibrium relationship are best estimated as an asymmetric process. Granger and Lee (1989) find the U.S. sales, production, and inventory display asymmetric error correction toward a long-run, multi-cointegrating relationship. Rahman and Serletis (2010) investigate the asymmetric effects of oil price shocks and monetary policy on macroeconomic activity, and find that that monetary policy is not only reinforcing the effects of oil price shocks on output, it is also contributing to the asymmetric response of output to oil price shocks.

Note 2. Energy intensity is a measure of the energy requirement per unit of output. Energy efficiency improves when a given level of service or output is provided with less amount of energy. As a result, the energy intensity measure has been greatly used in the literature as a proxy measure for energy efficiency (Adom, 2015).

Note 3. These energy-related variables are CO2 emissions, the efficiency of energy use, the ratio of industrial energy consumption to total energy consumption, and per capita energy consumption.

Note 4. The four candidate transition variables are GDP growth rate, energy consumption growth rate, the error correction term between energy consumption and output level, and a time trend.

Note 5. For example, Kleykamp and Wan (2014) indicates the long-run relationships between unemployment and labor force participation in the United States are regime dependent.

Note 6. The term 'threshold cointegration' is commonly referred to as studies of Granger and Terasvirta (1993), Balke and Fomby (1997), Hansen and Seo (2002) and Tsay (1998) who discuss nonlinearity within the framework of a linear cointegrating relationship while the adjustment process towards the long-run equilibrium contains threshold effects.

Note 7. Much of the early literature examined the causal relationship between energy and GDP within a bivariate framework. However, the problem with this approach is that omitted variables can lead to the wrong conclusions about causal inference (Lutkepohl, 1982). A multivariate setting, adding one or more variables in addition to energy and GDP is examined in subsequent literature. This strand of research is reviewed by Smyth and Narayan (2015).

Note 8. Masih and Masih (1998) incorporates real income, energy consumption and the consumer price index to study causality between energy consumption and output for two Asian developing economies, viz. Thailand and Sri Lanka. To avoid the problem of omitting relevant variables mentioned by Glasure (2002), the consumer price index (a variable revealed as being very influential on the relationship between real income and energy consumption) is also included in the framework of Climent and Pardo (2007). Belke et al. (2011) also takes energy prices into consideration while examining the relationship between energy consumption and real GDP for 25 OECD countries.

Note 9. The concept of short run causality, long run causality and strong causality are adopted by Masih and Masih (1998) and Belke et al. (2011).

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