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The impact of energy consumption on economic growth: Evidence from linear and nonlinear models in Taiwan

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Abstract

This paper considers the possibility of both a linear effect and nonlinear effect of energy consumption on economic growth, using data for the period 1955–2003 in Taiwan. We find evidence of a level-dependent effect between the two variables. Allowing for a nonlinear effect of energy consumption growth sheds new light on the explanation of the characteristics of the energy-growth link. We also provide evidence that the relationship between energy consumption and economic growth in Taiwan is characterized by an inverse U-shape. Some previous studies support the view that energy consumption may promote economic growth. However, the conclusion drawn from the empirical findings suggests that such a relationship exists only where there is a low level of energy consumption in Taiwan. We show that a threshold regression provides a better empirical model than the standard linear model and that policy-makers should seek to capture economic structures associated with different stages of economic growth. It is also worth noting that the energy consumption threshold was reached in the case of Taiwan in the world energy crises periods of 1979 and 1982.

Keywords: Energy consumption; Economic growth; Nonlinearity; Threshold regression model

1. Introduction

Because of the essential role played by energy in the economic development process, particularly in view of the two major global energy crises, whether or not an energy conservation policy can successfully be propagated within an individual country has been a topic widely investigated since the late 1970s. We are aware that the original issue arose when Kraft and Kraft [1] found evidence of economic growth having a positive influence on energy consumption. Hence, Uri [2] put forward the suggestion that a scarcity of resources had affected economic growth in the US, and that fluctuations in the prices of crude oil had affected employment as well as the unemployment rate [3]. The adoption of this standpoint resulted in many later studies that investigated the effects of policies over the past two decades in terms of the relationships between energy consumption and economic growth [4–6]. Thus, given the limited supply of resources, the price

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mechanism and the need for environmental conservation, countries have sought to find a middle ground between energy consumption and economic growth. For governments, this has imposed a heavy burden, especially in regard to the implementation of an energy conservation policy, and they have had to face the embarrassing situation of succeeding in avoiding a trade-off between energy consumption and growth.

These findings are, however, based on an individual country being used as the main focus of the analysis. This in turn gives rise to a phenomenon that needs to be carefully thought through because different results are found for different time periods within the same country. For example, Fatai et al. [7] found that energy consumption has a significant positive effect on economic growth in Indonesia and India, but Masih and Masih [8] obtained quite different results. Such a phenomenon also exists in the Philippines. For instance, Yu and Choi [4], Masih and Masih [8], and Fatai et al. [7] arrived at different results when they investigated the impact of energy consumption on economic growth. Again, as in the case of Sri Lanka, one cannot necessarily draw uniform conclusions [6,9]. To seriously review these turbulences in individual countries, the main purpose of this paper is to contribute to the discussion on the impact of energy consumption on real gross domestic product (GDP) growth in Taiwan by estimating two well-known general models, namely, a neoclassical growth model (a one-sector model) [10] and a two-sector model [11] using both the linear and nonlinear estimation approaches.[1] Our approach explicitly takes into account each of the alternative settings noted above, thereby enabling us to clear away some of the misunderstandings that arose in the past.

Generally speaking, the empirical results of the above studies have something in common, in that each of the econometric methods used adopt the linear approach. Owing to the fact that a macroeconomic series often contains unit roots [12], Poterba [13] estimates that, with a few exceptions, the expenditure shares of gasoline, fuel oil, natural gas, and electricity decrease at all income deciles along with increases in income. Hypothetically, if we instead adopt the nonlinear method, it needs to be asked whether we will obtain more meaningful results by incorporating such improvements in our estimation approach. If so, we will be able to make various policy suggestions.

Additionally, most of the previous studies have generally neglected nonlinearity in empirical macroeconomic modeling by using linear time series specifications [14]. In an effort to overcome this weakness, economists have lately witnessed an increased use of nonlinear models that can capture asymmetry in macroeconomic time series, namely, in relation to GDP, asset prices, consumption, etc. For instance, the famous models of applied economics are derived from the threshold regression (TAR hereafter) model that arises from Tong [15]. Since this structure is extended due to the requirement for energy as a key factor in the production process, it is linked to economic activity and development, such as electricity use [17]. This implies that once we deal with the data on energy consumption, we should take into account the nonlinear adjustment that characterizes the series [13,18].

There is a possibility that the relationship between two variables could be nonlinear. For instance, Kaboudan [19] applied an econometric model to forecast electricity consumption in Zimbabwe through the year 2010 using 1965–1984 data. Moon and Sonn [20] established an endogenous growth model by means of which a hypothetical social planner might set an optimal energy intensity. They described the existence of an inverse U-shape in Korean economic growth and energy intensity. This implies that the economic growth rate initially rises with productive energy expenditures, but subsequently declines. With the finding in the recent energy economics literature that energy economic variables are non-stationary, however, recent research shows that the autoregressive distributed lag (ARDL) model remains valid when the underlying variables are non-stationary [21]. According to empirical data on world-wide per capita energy consumption that have been analyzed for the past 150 years, Seifritz and Hodgkin [22] provide strong evidence that the per capita consumption of energy has the characteristic of being nonlinear. Similar viewpoints, like those in some important papers, such as Hamilton [23,24], Mork et al. [25] and Balke et al. [26], argue that there is a nonlinear relationship between oil and the economy. Specifically, these studies show that oil price increases are much more influential than oil price decreases, giving rise to an asymmetric relationship between crude prices and economic output. This suggests that the nonlinear relationship linkages between oil consumption and

[1] Our approach differs from Huang et al. [16] who argue that changes in the oil price appear to have different impacts on macroeconomic variables in different regimes that are classified according to threshold levels in the US, Canada, and Japan. We inquire into the situation that exists in a developing country (Taiwan) and construct a stricter model.

macroeconomic variables should be revealed. Same as the relationship between the demand for energy and temperature, which is clearly nonlinear [27].[2] In addition, Schafer [28] in illustrating the energy sector shifts for 11 world regions during 1971–1998, pointed out that the structural change in GDP must lead to a similar sectoral shift in the energy system. Moreover, Ussanarassamee and Bhattacharyya [29] noted that the energy intensity of industry has followed a U-shaped pattern but that, since 1997, the trend has been upward in Thailand. Since the nonlinear phenomenon was discovered in the past, but few engaged in empirical work in the previous literature, thus, we therefore perform a case study for Taiwan.

The advantages of a unitary country analysis are that it can keep track of national characteristics and also lead to more accurate inferences. For example, the view proposed by Jones [30] that time series studies of economic growth offer important advantages over cross-country growth regressions is gaining acceptance. Arestis et al. [31] also indicate that this method can provide useful insights into differences in such relationships across countries and may illuminate important details that are hidden in averaged-out results. Additionally, Yang [32] reports that the Taiwan case is interesting for several reasons. For instance, the Taiwan economy has enjoyed a remarkable growth rate of approximately 8% per annum in the past, and this rapid economic growth has created substantial changes in the structure of production in the nation's economic sectors. In addition, a rapid increase in energy consumption and carbon dioxide emissions along with Taiwan's economic growth following a trade-led strategy means that more reliance should be placed upon the production of less pollution-intensive goods. In this regard, we take into consideration the nonlinear relationship between energy consumption and economic growth.

It is well known that an environmental conservation agenda will always be part of the economic development process. In targeting economic growth, the industrial sector plays a core role in development projects and is the most important end-use sector in developing countries. For instance, in Taiwan, the facility system consumes most of the power used in the semiconductor fabs and machine tools processing consumes the second largest amount of the power [33]. However, Yang [32] points out that the rapid economic growth has yielded substantial changes in the structure of production in Taiwan's economic sectors. This has led to a rapid increase in energy consumption and carbon dioxide emissions. Another important case is China. Price et al. [34] found that China's use of energy in its industrial sector and its associated carbon dioxide emissions are still very high when compared with those of other countries. From a different point of view, Egelioglu et al. [35] argued that annual energy consumption in Northern Cyprus was strongly related to the number of customers. However, since many tourists are attracted by nature, it represents a double-edged problem for policy-makers who may find it hard to make relevant decisions, while the natural environment is an important component of the tourism trade.

In the course of its overall economic development from 1955 to 2003, Taiwan has experienced quite a few strong positive and momentous economic incidents.[3] However, in a way similar to other nations, Taiwan suffered through two world energy crises in the 1970s. Over the past 50 years, Taiwan has achieved an economic development miracle with its steady and abundant energy use policy playing an important role in the process. We can through related studies elaborate on the relationship between energy consumption and economic growth. Cheng and Lai [36] found evidence of an unidirectional relationship causality running only from GDP to energy consumption in Taiwan. Yang [37] revealed that there is an unidirectional relationship from GDP to coal consumption with no repercussions, either. However, Yang also reported some entirely different directions of causes that exist between GDP and various kinds of energy consumption [38]. However, based on the data spanning the period from 1982 to 1997, Chang et al. [39] suggested that only an unidirectional causality running from energy consumption to output exists. The results obtained from impulsive response and variance decomposition analysis tell similar stories. Energy consumption led to output growth in Taiwan over this period. In addition, the empirical results proposed by Lee and Chang [40] show

[2]Because energy consumption is an observed variable, we cannot use other nonlinear estimation models like the Markov switching model, which assumes that the variable which causes the structural change cannot be observed.

[3]After World War II, Taiwan achieved a remarkable record of high and sustained growth, often in the context of activist public policies. Between 1960 and 1985, real income per capita increased more than four times in Taiwan and more than doubled in the Southeast Asian newly industrializing economies (NIEs).

unanimously that in the long run energy acts as an engine of economic growth, and that energy conservation may harm economic growth.

Nevertheless, there are some common problems that still exist in these studies. First, economic theory suggests that a number of important time series variables should exhibit nonlinear behavior. Moreover, it has been established that downturns in the business cycle are sharper than recoveries in key macroeconomic variables [41]. Thus, the instability of an economic system may in fact be reflected in the parameters of the estimated models that can induce fallacious results [42]. Secondly, if one neglects the possibility that the impact of energy consumption on growth could be nonlinear, then the results obtained by using linear time series specifications often cause bias, due to using a false estimation method [14]. Third, we should refer to the critical issue proposed by Pao [43], who found that Taiwan's energy consumption has risen sharply because of rapid economic growth and higher living standards. Meanwhile, the linear and nonlinear statistical models are used to investigate the influence of the national income, population, GDP, and the consumer price index on the electricity consumption in Taiwan. He found that the forecasting performance of the nonlinear model was higher than that of the other linear models.

We put forward our findings as shown below. Our findings indicate that there exists a nonlinear relationship between energy consumption and economic growth by employing recent developments in the TAR model [15,44] that allow us to derive endogenous threshold values in energy consumption. We also provide evidence that the relationship between energy consumption and real GDP growth is inversely U-shaped in Taiwan, which means that the partial correlation between the growth rate of these variables is both significant and positive only for levels of energy consumption under an estimated threshold. Furthermore, such a significant relationship disappears, however, under higher levels of energy consumption. When the pure external effect is identified using a theoretically based empirical specification, it is both significant and negative for relatively high values of energy consumption and both significant and positive for low levels. Finally, we present the policy implications of the empirical results such as an energy conservation policy.[4] However, in contrast to some theories, we consider the variables capital, labor and energy consumption to be independent in our one- or two-sector model.

In addition to the generalization of the neoclassical growth equation with a one- or a two-sector model, this paper also implements Ramsey's RESET test as proposed by Ramsey [45] to test whether the model is linear or not. On the other hand, the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) test [46] procedures confirm the stability of the aggregate output function. Through the nonlinear estimation method, we hope the results can explain why the existing literature has to pay greater attention to the relationship between energy consumption and growth.

The major contributions of this paper are listed in what follows. First, a theoretical model is established under one or two sectors and, in accordance with the empirical results, we consider the possibility of a linear effect and a nonlinear effect of energy consumption on economic growth. Next, in the application of the TAR model, the threshold level determined by the data set delineates the sample into different regimes instead of using the arbitrary zero as a cutoff point. Hence, if the parlance regarding nonlinear relationships between energy consumption and growth can gain powerful support, these outcomes will have already responded modestly when the pioneers in this field would like to inquire into the issues of concern regarding energy consumption and the environment. Certainly, the potential nonlinear relationships that characterize these variables should be subjected to verification. Furthermore, in the TAR model, a fair discussion is provided in line with the relationship proposed in earlier studies. The full information is made available to policy-makers, which indicates that the government plays a useful role in establishing the business cycle policy and that policy-makers should grasp the economic structure associated with different stages of economic growth. Finally, we offer another clue to the follow-up research and discuss further which factors will actually give rise to a nonlinear relationship.

The remainder of the paper is organized as follows: Section 2 presents the theoretical framework in which the effect of energy consumption on economic growth is examined. Section 3 reports the results of the

[4]We only consider the impact of energy use on economic growth, and thus only energy conservation policies that give rise to other implications can be inquired into in our study.

empirical analysis by allowing for a nonlinear effect of energy consumption on growth. Section 4 concludes and provides suggestions for future research.

2. Energy consumption and economic growth: the theoretical framework

Pokrovski [47] suggested that the production system has to devour all available resources. For the production process, we formulate the simplest theory that includes three production factors, namely, the capital stock, labor services and productive energy that is also regarded as energy consumption [48].[5] Differing from the conventional concepts, which emphasize that the productive energy arises because of the production equipment and can be considered to be a capital service provided by the capital stock, the new formulation of the theory which contains the external sources of energy is established in our paper using a one- or two-sector model.

We illustrate our model based on the conventional neoclassical one-sector aggregate production function (referred to as Linear Model 1 hereafter), which represents the relationship between energy consumption and real GDP [47–49]. Thus we consider the following general production function:

$$Y_t = F(L_t, K_t, A_t) = A_t^{v1} L_t^{v2} K_t^{v3}, \quad v1, v2, v3 > 0, \tag{1}$$

where Y is real output, L is the aggregate labor force, K is the aggregate real capital stock, and A is a measure of technology. In considering the assumption broadly, both the energy consumption and the export sector are likely to have a technological progress effect on economic performance [11]. We assume that the effect is multiplicative, and that the growth rate of real output is given by

$$GY_t = \beta_0 + \beta_1 GK_t + \beta_2 GL_t + \beta_3 GX_t + \beta_4 GEC_t + \varepsilon_t, \tag{2}$$

where GY is the growth rate of real GDP, GK is the growth rate of the real capital stock, GL is the growth rate of the labor force, GX is the growth rate of real exports, and GEC is the growth rate of total energy consumption.[6] The term ε_t is assumed to be a Gaussian white noise error process with constant variance. This specification is, however, relatively ad hoc.

We can further consider the two-sector model (Linear Model 2 hereafter) of the economy, which is propounded by Feder [11], in order to study the effect of the export sector on economic growth. By reformulating the model using an energy sector instead of the original export-domestic sector division, a specification for the assessment of the energy-growth nexus which is empirically tractable can be found. The model is set up as follows. Assume that the economy is composed of two sectors—the energy sector (G) and the non-energy sector (C). The production functions of both sectors are expressed as follows:

$$C = C(L_C, K_C, G), \tag{3}$$

$$G = G(L_G, K_G), \tag{4}$$

$$Y = C + G, \tag{5a}$$

$$L_C + L_G = L, \tag{5b}$$

$$K_C + K_G = K, \tag{5c}$$

$$\frac{G_L}{C_L} = \frac{G_K}{C_K} = (1 + \delta). \tag{6}$$

Eq. (3) indicates the production function of the non-energy sector and Eq. (4) is the production function of the energy sector. Eq. (5a) provides that total output (Y) is the sum of C and G, and Eq. (5b) shows that the total labor force (L) is the sum of the non-energy labor input (L_C) and energy labor input (L_G). Eq. (5c) indicates that the total capital stock (K) is the sum of non-energy sector capital input (K_C) and energy sector

[5] Cardona and Piacentino [50] hold that energy demand, which is based on aggregate consumption data, can be satisfied with different output shares among the various components.

[6] Energy consumption is defined as a kind of productive energy [47].

capital input (K_G). Eq. (3) says that energy sector output (G) creates an externality effect to non-energy sector output (C).

In order to understand the difference in the marginal productivities of the factor input in the two sectors, $G_L = \partial G/\partial L$ in Eq. (6) indicates the marginal production of labor input in the energy sector, $C_L = \partial C/\partial L$ indicates the marginal productivity of the labor input to the non-energy sector, $G_K = \partial G/\partial K$ is the marginal productivity of capital input in the energy sector, and $C_K = \partial C/\partial K$ is the marginal productivity of the capital input in the non-energy sector. Here, δ refers to the difference in the marginal productivities of the factor inputs in the two sectors, while $\delta > 0$ indicates that the marginal productivity of the energy sector is greater than that of the non-energy sector, while $\delta < 0$ indicates that the opposite is the case.

We take the totally differentiated Eqs. (3) and (4) and put the results into Eqs. (5a) and (5b), which are total differentials. From Eq. (6), we can then conclude that

$$\mathrm{d}Y = C_L\,\mathrm{d}L + C_K\,\mathrm{d}K + C_G\,\mathrm{d}G + \frac{\delta}{1+\delta}\mathrm{d}G. \tag{7}$$

We next divide Eq. (7) by Y and set $\alpha \equiv C_K$ and $\beta \equiv C_L(L/Y)$, where α means the marginal production of capital in the non-energy sector and β means the production elasticity of labor in the non-energy sector. We find the equation as follows:

$$\frac{\mathrm{d}Y}{Y} = \alpha\left(\frac{I}{Y}\right) + \beta\dot{L} + \left(\frac{\delta}{1+\delta} + C_G\right)\frac{\mathrm{d}G}{G}\frac{G}{Y}. \tag{8}$$

In the above equation, C_G indicates the marginal externality effect which comes from the production of the energy sector imposed on the production of the non-energy sector. From Eq. (8), we can make the empirical regression equation as follows:

$$\dot{Y}_t = \alpha_0 + \alpha_1\left(\frac{I_t}{Y_t}\right) + \alpha_2\dot{L}_t + \alpha_3\dot{G}_t\left(\frac{G_t}{Y_t}\right) + u_t^*. \tag{9}$$

Eq. (9) shows that the variables which effect economic growth ($\dot{Y}$) include the investment rate (I/Y), labor force growth ($\dot{L}$), and the multiple effects of the growth of energy expenditure ($\dot{G}$) and energy use size (G/Y). According to the growth theory, α_1 and α_2 are both positive coefficients given that the investment rate and labor force growth have a positive impact on the real aggregate output growth. In addition, we identify the multiple effects through the sign of α_3. This indicates that the energy sector has a reciprocal effect on economic growth through two ways: one is the direct contribution of the energy sector and the other is the indirect effect of the energy sector through the non-energy sector (the externality effect).

3. Empirical results

This section presents the results of the estimation for the specifications proposed in the previous section using Taiwanese data. All data are of yearly frequency and the time period covered is 1955–2003. We also transform the data into a real series at 2001 prices, using a GNP deflator. The source of the data is the AREMOS economic–statistic databanks, compiled by the Ministry of Education in Taiwan. Based on Fig. 1, we can find in the diagram that both GY and GEC series exhibit a close relationship, but in the 1970s and 1980s there exists an obvious structural change. From Figs. 2–4 and Table 1, we notice that the mean and fluctuation for GX are the highest. Except for GEC in 2001, while all the other variables are at a minimum value and reveal negative growth. According to the viewpoint provided by a well-known critic on this island, the changes in the ruling political regime and the opposition towards building an additional nuclear power plant, along with the emergence of a crisis in investment confidence are the main reasons for these circumstances. In addition, the GEC is at its minimum in 1981 when Taiwan had just experienced two successive energy crises.

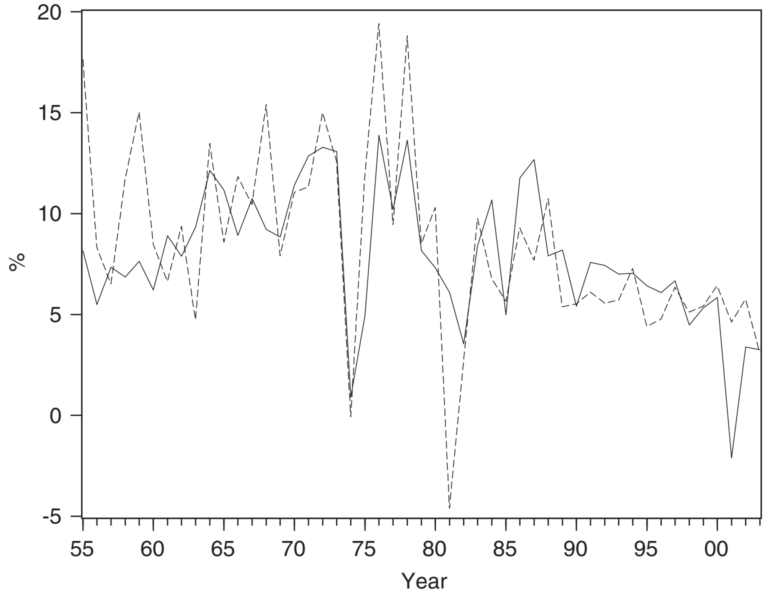

Fig. 1. Plot of real GDP growth rate (solid line) and energy consumption growth rate (dotted line) for Taiwan, 1955–2003.

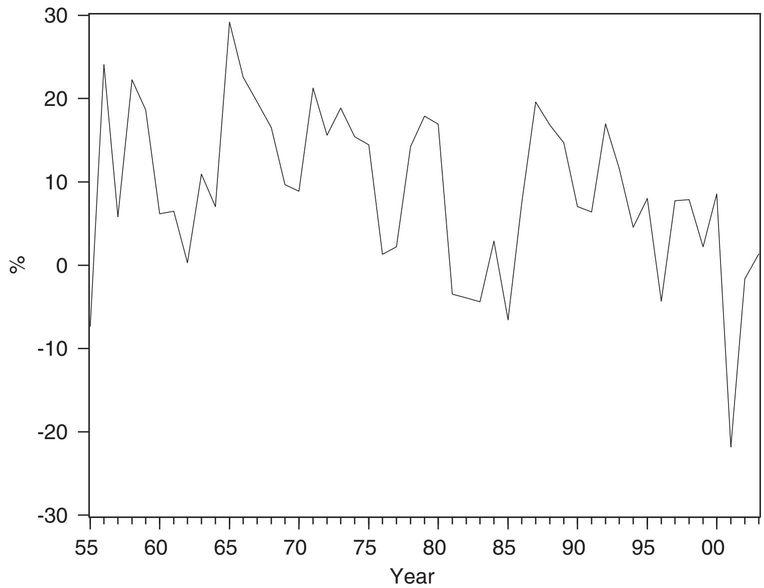

Fig. 2. Plot of real capital stock growth rate for Taiwan, 1955–2003.

3.1. The linear model results

We first concentrate on the linear specifications in Eqs. (2) and (9), namely, Linear Models 1 and 2, that correspond to the ad hoc model and the Feder [11] model, respectively. By going a step further, we generalize the specifications so as to allow for a nonlinear effect of energy consumption on real GDP growth that takes the form of nonlinear parameters. In that case, the effect of energy consumption on growth is allowed to vary depending on the overall level of energy consumption. In subsequently turning to the estimated results, and the second column in Table 2 that reports the estimated parameters in Eq. (2) using the ordinary least squares (OLS) approach, we note that almost 62% of the variation in real GDP growth is explained by the independent variables. A positive but insignificant influence is found to exist between all of the explanatory

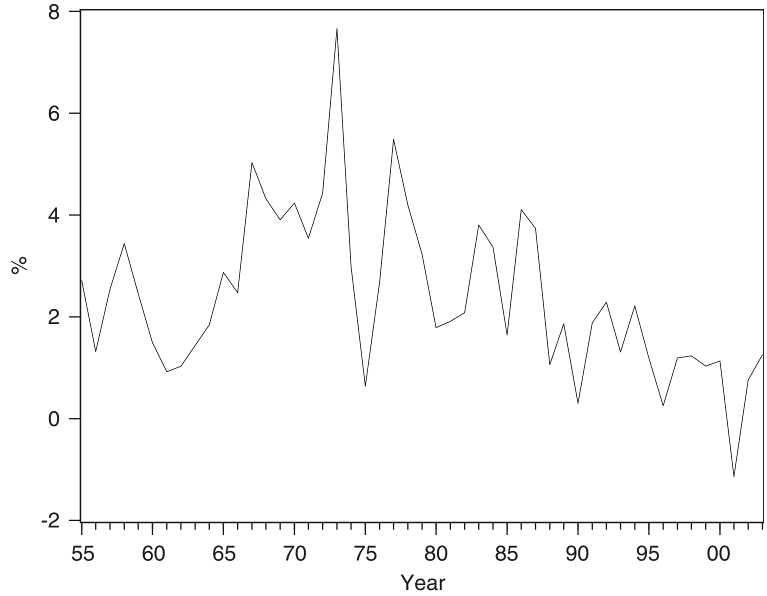

Fig. 3. Plot of labor force growth rate for Taiwan, 1955–2003.

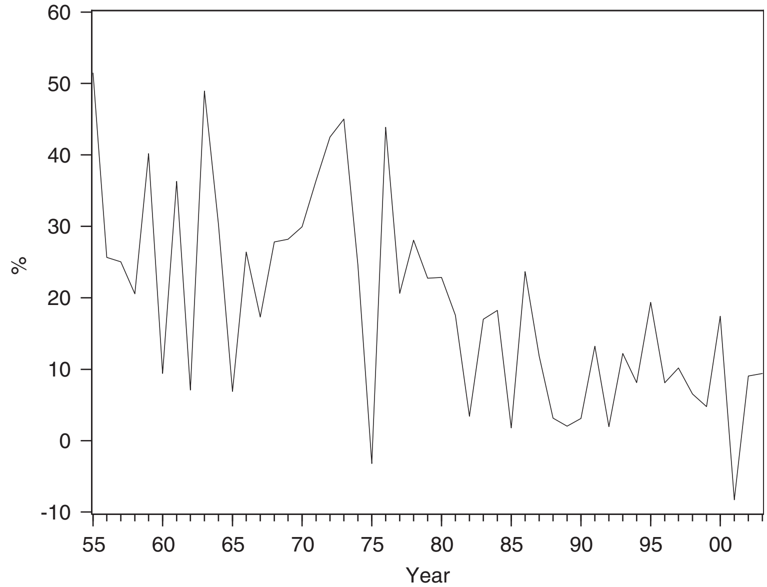

Fig. 4. Plot of real exports growth rate for Taiwan, 1955–2003.

variables and real GDP growth, except for the growth rate of the labor force. Although this result may serve as the first indication of a positive nexus between economic growth and energy consumption, the result is actually insignificant.

The distinction between the tests for specification and mis-specification resides in the alternative hypothesis in the test. The Ramsey RESET test is employed to test a linear specification against a nonlinear specification, and we then test for the functional form with an F-test. The null hypothesis is that the correct specification is linear, and the alternative hypothesis is that the correct specification is nonlinear. The test results are shown as RESET (1) at the bottom of Table 2. The result of Ramsey's RESET test, RESET (1) $= 2.955$, rejects the null hypothesis of no mis-specification in the linear model at the 10% level. It is thus reasonable to suspect that

Table 1
Descriptive statistical analysis of variables

Variable name	Mean (%)	Standard deviation	Maximum value	Minimum value
GY	7.88	3.33	13.87% (1976)	−2.10% (2001)
GEC	8.44	4.59	19.41% (1976)	−4.60% (1981)
GK	8.90	9.90	29.18% (1965)	−21.83% (2001)
GL	2.39	1.58	7.65% (1973)	−1.13% (2001)
GX	18.95	14.29	51.46% (1965)	−8.28% (2001)

() is the year.

Table 2
The linear regression results of energy consumption and economic growth (One-Sector Model)

Dependent variables	Linear model
Constant	2.700[a]
	(3.56)
GK	0.050
	(1.25)
GL	0.834[a]
	(3.83)
GX	0.039
	(1.31)
GEC	**0.237**
	(1.94)
$\bar{R}^2$	0.611
RESET (1)	2.955
	[0.08]
Number of samples	49

() is the *t*-value. RESET (1) is the Ramsey specification χ^2 test of the first order.
The *p*-values of the test are given in square brackets.
[a]Indicates significance at the 5% level.

nonlinearity could have caused these results. In order to re-check such a phenomenon, Fig. 1 also displays the extension of the energy consumption series changes in Taiwan. Clearly, energy consumption has behaved very differently prior to 1981. After 1981 the variation in energy consumption is relatively small by comparison, thus revealing its nonlinear characteristics indirectly.

Testing for the stability of the long-run coefficients obtained in estimating Eq. (2) is next carried out using the CUSUM and CUSUMSQ tests. These tests utilize CUSUM and CUSUMSQ, respectively, which are updated recursively and are plotted against the break points in the broken sample points to test the null hypothesis that all the coefficients in the growth linear model are stable. The graphical representations of the tests are presented in Fig. 5. According to Fig. 5, neither the CUSUM nor CUSUMSQ plots cross the 5% critical bounds, suggesting that the residual variance is somewhat stable except for 1974 when the first oil crisis took place, as also shown by an actual, fitted, and residual graph.[7]

Turning to the two-sector production function, Table 3 presents the estimates of the parameters of Eq. (9) for Taiwan covering the period 1955–2003. Again, the OLS estimators are reported, namely, the estimated parameters corresponding to the energy consumption variables in Eq. (9). Among these, the multiple effects of the growth of energy expenditure ($\dot{G}$) and energy use size (G/Y) change to have a significant positive effect on economic growth ($\dot{Y}$), and also on the growth of the labor force ($\dot{L}$), but not on the investment rate (I/Y). The test results are shown as RESET (1) at the bottom of Table 3, where RESET (1) = 1.503 and does not reject

[7]These views display the actual and fitted values of the dependent variable (the economic growth rate) and the residuals from the regression.

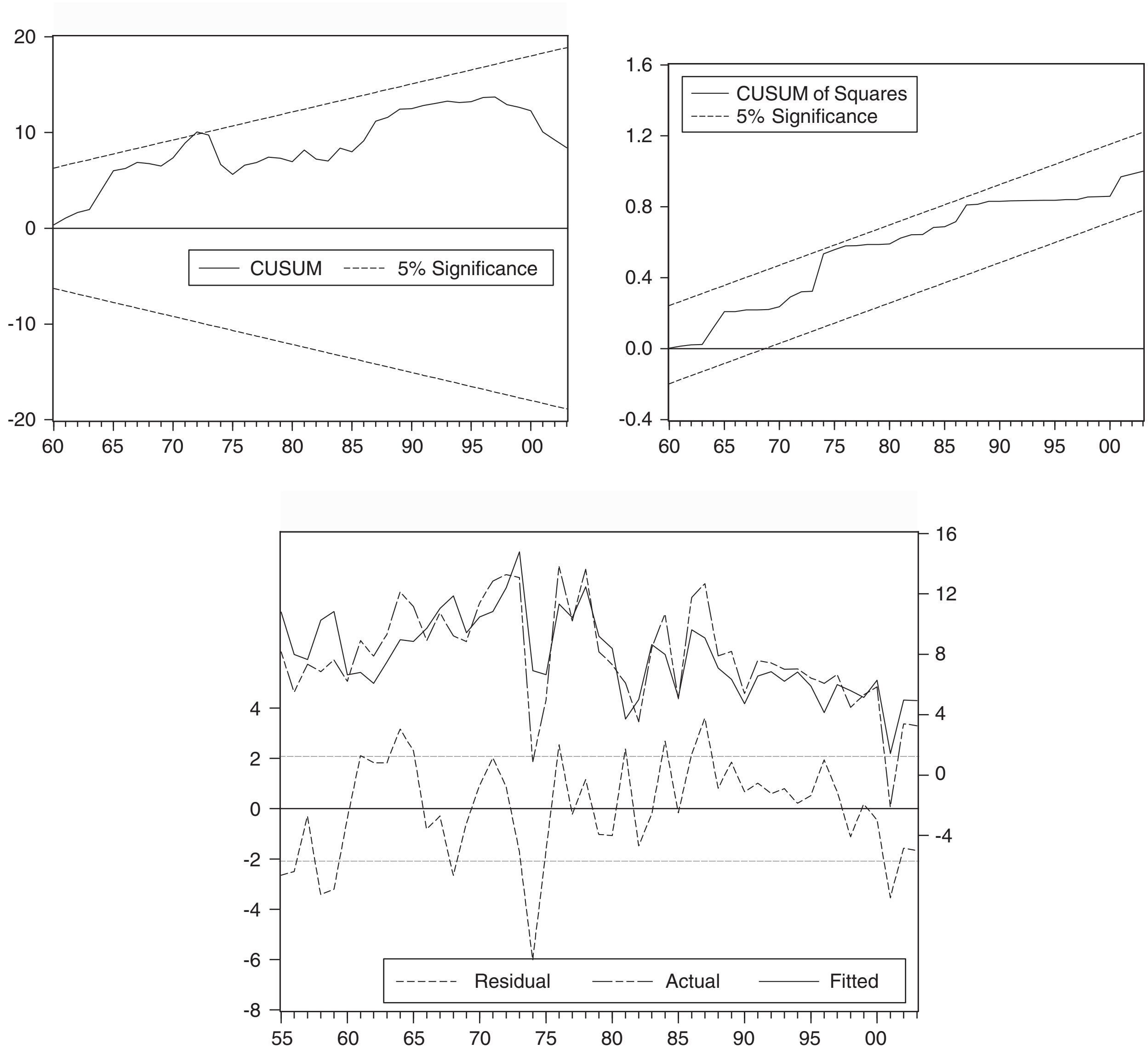

Fig. 5. Plots of CUSUM, CUSUMSQ, and actual-fitted-residual (Linear Model 1).

the null hypothesis of no mis-specification in Linear Model 2. Fig. 6 is similar to Fig. 5 in that the residual variance is somewhat stable except in 1974 due to its coming close to the critical bounds. The results for the Linear Model 2 framework thus appear to be mixed, depending on the theoretical setting used to estimate the effect of energy consumption on growth.

While the simple growth model given by Eq. (2) finds an insignificant positive correlation between changes in energy consumption and real GDP growth, the estimation based on the reduced form of the two-sector model given by Eq. (9) exhibits a significant positive relationship between the two variables. Why has this happened? As with the Philippines, Sri Lanka, Indonesia, and India, these results differ within the same country. We will therefore now adopt a nonlinear analysis approach to probe further into this issue.

3.2. Nonlinear counterpart

Eqs. (2) and (9) are traditional linear models, and we apply the linear models of Eqs. (2) and (9) into the two-regime TAR model of Tong [15] and Hansen [44]. This allows for a nonlinear energy-growth link and

Table 3
The linear regression results of energy consumption and economic growth (Two-Sector Model)

Dependent variables	Linear model
Constant	2.958[a]
	(3.94)
$\frac{I_t}{Y_t}$	0.222
	(0.97)
$\dot{L}_t$	0.960[a]
	(4.47)
$\boldsymbol{\dot{G}_t \frac{G_t}{Y_t}}$	**0.265**[a]
	(2.72)
$\bar{R}^2$	0.597
RESET (1)	1.503
	[0.200]
Number of samples	49

() is the t-value. RESET (1) is the Ramsey specification χ^2 test of the first order.
The p-values of the test are given in square brackets.
[a]Indicates significance at the 5% level.

provides a convenient framework for testing for linearity as given by

$$GY_t = \beta_0^j + \beta_1^j GK_t + \beta_2^j GL_t + \beta_3^j GX_t + \beta_4^j GEC_t + \varepsilon_t \tag{10}$$

and

$$\dot{Y}_t = \alpha_0^j + \alpha_1^j \left(\frac{I_t}{Y_t}\right) + \alpha_2^j \dot{L}_t + \alpha_3^j \dot{G}_t \left(\frac{G_t}{Y_t}\right) + u_t^*. \tag{11}$$

The level of total energy consumption, EC_t, is the variable that is responsible for the regime which is active—that is

$$j = \begin{cases} 1, & \text{if} \quad EC_t \leqslant \gamma, \\ 2, & \text{if} \quad EC_t > \gamma. \end{cases} \tag{12}$$

The threshold parameter, γ, needs to be estimated as well. We can predict the estimators and the parameters and arrive at the sum of squared errors as follows:

$$S_1(\gamma) = \hat{e}_t(\gamma)' \hat{e}_t(\gamma). \tag{13}$$

The optimum threshold value is given as

$$\hat{\gamma} = \operatorname{argmin} S_1(\gamma). \tag{14}$$

The variance of residual is expressed as:

$$\hat{\sigma}^2 = \frac{1}{T} \hat{e}_t' \hat{e}_t = \frac{1}{T} S_1(\hat{\gamma}). \tag{15}$$

The threshold value γ can be found by estimating Eqs. (11)–(13) through finding the minimum of the sum of squared errors in a re-ordered threshold variable. The threshold variable can be set by the exogenous variables out of the theoretical model. For example, in this paper we set energy consumption as the threshold variable. We can also apply the statistic coming from the threshold variable. For instance, we adopt the Lagrange multiplier (LM) of Hansen [44] to test the null hypothesis of the linear assumption.

Once the estimator can be found, we then start with the statistical test, but the test procedures of Eqs. (11)–(13) are different from those of the traditional test. Under the null hypothesis of no threshold effect existing, the threshold parameters will be unidentified. This will cause the traditional test statistic in a large

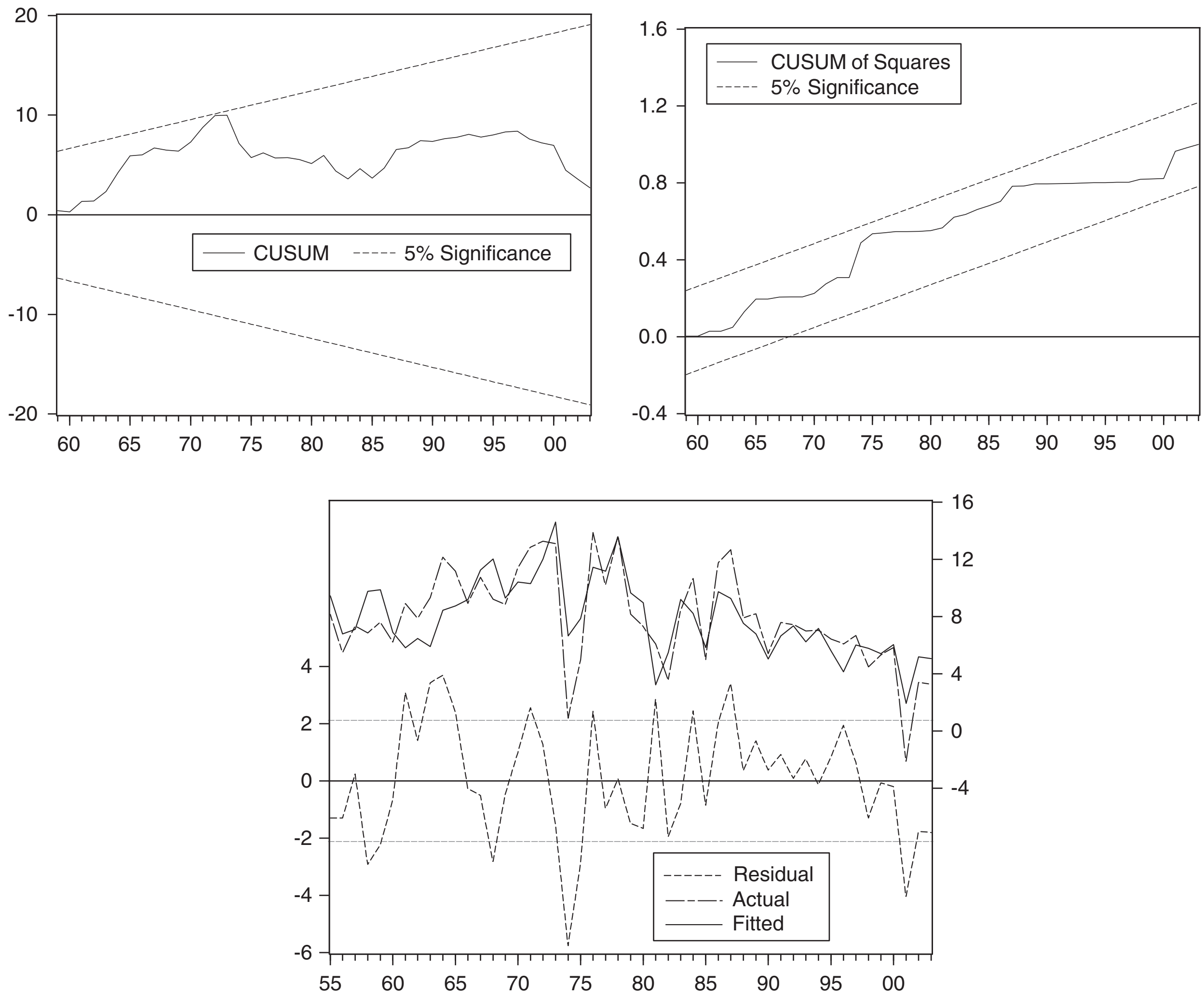

Fig. 6. Plots of CUSUM, CUSUMSQ, and actual-fitted-residual (Linear Model 2).

sample distribution to not belong to the χ^2 distribution, but instead to go to a non-standard and non-similar distribution that is affected by nuisance parameters. This causes the critical value of the distribution to not be estimated through simulation. In order to overcome this difficulty, Hansen [44] uses a statistic from his own large sample distribution function to transfer and calculate the asymptotic *p*-value of a large sample. Under the null hypothesis, the distribution of the *p*-value statistic is uniform, and this kind of transformation can be calculated using the bootstrap method.

Because of the existence of nuisance parameters, the asymptotic distribution is highly suitable for a non-normal distribution. Hence, Hansen [44] applies the maximum likelihood estimator to test the threshold value γ to achieve the asymptotic distribution of the statistic. The null hypothesis of the threshold value is H_0 : $\gamma = \gamma_0$ and the likelihood ratio statistics are:

$$\mathrm{LR}_1(\gamma_0) = \frac{S_1(\gamma_0) - S_1(\hat{\gamma})}{\hat{\sigma}^2}, \tag{16}$$

where $S_1(\gamma_0)$ and $S_1(\hat{\gamma})$ are the residual sum of squares from Eq. (13) given the true and estimated values, respectively. The asymptotic distribution of $\mathrm{LR}_1(\gamma_0)$ can be used to form valid asymptotic confidence intervals about the estimated threshold values. The statistics of $\mathrm{LR}_1(\gamma_0)$ are not normally distributed and Hansen [51]

Table 4
Threshold test for potential threshold variable (One-Sector Model)

Delay	0	1	2	3
F test	2.586	**5.131**[a]	3.913	3.866
	[0.29]	**[0.01]**	[0.06]	[0.06]
Threshold value	31,806,253	**28,975,994**	24,712,934	19,005,434

Delay and the threshold variable are energy consumption.
Values in parentheses are the *p*-value. The null is a linear relationship between energy consumption and growth and the alternative is a particular threshold relationship between energy consumption and growth. The boldface denotes the minimum *p*-value. Ten thousand replications are used in the bootstrap for the linearity test.
[a]Indicates significance at the 5% level.

computes their no-rejection region, $c(\alpha)$, where α is a given asymptotic level.[8] That is, if $\mathrm{LR}_1(\gamma_0) \leqslant c(\alpha)$, where $c(\alpha) = -2\ln(1-\sqrt{1-\alpha})$, then the null hypothesis of $H_0 : \gamma = \gamma_0$ cannot be rejected.

Through the theoretical introduction above, we should next conduct the threshold test for the potential threshold variable with the threshold parameter and the delay parameter being estimated simultaneously. Hansen [52] suggests carrying out a two-dimensional search over the parameter and delay parameter as well as estimating the TAR model for any given combination parameter and delay parameter by applying the method of sequential conditional least squares, and choosing the minimization as the residual variance. We also adopt Hansen's [44] advice to use the bootstrapping model to find the *p*-value. Table 4 reports the results of the threshold test for the potential threshold variable in Model 1 (one-sector model) and the bootstrap-calculated asymptotic *p*-value (using 10,000 replications). We find that the *F* test is 5.131 (see also Fig. 7), which is significant at the 5% level in one of the threshold tests, and the bootstraps *p*-value is 0.01. The estimation results of the TAR model also suggest that the estimated delay parameters have a lag of 1, because the model's estimated effect is the most significant and the residual sum of squares is the minimum in relative terms. The threshold parameter, γ, is estimated to be 28.975 million KLOE in 1982, and it divides the sample into two groups: the data below the threshold comprise 28 observations and the 21 remaining observations are over the threshold. By making comparisons with Fig. 1 and Table 1, we find that GEC exhibits a rapid decline and reaches its minimum value in 1981, which matches our threshold test accurately.

Next, Table 5 presents the estimated parameters from Eqs. (10) and (12), while the one-sector model is adopted, together with the two regimes for energy consumption being low and high, respectively. Another interesting phenomenon is that the adjusted R^2 increases when the nonlinearity is taken into account,[9] as compared with the linear model which is reported in Table 2. For the most essential conclusions, we make the following statement. For values of energy consumption above the threshold value (the right column in Table 5), the relationship between the two variables does not appear to be significantly different from the one found in the linear model. For values below the threshold, energy consumption has a significantly positive effect on economic growth. The results of the nonlinear model's estimation provide a deeper insight into the trade-off between the energy conservation policy [53] and the energy neutrality hypothesis [54]. While positive externalities seem to prevail for moderate levels of energy consumption, the positive effect of energy consumption on economic growth disappears when the level of energy consumption spending is found to be relatively high.

In order to obtain a diverse viewpoint as to the nature of the effect of energy consumption on growth, the nonlinear counterparts of Eqs. (11) and (12) are also estimated. Together with Model 1 using the nonlinear approach, the strategy adopted in the assessment is to find a threshold value first—the threshold test for the potential threshold variable in Table 6. Based on the *F* test (also see Fig. 8),[10] we find that the best estimated

[8]The no-rejection region of the confidence level is $(1-\alpha)$.
[9]Since the low and high regimes are estimated simultaneously, consequently, only a unity adjusted R^2 is presented in the estimated results, the purpose of this estimated process being that we can perform the comparison in the linear model.
[10]For the determination of a potential threshold variable, we adopt different lags for the energy consumption to conduct the threshold value test, and the threshold variable is determined when the *F* value is most significant. However, from Table 6, with lags 0, 1, and 2, we can receive the same threshold value, showing that the performance of the threshold test is pretty robust, in that it will not be implicated by lags.

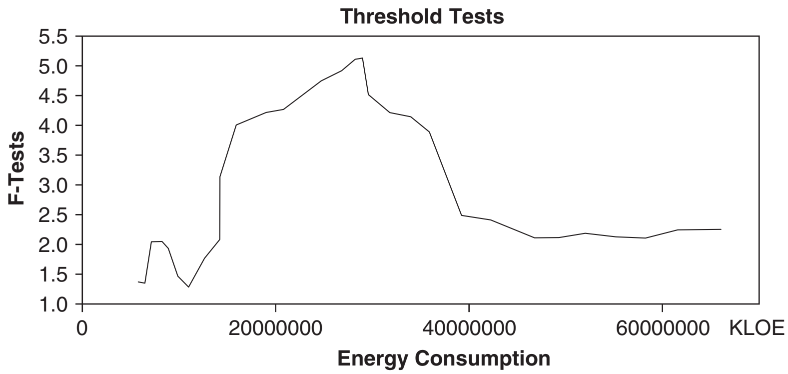

Fig. 7. Plot of threshold test in Nonlinear Model 1.

Table 5
The non-linear regression results of energy consumption and economic growth (One-Sector Model)

Dependent variables	Energy consumption is low		Energy consumption is high
Constant	2.943[a]		1.799
	(2.56)		(1.88)
GK	−0.393 × 10−3		0.125[a]
	(−0.01)		(5.01)
GL	0.633[a]		1.318[a]
	(3.11)		(4.43)
GX	0.048		0.056
	(1.32)		(1.55)
GEC	**0.276**[a]		**0.238**
	(2.14)		**(1.66)**
$\bar{R}^2$		0.665	
Number of samples	28		21

Threshold variable is the energy consumption (lagged by one period).
[a]Indicates significance at the 5% level and ( ) is the *t*-value. The trimming percentage is set to be 0.15.

delay parameters remain with a delay lag of 1, and the threshold value is 26.816 million KLOE in 1979. Table 7 presents the results of the nonlinear counterparts of Eqs. (11) and (12).

The external effect appears to be significant and positive for the regime below the threshold, while it is positive but insignificant for the regime corresponding to energy consumption above the threshold. The adjusted R^2 is also higher with respect to the linear Model 2 alternative. From this, for the low regime we find that energy consumption has a positive influence on economic growth, which is not the case with the high regime. With respect to the threshold value, the higher levels of energy consumption seem to be relevant, but have nothing to do with economic growth, as the energy neutrality hypothesis is created. Owing to the growth-promoting effect in the lower levels, the energy conservation policy cannot be propagated in Taiwan. Compared with the nonlinear Model 1, here we arrive at consistent conclusions. The empirical findings from the TAR model indicate that the energy consumption threshold for Taiwan did occur during the world energy crisis periods of 1979 and 1982.

Regarding the empirical finding that energy consumption has a positive growth effect under a certain threshold (in both nonlinear models), given that this condition applies, there are implications for future economic growth to the extent that resource scarcity and economic growth are interrelated [2]. However, the insignificant impact that is found beyond that threshold shows that the energy conservation policy is effective, because it does nothing to adversely affect economic growth. Such a policy could be implemented through an increase in energy taxes, looking for new subsidies, directly restricting the quantity consumed, and promoting the efficiency of usage [55]. At the same time, governments should encourage manufacturers to adopt

Table 6
Threshold test for potential threshold variable (Two-Sector Model)

Delay	0	1	2	3
F test	3.723	**5.310**[a]	5.380[a]	5.472[a]
	[0.11]	**[0.01]**	[0.01]	[0.02]
Threshold value	26,816,312	**26,816,312**	26,816,312	24,712,934

Delay and the threshold variable are energy consumption.
Values in parentheses are the *p*-value. The null is a linear relationship between energy consumption and growth and the alternative is a particular threshold relationship between energy consumption and growth. The boldface denotes the minimum *p*-value. Ten thousand replications are used in the bootstrap for the linearity test.
[a]Indicates significance at the 5% level.

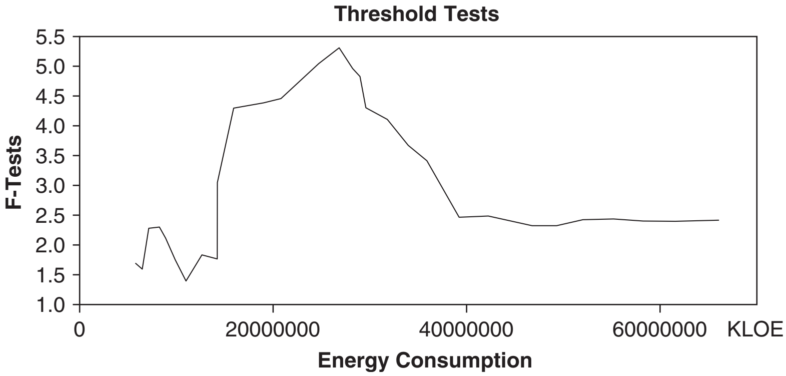

Fig. 8. Plot of threshold test in Nonlinear Model 2.

Table 7
The non-linear regression results of energy consumption and economic growth (Two-Sector model)

Dependent variables	Energy consumption is low		Energy consumption is high
Constant	3.748[a]		2.882[a]
	(2.55)		(4.70)
$\frac{I_t}{Y_t}$	−0.222		0.561[a]
	(−0.63)		(4.56)
$\dot{L}_t$	0.724[a]		1.694[a]
	(2.99)		(6.88)
$\dot{\mathbf{G}}_t \frac{\mathbf{G}_t}{\mathbf{Y}_t}$	**0.337**[a]		**0.040**
	(3.01)		**(0.52)**
$\bar{R}^2$		0.676	
Number of samples	25		24

Threshold variable is the energy consumption (lagged by one period).
[a]Indicates significance at the 5% level and ( ) is the *t*-value. The trimming percentage is set to be 0.15.

technology that can reduce pollution. Attention should be paid to the excessive use of energy that results in the environment becoming polluted. However, there is no free lunch, because environmental protection involves huge costs.[11] Thus, we need to increase current pollution abatement control expenditures in order to reduce expected future pollution liabilities [56].

[11]For example, Norsworthy et al. [58] subtract pollution abatement control expenditures from the value of the capital stock and measure productivity by adopting a growth approach. They find that such spending has a negative effect on labor productivity in manufacturing.

Even though Cheng and Lai [36] as well as Yang [37] provide evidence of only a unidirectional causality running from GDP to energy consumption in Taiwan, Yang [57] also refers to some entirely different directions of causes that exist between GDP and various kinds of energy consumption. However, the opposite viewpoint put forward by Lee and Chang [40] show unanimously in the long run that energy acts as an engine of economic growth. In providing more detail, Chang et al. [39] suggest that the results obtained from impulsive response and variance decomposition analysis tell similar stories. By comparing their findings with our theoretical model and our own empirical results, in the linear two-sector model it is observed that energy consumption has a significantly positive impact on economic growth (Table 3). However, in the nonlinear counterpart, the externality effect appears to be significant and positive for the regime below the threshold, while it is positive but insignificant for the regime corresponding to energy consumption that lies above the threshold. This performance matches that of Chang et al. [39] as well as Lee and Chang [40] at the lower energy-use level, but the results diverge at a relatively higher level when energy consumption exceeds the threshold value due to their not taking into consideration the nonlinear relationship between the observed variables.

Nevertheless, the main purpose of this paper is not to emphasize the causal relationship between energy and growth, but to point out that the linear relationship is unable to clearly point out that the energy use influences economic growth. What we are concerned with in the TAR model is that a clearer discussion can be provided instead of the more confused relationship that exists in the earlier literature. Meanwhile, more complete information is made available to the policy-maker. Hence, the findings indicate that the government would benefit from establishing a business cycle policy with an early warning function, and that policy-makers should distinguish between economic structures associated with different stages of economic growth [59].

4. Conclusions and policy implications

The recent developments in the TAR analytical approach have been extensively applied in various domains, for example, the purchasing power parity hypothesis [60], long-run money demand [61], business cycle fluctuations [62], the growth rates of various macroeconomic time series [14], and interest and inflation in the US [63]. Unfortunately, this econometric technology has never been applied to the topic of energy consumption and economic growth. Thus, we adopt this new technique and through this paper's conclusion hope to distinguish a clear pattern between energy consumption and economic growth in an individual country such as Taiwan.

We consider the possibility of a linear effect and a nonlinear effect of energy consumption on economic growth. Using the data for the period 1955–2003 in Taiwan, we report that the results for the linear model framework appear mixed, depending on the theoretical setting used to estimate the effect of energy consumption on growth. In the nonlinear case, we find evidence of a level-dependent effect between two variables. Allowing for a nonlinear effect of energy consumption on growth sheds new light on the explanation of the characteristics of the energy-growth link, as well as on the quantification and nature of the external effect of energy consumption. The results based on the nonlinear generalization indicate that while there is a positive externality effect and a negative size effect for low levels (compared with the threshold value) of energy consumption, the empirical findings from the TAR model indicate that the energy consumption threshold for Taiwan was reached during the world energy crisis periods in 1979 and 1982. In other words, we also put forward evidence that the relationship between energy consumption and real GDP growth takes the form of an inverse U-shape in Taiwan, and we also try to push back any previous controversy in Cheng and Lai [36] and Yang [37,57]. Naturally, such a nonlinear result may explain why existing studies on energy and growth appear to exhibit diversification and dissimilar results.

Our findings imply that changes in energy consumption contribute to one of the factors that cause structural change in the relationship between energy consumption and economic growth. Therefore, this structural change due to the existence of an energy consumption threshold should be taken into account when constructing estimation and prediction models of economic growth in the case of Taiwan. The policy implications derived from this study are that before policy-makers adopt any strategy to conserve or promote energy consumption, the role of energy use should not be neglected in the relationship between energy consumption and economic growth, or else such a policy may be detrimental to economic growth. Besides, with the emergence of the global village and continuous economic development and industrialization, the growth of the economy and energy consumption may bring considerable pressure to bear on the environment [64]. The government's energy policy should thus shift toward more energy efficient industrial processes to control greenhouse gas emissions in view of the fact that energy consumption and other negative impacts pose a serious challenge [28,65]. In other words, increasing energy efficiency ought to be the main goal of developing countries.

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