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Nonlinear Relationship between Energy Consumption and Economic Growth: The Role of Real Exchange Rate

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Abstract

In China's open economy, exchange rate fluctuations play an increasingly important role in economic growth. This study tested the possible relationship between energy consumption and economic growth using the approach of two-regime threshold co-integration with smooth transition and using annual data from 1980 to 2015 in China. Renminbi (RMB) real exchange rate was adopted as the threshold variable and capital and labor as the control variables. The results showed that in the long-term co-integration relationship between total energy (and different energy types) consumption and economic growth, there was a smooth transition from the first regime to the second one, which means the relationship between energy consumption and economic growth was nonlinear when affected by exchange rate fluctuations.

1. Introduction

The relationship between energy consumption and economic growth has received extensive attentions from various researchers. China has enjoyed rapid economic development in recent years that was mainly depended on the input of production factors, including energy, whose consumption in China will continue to be immense even though the country is changing its economic development pattern.

When empirically investigating the relationship between energy consumption and economic growth, the existing literature mostly conducts linear co-integration and causal analyses of macroeconomic variables. This paper, however, the authors studied the possible nonlinear relationship between the two variables and introduced exchange rate factors into discussions by applying the economic growth model proposed by Robert M. Solow.

The primary goal of this paper is to contribute to discussions of exchange rate using threshold co-integration with smooth transition to investigate the relationship between energy consumption and economic growth in China.

2. Model

There are two production factors in the fundamental hypotheses of neoclassical production functions: capital and labor. Nowadays, another factor - energy - has become a vital factor affecting economic growth as capital, labor, and technology progressed, especially after the "oil crisis" in the 1970s.

Rasche and Tatom (1977) were the first authors to introduce energy consumption into the Cobb-Douglas production function as the following form.

$$Y_t = K_t^{\alpha}(A_t a_t L_t)^{\beta} E_t^{\gamma} \qquad (1)$$

K_t: Capital in t, L_t: Labor in t , E_t: Energy in t, Y_t: output in t, A_t: technological progress

α, β, γ refer to the output elasticity of each variable and $\alpha+\beta+\gamma=1$.

Take the natural logarithm of both sides of the production function and set technological progress rate at zero, the growth equation will become the following:

$$y_t = c + mk_t + nl_t + we_t + \varepsilon_t \qquad (2)$$

To examine whether there is indeed a nonlinear relation between energy consumption and economic growth in China and whether the nonlinear influence is affected by exchange rate fluctuation, this paper utilizes a threshold co-integration model with smooth transition, following the approaches of Timo Teräsvirta (1994) and Zhigang Ouyang (2014). Equation (2) is extended together with the introduction of the nonlinear relation between energy consumption and economic growth. To test the role of exchange rate in the influence of energy consumption on economic growth, we set the exchange rate fluctuation as the threshold variable. A two-regime threshold co-integration model is given as below:

$$y_t = c + mk_t + nl_t + we_t + w_1 e_t f(\gamma_{t-d}; \lambda, c) + \varepsilon_t \qquad (3)$$

y_t is the total output, capital stock k_t and labor l_t are the two control variables, and e_t denotes energy consumption. $f(\gamma_{t-d}; \lambda, c)$ is defined as a nonlinear smooth transition function, exchange rate fluctuation γ_{t-d} is the threshold variable, and d is the position parameter, which can be used to determine the position for the mechanism transition. λ is a parameter to decide the mechanism smooth transition speed and is the threshold value. f(•) is the continuous function of threshold variable γ_{t-d} and its value changes continuously with the change of γ_{t-d}.

3. Data

This study used data from 1980 to 2015 in China to conduct an empirical analysis to estimate whether the RMB exchange rate presents threshold characteristics when changing. Variables included gross output, capital storage, labor input, energy input, and the RMB real exchange rate. Domestic macro-economic data was taken from the official website of the National Bureau of Statistics and the China Statistics Yearbook. The RMB exchange rate was shown as the real effective exchange rate in the IFS data provided by the IMF. Gross output was represented by GDP. Employment was used as an indicator for calculating labor input. Energy consumption per capita served as the total energy indicator; consumption per capita of coal, oil, and natural gas served as energy structure indicators. Capital stock data was estimated through the perpetual inventory method, drawing on Shan Haojie's approach (2008).

Stationary test: All variables were integrated in the first order and were stationary in the first difference in ADF and PP examinations.

4. Methodology and Empirical Test

4.1 Co-integration test

Janhansen's co-integration was used to test the relation between energy consumption and economic growth, and the results showed that the p-value rejects the Hull hypothesis of the no co-integration test, but it does not reject the 1 co-integration or 2 co-integrations tests. In the 3 co-integrations test, it rejects both trace statistics and maximum eigenvalue statistics. This finding confirms that the two factors have a long-term co-integration relation that may appear to be nonlinear.

4.2 Test for nonlinearity with the smooth transition-threshold co-integration model

4.2.1 Determining the mechanism transition position parameter d

Using the method devised by Timo Teräsvirta (1994, 1998), we conducted a third-order Taylor Expansion and introduced it into Eq. (3) to get Eq. (4):

$$y_t = c + mk_t + nl_t + e_t \sum_{i=0}^{3} \rho_i \gamma_{t-d}^i + w_1 e_t f(\gamma_{t-d}; \lambda, c) + \varepsilon_t \qquad (4)$$

We followed the approach by Timo Teräsvirta and Dick Yan Dijk (2003) and found out that the AIC reached its minimum when the order of was 4 for Panel A.

4.2.2 Determining specification of the smooth transition function

It was necessary to test nonlinearity for the transition functions. The Null hypothesis to test Eq. (4) was Ho: $\rho_1=\rho_2=\rho_3=0$. Using methods devised by Bruce E. Hansena and Byeongseon Seo (2002), Timo Teräsvirta (1994), and Zhigang Ouyang (2014), we constructed LM statistics and used bootstrap simulation to realize the nonlinear test.

The result indicates that, in the nonlinear test of this model (Null hypothesis H_0), the calculated LMT=45.086, which was higher than the critical value 3.531. The Null hypothesis was rejected. Therefore, the transition function showed significant nonlinearity.It was also necessary to choose correct forms of transition functions. There are two kinds of transition functions. One is a logistic-type function, and the other is an exponential-type function (Timo Teräsvirta, 1994).

Null hypothesis	LM^T	LM^b(10% quantile)
	Panel A: Total energy consumption (e_t)	
H_0: $\rho_1=\rho_2=\rho_3=0$	45.086	3.531
H_{01}: $\rho_3=0$	6.086	0.025
	Panel B: Coal consumption (ce_t)	
H_0: $\rho_1=\rho_2=\rho_3=0$	52.056	3.607
H_{01}: $\rho_3=0$	7.563	0.023
	Panel C: Oil consumption (le_t)	
H_0: $\rho_1=\rho_2=\rho_3=0$	7.874	1.408
H_{01}: $\rho_3=0$	0.004	0.023
	Panel D: Natural gas consumption (se_t)	
H_0: $\rho_1=\rho_2=\rho_3=0$	16.194	3.625
H_{01}: $\rho_3=0$	0.027	0.025

Table: Determination and test for transition function

The Null hypotheses is H_{01}: $\rho_3=0$; H_{02}: $\rho_2=0$ / $\rho_3=0$; H_{03}: $\rho_1=0$ /$\rho_2=0$, $\rho_3=0$.

The sequential tests were based on the above estimation procedures. If the result did not reject H_{01} but did reject H_{02}, the result showed in Eq. (3) f(•) was an exponential function, and if not, it was a logistic function. It could be inferred from the test results that the transition function in Eq. (3) was the logistic-type function: $f(\gamma_{t-d}; \lambda, c) = (1 + \exp(-\lambda(\gamma_{t-e} - c)))^{-1}$

4.2.3 Determination of threshold co-integration equation

The estimated threshold co-integration was given by:

$$y_t = -0.059 + 0.852k_t + 0.147l_t + 2.328e_t - 2.833e_t(1 + \exp(-51.5(\gamma_{t-4} + 0.129)))^{-1} \quad (5)$$

in which the logic transition function was:

$$f(\gamma_{t-4}; \lambda, c) = (1 + \exp(-51.5(\gamma_{t-4} + 0.129)))^{-1} \qquad (5a)$$

The residual error stationary test was conducted, and the results confirmed that Eq. (5) was the right model. The optimal lag length of threshold variable was d = 4. This figure means that the relation transition between Chinese economic growth and energy consumption appeared in the fourth lag period of the change in exchange rate. It also suggests that, when the current exchange rate fluctuates, the influence on the relation between energy consumption and economic growth will show up several years later.

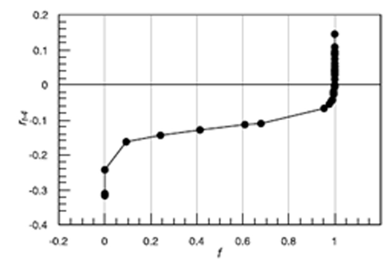

Fig. 1 Transition function (total energy consumption)

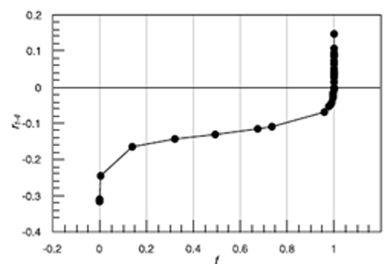

Fig. 2 Transition function (coal consumption)

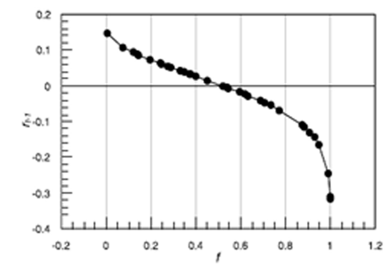

Fig.3 Transition function (oil consumption)

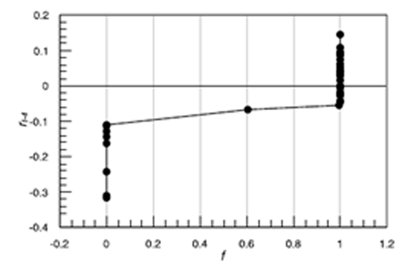

Fig. 4 Transition function (gas consumption)

5. Results and Discussion

We have confirmed that the impact of China's energy consumption on economic growth shows significant nonlinearity with respect to RMB exchange rate fluctuations. Although China's economy is changing its developing mode, the input of production factors is still sizable and, with economic growth, energy consumption also is increasing.

However, China's economy is changing its demand for energy with a gradual shift in its growth pattern. In light of this trend, we might incorporate a discussion of the effects of China's actual energy consumption on economic growth to make the results of this study even more convincing.

Here the authors examine three kinds of energy – coal, oil, and natural gas – to analyze their influence on China's economic growth respectively, considering the role of the changing RMB exchange rate. With the same estimation procedure shown above, three threshold co-integration equations, in which three smooth transition functions were not equal to zero, were determined. The NLS estimation error for the three threshold co-integration equations was examined as stationary series in Eq. (6) to (8). Thus, the effects of these three energy forms on economic growth, in terms of the impact of exchange rate volatility, exhibit certain nonlinearity. The three threshold co-integration equations are given as follows and their corresponding transition functions are shown in Figs. 2 to 4.

① For coal consumption

$$y_t = -0.039 + 0.819k_t - 0.015l_t + 2.437ce_t - 2.132ce_t(1 + \exp(-54.8(\gamma_{t-4} + 0.123)))^{-1} \quad (6)$$

where the logistic transition function is

$$f(\gamma_{t-4}; \lambda, c) = (1 + \exp(-54.8(\gamma_{t-4} + 0.123)))^{-1} \quad (6a)$$

② For oil consumption

$$y_t = -0.078 + 1.032k_t + 0.209l_t - 0.108le_t + 1.006le_t(1 - \exp(-28.38(\gamma_{t-1} - 0.161)^2)) \quad (7)$$

where the logistic transition function is

$$f(\gamma_{t-1}; \lambda, c) = 1 - \exp(-28.38(\gamma_{t-1} - 0.161)^2) \quad (7a)$$

③ for natural gas consumption

$$y_t = -0.048 + 1.023k_t - 0.092l_t + 0.767se_t - 0.805se_t(1 + \exp(-350.9(\gamma_{t-4} + 0.069)))^{-1} \quad (8)$$

where the logistic transition function is

$$f(\gamma_{t-4}; \lambda, c) = (1 + \exp(-350.9(\gamma_{t-4} + 0.069)))^{-1} \quad (8a)$$

6. Conclusion

(1) There is a long-term stable relationship between energy consumption and economic growth. Energy is an important input in the process of economic growth, as the impacts of energy consumption on economic growth show nonlinear characteristics caused by the threshold effect of RMB exchange rate volatility.

(2) The nonlinear threshold co-integration tests for total energy consumption and oil and gas consumption indicate that RMB depreciation will increase energy consumption and stimulate economic growth. There are significant nonlinear relationships between the three types of energy consumption and economic growth, but each relationship performs differently.

(3)The estimation of oil energy consumption on economic growth shows that the influence of oil energy consumption on economic growth is more sensitive to changes in the exchange rate. This sensitivity is due to the fact that oil energy supply and demand depend heavily on import and export.

7. Policy Implications

(1) Energy consumption may promotes economic growth in the case of depreciation of the RMB exchange rate, but it is not sustainable. Measures should therefore be taken to reduce dependence on energy imports so as to alleviate the influence of exchange rate fluctuation on economic growth due to energy consumption. Moreover, it is necessary to energy conservation technologies, adjust the energy consumption structure and optimize the economic structure and weed out outdated approaches.

(2) In recent years, the degree of marketization of the RMB exchange rate system has continually deepened, and its fluctuation situation also has been uncertain. However, if the RMB exchange rate fluctuates beyond a certain scope, the influence of energy consumption on economic growth will undergo a mechanical transition with a relatively fast transition speed. So it is necessary to maintain managed floated exchange rate mechanisms for a certain period of time. Also, to perfect the RMB exchange rate forming mechanism, the monetary authority should improve China's macro-economic environment, intervene less in the foreign exchange market, facilitate the formation of an exchange rate market, and positively advance RMB internationalization.