Research on co-integration and causal relationship between China's energy consumption and economic growth

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Abstract. This paper selects the annual data of China's total energy consumption and GDP from 1978 to 2016 as a research sample, and uses Eviews to perform unit root test, cointegration test, Engle-Grange causality test and VEC model on GDP and energy consumption time series. The results show that the first-order difference between GDP and total energy consumption is stable at a significant level of 10%; GDP, total energy consumption and sub-category energy consumption have a co-integration relationship at a significant level of 5%; Engle-Grange causality test results show that at the 5% significant level, the causal relationship between GDP and energy consumption is obvious, and there is a two-way Granger causality.

1. Introduction

The annual report of World Energy Outlook released by the International Energy Agency (IEA) in September 2010 predicts that China's energy demand will surge by 75% between 2008 and 2035, and by 2035 China's energy demand will grow twice as fast as the world. This paper explores the relationship between China's economic growth and energy consumption, and takes 2006 as a node to analyze the changes of the relationship between energy consumption and economic growth before and after China put forward the "energy saving and emission reduction policy".

Chang et al. (2013) applied panel causality test to examine the relationship between economic growth and energy consumption in 12 Asian countries from 1970 to 2010, and concluded that the two are causal [1]. Jalil Abdul &amp; Feridun Mete (2014) used ARDL model to discuss the relationship between economic growth and energy consumption in China from 1952 to 2008. The results show that energy consumption plays a more significant role in promoting China's economic growth [2]. Based on the data from 1990 to 2011, Liu Xiantao and Shijun (2014) used co-integration analysis to study the long-term relationship between energy consumption and economic growth in China. The results showed that there was no stable long-term relationship between them [3]. Industrial structure, technological progress, population, economic growth and so on affect the energy efficiency of each province, and have a long-term balanced and stable relationship [4]. In the short run, a big driving force of China's economic development is the consumption of new energy, but in the long run, the development of economy in turn promotes the development of new energy [5].
2. Empirical analysis

2.1. Data processing

(1) Data sources
From 1978 to 2016, China's total energy consumption, oil consumption, coal consumption and electricity consumption came from the National Bureau of Statistics and the National Energy Administration of China. 21978-2016 China's population and GDP data are from the National Bureau of Statistics.

(2) Symbolic representation

| Symbol | Representative content |
|--------|------------------------|
| GDP    | Per capita GDP (10,000 yuan per person) |
| PGC    | Per capita natural gas consumption (tons of standard coal/person) |
| TEC    | Total energy consumption per capita (tons of standard coal/person) |
| POC    | Per capita oil consumption (tonnes of standard coal/person) |
| PCC    | Per capita coal consumption (tons of standard coal/person) |
| PEC    | Per capita electricity consumption (tonnes of standard coal/person) |

(3) Data processing
In this study, China's per capita energy consumption and per capita GDP data are used to eliminate the impact of population growth; since the data logarithm does not change the original co-integration relationship, and can linearize its trend, eliminate the heteroscedasticity in the time series, this paper carries out natural logarithm transformation of variables. Because the price factor has a great influence on GDP, the GDP data are processed in the form of 1978 as the base year.

Through the original data graph in figure 1, we can find that the growth rate of total energy consumption and total coal consumption is obviously faster than the growth trend of economic growth. The development trend of different energy consumption is more synchronous.

![Image of Economic growth and energy consumption trend chart 1978-2016.](image)

2.2. The stability test of sequences
The unit root test of GDP and energy consumption series is to avoid two variables of non-stationary time series. In the subsequent cointegration and causality test, the original two unrelated variables appear the fallacy of causality or the conclusion of meaningless regression.
Through the graphical analysis of the variables, it can be found in Figure 2 that all the six variables have the same trend of growth, the direction of change is basically the same, and the variables show an unstable upward trend. The ADF test of the variables is further carried out.

It can be seen from Figure 3 that the first-order difference of each variable fluctuates near zero and tends to be stable. Next, the unit root test is performed on the variables and the results are performed in Table 2.

**Table 2. Unit Root Test Results.**

| Variables | Test type (c,t,k) | ADF   | P      | conclusion |
|-----------|------------------|-------|--------|------------|
| lngdp     | 2                | -1.0091 | 0.9301 | Unstable   |
| dlngdp    | 1                | -3.5933 | 0.0046 | stable     |
| lntec     | 1                | -2.8956 | 0.1754 | Unstable   |
| dlntec    | 1                | -2.6362 | 0.0953 | stable     |
| lnpec     | 1                | -2.8798 | 0.1803 | Unstable   |
| dlnpec    | 0                | -1.7551 | 0.0753 | stable     |
| lnpec     | 0                | -1.3143 | 0.8691 | Unstable   |
| dlnpec    | 0                | -6.7468 | 0.0000 | stable     |
| lnpec     | 0                | -4.5026 | 0.0048 | stable     |
| dlnpec    | 0                | -4.6123 | 0.0037 | stable     |
| lnpec     | 1                | -2.0681 | 0.5459 | Unstable   |
| dlnpec    | 0                | -4.1636 | 0.0117 | stable     |

c,t,k 123 represents intercept term, trend term and lag order respectively. The selection criteria of lag period refer to AIC and SC criteria.

Through unit root test of variables in Table 2, we can find that per capita GDP, per capita total energy consumption, per capita electricity consumption, per capita coal consumption and per capita natural gas consumption are first-order stable at 10% confidence level, and their mean and variance do not change with time, showing the same-order monolithic. The co-integration relationship between variables can be further validated. However, the original sequence of per capita oil consumption is stable, which is not the same order as GDP, so no further test is made.

### 2.3. Establishing VAR model to determine lag time

**Table 3. Variable Delay Period.**

| Lag | LogL  | LR     | FPE   | AIC   | SC     | HQ     |
|-----|-------|--------|-------|-------|--------|--------|
| 0   | 137.6259 | NA     | 4.34e-10 | -7.368104 | -7.148171 | -7.291341 |
| 1   | 392.3130 | 424.4786 | 1.27e-15 | -20.12850 | -18.80890* | -19.66793 |
| 2   | 435.4460 | 59.90692* | 5.04e-16* | -21.13589* | -18.71662 | -20.29150* |
| 3   | 457.5946 | 24.60951 | 7.45e-16 | -20.97748 | -17.45855 | -19.74928 |
A VAR model is established for stationary variables of the same order to determine their lag time. It can be found from the table 3 that according to AIC criterion and considering the comprehensive test, the second-order lag period is adopted for variables.

2.4. Cointegration test

Table 4. Cointegration Test Results.

| Hypothesized No. of CE(s) | Eigenvalue | Trace Statistic | 0.05 Critical Value | Prob.** |
|--------------------------|------------|-----------------|---------------------|--------|
| None *                   | 0.798872   | 102.2310        | 69.81889            | 0.0000 |
| At most 1                | 0.417376   | 42.88990        | 47.85613            | 0.1353 |
| At most 2                | 0.318838   | 22.90200        | 29.79707            | 0.2509 |
| At most 3                | 0.209295   | 8.695642        | 15.49471            | 0.3943 |
| At most 4                | 0.000187   | 0.006904        | 3.841466            | 0.9332 |

Trace test indicates 1 cointegration at the 0.05 level

| Hypothesized No. of CE(s) | Eigenvalue | Trace Statistic | 0.05 Critical Value | Prob.** |
|--------------------------|------------|-----------------|---------------------|--------|
| None *                   | 0.798872   | 59.34113        | 33.87687            | 0.0000 |
| At most 1                | 0.417376   | 19.98790        | 27.58434            | 0.3420 |
| At most 2                | 0.318838   | 14.20636        | 21.13162            | 0.3483 |
| At most 3                | 0.209295   | 8.688738        | 14.26460            | 0.3130 |
| At most 4                | 0.000187   | 0.006904        | 3.841466            | 0.9332 |

Max-eigenvalue test indicates 1 cointegration at the 0.05 level

Johansen cointegration test is performed in the order of the number of cointegration relations r=0 to r=k-1 until the corresponding original hypothesis is rejected. Table 4 shows the results of cointegration test. In order to illustrate the test results, the first column of "None" means that the original hypothesis of the test is "there is zero co-integration relationship", under which the trace statistics are equal to 102.2310, the critical value of 5% is equal to 69.81899, and the trace statistics are greater than the critical value. Therefore, the original hypothesis is rejected, indicating that there is at least one co-integration relationship. Then we examine the original hypothesis of "Atmost1", which indicates that there is at most one co-integration relationship. The trace statistics under this hypothesis are 42.88990, and the critical value is 47.85613, which is less than 5%. Therefore, we accept the original hypothesis and show that there is at least one co-integration relationship. Trace statistics test results show that there is a co-integration relationship at the level of 5%.

The results of maximum eigenvalue test are not consistent with those of trace statistics test. Trace statistics are generally the main test because they are more effective in general. The test results of trace statistics are consistent with the test results of maximum eigenvalue. Therefore, there is a co-integration relationship between per capita GDP, per capita energy consumption, per capita electricity consumption, per capita coal consumption and per capita natural gas consumption in China from 1978 to 2016. Cointegration equation 7 is:

\[ \text{LNGDP} = 11.59286 \text{LNTEC} – 7.783920 \text{LNPC} – 1.876573 \text{LNPEC} – 0.749156 \text{LNPGC} \]  

Cointegration equation shows that LNGDP and LNTEC have a positive long-term equilibrium relationship, that is, every 1% increase in total energy consumption leads to an 11.59% increase in GDP, while GDP and coal consumption, electricity consumption and natural gas consumption show a reverse long-term equilibrium relationship, because the total energy consumption is composed of various types of energy consumption, energy consumption and economic growth. The co-integration relationship is also in line with China's actual situation. The overall scale of economic growth will have an impact on energy consumption. With the continuous expansion of economic scale, energy consumption will inevitably increase.

2.5. Establishment of VEC model

2.5.1. Model Estimation. The long-term equilibrium relationship between energy consumption and economic growth can be reflected by the co-integration equation. The short-term change of energy consumption can be analyzed by using VEC model. Table 5 shows the parameter estimation results of VEC Model.
Table 5. Parameter Estimation Results of VEC Model.

| Error Correction | D(LNGDP)  | D(LNPCC)  | D(LNPEC)  | D(LNPGC)  | D(LNTEC)  |
|------------------|-----------|-----------|-----------|-----------|-----------|
| CointEq1         | -0.002279| -0.009734| 0.012745  | -0.054189 | -0.014174 |
| D(LNGDP(-1))     | 0.826296 | -0.147886| 0.086792  | 0.053819  | -0.107152 |
| D(LNGDP(-2))     | -0.310306| -0.100208| -0.074743 | -0.317751 | -0.047824 |
| D(LNPCC(-1))     | -0.355027| 0.771373  | 1.274628  | 1.915042  | 0.921596  |
| D(LNPCC(-2))     | -0.094231| 0.436637  | -0.259216| 1.090312  | 0.343050  |
| D(LNPEC(-1))     | -0.124262| 0.150046  | -0.050026| 0.053819  | 0.062181  |
| D(LNPEC(-2))     | -0.098494| 0.040149  | -0.143535| -0.317751| -0.047824 |
| D(LNPGC(-1))     | -0.166303| -0.101410| 0.441273  | 0.181049  | -0.046167 |
| D(LNPGC(-2))     | -0.033412| -0.137134| 0.272381  | 0.027518  | -0.085343 |
| D(LNTEC(-1))     | 0.853897 | -0.031968| -1.037935| -1.964717| -0.332858 |
| D(LNTEC(-2))     | -0.006164| -0.459417| -0.654482| -1.457387| -0.531334 |
| C                | 0.025400 | 0.019827  | 0.084351  | 0.124658  | 0.040300  |

\[ CointEq1 = D(LNGDP) - 12.82490LNPCC - 9.083319LNPEC + 2.689285LNPGC + 18.88082LNTEC - 16.68210 \] 

The expression of the error correction term is consistent with that of Johansen’s cointegration test, but the coefficients are estimated differently by introducing a constant term into the cointegration test relation. The expression of VEC model is as follows:

\[ \Delta Y = \begin{bmatrix} D(LNGDP) \\ D(LNPCC) \\ D(LNPEC) \\ D(LNPGC) \\ D(LNTEC) \end{bmatrix} = \begin{bmatrix} -0.31 & -0.09 & -0.10 & -0.03 & -0.01 \\ -0.10 & 0.44 & 0.04 & -0.14 & -0.46 \\ -0.07 & -0.26 & -0.14 & 0.27 & -0.65 & + \epsilon; \\ -0.32 & 1.09 & -0.36 & 0.03 & -1.46 \\ -0.05 & 0.34 & -0.01 & -0.09 & -0.53 \end{bmatrix} \] 

For the V AR model with K endogenous variables and P * k roots, the AR characteristic polynomial has 6 roots. If the reciprocal of all roots of the estimated V AR model is less than 1, i.e. within the unit circle, the V AR model is stable. The figure 4 shows that the 10 roots involved in the VEC model are in the unit circle, which shows that the VEC model is stable.
2.5.2. Impulse response function

Through the impulse response function in figure 5, we can find the impact of a standard deviation of energy consumption on GDP. After being shocked by energy consumption, GDP began to rise in the first period and maintained a stable trend in the fourth period.

2.5.3. Variance decomposition

From the variance decomposition graph in figure 6, it can be found that the explanatory part of variables decreases gradually with the increase of periods, while the explanatory part of other variables increases gradually. The figure shows that the explanatory part of total energy consumption to GDP changes.
increases gradually and reaches the peak in the tenth period, that is, about 20% of the variance of GDP changes can be explained by the change of total energy consumption.

2.6. Granger causality test

Table 6. Granger causality test results.

| Hypothesis | Lagged term | F  | P    | conclusion |
|------------|-------------|----|------|------------|
| LNPCC is not the Granger Cause of LNGDP | 2 | 0.96152 | 0.3931 | No rejection |
| LNGDP is not the Granger Cause of LNPCC | 2 | 3.39579 | 0.0460 | rejection |
| LNPEC is not the Granger Cause of LNGDP | 2 | 0.28239 | 0.7558 | No rejection |
| LNGDP is not the Granger Cause of LNPEC | 2 | 0.06302 | 0.9390 | No rejection |
| LNPCC is not the Granger Cause of LNGDP | 2 | 0.96152 | 0.3931 | No rejection |
| LNGDP is not the Granger Cause of LNPCC | 2 | 3.39579 | 0.0460 | rejection |
| LNPEC is not the Granger Cause of LNGDP | 2 | 0.28239 | 0.7558 | No rejection |
| LNGDP is not the Granger Cause of LNPEC | 2 | 0.06302 | 0.9390 | No rejection |
| LNPCC is not the Granger Cause of LNGDP | 2 | 0.96152 | 0.3931 | No rejection |
| LNGDP is not the Granger Cause of LNPCC | 2 | 3.39579 | 0.0460 | rejection |
| LNPEC is not the Granger Cause of LNGDP | 2 | 0.28239 | 0.7558 | No rejection |
| LNGDP is not the Granger Cause of LNPEC | 2 | 0.06302 | 0.9390 | No rejection |

Granger causality in table 6 shows that there is a single Granger causality between coal consumption and GDP in the 5% confidence interval, while there is no Granger causality between electricity consumption and GDP, there is a single causality between natural gas consumption and GDP, and there is a two-way Granger causality between total energy consumption and GDP. That is to say, the growth of economy leads to the increase of energy consumption, and the increase of energy consumption promotes economic growth. This is because with the rapid economic growth, the increase of carbon-based energy consumption will inevitably accompany the increase of energy consumption. Economic growth is the main driving factor of the increase of energy consumption. With the increase of energy consumption, the economy will also grow. This is because China's economic growth is accumulated by energy consumption, which also means China's extensive economic growth mode.

3. Conclusion

The relationship between China's economic growth and energy consumption shows that China's economic growth is inseparable from energy consumption to a certain extent, and energy consumption brings a series of environmental pollution problems, coupled with the increasing depletion of non-renewable energy, resulting in resource-dependent development difficult to sustain.

As China is in the process of economic development, it is inevitable to experience some major events that have had a huge impact on the Chinese economy. The oil crisis of 1973; reform and opening up policy was proposed in 1978; the financial earthquake in 1987; the establishment of the socialist market economic system in 1992, the exploration stage of the market economy; the Asian financial crisis in 1997; the global financial crisis in 2008; 2016 is in a stable phase of the market economy. These events have a certain degree of influence on the relationship between China's economy and energy, which will cause certain errors in the long-term cointegration and causal relationship analysis of China's energy and economy. In the future, the research will go deep into the time nodes of major events and further talk about the development relationship between China's energy and economy.

Acknowledgments

This work was supported by the Energy Economic Development Strategy Research project of the Science and Technology Department of Hebei Province (grant number 12457206D-22).
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