Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 27 March 2017 doi:10.20944/preprints201703.0197.v1

Co-integration and Causality Analysis of Carbon Intensity and Coal Consumption of China

Xing Wang [1,*], Zhongqi Fan [1] and Ying Zhang [2]

[1] School of Management, China University of Mining and Technology-Beijing, Beijing 100083, China

[2] School of Economics and Management, Beijing Forestry University, Beijing 100083, China

* Correspondence:13141290982@163.com

Abstract: Co-integration and Causality was built to conduct studies on causality relation between carbon intensity and coal consumption leading to providing important basis for the transition to a low carbon economy. The EG two-step method was performed to study the relation between carbon intensity and coal consumption of China during 1990-2015 and the co-integration and Granger test was constructed to build up the co-integration and error correction models for analysis of the interaction between carbon intensity and coal consumption. The results showed that in long term there is a stable co-integration relation and a positive correlation between carbon intensity and coal consumption; whereas fluctuations exist in short term and there is a one-way Granger causality of carbon intensity with respect to coal consumption.

Key words: carbon intensity; coal consumption; co-integration test; Granger causality; error correction model

1. Introduction

Various studies have been conducted on the mutual influence between carbon intensity and coal consumption. Stnton, et al studied the influence of energy structure on carbon emission[1]. Chang and Zhou, et al made empirical analysis on the influencing factors of carbon emission using econometrics[2,3]. Hammond, et al conducted decomposition analysis on carbon emission of British manufacturing industry based on statistic data from 1990-2007 and discovered energy intensity to be the determinant of carbon emission reduction[4]. Freitas, et al analyzed the relations of carbon emission with carbon emission intensity and energy structure through logarithmic-exponential method and concluded that energy structure and carbon emission intensity are main factors influencing carbon emission[5]. Xu, et al conducted empirical analysis on multiple factors influencing the CO_2 emission in Chinese cement industry using LMDI method[6]. Du, et al explored the influencing factors of carbon emission with data from 1995-2009[7]. Chinese researchers Cheng Yeqing,et al have been constructed with a panel econometric model coupled with the energy structure and carbon emission[8]. Deng Jixiang, et al carried out empirical analysis on energy structure and carbon emission with logarithmic-exponential decomposition method[9]. Zhai Jiayu analyzed the interaction between energy consumption and carbon emission[10]. Fan Fengyan has been studied the influence of changes in energy structure of Beijing on carbon emission and found that energy structure and carbon emission are in inverse relation[11].

In summary, there are some present studied on the relation between carbon intensity and coal consumption but their conclusions vary considerably with respect to the country and data selected. Furthermore, the research subjects in this area are mainly from foreign countries with few empirical researches carried out in China. Among them Ang, et al made quantitative researches on the interaction of the changes in energy intensity and energy structure with carbon emissions from manufacturing industries of China, South Korea and Taiwan with Divisia decomposition method[12]. Gabriel, et al studied influences of multiple factors such as economy and environment on energy structure[13]. Nakata, et al made empirical analysis on the influences of economic and population growth and environmental and other factors on energy consumption structure and found that great emphasis on renewable energy development is important for establishing a low carbon economy[14]. Ma, et al made decomposition analysis on carbon emission data from 1980-2003 and found that energy consumption and carbon emission are in positive correlation[15]. Dagoumas, et al carried out empirical analysis on influencing factors of British carbon emission with macroeconomic model and found that transport and power sectors contribute mostly to carbon emission[16]. Li, et al made empirical research on the potential of green energy in contributing to carbon emission reduction[17]. Chinese researchers Lin Boqiang, et al have studied the relation between energy structure and carbon emission using CGE model[18]. Hong Yeying conducted quantitative analysis on the influence of energy structure on carbon emission based on the energy consumption data of Chongqing from 1978-2013[19]. Zhu Ni, et al studied the relation of energy consumption structure with carbon emission in Shanxi Province using vector auto-regression model based on the data from 1989-2011[20]. In recent years most studies on the relation between carbon intensity and coal consumption focus on quantitative research and causality analyses on carbon intensity and coal consumption of China are still very few among literature. Therefore this study was presented the co-integration analysis and Granger test to research on the relation between carbon intensity and coal consumption with a view to provide reference for carbon emission reduction policy.

2. Data and Methods

2.1. Data

Carbon Intensity (*CI*): Due to the lack of carbon emission data in the statistic yearbook, various estimation methods have been taken by different researchers. The carbon emission quantity acquired for this study is the consumption quantity of fossil fuels multiplied by corresponding carbon emission coefficients. Since the proportion accounted for by hydropower, wind power and nuclear power in primary energy consumption is comparatively small;thus,they has little influence on the result, this study will not consider hydropower, nuclear power and wind power in carbon emission calculation. The values of carbon emission coefficients for energy have been selected with reference to many domestic literatures [21,22], and a mean value calculated from multiple structures is adopted to calculate carbon emission. The detailed calculation results are shown in Table 1.

Table 1 Carbon Coefficient of Various Types of Energy

Research Institute	Scoal	Oil	Gas
DOE/EIA	0.7020	0.4780	0.3890
Institute of Energy Economics	0.7560	0.5860	0.4490
Chinese Academy of Engineering	0.6800	0.5400	0.4100
NDRC Energy Research Institute	0.7476	0.5825	0.4435
NEPB Greenhouse Gas Control Project	0.7480	0.5830	0.4440
TSSTC on Climate Change Project	0.7260	0.5830	0.4090
Mean	0.7266	0.5588	0.4241

Coal Consumption (*SC*): This study uses coal consumption proportion to represent coal consumption.
The data used in this study comes from China Statistical Yearbook 2016 with the period of 1990-2015. Logarithms are taken for both carbon intensity *CI* and coal consumption *SC*, e.g. $LNCI$ and $LNSC$ respectively, to reduce data fluctuation.

2.2. Methods

2.2.1 Cointegration Test

The Cointegration Test can be interpreted as the long-term equilibrium and the short-term fluctuation relationship between non-stationary time series.The so-called stationary time series is that its mean, variance and autocovariance don't depend on time t. If a sequence is nonstationary, but its first-order difference of sequence is stationary,it is said that the sequence has one unit root;the sequence is integrated of order one.If a sequence is nonstationary,but its d-order differences of sequence is stationary, it is said that the sequence has d unit roots;the sequence is integrated of order d.Engle and Granger proposed EG two-step test of cointegration analysis which used to test the cointegration relationship between variables in 1987s. Thus, this paper has applied EG two-step method to test whether there is a cointegration relationship between carbon intensity and coal consumption.

First,the co-integration equation between $LNCI$ and $LNSC$ is given by the following equations.

$$LNCI_t=\beta + \delta LNSC_t+\varepsilon_t,$$

Second,ADF method is used to conduct stationary test for residuals, the results of test is shown：

$$\Delta\varepsilon_t=\alpha\varepsilon_{t-1}+\sum_{j=2}^{p}\delta_t\,\Delta\varepsilon_{t-j+a}+\mu_t$$

If results of ADF test show that sequences of residuals are stationary, there is co-integration relation between carbon intensity and coal consumption.

2.2.2. Granger Causality Test

Formally,the Granger causal relations between $LNCI$ and $LNSC$ in levels can be expressed using the parameters of equations (1) and (2):

$$LNCI_t=\alpha_0+\alpha_i\sum_i^m LNCI_{t-i}+\beta_i\sum_i^m LNSC_{t-i}+\varepsilon_i \qquad (1)$$

$$LNSC_t=\alpha_0+\alpha_j\sum_j^m LNSC_{t-j}+\beta_j\sum_j^m LNCI_{t-j}+\varepsilon_j \qquad (2)$$

There is causality from $LNCI$ to $LNSC$ if β_i=0 and $\beta_j \neq 0$ ∀ i,j.Similarly,there is causality from $LNSC$ to $LNCI$ if $\beta_i \neq 0$ and β_j=0 ∀ i,j.The causality is considered as mutual if $\beta_i \neq 0$ and $\beta_j \neq 0$ ∀ i,j. There is no link between $LNCI$ and $LNSC$ if β_i=0 and β_j=0 ∀ i,j.

3. Results

3.1. Unit Root Test of variable

Because co-integration test requires stationary sequence, ADF method is used in this study to conduct stationary test for $LNCI$ and $LNSC$,the results of test is shown in Table 2.

Table 2 ADF Unit Root Test of Series

Series	Inspection Form	ADF statistic	5% level	Stationarity
LNCI	（C，0，9）	-1.230185	-2.991878	no
LNSC	（C，0，10）	-0.027197	-2.986225	no
DLNCI	（C，0，10）	-4.276975	-3.098896	yes
DLNSC	（C，0，0）	-4.056321	-3.612199	yes

Table 2 illustrated that under a significant level of 5%, test values of $LNCI$ and $LNSC$ are non-significant which means $LNCI$ and $LNSC$ are not stationary. Whereas the test values of first-order differences of $LNCI$ and $LNSC$ are significant which means sequences $DLNCI$ and $DLNSC$ are stationary, e.g. $LNCI$-I (1) and $LNSC$-I(1).

3.2. EG Co-integration Test of Sequences

EG two-step method is taken to test whether there is co-integration relation between $LNCI$ and $LNSC$. The co-integration equation between $LNCI$ and $LNSC$ is given by the following equation.

$$LNCI_t=-22.4390+5.4241LNSC_t+\varepsilon_t \qquad (3)$$

（-11.4412）（11.7920）

adj. R^2=0.8528 S.E.=0.1039 F=139.0522 DW=0.4313

A goodness of fit of 85.28% for the model suggests a good model fitting. But the DW value is mere 0.4313, which means that the model has serial autocorrelation. Therefore LM statistic is used to test whether a serial autocorrelation exists, the results of test is shown in Table 3.

Table 3 LM Test Results of Residual Autocorrelation

Breusch-Godfrey Serial Correlation LM Test			
F-Statistic	14.4152	Prob.F(2,62)	0.0001
White Heteroscedasticity Statistic	14.7469	Prob.Chi-Square(2)	0.0006

Results of LM test showed that probability of White Heteroscedasticity test is 0.0006, which means that autocorrelation can be considered to exist in ε_t. Therefore a lagged variable can be added to the equation and we have the lagging model for $LNCI$ and $LNSC$:

$$LNCI_t=1.1075+1.7390LNSC_t+0.9803LNCI_{t-1}-2.0018LNSC_{t-1}+\varepsilon_t \quad (4)$$

(0.7220) (4.7593) (16.4059) (−4.7814)

adj. R^2=0.9892 S.E.=0.0273 F=640.8498 DW=1.7298

Table 4 LM Test Results of Residual Autocorrelation

Breusch-Godfrey Serial Correlation LM Test			
F- Statistic	0.1445	Prob.F(2,62)	0.8664
White Heteroscedasticity Statistic	0.3747	Prob.Chi-Square(2)	0.8292

Test results showed that the White Heteroscedasticity statistic is not significant, meaning ε_t does not have autocorrelation. ADF method may be used to conduct further stationary test for residuals, the results of test is presented in Table 4.

Table 5 ADF Unit Root Test of Residual Series

Null Hypothesis:one unit root of residual series	t-Statistic	Probability
ADF value	-4.1886	0.0036
1% level of the standard ADF value	-3.7378	
5% level of the standard ADF value	-2.9919	
10% level of the standard ADF value	-2.6355	

It can be seen from Table 5 that there is co-integration relation between sequence $LNCI$ and sequence $LNSC$, suggesting the validity of the co-integration regression model for carbon intensity and coal consumption built up in this study. In the short term coal consumption will lead to the temporary deviation from equilibrium state of carbon intensity. In the long term, however, coal consumption will bring carbon intensity back to the equilibrium state, facilitating the sustainable economic development.

3.3. Granger Causality Test

Co-integration test has showed that there is co-integration relation between carbon intensity and coal consumption. But is this co-integration relation caused by carbon intensity to coal consumption or by coal consumption to carbon intensity? To find out we need to conduct Granger causality test for $LNCI$ and $LNSC$,the results are shown in Table 6.

Table 6 The Granger Causality Test of Variable

Null Hypothesis	Lag length	F-Statistic	Probability
LNSC does not Granger Cause LNCI	2	1.97736	0.1659
LNCI does not Granger Cause LNSC	2	5.09658	0.0169

As presented in Table 6, in short term, carbon intensity is Granger causes of coal consumption but coal consumption is not Granger causes of carbon intensity. This means that the reduction of carbon intensity, which reflects the continuous growth in low-carbon technology level, carbon reduction efficiency and energy comprehensive utilization efficiency in China, as well as the constant optimization of energy structure and the increase of proportion of such clean energy as hydropower and geothermal power, leads to the reduction of carbon emission.

3.4. Error Correction Model

OLS estimation method is used to set up an error correction model with coal consumption $LNSC$ being explanatory variable and carbon intensity $LNCI$ being explained variable as follow:

$$DLNCI=-0.0273+1.7835DLNSC+0.0586ECM \quad (5)$$

T-Statistic （-4. 0415）（4. 5607） （0. 8919）

$$ECM=LNCI+22.4390-5.4241LNSC$$

The fluctuations of carbon intensity can be attributed to two aspects: fluctuations of coal consumption and deviation from equilibrium level. By examining the coefficient of Equation (5) we can see that variation of coal consumption will cause the variation of carbon intensity in the same direction, meaning that coal consumption certainly promote carbon intensity. And for every 1% growth in coal consumption, carbon intensity will increase by 1.7835%, with the coefficient of error correction item being 0.0586, that is, the system tends to stabilize with a small strength of 5.86%.

4. Discussion

Based on above results,some questions are raised to discuss:

(1)Improve energy consumption structure, promoting the transition from “high-carbon” to “low-carbon” energy structure in China. Since the current energy structure of China featuring “large amount of coal, less oil and little gas” is difficult to change in the short term, we should boost the utilization of renewable energy such as wind power, solar power and hydropower, accelerating their development and gradually increasing their proportions. Meanwhile in light of the resource shortage condition of China, we should develop and introduce advanced energy conservation technologies, increase supply by encouraging competition, set out energy development plan, improve energy mechanism and enrich our energy-conservation and emission reduction measures to achieve an energy structure of low carbon, cleanness, less total amount and intensity.

(2)Develop low-carbon technology and increase energy efficiency. According to economic theory, low-carbon technologies can promote economic growth and their promotion and utilization can well facilitate energy conservation and emission reduction. Therefore, government should make full use of such policies as financial subsidy and taxation to improve the corresponding low-carbon policy system and energy system, learn and introduce advanced foreign low-carbon technologies, encourage enterprises to make more investment in research and raise their technical and management experience, implement a double control policy for both carbon intensity and total coal consumption and develop a reasonable and effective scheme for total energy consumption and perfect supporting policies and measures so as to realize the transition to a low-carbon economy and increase the energy efficiency.

(3)Optimize economic growth pattern and social consumption model. Government should develop reasonable incentive and supporting policies to raise the citizen’s awareness of energy conservation and emission reduction, establish a diligent and thrifty energy consumption concept, guide the low-carbon consumption and create a low-carbon environment to ultimately achieve carbon emission reduction step by step.

5. Conclusion

Based on the results discussed above,it can concluded that:

(1)This study has analyzed the co-integration and causality relations between carbon intensity and coal consumption in China based on statistic data on Chinese carbon intensity and coal consumption from 1990-2015. The results shows that in short term there are fluctuations between carbon intensity and coal consumption; but there is a long-term equilibrium relation between them in the long run.

(2)Analysis with error correction model has demonstrated that coal consumption can cause the positive fluctuations of carbon intensity and for every 1% growth in coal consumption carbon intensity increases by 1.7835% with an error correction coefficient of 0.0586 which means the system tends to come to a long-term equilibrium state with strength of 5.86%.

(3)Granger causality test we have found out that there is a one-way Granger relation from carbon intensity to coal consumption, e.g., reduction in carbon intensity would directly lead to reduction in coal consumption. Whereas coal consumption is not a Granger cause of carbon intensity, e.g., increase in coal consumption would not cause the increase in carbon intensity or coal consumption is not a significant influencing factor for carbon intensity. This,on the one hand demonstrates that rapid economic growth, upgrading of industrial structure and constant adjustment and optimization in energy structure promote the increase in the proportion of renewable energy utilization in primary energy structure and a steady reduction of carbon emission and thus reduction in coal consumption; on the other hand, this reflects that low-carbon technology level, carbon emission reduction efficiency and energy comprehensive utilization efficiency have been increasing and the economy has come to the post-industrial development phase, and consequently the secondary industry accounts for a smaller proportion and people are depending less on fossil fuels like coal, which then leads to less utilization of fossil fuels and considerable reduction in carbon emission, therefore many production and living activities of people no longer generate carbon emission and coal consumption is significantly reduced, and ultimately energy consumption significantly reduces.

Conflicts of Interest

The author declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

The author would like to thank the National Key Research and Development Program (2016YFC0500905) and Forestry soft science research project (2015-R019) for supporting their reaearch works.

References

1.Stnton,J.E.;Fridley,D.G.Growth in China′s Carbon Dioxide Emissions is Slower than Expected.Sinosphere.2001,4,3-5.

2.Chang,C.C.A Multivariate Causality Test of Carbon Dioxide Emissions,Energy Consumption and Economic Growth in China.Applied Energy.2010,87,3533-3537.

3.Zhou,P.;Ang,B.W.;Han,J.Y.Total Factor Carbon Emission Performance:A Malmquist Index Analysis.Energy Economics.2010,32,194-201.

4.Hammond,G.P.;Norman,J.B.Decomposition Analysis of Energy-Related Carbon Emission from UK Manufacturing.Energy.2011,12,1-8.

5.Luciano,C.D.F.Shinji K.Decomposing the decoupling of CO_2 emissions and economic growth in Brazil.Ecological Economics.2011,70,1459-1469.

6.Xu,J.H.;Fleiter,T.;et al.Energy Consumption and CO_2 Emission in China′s Cement Industry:A Perspective from LMDI Decomposition Analysis.Energy Policy.2012,50,821-832.

7.Du,L.;Wei,C.;Cai,S.Economic Development and Carbon Dioxide Emission in China:Provincial Panel Data Analysis.China Economic Review.2012,23,371-384.

8.Cheng,Y.Q.;Wang,Z.Y.;Zhang,S.Z.;et al.A Spatial Econometric Analysis for Carbon Emission Intensity of Chinese Energy Consumption and Its Influencing Factors.Acta Geographica Sinica.2013,68,1418-1413.

9.Deng,J.X.;Liu,X.;Wang,Z.Feature Analysis and Factor Decomposition for the Regional Differences and Evolution of Chinese Carbon Emission. Journal of Natural Resources.2014,29,189-200.

10.Zhai,J.Y.A Research on the Relations Between Energy Consumption, Economic Growth and Carbon Emission of Hebei Province. Hebei: Hebei University of Economics and Business,2016.

11.Fan,F.Y.A Research on Influencing Factors of Carbon Emission and Emission Policy of Beijing City. Beijing:China University of Geosciences,2016.

12.Ang,B.W.;Pandiyan,G.Decomposition of Energy-induced CO_2 Emissions in Manufacturing. Energy Economics.1997,19,363-374.

13.Gabriel,S.A.;Kydes,A.S.;Whitman,P.The National Energy Modeling System:A Large-scale Energy-economic Equilibrium Model.Operations Research.2001,49,14-25.

14.Nakata,T.Energy-economic Models and the Environment.Progress in Energy and Combustion Science.2004,30,417-475.

15.Ma,C.;Stern,D.I.China′s Changing Energy Intensity Trend:A Deconmosition Analysis.Energy Econonics.2008,30,1037-1053.

16.Dagoumas,A.S.;Barkera,T.S.Pathways to a Low-carbon Economy for the UK with the Macro-econometric E3MG Model.Energy Policy.2010,38,3067-3077.

17.Li,H.Q.;Wang,L.M.;Shen,L.;et al.Study of the Potential of Low Carbon Energy Development and Its Contribution to Realize the Reduction Target of Carbon Intensity in China.Energy Policy.2012,41,393-401.

18.Lin,B.Q.;Yao,X.;Liu,X.Y.The Strategic Adjustment of Chinese Energy Structure under Constraints of Energy Conservation and Carbon Emission. Social Sciences in China.2010,4,59-72.

19.Hong,Y.Y.Analysis on the Influence of Changes in Industrial Structure and Energy Structure on Carbon Emission: Based on Environmental Kuznets Curve Test. Environmental Science & Technology.2015,38,266-272.

20.Zhu,N.;Zhang,Y.F.Analysis on Impact of Evolution of Energy Consumption Structure and Industrial Structure in Shaanxi Province on Carbon Emission Intensity. Arid Land Geography 2015,38,843-850.

21.Peng.J.W.;Hang,X.J.;Zhong,T.Y.;et al.A Research on the Unhook of Economic Growth and Energy Carbon Emission in China. Resources Science.2011,33,626-633.

22.Jiang,J.H.Measurement and Calculation of Chinese Carbon Emission and Analysis on Its Influencing Factors. Resources Science.2011,33,597-604.

23.Wang,X.;Fan,Z.Q.;Zhang,R.Empirical Analysis on the Relation of Chinese Energy Efficiency and Energy Structure Based on VAR. Industrial Technology Economics.2016,9,128-134.

24.Franziska,W.;Dinesh,S.;Anirudh,Singh.;Walter,Leal.Energy access and security strategies in small island developing state.Energy policy.2016,98,663-673.

25.Jayjit,Roy.;Mahmut,Y.Energy efficiency and exporting:Evidence from firm-level data.Energy Economics.2015,52,127-135.

26.Li,D.;Zheng,Y.M.;Liu,C.Y.;Wu,G.Z.Numerical analysis on thermal performance of roof contained PCM of a single residential building.Energy conversion and management.2015,100,147-156.

27.Jacek,K.Complex thermal energy conversion systems for use of locally available

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 27 March 2017 doi:10.20944/preprints201703.0197.v1

biomass.Energy.2016,110,105-115.
28.Russel,S.;Paresh,K.N.Applied econometrics and implications for energy economics research.Energy Economics.2014,50,351-358.
29.Ohara,B.Y.;Lee,H.Exergetic analysis of a solar thermoelectric generator.Energy.2015,91,84-90.
30.Chen,Y.C.;Alan,M.Fuel consumption impacts of auto roof racks. Energy policy.2016,92,325-333.
31.Zheng,W.D.;Ye,T.Z.;You,S.J.;Zhang,H.The thermal performance of seawater-source heat pump systems in areas of severe cold during winter. Energy conversion and management.2015,90,166-174.