DETERMINANTS OF CARBON EMISSION IN AN OPEN ECONOMY: EMPIRICAL EVIDENCE FROM CHINA

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Abstract - This paper aims to examine the long-run equilibrium relationship and causal relationship between the variables of economic growth, carbon emissions, energy consumption and foreign trade in case of China for the period 1971-2013.The ARDL bound testing approach is applied to explore the long run cointegration relationship among the variables. Meanwhile,VECM Granger causality test is conducted todetect the causality between each variable in this study. The finding shows that long run cointegration relationship exists in CO_2 emissions, energy consumption, economic growth and trade openness, but it is not valid in the short-run. This result confirms that EKC hypothesis is a long run phenomenon in case of China. In addition, the Granger causal approach shows that bidirectional causal relationship can be found between CO_2 emissions and energy consumption in the long-run. In the short-run uni-directional causality running from trade openness to CO_2 emissions, this means government can reduce CO_2 emissions in a variety of different ways without affecting economic growth.

Keywords - ARDL method, carbon emissions, Environmental Kuznets curve, foreign trade

I. INTRODUCTION

Over the past 20 years, global climate change has become a common concern of international community. According to National Aeronautics and Space Administration (NASA) data show that for a century, global temperatures have risen by 0.75 degrees Celsius. Some island countries are facing the danger of being flooded by sea water. All of this is due to human being burning fossil fuels whichresults in large amounts of greenhouse gases emitted into the atmosphere, leading to the greenhouse effect and Earth's climate change dramatically. Therefore, climate change and global warming have become common threats for all mankind In early 1990s Grossman and Kruger [5] proposed the environmental Kuznets curvehypothesis based on the Kuznets theory which concerned with the relationship between economic development and environmental degradation. The EKC hypothesis states that environmental degradation is exacerbated at the beginning of economic development, but when a certain point is reached, environmental degradation is gradually weakened, forming an inverted U-shaped curve. So from another perspective, economic growth seems to be the cure to the environmental degradation. In the context of economic globalization, China as a developing country, economic growth is increasingly dependent on import and export trade .Now China is facing an embarrassing situation. One hand since accessed the WTO (World Trade Organization) in 2001, with the increasing intensification of liberalization and globalization of world trade, China's imports and exports volume have jumped from 509.6 billion US dollars to 3.953 trillion US dollars in 2016, is about 8 times as much as when China accession to the WTO. China is a country heavily dependent on foreign trade, trade dependence is often maintained above 40% [23].On the other hand along with the rapid expansion of China's foreign trade and economic development. China's energy consumption is increasing. China had overtaken US became the largest energy consumer in 2009.According to International Energy Agency (IEA), In 2015, China's total energy consumption is 3014.0 Mtoe, accounting for 23% of global energy consumption, while the United States consumption 2280.6 Mtoe, the absolutespreadis 32% [7].The Rapid economic development and energy demand growth caused fast growth in carbon emission. In the next period of time, China will face a series of environmental problems caused by carbon dioxide.

In this paper, short run and long run causality between the national income, carbon emission, energy consumption and trade openness can be detected by using Granger causality test based on the framework of vector error correction model (VECM).Moreover,the short run and long run cointegration relationship among variables can be derived from autoregressive distributive lag modelling (ARDL) cointegration approach .After this, in order to test our results is robust or not, Johansen and Juselius approach is considered as an effective method to verify the findings. Finally EKC hypothesis is confirmed when trade openness is set as a potential carbon dioxide influencing factor in case of China. Therefore, we can draw a conclusion that trade openness is a vital influencing factor on China's economic development and energy consumption, policymakers need to take trade openness into pollution control policy programs.

This research is structured as follows: Section 2 reviews the previous study, Section 3 illustrates the data and model used, Section 4 explains the estimation methodology, and Section 5 interprets the empirical results.Finally Section 6 concludes the paper.

II. SUMMARY OF LITERATURE

In the 1990s, Grossman and Krueger [5] studied the relationship between environmental pollution and income per capital for the first time, this is the embryonic form of Environmental Kuznets Curve theory. Panayotou [18] formally defined this relationship between environmental quality and per capita income as environmental Kuznets curve in 1993. In recent years, mankind has faced an unprecedented environmental challenge, so numerous literature about the impact of economic growth on the environment appeared. For instanceLau et al [11] examine the environmental Kuznets curve for Malaysia during the period 1970-2008 and the results confirmed that EKC hypothesis exists in both short-run and long-run. Arouri et al[2] used panel unit root test approach and panel error correction models in their paper to test the relationship between carbon emissions, energy consumption, real GDP for 12 Middle East and North African Countries (MENA) cover the period 1981 to 2005.The results indicate that energy consumption lead to CO_2 emissions in the long-run and real GDP has a squared relationship with CO_2 emissions. And EKC hypothesis can be proved exist in most studied countries but the evidence is weak and poor. Finally according to the empirical evidence the author suggested that MENA region countries can achieve the aim of reducing carbon dioxide emissions while the economy continues to grow. Ozturk and Acaravci[15] examine the long run relationship between the variables of trade openness, economic growth, financial development energy consumption and CO_2emissions. Based on the F-statistic of bound testing, author confirms the presence of EKC hypothesis in case of Turkey. Sbia et al [20] examined the relationship between foreign direct investment (FDI), clean energy, trade openness, carbon emission and economic growth in case of United Arab Emirates by using the quarterly time series data from 1975Q1-2011Q4.ARDL bounds testing combined with Granger causal relationship test are running in this research. The empirical results show that there are multiple bidirectional causal relationships among the variables like FDI with clean energy, carbon emission with economic growth, energy consumption with carbon emission. At last author concluded that foreign direct investment, trade openness and carbon emissions decline energy demand. Economic growth and clean energy consumption amount have positive impact on energy consumption.

In case of China. Xu and Lin [24] use 30 provinces annual data since 2000 to 2013 with nonparametric additive regression models to detect the source of CO2 emissions in China's manufacturing industry. The results show the evidence to support EKC hypothesis. Hao et al [6] probe the panel data of 29 provinces for the period of 1995-2012 to test the valid of EKC hypothesis. Finally EKC for the coal consumption is discovered. Ren et al [19] used industrial panel data based on two step GMM estimation to test the impact of FDI, trade openness, and economic growth on CO2 emission. The inverted U-shape relation was found in the research and EKC hypothesis is valid in China. Jalil and Mahmud [9] use the annual time series data onenergy pollutant, foreign trade, energy consumption and real incometo investigate the long-run relationship between those variables in the case of China's over the period 1975-2005.The purpose of this paper is testing whether Environmental Kuznets curve (EKC) hypothesis is valid or not. In this paper ARDL approach is used to test the long-run cointegraion relationship, and the results show that between income and CO2 emission there is a quadratic relationship exist in. Therefore it can be an evidence to prove EKC relationship. After that author used Granger causality test to find out the casual relationship and their direction. The results show that economic growth and also it square form are Granger cause carbon emissions but not vice versa. This study also indicates that real income and energy consumption are two major contributors to carbon emissions in the long-run.

III. MODEL CONSTRUCTION AND DATA

In order to test the existence of environmental Kuznets curve for China. Annual data of GDP per capital (current US$), energy consumption per capital, trade (% of GDP) and CO2 emissions (metric tons) per capital are obtained from World Development Indicators database. And all series are converted into natural logarithms forms so that results can be more efficient and consistent. The relationship between all variables can be estimated as follows:

$$C_t = f(Y_t, Y_t^2, E_t, T_t) \quad (1)$$

where C_t is CO_2 emissions per capita, Y_t (Y_t^2) are national income per capita and its squared form respectively, E_t is carbon emissions per capita, and T_t represents trade openness .In order to test whether Environmental Kuznets curve hypothesis is valid in China by incorporating pollutant emissions and trade openness as potential influencing factors, we transform all variables into natural log-form to obtain the consistent and efficient results. The model can be estimated like follows:

$$\ln C_t = \beta_1 + \beta_2 \ln Y_t + \beta_3 \ln Y_t^2 + \beta_4 \ln E_t + \beta_5 \ln T_t + \varepsilon_t \quad (2)$$

where $\ln C_t$is natural logarithmof CO2 emissions per capita,$\ln Y_t$ and$\ln Y_t^2$ are economic growth represented by GDP per capita and its square term,$\ln E_t$ is energy consumption per capita, $\ln T_t$ is trade openness(proportion of exports+ imports to GDP) per capita,ε_t is white noise. For the EKC hypothesis, each coefficient in the model should be like that: β_1 is constant term and could be $\beta_1 > 0$or $\beta_1 < 0$, and $\beta_2 > 0$ which means at the initial stage, the carbon

dioxide emissions increased with economic growth, while $\beta_3 < 0$, it implies that after economy research to a certain stage,CO2 emission will decline gradually. The consumption of energy will inevitably lead to an increase in carbon emissions, so β_4 should be positive i.e.,$\beta_4 > 0$.At last we cannot determine whether trade openness has a positive or negative impact on environment, so it would be $\beta_5 > 0$ or$\beta_5 < 0$.For this research, annual data for real GDP per capita (constant 2000 US$), carbon dioxide emissions (metric tons) per capita, energy consumption per capita and trade as share of GDP for China from 1971-2013 are collected from world development indicators(WDI-2016),World Bank.

IV. METHOLODOLOGY

Autoregressive distributed lag modelling (ARDL) or bounds testing approach proposed by Pesaran et al [16], which is utilized in this paper to detect the cointegration relationship among the whole variables. Compared with some traditional cointegration methods like Engle and Granger [4] two-step procedure or Johansen and Jeselius [9] approach, the ARDL model is exercisable when the variables are integrated at I (0), I (1) or mixture of I (0) and I (1).However if any integrated variables order higher than 1, it will not be processed.In terms of adaptability, bound testing has better property in small sample dataWhile Johansen cointegration approach is applicable only for large sample data and E&G two-step procedure is workable for two variables. Besides that, the ARDL model still remains long-run information while combining short–run dynamic and long-run equilibrium with unrestricted error correction model (UECM).The UECM can be expressed like that:

$$\Delta \ln C_t = \eta_1 + \eta_Y \ln Y_{t-1} + \eta_{Y^2} \ln Y^2_{t-1} + \eta_E \ln E_{t-1} + \eta_T \ln T_t + \sum_{j=1}^{p} \eta_j \Delta \ln C_{t-j} + \sum_{k=0}^{q} \eta_k \Delta \ln Y_{t-k} + \sum_{l=0}^{r} \eta_l \Delta \ln Y^2_{t-l} + \sum_{m=0}^{s} \eta_k \Delta \ln E_{t-m} + \sum_{n=0}^{t} \eta_k \Delta \ln T_{t-n} + \mu_i \quad (3)$$

Before examine the cointegration relations between the variables, an appropriate lag length should be confirmed by using Akaike information criteria (AIC). Then we use the critical bounds developed by Narayan [14].Compared to Pesaran et al [16]initial critical value, the new critical value generated byNarayan [14]is more suitable for small sizedata ranging from 30-80 observations, in order to determine whether there is cointegration between variables. The null hypothesis of no cointegration is $\eta_C = \eta_Y = \eta_{Y^2} = \eta_E = \eta_T = 0$ and alternative hypothesis of cointegration is $\eta_C \neq \eta_Y \neq \eta_{Y^2} \neq \eta_E \neq \eta_T \neq 0$.If F-statistic is higher than upper critical bound value then we reject the hypothesis of no cointegration.If F-statistic less then lower critical bound, which means no cointegration among the variables and we cannot determine the relationship of each variable if F-statistic is within the upper and lower critical bound. Once cointegration relationship confirmed, vector error correction model (VECM) should be applied to test the causal relationship between the variables. The VECM Granger causality test can be expressed as follows:

$$(1-L)\begin{bmatrix} \ln C_t \\ \ln Y_t \\ \ln Y_t^2 \\ \ln E_t \\ \ln T_t \end{bmatrix} = \begin{bmatrix} \tau_1 \\ \tau_2 \\ \tau_3 \\ \tau_4 \\ \tau_5 \end{bmatrix} + \sum_{i=1}^{p} (1 - L) \begin{bmatrix} b_{11i} b_{12i} b_{13i} b_{14i} b_{15i} \\ b_{21i} b_{22i} b_{23i} b_{24i} b_{25i} \\ b_{31i} b_{32i} b_{33i} b_{34i} b_{35i} \\ b_{41i} b_{42i} b_{43i} b_{44i} b_{45i} \\ b_{51i} b_{52i} b_{53i} b_{54i} b_{55i} \end{bmatrix} \times \begin{bmatrix} \ln C_{t-1} \\ \ln Y_{t-1} \\ \ln Y_{t-1}^2 \\ \ln E_{t-1} \\ \ln T_{t-1} \end{bmatrix} + \begin{bmatrix} \delta_1 \\ \delta_2 \\ \delta_3 \\ \delta_4 \\ \delta_5 \end{bmatrix} \times ECT_{t-1} + \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \\ \mu_{3t} \\ \mu_{4t} \\ \mu_{5t} \end{bmatrix} \quad (4)$$

where $(1-L)$ is difference operator and ECT_{t-1} is lagged error correction term, comes from long run error terms group. In this model, long run causality is captured by significant coefficient of ECT_{t-1} term using t-statistic. The short run causal relationship is expressed by a significant F-statistic using Wald-test by involving all the independent variables in the model. Moreover joint long-run and short-run causality can be derived from Wald-test as well. The next procedure we can apply the diagnostic test to examine the serial correlation, normality of error term, functional form and heteroscedasticity in the model. The stability of coefficients in short run and long run can be checked through cumulative sum (CUSUM) test and cumulative sum of squares (CUSUMSQ) test suggested by Pesaran and Shin [17].

V.RESULTS AND INTERPRETATIONS

At first is to test the stable condition of whole variables by using ADF test and PP test, because The ARDL model cannot process the variable integrated over order 1. The results of unit root tests are shown in Table 1.It can be seen that all variables are non-stationary at their level form and after 1st differencing unit root problem vanished.it implies that all variables are integrated at I (1), hence ARDL and Johansen and Juselius [8] approach are applicable for cointegration.The following step, before running the ARDL cointegration bound testing, asuitable lag length should be determined, so we choose AIC criterion because it has superior properties for small

sample data pointed by Lütkepohal [12]. The results show that the optima lag order is 1.Finally,it needs to determine whether there is a cointegration among the variables based on the calculated F-statistics. The F-statistics are reported in Table 2.

Variable	ADF		PP	
	I(0)	I(1)	I(0)	I(1)
$\ln C_t$	-1.95	-3.85**	-1.24	-3.87**
$\ln Y_t$	-0.36	-4.52***	-0.15	-6.25***
$\ln Y_t^2$	0.28	-5.45***	0.65	-5.45***
$\ln E_t$	-0.43	-4.38***	-0.08	-4.38***
$\ln T_t$	-1.77	-5.06***	-1.92	-5.09***

Table 1 - Unit root tests

Note: **, ***are Significant at 5% and 1% level of significance. The optimal lags was selected automatically using the AIC for ADF test and PP test.

Dependent variables	F-statistic	
$\ln C_t$	3.969**	
$\ln Y_t$	9.195***	
$\ln Y_t^2$	8.964***	
$\ln E_t$	1.5817	
$\ln T_t$	3.533*	
Critical value	Lower bounds	Upper bounds
1% Level	3.657	5.256
5% Level	2.694	3.289
10 Level	2.276	3.297

Table 2 -ARDL cointegration results

Note:*, ** and * represent significance at 10, 5 and 1% levels.Critical value are taken from Narayan [14] Appendix**

Hypothesis	Trace statistic	Max.Eigen value
R=0	73.304*	34.080*
R=1	39.223	23.848
R=2	15.374	10.014
R=3	5.360	4.997
R=4	0.3630	0.3630

Table 3 -Results of Johansen cointegration test

Note:* represents significant at 1% level

Dependent variable: $\ln C_t$			
Variable	Coefficient	Std.error	t-statistic
Long run results			
Constant	-8.705	0.929	-9.370***
$\ln Y_t$	0.435	0.163	2.663**
$\ln Y_t^2$	-0.028	0.011	-2.344**
$\ln E_t$	1.169	0.115	10.104***
$\ln T_t$	0.052	0.039	1.329
Short run results			
Constant	-0.002	0.007	-0.393
$\Delta \ln Y_t$	0.099	0.182	0.542
$\Delta \ln Y_t^2$	-0.004	0.023	-0.355
$\Delta \ln E_t$	1.163	0.125	9.291***

$\Delta \ln T_t$	0.071	0.034	2.115**
ECM_{t-1}	-0.495	0.151	-3.2588***
R^2	0.963		
$Adj - R^2$	0.942		
F-Statistic	7.425		

Diagnostic test	F-statistic	Probability
χ^2 *SERIAL*	1.427	0.240
χ^2 *NORMAL*	0.174	0.916
χ^2 *ARCH*	2.155	0.150
χ^2 *REMSAY*	2.413	0.129
χ^2 *WHITE*	0.116	0.734

Table 4 - Long run and short run results

Note: *, **,* are significant at 1, 5 and 10% respectively.**

The results show that our F-statistic value i.e., 3.969, 9.195(8.964) and 3.533 arehigher than the upper bounds critical value at 1, 5 and 10% levels of significance respectively. So the long run cointegrationrelationship can be confirmed, when CO2, GDP (GDP2), Energy consumption and Trade openness are treated as forcing variables. Furthermore, in order to examine the robustness of long-relationship, Johansen and juselius [8] cointegration approach was applied and the results are shown in Table 3.The finding confirms the robustness of long-run relationship among the variable of energy consumption ,economic growth, trade openness and carbon emissions. The results of marginal impact of economic development, energyconsumption and trade openness on carbon emission are presented in Table 4.The results approve that inverted-U shape relationship does exist between economic growth and CO2 emissions. The positive and significant coefficient of GDP implies that 1% raise in real income will increase 0.435% in CO2 emissions, while the negative coefficient of square term of GDP shows that 1% increase in real GDP will associated with a decline in pollutant emissions in the later period of time. These evidence support the EKC theory as carbon emissions will increase with economic development in the early stage while reach a threshold it will turns down. This conclusion is consistent with Lin and Wang [10], Song et al [21].

The results show that energy consumption is the major contributor to the pollutant emissions in the long-run. A 1% raise in energy consumption is linked to 1.16% increase in CO2 emissions. According to BP Statistical Review of World Energy 2016[3], China is the largest energy consumption country for 15 consecutive years. Due to the own resource advantage, coal accounts for more than 60% of primary energy consumption in China. Crude oil is also one of the major energy in China, accounting for more than 15% of China's total energy consumption, In 2011 China exceeded the United States as the largest oil importer and consumer. Facing enormous energy and environmental pressures, the Chinese government has issued a series of laws on energy conservation. By 2015, the dominance of coal in China's energy structure has declined, accounting for 63.7%, a record low. At the same time hydropower, wind power, nuclear power and other clean energy consumption is also booming. At present, China's hydropower, wind power, and solar power installed capacity ranks first in the world. The sign of trade openness is positive but not significant. The coefficient of trade openness is 0.052 in the long run, which implies trade openness is responsible for CO_2 emission, but the share is very small compared to other influencing factors. Jalil and Mahmud [9] has discussed in their research, they believe the fact that the coefficient of trade is not significant could be attributed to the relative strength of several opposing factors. The short run results arepresented in the other part of Table 4.it is obvious that both in linear and nonlinear term, real GDP and its square form have the expected sign but insignificant, it indicates that EKC hypothesis does not valid in short run for China. A possible explanation could be that EKC hypothesis is a long run phenomenon.

This conclusion is consistent with Ahmad et al [1], Nasir and Rehman [13]’s finding in Croatia and Pakistan. Furthermore, the error correction term (ECM_{t-1}) is significant and has negative sign, confirming the long run association exist in the variables and it is stable. The coefficient is -0.495 indicates that any variation in CO_2 emissions in previous year would corrected by 49.5% over the following year.

Diagnostic tests results are also presented in the Table 4.The short run model has passed all diagnostic tests such as serial correlation, white heteroscedasticity ,non-normality of error term, autoregressive conditional heteroscedasticity and model specification. At last cumulative sum (CUSUM) andcumulative sum of squares (CUSUMSQ) are conducted to test the stability of the short run and long run parameters. The plotof CUSUM and

CUSUMSQ are presented in Fig 1 and Fig 2.it is find that both statistics are well within the critical bounds. This confirms the stability of estimated parameters over the study period.

Dependent variable	Short run(probability)					Long run
	$\ln C_t$	$\ln Y_t$	$\ln Y_t^2$	$\ln E_t$	$\ln T_t$	ECM_{t-1} (t-statistic)
$\ln C_t$	_____	1.151 [0.2832]	0.556 [0.455]	0.985 [0.320]	3.110* [0.077]	-0.3912*** [-3.660]
$\ln Y_t$	0.222 [0.640]	_____	4.055** [0.044]	0.639 [0.424]	1.781 [0.183]	-0.117 [-0.468]
$\ln Y_t^2$	0.222 [0.637]	5.304*** [0.021]	_____	0.977 [0.322]	2.008 [0.156]	0.045 [0.843]
$\ln E_t$	1.086 [0.297]	1.796 [0.180]	1.6368 [0.200]	_____	0.569 [0.450]	-1.153*** [3.510]
$\ln T_t$	0.021 [0.883]	7.453*** [0.0063]	9.631*** [0.0019]	0.022 [0.881]	_____	-0.374*** [3.265]

Table 5 -VECM Granger causality results

Note: ECT represents error correction term.*, **, * are 10%, 5% and 1% significance level, respectivel**

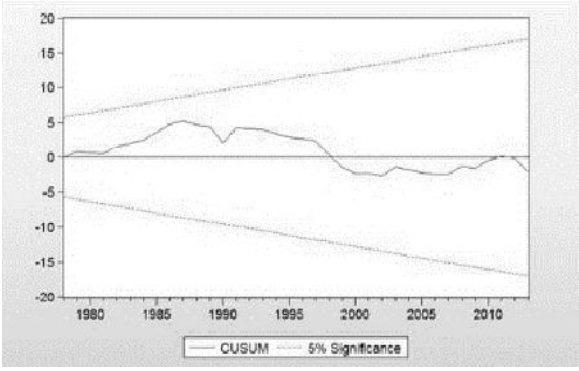


Figure 1: Plot of cumulative sum of recursive residuals. (The straight lines represent critical bounds at 5% significance level)

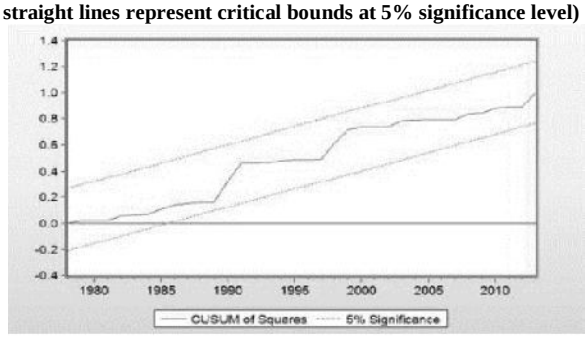


Figure 2: Plot of cumulative sum of squares of recursive residuals. (The straight lines represent critical bounds at 5% significance level)

A. The VECM Granger causality analysis

After the short run and long run cointegration relationship between the variables is determined, the next step we should specify the direction of causality among the variables. For this reason, the directional short run and long run causality is checked through VEC model. The findings are presented in Table 5, where we can find that unidirectional causal relationshipfrom trade openness to CO_2emissions in short run. Furthermore, unidirectional causality running from economic growth to trade openness is also found exist in short run. In the long run, there is a unidirectional Granger causality running from economic growth to CO_2emissions, this confirms EKC hypothesis is valid in case of China. Moreover, bidirectional causality also can be found betweenenergy consumption and carbon emissions, trade opennessand carbon emissions. Not only that it is observed that energy consumption and trade openness Granger cause each other in the long run. This conclusion is consistent with Sadorsky [22]'s finding for South Amrica.

CONCLUSION AND POLICY IMPLEMENTION

In this study, we investigates the short run and long run and causal relationship between CO_2 emissions, economic growth, energy consumption and trade openness in case of China over the period 1971-2013.The ARDL bound testing approach is used to detected the cointegration relationship among those variables, the bound testing F-statistic supporting the evidence of cointegration relationship among the variables in the long run .For the short run, significant and negative sign of lagged error term indicates the short run equilibrium adjust to the long run in the speed of 49.5% a year. However,with expected sign but non-significant of economic growth states that EKC hypothesis a long run phenomenon rather than short run. This study also test the causality between the variables by using VEC model. The short run and long run Granger causality tests results are summarized as follows:

1. In the short run.Unidirectional causal relationship is find running from trade openness to carbon emission. Moreover, economic growth is a Granger cause of trade openness and not vice versa.
2. In the long run. Bidirectional causality can be found between energy consumption and CO_2emissions, same conclusion also can be found between trade openness and CO_2emissions. Energy consumption and trade openness Granger cause each other.

From the results we obtained, it is obvious that trade openness is an important factor in affecting CO_2 emissions in the short run and long run. Since China joined the WTO (World Trade Organization) in 2001, export-oriented trade pattern has made a great contribution to the Chinese economy, foreign trade is growing faster than economic growth. In this context, the policy makers in China should incorporate environmental protection into the foreign trade enterprise assessment system. In the meantime, encouraging and supporting local industries to learn advanced foreign technology, reducingtaxes and fees of green industry and high-tech industry. Because unidirectional Granger causality running from economic growth to carbon emissions, furthermore, energy consumption and CO_2 emissions Granger cause each other. Therefore, carbon emissions can be reduced by controlling energy consumption without affecting economic development. This means that while continuing to promote energy conservation policies, China can develop alternative clean energy, such as solar energy, wind energy, hydro energy.

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