JOURNAL OF PURE AND APPLIED MICROBIOLOGY, Sept. 2015. Vol. **9**(3), p. 1867-1874

The Dynamic Relationship between Carbon Emissions and Economic Growth in China

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(Received: 09 April 2015; accepted: 21 May 2015)

The relationship between economic growth and carbon emissions has become a hot issue of research. We use the dynamic correlation multivariate stochastic volatility model to study the dynamic relationship between carbon emissions and the economic growth. We firstly exam the co-integration and Granger causality relation. We find that they have a long-term stable relationship and the economic growth is the Granger cause of carbon emissions. We then use DC-MSV model to recover the time-varying correlation coefficient between Chinese GDP. We find that the correlation coefficient is very high and has great time-varying property. Lastly we use the time-varying correlation coefficient to forecast Chinese green economic growth rate and has great forecast power.

Key words: Multivariate Stochastic Volatility Model; Time-varying Correlation Coefficient; Green Economic Growth Rate.

With the rapid development of Chinese economic, the carbon emissions grows rapidly. Face to the deteriorating natural environment, the view of the Chinese government on economic development and environment development become the primary consideration question that whether China can realize the sustainable development. Which is very worthy of study is the correlation between carbon emissions and economic development of China.

From the existing research, Selden *et al* (1994), Hocaoglu *et al* (2011), Peters *et al* (2012) have researched carbon emissions and economic development of developed countries. From the domestic research, Zhu Yongbin *et al* (2009) did the improvement base on the endogenous economic growth model, the new model can effectively reflect the dynamic mechanism between carbon emissions and economic development. Zhao Aiwen *et al* (2011) have studied the cointegration and Granger causality relation between carbon emissions Chinese economic development, find that they have a long-term and reciprocal causation relationship, Error correction model is a better choose. This paper put forward the "low carbon economy" suggestions. Zheng Changde (2011) by using the method of spatial econometrics to study the relationship between carbon emission and economic growth of provinces in the Chinese. The results showed that the carbon emissions showed a certain spatial correlation in space. There was a positive correlation between and carbon emissions and the region's economic development level. Under the realistic background of the improving carbon emissions in China, Zhang (2011) studied the influence factors of carbon emissions in different regions in China. Du Qiang *et al* (2013) predicted carbon emissions by the Logistic model and

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showed the great accuracy. Wang *et al* (2014) studied the relationship between the economic development and carbon emissions of Guangdong Province.

By reading existing literature we found, scholars generally believe that there is a positive correlation between carbon emissions and economic development. However, as we can see, the existing research about carbon emissions and Chinese economic development is static analysis, almost no articles discuss the dynamic correlation between carbon emissions and Chinese economic development. From the intuition we can obviously feel relationship between the economic development and carbon emissions is not fixed, in some years, it's high, but in some years, it's low. What the information about this change is worthy of our in-depth analysis. So this paper focused on the dynamic correlation between the carbon emissions and economic development and its prediction ability.

The main work can be divided into three parts: (1) the basic research on the relationship between carbon emissions and economic growth, including the Cointegration and Granger causality; (2) Using the dynamic correlation multivariate stochastic volatility model (DC-MSV model) to extract correlation coefficient between carbon emissions and Chinese gross domestic product (GDP); (3) Using the regression analysis method to study the prediction ability of the dynamic correlation coefficient on the Chinese green economic growth rate.

Compared with the existing studies, the paper has the following characteristics: First of all, this paper firstly uses the DC-MSV model to extract the time-varying correlation coefficient between carbon emissions and GDP. Compared with the existing static analysis, the economic implications of time-varying correlation coefficient is clearer; secondly, we construct a simple green economic growth index; thirdly, this paper analyzes the predicting ability of the dynamic coefficients on the green economic growth rate.

The subsequent sections of the article is as follows: The second part introduces the research method of this paper, mainly introduces the theoretical model and the empirical design, the third part is the empirical analysis, and the fourth part is the conclusion and the policy suggestions.

Research methods

Model introduction

In this paper, the main research work is studying time-varying correlation between carbon emissions and economic development in China. By reading existing literature, we can use the multivariate GARCH model and the multivariate stochastic volatility model (MSV model) to launch the analysis. By comparing the multivariate GARCH model and the multivariate stochastic volatility model, we found the multivariate GARCH model has an obvious shortage in describing randomness. It considers the volatility equation is purely a functional relationship without considering the randomness of the volatility. This serious deficiency makes the application of the multivariate GARCH model unsatisfactory. To solve this problem, researchers have proposed a multivariate stochastic volatility model. The model introduced a random item in the volatility equation, and the random process was introduced in the model, so that the accuracy of the model greatly enhance. So this paper uses multivariate stochastic volatility model to study the correlation between carbon emissions and economic development. In order to estimate the time-varying correlation coefficient, so this paper select the dynamic correlation multivariate stochastic volatility model (DC-MSV model) in all MSV model to do the research. The model is as follows:

Suppose y_t is the logarithmic growth rate at time t.

$y_t = (y_{1,t}, y_{2,t})', t = 1,2,3\ldots T$; $\varepsilon_t = (\varepsilon_{1,t}, \varepsilon_{2,t})'$;

$\eta_t = (\eta_{1,t}, \eta_{2,t})'$; $u = (u_{1,t}, u_{2,t})'$; $h_t = (h_{1,t}, h_{2,t})'$;

$\Omega_t = diag(\sigma_t)$;

$$\phi = \begin{pmatrix} \phi_{11} & \phi_{12} \\ \phi_{21} & \phi_{22} \end{pmatrix}; \ \Sigma\varepsilon = \begin{pmatrix} 1 & \rho_\varepsilon \\ \rho_\varepsilon & 1 \end{pmatrix}; \ \Sigma\eta = \begin{pmatrix} \sigma_{\eta1}^2 & \rho_\eta\sigma_{\eta1}\sigma_{\eta2} \\ \rho_\eta\sigma_{\eta1}\sigma_{\eta2} & \sigma_{\eta2}^2 \end{pmatrix}$$

DC-MSV can be expressed as:

$$y_t = \Omega_t\varepsilon_t \qquad \varepsilon_t \sim N(0, \Sigma\varepsilon, t) \qquad \Sigma_{\varepsilon,t} = \begin{pmatrix} 1 & \rho_{\varepsilon,t} \\ \rho_{\varepsilon,t} & 1 \end{pmatrix} \qquad \ldots(1)$$

$$\mathbf{h}_{t+1} = \mu + diag(\phi_{11}, \phi_{22})(\mathbf{h}_t - \mu) + \eta_t$$

$$\eta_t \sim \mathrm{N}(0, \mathrm{diag}(\sigma_{\eta1}^2, \sigma_{\eta2}^2)) \qquad \ldots(2)$$

$$q_{t+1} = \psi_0 + \psi(q_t - \psi_0) + \sigma_\rho \upsilon_t \ \ \upsilon_t \sim N(0,1)$$

$$\rho_t = \frac{\exp(q_t) - 1}{\exp(q_t) + 1}$$

$h_0=\mu$, Formula (1) is the logarithmic growth rate equation of the sample, $\mathbf{y_t} = (r_t^c, r_t^g)'$ t=1,2...T are from the logarithmic growth rate from t-1 to t moments. $W_t=\text{diag}(h_t)$, $h_t= (h_{1,t},h_{2,t})'$ are the two-dimensional standard deviation vector. $\varepsilon_t=(\varepsilon_{1,t},\varepsilon_{2,t})$ Obey the two-dimensional multivariate normal distribution. Its mean value is 0. $\sum_{\varepsilon,t} = \begin{pmatrix} 1 & \rho_{\varepsilon,t} \\ \rho_{\varepsilon,t} & 1 \end{pmatrix}$ is the covariance matrix. ρ_ε is the correlation coefficient.

Formula (2) is the volatility equation. $\mu=(\mu_1,\mu_2)$ is 2×1 dimensional parameter vector. $\phi_{11} 0 \phi_{22}$ are parameters. $\eta_t=(\eta_{1,t},\eta_{2,t})'$ $\mathbf{\eta_t} = (\eta_{1,t}, \eta_{2,t})'$ is normal distribution which mean is 0 and variance is $diag(\sigma_{\eta1}^2,\sigma_{\eta2}^2)$. $\sigma_{\eta1}^2\, 0\, \sigma_{\eta2}^2$ are parameters.

Formula (3) is the correlation coefficient equation. We can see from (3), correlation coefficient is a function of q .So it can clearly show the time-varying property. This article get the correlation coefficient between carbon emissions and Chinese GDP according to this model.

Empirical design

We need to go through several steps as follows in the entire empirical design:

a) Data selection and testing. We choose Chinese carbon emissions data and GDP data between 1980 and 2012 to do the empirical analysis. The data is from the Chinese statistical yearbook. When collecting the data, we found there is some missing data in some years. So we uses three times spline (Cubic Spline) interpolation method to cover the problem. In the data test, the first thing to do is to stationary test. In this paper, we use the ADF test method to do the stationary test. If the data is not stationary, we use log or difference method to make the data stationary.

b) Cointegration Analysis and Granger causality test. In the study of the relationship between carbon emissions and economic development, we need to test the causal relationship between them. In this paper, we use the Granger causality method to test the relationship between them. In order to further explain the relationship between them, this paper use the method of regression to study the relationship between them, the two model constructed as follows:

$$\text{carbon}_t=a+b\text{GDP}+\varepsilon_t \qquad ...(4)$$

$$\text{GDP}_t = c + d\text{carbon}_t + \varepsilon_t \qquad ...(5)$$

c) Extracting the time-varying correlation coefficient. In this section we mainly use the sample data of carbon emissions and GDP from 1980 to 2012 and DC-MSV model to do the empirical analysis. Doing the parameter estimation and extracting the time-varying correlation coefficient.

d) Using the time-varying correlation coefficient to do the prediction. When we get the time-varying correlation coefficient, we want to test the information of the coefficient. The main work is the forecast the Chinese green economic growth rate by using time-varying correlation coefficient.

The empirical results

Stationary test of carbon emissions and GDP time series

We found that there are some missing values in the samples of carbon emissions, so we use the method of Cubic Spline to do the interpolating. The time sequence of carbon emission and GDP, are shown below:

From Figure 1 and Figure 2 we can see clearly that carbon emissions and GDP have obvious rising trend year by year, it is clear that the two time series are not stationary, so we should further to do the time series stationary test.

In this paper, we use the ADF test for stationary analysis, for the non-stationary time series we use the logarithmic and logarithmic growth rate to verify, and then test the non-stationary again. The result is shown in table 1.

From the results in table 1, we can see that the data of carbon emission and GDP themselves and their logs are non-stationary time series. The logarithmic growth rate of carbon emission and GDP are stationary time series. Their P-values are 0.03 and 0.01. So it can reject the null hypothesis of unit root exists at a confidence level of 5% and 1%. It can be said that the logarithmic growth rate time series are stationary time series.

2. Co-integration Analysis and Granger causality test

Co-integration Analysis

From the stationary test we found that, the first order difference of the logarithm of the GDP and carbon emissions are stationary time series. It shows that the two groups of time series are integrated of order. Thus we have to consider whether there is a long-term stable relationship between them, That is, the co-integration relationship. In this paper, we use the commonly used "Engel- Grainger two step method" to test the co-integration relationship between them.

First of all, using the regression method to do the regress between In(carbon) and In(GDP). We find it was autocorrelation. So we further addition of lags in the regression model. Results as shown in the following table.

Table 1. Stationary test of the time series

Series	t-value	P-value	Conclusion
carbon emissions	1.026	0.99	non-stationary
Log of carbon emissions	-0.27	0.92	non-stationary
Log growth rate of carbon emissions	-3.14	0.03	stationary
GDP	2.76	1.00	non-stationary
Log of GDP	-0.83	0.79	non-stationary
Log growth rate of GDP	-3.57	0.01	stationary

Table 2. Regression results between in (carbon) andin (GDP)

Dependent Variable	constant	ln(GDP)	ln(GDP (-1))	ln(GDP (-2))	ln(carbon (-1))	ln(carbon (-2))	adj.R^2
ln(carbon)	-0.06	0.35*	-0.56*	0.24*	1.5***	-0.6***	0.99

Table 3. Granger causality test between In (carbon) and In(GDP)

Null hypothesis	F-value	P-value	conclusion
In (GDP) is not Granger cause of In (carbon)	6.05	0.01	Reject
In (GDP) is not Granger cause of In (carbon)	0.29	0.94	Cannot reject

Table 4. Estimation results of the DC-MSV model

Para	mean	S.D.	MC error	2.5%	Median	97.5%	Start	Num
u_c	-5.45	0.46	0.018	-6.41	-5.44	-4.58	40001	60000
u_g	-3.65	0.30	0.015	-4.27	-3.65	-3.08	40001	60000
f_{cc}	0.90	0.07	0.002	0.72	0.92	0.99	40001	60000
f_{gg}	0.86	0.10	0.01665	0.60	0.88	0.99	40001	60000
$s_{\eta c}$	33.63	35.2	1.67	4.37	20.98	133.9	40001	60000
$s_{\eta g}$	98.42	62.69	1.97	16.62	85.73	255.4	40001	60000
ψ_0	2.38	0.48	0.03	1.58	2.33	3.47	40001	60000
ψ	0.86	0.11	0.002	0.59	0.89	0.99	40001	60000
σ_p	96.08	63.47	2.33	13.55	82.67	253.9	40001	60000

Table 5. On the prediction ability of the time-varying correlation coefficient

Dependent Variable	constant	gradient	adj.R^2
$GGDP_{t+1}$	103.47***	-125.83***	0.62

The DW statistic is 2.14. it can say that the residuals does not exist autocorrelation. From the regression results we can see, except the constant term, the other items are significantly different from 0. Using these regression coefficient, we can get the long-term relationship between GDP and carbon emissions. The coefficient of long-term relationship is calculated as follows:

$$b = \frac{0.35 - 0.56 + 0.24}{1 - 1.25 + 0.6} = 0.86$$

So we can say the long-term relationship between GDP and carbon emissions is:

In(carbon) = 0.86 In (GDP)

Then stationary test of the residuals of the regression. Also using ADF method to test stationary of residuals. The result show that the t-value of the ADF is -5.62 and the P-value is 0.0001. So there is reason to believe that the residuals are stationary time series. Using this two steps method we can say that the relationship between In(carbon) and In (GDP) is long and stable.

Granger causality test

From the above analysis we see that there is a long-term stable relationship between economic growth and carbon emissions, then we will ask, economic growth and carbon emissions, who is the cause, who is the result? So we further use the Granger causality test methods to determine the causal relationship between them. The result is shown in table 3.

From the results of Granger causality test, we can think that the increase of GDP is the Granger reason of the increasing carbon emissions, but the carbon emissions increasing is not the Granger causality of the growth of GDP. The results show that, when the economy is growing, the national income increases, the people's consumption level increases, the carbon emissions will increase. But conversely, increasing carbon emissions is not the

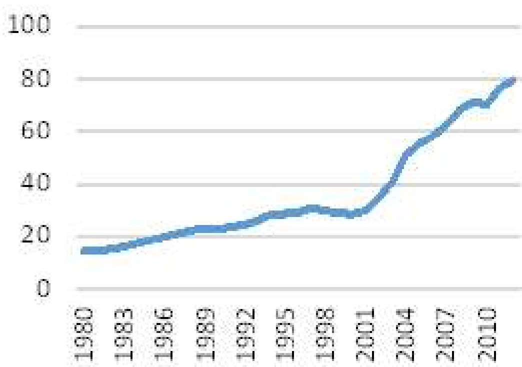

Fig.1 Time series of carbon emission

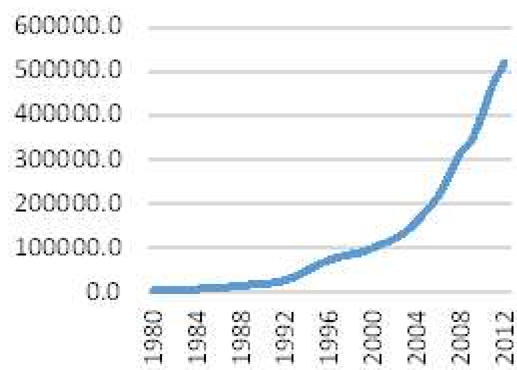

Fig.2. Time series of GDP

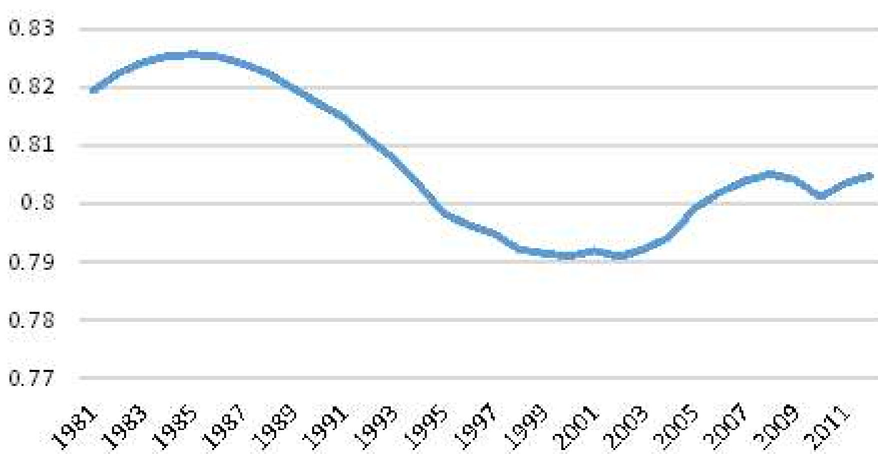

Fig.3. The dynamic correlation between the logarithmic growth rate of carbon emission and GDP

cause of economic growth. This suggests that economic growth does not necessarily rely on the increase in carbon emissions. The China low carbon environmental protection economic growth route in China has its economy basis.

The correlation coefficient between carbon emissions and GDP

From the above analysis, we can clearly see that there exist a very significant correlation between carbon emissions and GDP. The main contents of this section is further studying the time-varying correlation between carbon emissions and GDP. We use the dynamic correlation multivariate stochastic volatility model to do the research. The concrete form of model can be seen in section 2. The stochastic volatility model can well describe the random fluctuations of the volatility, it has a better result than the GARCH model. But because of the more troublesome of its parameter estimation, especially the multivariate stochastic volatility model multivariate GARCH model. It is not as widespread as GARCH model. With the development of Bayesian parameters estimation method, using the method of Markov Monte Carlo (MCMC) to estimate the stochastic volatility model has become more and more important. This method is a good solution to the parameter estimation of stochastic volatility model. MCMC greatly enhance the application of the stochastic volatility model. Just as Wang Yifeng(2012) used Slice Sampling method to do the MCMC.

The basic idea of MCMC method is to construct a Markov chain with stationary distribution $\pi(\theta+x)$. Then a large number of iterations are processed, until the distribution on the chain is close enough to the stationary distribution. At this time, repeated sampling, viewing the samples from the chain as coming from $\pi(\theta+x)$, do the parameter estimation based on these samples. When the Markov chain is stationary, the resulting value from sampling can be considered the values obtained from $p(\theta+y)$.

The core of construct a Markov chain is to determine the transfer kernel p(.,.). The different MCMC method has different nuclear transfer method. Such as the Metropolis-Hasting sampling, Gibbs sampling. In this paper we select the Gibbs sampling method to estimate MCMC parameter.

We use the WinBUGS software to do the parameter estimation of the DC-MSV model. We found that DC-MSV model has following parameters: υ_c 0 υ_g 0 ϕ_{cc} 0 ϕ_{gg} 0 $\sigma_{\eta c}$ 0 $\sigma_{\eta g}$ 0 ψ_0 0 ψ 0 σ_ρ. We do 100000 times iterations. In order to obtain a smooth sequence, we omit the first 40000 times results, use last 60000 iteration results to do the parameter estimation. It is worth noting, when we use the multivariate stochastic volatility model, the sample need to be the stationary time series. So we use their logarithmic growth rate to do the empirical analysis. Parameter estimation results as shown in the following table.

According to the calculation formula of t value, we find the above parameters are significantly different from 0. Using the above estimation results, we can get the dynamic correlation coefficient between the logarithmic growth rate of carbon emissions and GDP. The result is shown in Figure 3.

First of all, there exist a very strong correlation between the logarithmic growth rate of carbon emissions and GDP. From 1980 to 2012, the correlation coefficient between them is above 79%, which shows that there is a strong positive relationship between economic development and carbon emissions in china. The result further shows that the economic growth in china is a kind of extensive economic growth mode in the past many years. Economic development is closely related to carbon emissions. The dynamic correlation further tells us that we need to take the road of sustainable development.

Secondly, from 1980 to 2012, the overall correlation coefficient between Chinese economic growth and carbon emission becomes small. This is a very good news, it suggest that after years of development, China has recognized the relationship between economic growth and environmental protection. The reducing of the correlation coefficient suggest that the development of Chinese economic is gradually getting rid of high carbon emissions.

Thirdly, after 2003 the correlation coefficient increases. We think the main reason is Chinese entering a new round of economic development period. Since 2003, the real estate market and the infrastructure construction play a great role. It make great contribution to the economic growth. But due to the poor utilization rate of the resource, these investment greatly increased carbon emissions, makes the correlation between economic growth and carbon emissions further increase. The increase of the correlation coefficient can be a reason for Chinese deteriorating ecological environment recent years. This is also an important reason for the haze in recent years in China.

The predictive ability of the correlation coefficient

From Figure 3 we can see that the correlation coefficient between carbon emissions and GDP has strong time variant property. The time-varying illustrates the dependence between Chinese economic development and carbon emissions, we naturally want to know the information about the coefficient correlation. Whether it has predict power in forecasting the Chinese green economic growth. So in this segment, we use the regression analysis method to study the prediction ability. Mainly use the time-varying correlation coefficient to predict the "green" rate of growth.

We construct the green economic growth index by ourselves. Although we can find some index which can stand for green economic growth in some database, but the data time is too short to have a substantive help for our research. So this paper construct an index which can reflect green economic growth index- Green Economic Growth Rate (GEGR). Its construction method is as follows:

(1) We use Chinese GDP and carbon emissions data in1980 for the base period.
(2) We use GDP and carbon emissions data every year, divided by the base period and then minus 1 to get the GDP growth rate and carbon emissions growth rate.
(3) We get Green Economic Growth Rate by using the GDP growth rate minus the carbon emissions growth rate. In our green economic growth rate we have deduced the effect of carbon emissions. We can think this rate can better reflect Chinese green economy development than GDP growth.

In this paper, we use to correlation coefficient between carbon emissions and GDP to predict green economic growth rate. The model is as follows:

$$GGDP_{t+1} = \alpha + brhoep_t + \varepsilon_t \qquad ...(6)$$

$rhoep_t$ is the correlation coefficient between GDP and carbon emissions at time t. $GGDP_{t+1}$ is the green economic growth rate at time t+1. The regression results as shown in the following table.

From the results of the regression in Table 5 we can see, time-varying correlation coefficient has great predictive power on Chinese green economic growth rate:

First of all, from the regression coefficient, the slope of regression is -127.47. That means when the correlation coefficient rises, Chinese green economic growth rate will decline. The conclusion is consistent with the actual situation. The results of this regression shows that, when the correlation coefficient rises, the relation between the Chinese economic development and carbon emissions more closely. It cause Chinese green economic growth rate dropped, so that the green development strategy becomes more difficult.

Secondly, from the view of the adjusted R square, it's 62%. That says the current correlation coefficient has great explanation capability for the next phase of green economic growth rate, it has a good prediction effect. To prove this point, we use sample data from 1980 to 2011 to forecast Green economic growth rate of 2012, and compared with the true value of the Green economic growth rate of 2012. The predictive value is 4.5861, the true value is 4.6548. The prediction result is in the area of the two standard deviation. We can see that the forecast value and is very close to the actual value. So we think that using dynamic correlation coefficient between carbon emissions and GDP is a good predictor of Chinese green economic growth rate.

CONCLUSIONS

Through the analysis, we found that

(1) There is a long-term stable relationship between carbon emissions and economic growth: In (carbon). This shows that the logarithm of GDP each increase of 1 units, will make the logarithmic carbon emissions increased by 0.86 units.
(2) The GDP growth is the Granger reason for carbon emissions, but carbon emissions is not the Granger cause GDP growth;
(3) There is a very strong time-varying correlation between carbon emissions and GDP, The time varying correlation coefficient is between

0.79 and 0.83.

(4) Time-varying correlation has great forecasting effect in green economic growth rate.

Policy recommendations

According to the research results of this paper, we give the following policy recommendations:

(1) Developing the low carbon economy, reducing carbon emissions and improving the level of economic development. From the results of Granger causality test, carbon emissions is not the Granger cause of the economic development. This shows that economic development is not totally dependent on high carbon emissions, so we can improve the level of economic development by developing the low-carbon economy.

(2) Reduce the dependence of carbon emission, realize the green economy. We can see from the result of the prediction of the correlation coefficient, when the correlation coefficient of GDP and carbon emissions is low, green rate of economic growth in China is high. From this we can clearly see that, when we can reduce the correlation coefficient between economic development and carbon emissions, the green economic growth rate will increase substantially, and it will realize sustainable development.

(3) Vigorously develop renewable energy, promote recycling economy. This study shows that, the lower correlation coefficient between GDP and carbon emissions will increase the green economic growth rate. So in order to reduce the correlation coefficient, Chinese should vigorously develop renewable energy, including Nuclear energy, wind energy, tidal energy and so on. At the same time, developing the recycling economy, improving the utilization rate of the product are effective ways to reduce carbon emissions.

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