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Efficiency of Financial Development on Improving Technological Innovation: Interactions with Carbon Markets

Li Zhou, Qing-Yi Chen and Ning Zhang
School of Management, Minzu University of China, Beijing, 100081, China

Abstract: Along with the global climate warming and the arrival of the energy crisis, low-carbon economy got more concerns from people. Previous studies showed that financial development will promote enterprise technological innovation and industrial upgrading; enterprises can increase the investment in R and D sector by financial support and this action will finally improve the production efficiency. By constructing the endogenous growth model, it proved that technological innovation is the basic reason to promote the low-carbon economy. In addition, by building the vector auto regression model to analyze the relationship between financial development and energy efficient, the result shows that: First, financial development is the granger reason to energy efficient increased; Second, there exists a long-term equilibrium relationship between financial development and energy efficiency; Third, variance decomposition also shows that financial development can certain explain the improvement of energy efficiency, the contribution degree of financial development to energy efficiency is about 30-40% in the all time period. To sum up, financial development is the main factor to improve energy efficiency.

Key words: Low-carbon economy, financial development, energy efficient, variance decomposition, co-integration analysis

INTRODUCTION

In recent decades, the energy consumption growing faster with China's rapid economic grows. However, the energy efficiency in China is still at a low stage, so that how to improve the energy efficiency has become an important concern. Fossil fuel consumption was increased significantly and resulting in environmental pollution and climate warming. This has seriously affected the ecological balance and human health. At present, China has put forward the strategic goal of improving energy efficiency. Low-carbon economy requires changing the present situation of high energy consumption and improving energy efficiency through the energy structure optimization and innovation. Previous studies showed that financial development will promote enterprise technological innovation and industrial upgrading; enterprises can increase the investment in R and D sector by financial support and this action will finally improve the production efficiency. However, as China is an emerging country, this financial institution and financial service is not efficient, so that it still need research on the effectiveness of how the financial development will effect on China's low-carbon Economic Growth.

With the rapid economic growth in China, China has also facing a sharp energy consumption growth. China's total energy consumption equals as 3.62 billion tons of standard coal in 2012, increased by 3.9% from the previous year. Although in recent years China's energy efficiency has improved significantly but China's energy efficiency is still at the low stage when compared with other developed countries. Yuan *et al*. (2008) pointed out that China's economic growth has a stable relationship with energy consumption. That means China is an energy-dependent economy and energy is a limiting factor to output growth in China. By comparing China's annual energy consumption and economic growth data from 1990 to 2011, the result indicates that the energy consumption and economic growth have synchronous growth trend, as shown in Fig. 1.

In Fig. 1, primary Y-axis (left side) indicates China's gross domestic product (GDP), the unit is one hundred million RMB; secondary Y-axis (right side) indicates energy consumption, the unit is ten thousand tons of standard coal. From Fig. 1, it shows that the rapid growth of China's Gross Domestic Product (GDP) is based on increased energy consumption. From year 2002 China's GDP began to rapid growth while energy consumption has started to increase sharply. Meanwhile, China's current energy efficiency is low; the economic growth mainly depends on

Corresponding Author: Li Zhou, School of Management, Minzu University of China, Beijing, 100081, China

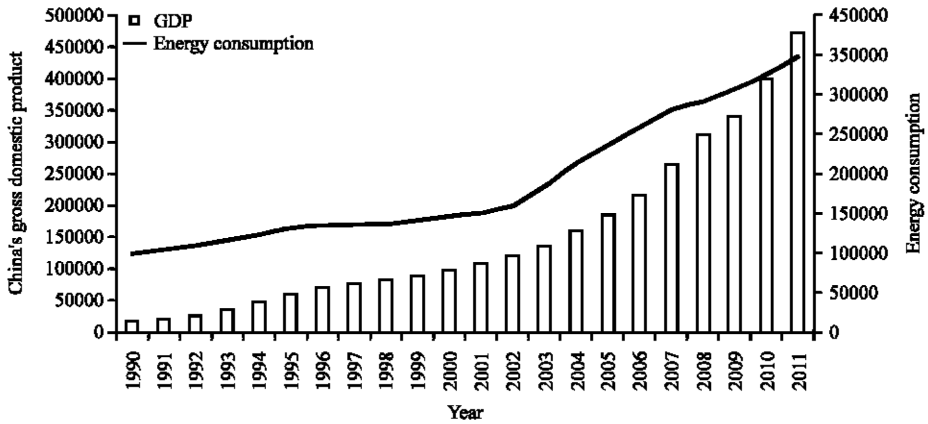

Fig. 1: Trend of GDP and energy consumption during 1990-2011 in China

the energy consumption, so that the extensive economic growth mode is still the main development pattern.

Osborne and Kiker (2005) pointed out that although developing countries adopted a variety of measures in climate change mitigation but the decrease of energy production will effects the economic benefits, so the final solution will ultimately come from in improving energy efficiency. Sarkar and Singh (2010) pointed that how to improving energy efficient is still a challenge in development countries. The result shows that financial instruments will proved adequate liquidity and can be used for accelerating the process of low-carbon economy. Carraro *et al.* (2012) pointed that carbon tax revenues are very high in developing countries, however, the investment in R and D still occupy a low share of GDP. Therefore, the government should make out effective taxation schemes, both to reduce greenhouse gas emissions and promote low-carbon technology innovation. Chevallier (2011) used factor-augmented vector auto regression model to analyze how international economic shocks impacts on carbon markets, the result shows that carbon prices has obvious relationship with most global economic indicators.

Zou *et al.* (2011) pointed out that China government has began to strengthen efforts to propagate and support carbon finance, however, carbon finance is still faced with management problems and risks. So that, commercial banks are required to improve their service level and develop new carbon trading products. Ying-Hua and Dan-Dan (2012) pointed out China's low-carbon economy could be fulfilled through the technical innovation and efficient energy utilization. There are also some researches about how technical innovation effects on energy efficiency (Herring and Roy, 2007; Noailly, 2012; Liu and Shen, 2011). Based on previous studies, it shows that the development of finance can promote enterprise technological innovation and industrial upgrading, enterprise through financial support can strengthen the investment to R and D department and the enterprises can promote energy efficiency and reduce carbon emissions through technological innovation.

There are also many academic scholars research about carbon finance and low-Carbon strategy in China. Li and Colombier (2011) find that the current China's energy efficiency standard become to one of the best practices in the world and with international support such as carbon finance, the energy efficiency improvement will facilitate city's transition to low-carbon supply in the longer term. Zhou (2010) pointed out that carbon finance is related to all financial transaction activity that can reduce carbon emissions. The development of carbon finance can make contribute to economy transform and accelerate the optimization of economic structure. Zhao and Zhang (2012) analyzed the internal and external factors which affect carbon finance in China and put forward the reasonable path of how to develop carbon finance in China. Also, Zhao and Zhang (2012) pointed out that China government should set up a full range of policies and regulations.

Sun and Zhu (2008) using panel data from 23 provinces in China and find out that the technology innovation level had been gradual increased in these areas with the financial development. The empirical result shows that there had been a gradual growth in the TFP and technological progress from 2001 to 2005 which is tested by variant intercept model in panel data. Qian and Zhou (2011) analyzed the data of all 28 provinces in China from 2000-2008. By using the fixed effects panel data regression with AR(1) approach to estimate the TFP and the level of financial development in all regions, the result indicates that after controlling the other relevant variables, financial development also plays a positive role in technological progress and industrial upgrading.

To sum up, financial development can promote technology innovation and improve energy efficiency; at the same time, through the continuous improvement of the carbon financial market system in China, China's carbon emissions will reduce further (Lai *et al*., 2012; Wang *et al*., 2012).

Based on the discussion above, this study first construct an endogenous growth model and try to find out what is the main factor that effect on low-carbon economy growth. Then, using vector auto-regression model to make an empirical analysis about how financial development will effect on energy efficiency.

MATERIALS AND METHODS

Model building: By constructing a closed economy which has five sectors such as R and D sector, human capital sector, the final product sector, intermediate products sector and energy production sector. First, assuming that the technology in R and D sector is non-exclusive; so, technology innovation mainly depends on the Department's human capital investment and the existing technical stock. The R and D sector production function:

$$\dot{A} = \delta_A H_A A \tag{1}$$

A represent the technical stock in economy; δ_A represent possibility of technological innovation, the greater the δ_A is the higher the possibility of technological innovation; H represent the human capital investment. Human capital mainly depends on the production efficiency of human capital and input quantity, therefore, the human capital production function:

$$\dot{H} = \delta_H (H - H_r - H_A) \tag{2}$$

Also, assuming that the final product production function is a D-S function, so the function of final product sector will be written as:

$$Y = H_r^{a_1} \int_0^A X_i^{a_2} di E^{a_3} \tag{3}$$

In equation 1, $0<a_1<1$; $0<a_2<1$; $0<a_3<1$ and $_{a1}+a_2+a_3 = 1$. H_r represent human capital which has been put into final product sector, Y represent per capita output, A is the type number of intermediate products, represent the stock of technical knowledge. Presuming A is continuous; X_i is the quantity of intermediate product i; E is non-renewable energy that put into final production department. In the intermediate products sector, the capital amount can be expressed as:

$$K = \int_0^A X_i di \tag{4}$$

According to the final product sector production function, the entire intermediate product X_i is asymmetrical and the input requirement is same. For $\forall i \in [0, A]$, so that, $X_i = X = K/A$. Put this into the final product production function, then the final product production function can be shown as:

$$Y = H_Y^{a_1} A x^{a_2} E^{a_3} = H_Y^{a_1} A^{1-a_2} K^{a_2} E^{a_3} \tag{5}$$

Presuming there is no capital depreciation, therefore, the increase of capital stock value equals to the total output subtracts consumption and thus the material capital accumulation equation is:

$$\dot{K} = Y - C \tag{6}$$

In energy production sector, assuming S is the stock of non-renewable; E is energy into flow the final product production process, the initial stock of energy is S_0 and then the stock of energy is:

$$S = S_0 - \int_0^1 E(v) dv \tag{7}$$

Based on the derivation of time t, then the consumption changes of non-renewable energy can be shown as:

$$\dot{S} = -E \tag{8}$$

For the consumer preferences, assuming representative consumer has a standard fixed elastic utility function in the infinite domain as:

$$U(C) = \int_0^\infty \frac{c^{1-\sigma} - 1}{1-\sigma} L e^{-\alpha} d_1 = \int_0^\infty \frac{c^{1-\sigma} - 1}{1-\sigma} e^{-\alpha} di \tag{9}$$

In this equation, c represents per capita consumption, L represents the total population. Assuming the total population is 1, thus, the per capita consumption is equal to total consumption. In this equation, σ is marginal utility elasticity in this formula and ρ is the consumer's time preference. According to input and output of the final product department, human capital development of human capital department, technology research and development of the R and D department, production of product department and non-renewable energy consumption, Social dynamic optimization mathematical expression can be shown as:

$$\max U(C) = \max \int_0^{\infty} \frac{C^{1-\sigma}-1}{1-\sigma} e^{-\alpha} d_t \quad (10)$$

$$\text{s.t.} \quad Y = H_r^{a_1} A^{1-a_2} K^{a_2} E^{a_3}$$

$$\dot{K} = Y - C \quad (11)$$

$$\dot{H} = \delta_H (H - H_r - H_A) \quad (12)$$

$$\dot{A} = \delta_A H_A A \quad (13)$$

$$\dot{S} = -E \quad (14)$$

By using Hamilton function to calculate the value of this dynamic optimization model, the equation is:

$$H_C = +\lambda_3(\delta_A H_A A)+\lambda_4(-E) \quad (15)$$

In the Hamilton function, K, H, A, S are state variables; G, H_r, H_A, E are control variables; λ_1, λ_2, λ_3, λ_4 are costate variable and these four costate variables are the shadow prices of K, H, A, S. According to the optimization theorem, the first-order condition for maximize H_c is:

$$\frac{\partial H_c}{\partial C} = 0 \Rightarrow C^{-\sigma} = \lambda_1 \quad (16)$$

$$\frac{\partial H_c}{\partial H_Y} = 0 \Rightarrow \frac{\lambda_1 a_1 Y}{H_Y} = \lambda_2 \delta_H \quad (17)$$

$$\frac{\partial H_c}{\partial H_A} = 0 \Rightarrow \lambda_3 \delta_A A = \lambda_2 \delta_H \quad (18)$$

$$\frac{\partial H_c}{\partial E} = 0 \Rightarrow \lambda_4 = \frac{\lambda_1 a_3 Y}{E} \quad (19)$$

λ_1, λ_2, λ_3, λ_4 make derivation on t, respectively, then the equation can be shown as:

$$\dot{\lambda}_1 = \frac{d_{\lambda_1}}{d_t} = \rho\lambda_1 - \lambda_1 \alpha_2 \frac{Y}{K} \quad (20)$$

$$\dot{\lambda}_2 = \frac{d_{\lambda_2}}{d_t} = \rho\lambda_2 - \lambda_2 \delta_H \quad (21)$$

$$\dot{\lambda}_3 = \frac{d_{\lambda_3}}{d_t} = \rho\lambda_3 - \lambda_1 (1-\alpha_2) \frac{Y}{A} - \lambda_3 \delta_A H_A \quad (22)$$

$$\dot{\lambda}_4 = \frac{d_{\lambda_4}}{d_t} = \rho\lambda_4 \quad (23)$$

Transversality conditions for:

$$\lim_{t\to\infty} \lambda K e^{-\rho t} = 0$$

On the balanced growth path, each variable growth rates were constant. According to relationship of consumption, investment and output, it can known that the economic variables Y, C, K have the same growth rate and g_r, g_c, g_x are the same constant. According to the above formula, g_r and g_s can be written as:

$$g_r = g_c = g_K = \frac{\alpha_1 \delta_H}{1-\alpha_2} \left(\frac{\delta_A H_A - \rho}{\sigma} \right) \quad (24)$$

$$G_S = g_E = (1-\sigma) g_r - \rho \quad (25)$$

Then the only transversality condition is:

$$(A-\sigma) g_r - \rho < 0$$

According to the substance of low carbon economy growth, the necessary condition to achieve a low carbon economy growth is: $g_r>0$, $g_E<0$, it means the per capita output increases ceaselessly, the consumption of non-renewable energy sources ceaselessly reduce. To achieve this conditions need δ_H,δ_A sufficiently large; ρ sufficiently small and $\sigma \geq 1$. Therefore, once the economy has enough human capital accumulation efficiency and technical efficiency, it will resulting in higher efficiency of technological innovation and can reduced consumption of non-renewable energy sources, achieve the low-carbon economy growth.

Data collection and processing: Using financial intervnational ratio to represent the financial development level and using energy efficiency index to represent the level of Low-carbon economy. The equation of financial intervnational ratio is M2/GDP and the equation of energy efficiency index equals GDP/ (energy consumption). The data was then undertook log processing, noted as LnFIR and LnEE. All data was collected from “China statistical yearbook 2012”.

RESULTS AND DISCUSSION

ADF unit root test: In statistics and econometrics, an augmented Dickey-Fuller test (ADF) is a test for a unit root in a time series sample. By using augmented Dickey-Fuller unit root tests, the result as is shown in Table 1.

Through the test results in Table 1, it shows that, LnFIR and LnEE are non-stationary at 10% critical value. However, after differential calculation d.LnFER and d.LnCPI are stable, so that VAR model can be used to analyze the data.

VAR model: Vector Auto Regression (VAR) model is the simultaneous form of autoregressive model, A VAR (p) model of a time series y (t) has the form:

$$A_0 y_{(t)} = A_1 y_{(t-1)} + \cdots + A_p y_{(t-p)} + \varepsilon_{(t)}$$

According to the analysis above, the VAR regression model of LnFIR and LnEE can be constructed. Before constructing the VAR model, the lag of VAR Model should be determined. By using STATA software to calculate the lag length, the result was shown in Table 2. From the Table 2, the result shows that the optimal lag length is at lag 2. By choosing lag 2, then the VAR model can be shown as:

$$LnEE = -0.197+0.568\ LnFIR_{t-1} +0.198 LnFIR_{t-2} +1.807 LnEE_{t-1} -0.989 LnEE_{t-2}$$

According to this equation, it shows that the financial development will promote energy efficiency index increase. LnFIR at lag 1 period increased one percentage will lead LnEE increased by 0.56% points and LnFIR at lag 2 period increased one percentage will lead LnEE increased by 0.19% points. so the effect of financial development to energy efficiency is obvious. Then, by using granger causality test to analyze the relations between LnFIR and LnEE, the result is shown in Table 3.

From Table 3, the result shows that LnEE rejected the null hypothesis as "Excluded LnFIR as the granger reason to LnEE", so that, LnFIR is the granger reason to LnEE which means financial development is the reason promotes energy efficiency index increase. However, it shows that LnEE is not the reason for LnFIR. At the same time, by taking Johnson co-integration test to analyze the long-term relations between LnFIR and LnEE, the result is shown in Table 4. From Table 4, the result shows that there exist at least one direct co-integration relationship between LnFIR and LnEE which means that there exists a long-term equilibrium relationship between financial development and energy efficiency.

Impulse-response analysis and variance decomposition: Impulse-response function and cholesky variance decomposition can be used to further analyze the VAR model. An impulse response refers to the reaction of any dynamic system in response to some external change.

The result of Impulse-response analysis was shown in Fig. 2. In Fig. 2, X-axis indicates the time period and Y-axis indicates the strength of response. From Fig. 2a, the result shows that when LnFIR received one unit impact, it will lead LnEE increase currently, LnEE will reach the max at t = 5 period and then begin to stable. It illustrates there is long-term effect between financial development and energy efficiency increase. From Fig. 2b, the result shows that when LnEE received one unit impact, it will lead LnEE increase currently. However, LnEE will reduce to 0 at =5 period which means the impulse of LnEE only has short-term effects to itself. ccording to the impulse analysis results, it shows that financial development will significant influence energy efficiency.

Table 1: Data stationarity test through augmented dickey-fuller analysis

Variable	Test statistic	1% critical value	5% critical value	10% critical value	Result
LnEE	0.301	-3.750	-3.000	-2.630	Unstable
LnFIR	-1.383	-3.750	-3.000	-2.630	Unstable
D.LnEE	-3.599	-3.750	-3.000	-2.630	Stable
D.LnFIR	-3.655	-3.750	-3.000	-2.630	Stable

LnEE is log (energy efficiency) = log (GDP/energy consumption), LnFIR is log (financial international ratio) = log (M2/GDP), D.LnEE is the differential of LnEE, D.LnFIR is the differential of LnFIR

Table 2: Result of optimal lag-order selection for VARs

Lag	LL	LR	df	p	FPE	AIC	HQIC	SBIC
0	15.2675				0.000785	1.47416	1.46052	1.37523
1	68.1441	105.7500	4	0.000	3.5e-0600	-6.90489	-6.86397	-6.60810
2	77.4148	18.5420*	4	0.001	2.0e-0600*	-7.49054*	-7.42233*	-6.99588*
3	79.9482	5.0667	4	0.281	2.5e-0600	-7.32758	-7.23209	-6.63507
4	81.5312	3.1660	4	0.530	3.6e-0600	-7.05902	-6.93625	-6.16865

*Means that lag 2 is the optimal lag order. Abbreviations are log likelihood (LL), likelihood ratio (LR), final prediction error (FPE), Akaike's information criterion (AIC), Schwarz's bayesian information criterion (SBIC) and the Hannan and Quinn information criterion (HQIC)

Table 3: Causal relationship test through granger causality analysis

Equation	Excluded	χ^2	df	Prob>χ^2
LnEE	LnFIR	8.3984	2	0.015
LnFIR	LnEE	10.423	2	0.305

χ^2 means chi-squared test, Prob>χ^2 means the probability that the null hypothesis was established, LnEE is log (energy efficiency) = log (GDP/energy consumption), LnFIR is log (financial intervnational ratio) = log (M2/GDP)

Table 4: Long-term equilibrium relationship test through Johnson Co-integration analysis

Rank	Parms	LL	Characteristic value	Statistic	Significant 5% level
0	N/A	13.5214*	15.41	0	N/A
1	0.45382	2.0299	3.76	1	0.45382

*Means that rank 0 is the optimal rank, that means there exist at least one co-integration relationship, abbreviation LL is log likelihood

The variance decomposition indicates the amount of information each variable contributes to the other variables in the auto regression. It determines how much of the forecast error variance of each of the variables can be explained by exogenous shocks to the other variables. The result of variance decomposition was shown in Fig. 3.

From Fig. 3a, the result shows that the contribution degree of LnFIR to LnEE is gradually increased, the contribution degree of LnFIR to LnEE is about 30-40% in the all time period which means LnFIR has strong a degree of contribution to LnEE. From Fig. 3b, the result shows that the contribution degree of LnEE to LnEE is gradually reduced, the contribution degree of LnEE to LnEE is 100% at t = 1 period and reduced to 40% at t = 10 period. This shows that financial development has significant effect on the energy efficiency and can explain the improving the energy efficiency.

To sum up, by constructing the endogenous model, it proved that technological innovation is the main reason to achieve low-carbon economic growth, the result is same to the research from Ying-Hua and Dan-Dan (2012), Herring and Roy (2007) and Noailly (2012). The result of empirical study shows that financial development is the granger reason to the improving of energy efficient. Once financial development received one unit impact, it will lead energy efficient increase currently. The result is same to the research from Sarkar and Singh (2010) which proved financial development will accelerate the process of low-carbon economy. However, the empirical study in section 3 did not test whether financial development will effect on technological innovation, it didn't prove that financial development first improve R and D and then the improving of R and D effects on energy efficient. According to the literature from Sun and Zhu (2008) and Qian and Zhou (2011), it shows that financial development in China will promote technological innovation. At the same time, technological innovation will finally effects on the improving of energy efficient. So that, it can be proved that financial development will accelerate the process of China's low-carbon economy.

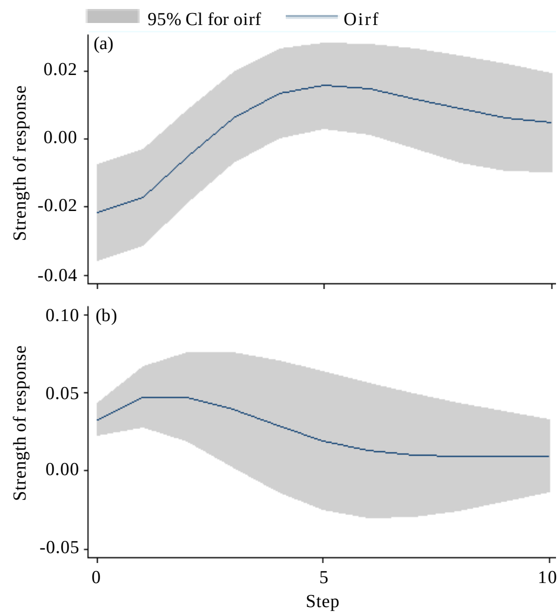

Fig. 2(a-b): Result of impulse-response analysis for (a) Response of LnEE when LnFIR received one unit impact and (b) Response of LnEE when LnEE received one unit impact

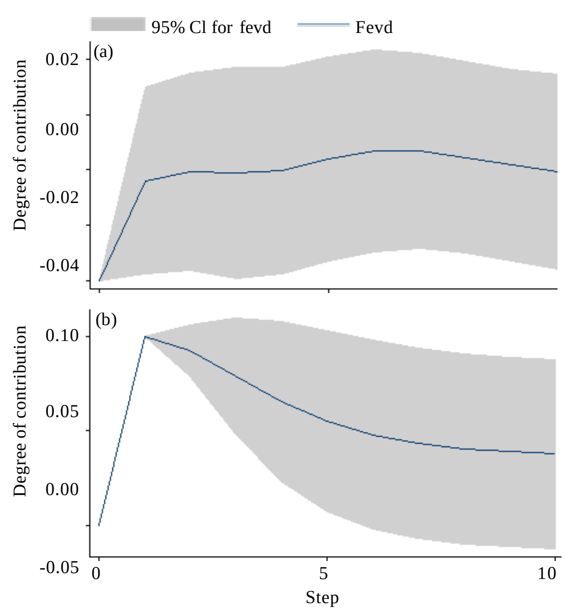

Fig. 3(a-b): Result of Cholesky variance decomposition for (a) Contribution degree of LnFIR to LnEE and (b) Contribution degree of LnEE to LnEE

CONCLUSION

In conclusions, the result of VAR model shows that financial development is the Grainger reason to energy efficiency. According to the VAR model, it shows that the financial development will promote energy efficiency index increase. Financial development index at lag 1 period increased 1 percentage will lead energy efficient increased by 0.56% points and financial development index at lag 2 period increased 1% will lead energy efficient increased by 0.19% points. At the same time; the result of Johnson Co-integration analysis shows that here exists a long-term equilibrium relationship between financial development and energy efficiency. From the variance decomposition results, the result shows that the contribution degree of financial development to energy efficient is gradually increased; also the contribution degree of financial development to energy efficient is about 30-40% in the all time period which means financial development has strong a degree of contribution to energy efficient. The results prove that financial development can certain explain the improvement of energy efficiency, so that in the long run, financial development is the main factor to improve energy efficiency. In recent decades, the demand of energy fuel was increased dramatically with China's rapid economic growth, as the financial industry could be an important support to the low-carbon economy, so the government should strengthen the financial factor as reform of the financial system, provides the corresponding policy support for China's carbon finance market and promote innovation of carbon financial products.

In order to improve the effectiveness of low carbon development strategy, the government should put forward effective policies. First of all, in the process of low carbon economy development strategy, the government should play the leading role. Government should give more support and provide a good policy environment by establishing and improving the relevant policies and regulations. Also the government should establish the China's carbon finance system and promote the innovation of carbon financial products. At the same time, the Chinese government should ensure the implementation of low-carbon economy strategy by using tax and subsidy policies. Second, commercial banks should increase financial products and services to low-carbon industry. Because of the money demand for low-carbon projects is very large, commercial banks should develop new loan products provide carbon financial services, so that commercial banks can provide the necessary financial support to the Low-carbon innovation in enterprises.

However, this study still has some drawbacks. First, the empirical analysis did not test the promotion function of financial development for technical innovation; also the measure of financial development can be more comprehensive. Second, as China's energy consumption has obvious regional differences, so that the impact of financial development on energy efficient will be difference in different areas. These problems still need further research.

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