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HAS FINANCIAL DEVELOPMENT IMPROVED CARBON EMISSION EFFICIENCY? AN ANALYSIS BASED ON SUPER EFFICIENCY UNDESIRABLE - SBM MODEL AND MULTINATIONAL PANEL DATA

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Abstract

Based on transnational panel data of 30 countries with different development levels in the world from 1990 to 2016, this paper tests different degrees varying from the prospective of financial development possible impact that could have been shown on the scale and efficiency of carbon emissions, using the structure, scale, and efficiency, such pivotal aspects of both financial institutions and financial markets as different indexes to estimate financial development. As suggested from the results, in the high-income nations, the effect of financial institutions on carbon emission efficiency is larger than that of others. This is because the high-income nations have better financial development, which can support environmental protection investment and improve carbon emission efficiency. For middle high-income nations, both financial institutions and financial markets can improve carbon emission efficiency. For middle low-income countries, financial and economic development can increase the efficiency of carbon emission. Later, by robustness test, it is found that the financial development stage has different effects on the scale and efficiency of carbon emission, with a U-shaped curve is clearly shown on the carbon emission scale, while on the carbon emission efficiency, an inverted U-shaped curve. This shows that financial development can reduce the scale of carbon emissions and it can improve carbon emissions efficiency to a certain extent at the same time.

Key words: carbon emission efficiency, financial development, super-efficiency undesirable-SBM model

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1. Introduction

It has been generally agreed that economic growth undoubtedly can be promoted by financial development, and the ensuing environmental problems have also become prominent. While financial development, relying on its characteristics, gradually promotes economic growth, it increases the consumption of primary energy, increases carbon dioxide emissions, and deteriorates the environment; it cannot be ignored that financial development can provide more funds to the investment in environmental protection projects or sustainable development. This can reduce carbon dioxide emissions by technological transformation, and then to improve the environmental quality. Therefore, it is very significant to discuss that what kind of relationship it is that exists between financial development and carbon dioxide emissions. However, this issue has not been unanimously considered in the related literatures. A more widespread view is that financial development has played a beneficial role in reducing carbon emissions. For example, Frankel and Romer (1999) highlighted that financial development

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can attract FDI and high-level R & D investment to promote technological progress and help solve environmental pollution problems. And the influence of financial development was analyzed by Zhang (2011) on carbon emissions with sample data of China. Gu and He (2012) also discussed this, using provincial data of China, and they argued that apparently, the carbon emissions can be reduced by financial development. But Guo et al. (2012) showed that the higher the income level, financial openness's degree, and financial development's degree would increase the negative impact on carbon emissions.

Shahbaz et al. (2013) showed that economic growth increased the energy emissions, while financial development reduced energy emissions. Within the framework of environmental Kuznets Curve (EKC), carbon emissions have been significantly reduced with financial development, e.g. Ozturk and Acaravci (2013) showed that without doubt, the EKC hypothesis proved valid in the Turkish economy. Boutabba (2014) proved the EKC hypothesis existed in Indian economy. Zaidi et al. (2019) demonstrated the results verified the EKC hypothesis in APEC countries. The systematic GMM model is used to empirically test this relationship, concluding that carbon emissions are possibly to be brought down by financial development (Chen and Liu, 2015).

The technological upgrading effect, brought by financial development, helps reduce carbon dioxide emissions (Yan et al., 2016). Financial development is beneficial to the reduction of carbon dioxide emissions (Abbasi and Riaz, 2016; Shao and Liu, 2017; Shahbaz et al., 2018). It has recently shown that financial development is conducive to achieving a win-win balance for the Chinese economy; its positive impact on economic growth is far greater than its impact on environmental protection; the development of the capital market promotes both economic growth and promotion Environmental protection (Yue et al., 2018). Hu and Wang (2018) found an inverted U-shaped relationship existing between the two. In the meantime, financial development suppresses carbon emissions by promoting enterprise technological innovation. Li et al. (2019), using the GMM method, discussed the positive influence on carbon dioxide emissions reduction, which was brought by financial development. Jian et al. (2019) conducted empirical tests and found positive effects brought by financial development as well as energy consumption on carbon dioxide emissions. Zaidi et al. (2019) demonstrated the results verified the EKC hypothesis in APEC countries.

Carbon emissions have been significantly reduced by globalization and financial development, while increased by economic growth and energy intensity. From a long-term perspective, economic growth may curb carbon emissions. Financial innovation should be carried forward. G7 financial development impact in terms of carbon emissions is weak determinant (Raheem et al., 2020). Shoaibet et al. (2020) used the ARDL model to verify the significant positive impact on carbon emissions that brought by financial development by calculating financial development index using principal component analysis method. Acheampong et al. (2020) proved that for independent financial economies, financial markets didn't affect carbon emission intensity directly, including other indicators of financial markets. There different financial development in different nations will result in financial development having a non-linear reflection clearly shown on the intensity of carbon emission, but regulation's role is not the same way.

This paper introduces financial development as one of influencing factor of carbon emission and in the meanwhile, analyzes the impacts that financial development would have on carbon emissions, which is calculated by two indexes: one is carbon emissions per capita, the other is carbon emission efficiency evaluated by SBM super-efficiency model considering undesired output. At the same time, it hopes, with the development of financial institutions and financial markets, to improve carbon emission efficiency. This paper's main contributions are shown as following: First, the paper examines the impact that financial development could have on carbon emission efficiency, differently from which could possibly be on carbon emissions or carbon emission intensity. Second, with the authoritative data collected from IMF and the IEA, it carries out comparative structural analysis, and conducts empirical tests on the impacts that financial development can have on carbon emission in different countries that are selected at varying levels of development, which emphasizes the impacts of structural factors.

The rest of the study is as follows: Part two discusses the methodology, covering model setting, variables explanation and sample data. Part three introduced the empirical test results to, in a careful and methodical manner, further analyze the financial development's possible way of influencing carbon dioxide emissions. And finally, this paper gives the conclusions and policy recommendations.

2. Methods

2.1. Model settings

According to Guo et al. (2012) model, we sets up the following model to test the possible influence brought by any kind of financial development on carbon dioxide emissions, shown as Eqs. (1-2):

$$carbper_{it} = \beta_0 + \beta_1 fd_{it} + \beta_2 X_{it} + \nu_i + \eta_t + \varepsilon_{it} \tag{1}$$

$$effval_{it} = \alpha_0 + \alpha_1 carbper_{it} + \alpha_2 fd_{it} + \alpha_3 X_{it} + \nu_i + \varphi_t + \varepsilon_{it} \tag{2}$$

Carbper represents carbon dioxide emissions per capita, *effval* represents carbon emission efficiency, *fd* denotes financial development level, and *X* mainly refers to control variables. ν represents the fixed effect of the country, η represents the annual fixed effect, and *e* refers to the random error term, *i* means country, *t* means year.

We uses Eq. (1) to evaluate the impacts that financial development can possibly have on carbon dioxide emissions. A relatively important factor affecting the efficiency of CO_2 emissions is the amount of CO_2 emitted, so we construct the equation (2), to examine the combined effects of financial development and CO_2 emissions on the efficiency of per capita CO_2 emissions.

2.2. Variables

2.2.1. Carbon dioxide emissions.

On this basis, we measure the scale and efficiency of carbon dioxide emissions. Per capita carbon dioxide emissions (carbper) is the basis for calculating the size of carbon dioxide emissions, which is equal to the value of carbon dioxide emissions divided by the number of people. The carbon dioxide emission efficiency (effval) is calculated using the non-ideal output SBM super-efficiency model, in which the input factors include labor, capital, foreign investment net inflows and primary energy consumption, and the expected output is the value of each country's GDP, and for another, carbon dioxide emissions are undesirable. We have sample data on primary energy consumption and CO_2 emissions, which are collected from World Energy Statistical Yearbook 2019, and other sample data comes from the World Bank public database. And the calculation details are shown in part 2.3.

2.2.2. Financial development

The measurement of financial development (fd) has been controversial. In view of the fact that this article is cross-country data, here is a reference to the 2016 IMF report, in which financial development is consisted of the development of financial institutions and financial markets. And they can be measured by developing depth, availability, and efficiency. The indicators are as follows: the depth of financial institution development (fid), it is calculated by four values: the ratio of private sector credit to GDP, the ratio of pension fund assets to GDP, the ratio of mutual funds to GDP, the ratio of insurance premiums to GDP. The availability of financial institution services (fia) is calculated by two values: the number of bank branches that exists covering every 100 thousand adults and automatic deposit machines that exists covering every 100 thousand adults.

The variable of financial institutions development efficiency (fie) uses six indicators to measure, they are return on assets, net interest spread, the ratio of non-interest income to total income, deposit and loan spreads, the ratio of management fees to total assets and return on equity. The depth of financial market development (fmd) is calculated by the ratio of stock market value to GDP, the ratio of stock turnover to GDP, the ratio of government international bonds to GDP, the ratio of financial company bonds to GDP, and the ratio of non-financial company bonds to GDP. The availability of financial market services (fma) is calculated by the market value rate of non top ten companies, the financial market development efficiency (fme) is calculated by the stock market turnover rate, and the calculation method is stock turnover/Market value. After all indexes are weighted, the value is between 0 and 1, but the closer the value is to 1, the higher the financial development level.

2.2.3. Control variables

Combined with existing research, the economic development level (pgdp), energy consumption (ener), openness (open), and manufacturing level (manu) are used as control variables. For each, the variable of economic development (pgdp) is calculated by GDP per capita, the variable of energy consumption (ener) is calculated by primary energy consumption/GDP, the variable of openness (open) is calculated by exports of goods and services/GDP, in which employee compensation and investment income and transfer payments are not included; the level of manufacturing is calculated by manufacturing value added/GDP. The manufacturing industry is calculated according to the 15-37 industries in the International Standard Industrial Classification (ISIC). GDP is calculated at 2011 purchasing power parity.

2.3. Measurement of carbon emission efficiency

Accompanied by global environmental awareness, non-ideal output of production and social activities (such as pollution and hazardous waste) is gradually being regarded as dangerous and undesirable. Therefore, achieving technological progress with very little non-ideal output is an important concern in every production area. The theory of data envelopment analysis (DEA) generally believes that getting more output with less input resources is an efficiency criterion. However, in the case of non-ideal output, the technology of obtaining more ideal output (good output) and less non-ideal output (bad output) with less input resources should be regarded as efficient. Klodawski et al. (2018) have recently shown the efficiency of how to filter orders under congestion, Xu and Yin (2018) have established the objective decision model of discrete system through the description of the objectives such as cost, efficiency and greenness. As Xu et al. (2018) demonstrated the mathematical model with the goal of minimizing the cost and time in the multiple location decision problem. Suppose there are n unit of decision units (DMUs), and each unit DMU has three indicators: input, good output, and bad output, which are represented by three vectors, where m, s_1, and s_2 are the number of input indicators, the number of good output indicators and the number of bad output indicators respectively. In addition, set the pending decision-making unit to DMU_0. According to Tone (2001), the non-ideal output SBM model as follow (Eq. 3).

Among them, vector $s \;\square\, R^m$ and $s^b \,\square\, R^{s_2}$ respectively correspond to input redundancy and bad output shortage, and $s^g \in R^{s_1}$ express good output shortage. The objective function strictly decreases with respect to, $s_i \ (\square i)\ s_r^g (\square r)$, and $s_r^b (\forall r)$ and the target value satisfies. Let the optimal solution of the above problem be $(\lambda^*, s^{\ *}, s^{g*}, s^{b*})$. Therefore, if and only if $\rho^* = 1$, $s^{\ *} = 0$, $s^{g*} = 0$ and $s^{b*} = 0$, DMU_0 is effective in the non-ideal output situation. When d = 0 and 1, the scale returns are constant and the scale returns are variable.

$$[SBM\text{-}Undesirable] \quad \rho_o^* = min \frac{1 \quad \frac{1}{m}\sum_{i=1}^{m}\frac{s_i}{x_{io}}}{1+\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{ro}^g}+\sum_{r=1}^{s_1}\frac{s_r^b}{y_{ro}^b}\right)}$$

$$s.t. \quad x_o = \sum_{j=1}^{n}\lambda_j x_j + s$$

$$y_o^g = \sum_{j=1}^{n}\lambda_j y_j^g \quad s^g$$

$$y_o^b = \sum_{j=1}^{n}\lambda_j y_j^b + s^b$$

$$d\sum_{j=1}^{n}\lambda_j = d$$

$$s \ \ \geq 0, s^g \geq 0, s^b \geq 0, \lambda \geq 0 \tag{3}$$

Since the efficiency of all effective DMUs of the model [SBM-Undesirable] is 1, it is impossible to solve the efficiency ranking and comparison of these DMUs. In view of this, Huang et al. (2014) have recently shown a non-ideal output super-efficiency SBM model. All DMUs with an efficiency of 1 in the [SBM-Undesirable] model will be greater than or equal to the [SuperSBM-Undesirable] model 1 as given by (Eq. 4).

When measuring the scores of effective decision-making units in SBM, the increase in undesirable production may exceed 100%. It may make the denominator of the target function negative, so that the objective function is unbounded and the optimal value tends to negative infinity.

Therefore, add a fourth constraint to limit the denominator of the objective function to a positive number. In the existing Energy Environment input-output study, the expected production and the undesired output are usually included in the set of production possibilities. Considering the production function of the low-carbon economy, the input variables are in addition to capital and labor. Contains the input of primary energy, capital includes the net inflow of domestic capital and foreign investment capital.

$$[SuperSBM\text{-}Undesirable] \quad \rho_o^* = \min \frac{1+\frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{io}}}{1-\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{ro}^g}+\sum_{r=1}^{s_1}\frac{s_r^b}{y_{ro}^b}\right)}$$

$$s.t. \quad \mathbf{x}_o \geq \sum_{j=1,\neq o}^{n}\lambda_j x_j - \mathbf{s}^-$$

$$\mathbf{y}_o^g \leq \sum_{j=1,\neq o}^{n}\lambda_j y_j^g - \mathbf{s}^g$$

$$\mathbf{y}_o^b \geq \sum_{j=1,\neq o}^{n}\lambda_j y_j^b + \mathbf{s}^b$$

$$d\sum_{j=1,\neq o}^{n}\lambda_j = d$$

$$\mathbf{s}^- \geq \mathbf{0}, \mathbf{s}^g \geq \mathbf{0}, \mathbf{s}^b \geq \mathbf{0}, \boldsymbol{\lambda} \geq \mathbf{0}$$

$$1-\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{y_{ro}^g}+\sum_{r=1}^{s_1}\frac{s_r^b}{y_{ro}^b}\right) \geq \varepsilon \tag{4}$$

Total capital formation (formerly known as total domestic investment) consists of new fixed asset expenditures plus net changes in inventory. Fixed assets include the following: the improvement of the land, the purchase of the required plant and equipment, the required construction of roads, railways, hospitals and schools, private residences, and industrial and commercial buildings. Inventory is the goods stored by the enterprise to meet the temporary needs of production or sales or unexpected fluctuations, as well as work in progress.

According to the 1993 national economic accounting system, the net income of valuables is also regarded as capital formation. Foreign direct investment is calculated by the sum of equity capital, return to reinvestment, other long-term capital and short-term capital in the balance of payments. It shows the net capital inflows (the spread of new capital inflows minus capital outflow) in reporting nations. The data are calculated in terms of current dollars. The total labor force includes all groups who are over 15 years old and meet the ILO's definition of working population. Non-renewable energy refers to coal, oil, natural gas, chemical energy, nuclear fuel, etc. The primary energy consists of two kinds of energies, one is renewable energy and the other is non-renewable energy, of which non-renewable resources are the main source of carbon emissions. The data comes from the IEA website.

In the output indicator, Gross Domestic Product (GDP), at buyer's prices, is equal to the value added by all resident producers in an economy, plus any product taxes, minus subsidies that do not take into account the value of the product. The data is in current US dollars. The USD data of GDP is converted from the currencies of various countries using the official exchange rate in a year. The sample data comes from both the national accounts data of World Bank and the national accounts data of the OECD. Carbon dioxide is emitted from combustion of fossil fuels and cement production, which means carbon dioxide emission can be from burning solid, liquid and gaseous fuels and natural gas.80% of greenhouse gas emissions are constituted by carbon dioxide emissions. The total carbon dioxide emissions here refer to the carbon dioxide burned by the fuel, not including carbon sinks, nor LULUCF. The carbon emission efficiency here is calculated based on the function of production technology. It calculates the distance from each decision unit to the optimal production frontier by directional distance function. According to the above non-ideal output super efficiency SBM model, the expected output is the GDP of each country The undesirable output is carbon dioxide emissions. Use MATLAB software to calculate the carbon emissions efficiency of the sample countries during the period 1990-2016.

According to the classification of World Bank, if the GNI per capita of a country is less than US$995, it is considered as a low-income country, if the GNI per capita is greater than US$12,055, it is the high-income country, and if the GNI per capita is between US$3896 and US$12,055, it indicates a middle-high income country. Those GNI per capita between US$995 and US$3,896 belong middle-low income countries. Accordingly, the United States, the United Kingdom, Germany, Japan, and France, Greece, Sweden, Finland, Netherlands, Norway, New Zealand, South Korea, Singapore, Chile, Argentina and Saudi Arabia are high-income countries; Brazil, Malaysia, Mexico, Iran, Thailand, South Africa and China are middle and high income countries; India, Pakistan, Bangladesh, Sri Lanka, Egypt, Morocco and the Philippines are middle- low income countries.

The sample data comes from the World Bank's public database. The sample countries are shown in Table 1. The carbon emission efficiency values and average values of major countries grouped by different incomes are shown in Fig. 1. As it can be seen from Fig. 1, high-income countries have higher average efficiency than other countries. The possible reason is that these countries have a high level of financial development and are able to invest in environmental protection and control pollution.

All countries with different income are facing development problems. For example, China is in a period of development, so its carbon dioxide emission efficiency is low. With the development of finance, more investment in environmental protection and new energy industries and capital Carry out the treatment of environmental pollution, so the carbon emission efficiency will be significantly improved after 2015.

2.4. Sample data

Considering the differences in the impact of regional differences in income and financial development on environmental issues, and considering the availability of data, this article uses a sample of 30 countries from 1990 to 2016. The IMF (International Monetary Fund) comprehensive financial development index is used here, and some of the countries involved are comparable because of the backward financial development, so according to the available data, statistics are up to 2016. The descriptive statistics of each variable are shown in Table 2.

Table 1. Sample countries

Income-level	***Country***
High-income	the United States, the United Kingdom, Germany, Japan, and France, Greece, Sweden, Finland, Netherlands, Norway, New Zealand, South Korea, Singapore, Chile, Argentina and Saudi Arabia;
Middle-high	Brazil, Malaysia, Mexico, Iran, Thailand, South Africa and China
Middle-low	India, Pakistan, Bangladesh, Sri Lanka, Egypt, Morocco and the Philippines.

Data Source: the World Bank's public database

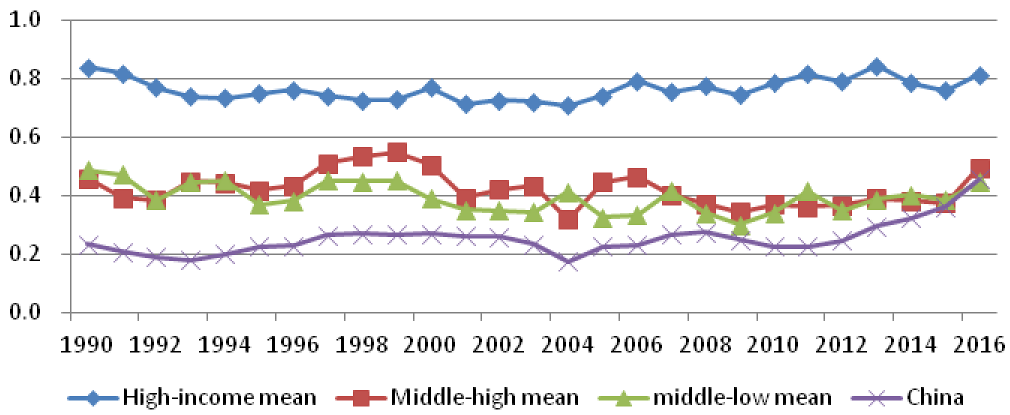

Fig. 1. Average carbon emission efficiency of countries at different income levels

Table 2. Statistics summary of main variables

Variable	*Obs*	*Mean*	*Std.Dev.*	*Min*	*Max*
effval	810	0.599	0.318	0.174	2.131
lncarbper	810	3.740	1.072	0.380	5.307
fid	810	0.457	0.288	0.036	1
fia	810	0.396	0.257	0.0346	0.964
fie	810	0.729	0.127	0.147	0.954
fmd	810	0.436	0.298	0.003	0.995
fma	810	0.407	0.226	0.0003	1
fme	810	0.505	0.342	0.002	1
fd	810	0.500	0.203	0.116	0.937
fi	810	0.544	0.204	0.211	0.937
fm	810	0.449	0.231	0.004	0.946
lnpgdp	810	9.205	1.408	5.990	11.43
ener	810	5.343	2.070	1.993	21.18
open	810	36.23	34.22	5.908	231.2
manu	810	17.43	5.861	6.605	33.65

3. Results and discussion

3.1. Financial development and carbon dioxide emissions per capita

According to Hausman's test, fixed effect analysis was used. In order to avoid the multicollinearity, different financial development variables are used, and multiple estimates are made. Only one development variable is considered in the independent variable each time. The regression results are shown in Table 3.

According to the results above, column (1) contains all financial development variables. Due to the mutual influence of financial development variables, fid, fia, fmd, and fma significantly reduce carbon emissions, indicating the scale of financial institutions and financial markets Expansion can reduce carbon emissions. The more availability, the more branches, the carbon emissions can also be reduced. Columns (2)-(7) all contain an independent variable related to financial development. From the estimated results, the value of each financial development variable (except for the efficiency of the financial market) becomes very significant. This shows that financial development in depth and structure will reduce carbon emissions per capita. The efficiency of financial institutions has significantly increased carbon emissions, interest margins have increased, and bank efficiency has increased, while interest rates for loans have increased, and the cost of economic growth has been the increase in the amount of carbon emissions.

However, when fme returns alone, it increases the carbon emission change from a significant level of 1% to not significantly reduce carbon emissions. This shows that the development of financial markets, to a certain extent, improves scale and efficiency, and can support green projects to some extent. Energy conservation and emission reduction projects have improved the environmental governance efficiency. Different countries have different priorities in financial development at different stages of development.

3.2. Financial development and carbon emissions efficiency

First, select labor, capital, foreign investment net inflows, and primary energy consumption as input variables in the selection of variables by using the SBM model. Regard each country's gross domestic product as expected output while carbon dioxide emissions as unexpected output, using MATLAB software to carry out the calculation of carbon emission efficiency and with which to obtain the efficiency value of each country.

By comparing annual average efficiency of different income countries, it can be found that low-income countries have low industrialization and financial development, so carbon emissions efficiency is also relatively low. Since the 1990s, high-income countries have higher average efficiency than other countries, the main reason is that the Environmental Kuznets curve is inverted u-shaped, most high-income countries have passed the stage of industrialization, and the degree of financial development is high, which can support environmental protection investment, reduce carbon emissions, and improve carbon emissions efficiency. Second, according to Hausman's test, the fixed effect is used for estimation. The results are shown in Table 4.

For high-income countries, as it has been indicated that it is possible that the depth of financial institutions can possibly improve carbon emissions efficiency. For example, it is true that the higher the share of private sector credit in GDP, the higher output can be considered with less input, while for middle- and high-income countries In other words, the availability of financial institutions can increase efficiency, and the availability of financial markets can also significantly improve carbon emissions efficiency. For example, the development of the green bond market, China has done very well in this regard, and has occupied the first place in the world, especially Green bonds provide financing for companies that need to reduce emissions. However, there are many obstacles to the implementation of green credit in financial institutions in high- and middle-income countries.

The more efficient financial institutions mean the higher the interest rate spread, mainly due to profitability considerations. Green credit has a long investment period and slow recovery. It is difficult to determine that there are also many problems in supervision, so the depth and efficiency of financial institutions have significantly reduced the efficiency of carbon emissions, resulting in that apparently, it is feasible to take the lead in green finance from the financial market.

Table 3. Estimation result of model (1)

	(1)	*(2)*	*(3)*	*(4)*	*(5)*	*(6)*	*(7)*
fid	-0.192*** (-2.73)	-0.341*** (-5.25)					
fia	-0.120** (-2.03)		-0.160*** (-2.77)				
fie	0.180*** (3.03)			0.124** (2.08)			
fmd	-0.140*** (-3.41)				-0.137*** (-4.47)		
fma	-0.079** (-2.03)					-0.149*** (-4.20)	
fme	0.060*** (2.80)						-0.001 (-0.05)
lnpgdp	1.213*** (42.01)	1.174*** (46.41)	1.162*** (41.68)	1.110*** (46.42)	1.152*** (47.43)	1.159*** (46.25)	1.120*** (47.37)
lnener	1.046*** (24.77)	1.041*** (27.10)	1.070*** (26.47)	1.040*** (26.68)	1.016*** (26.06)	1.071*** (27.21)	1.040*** (26.53)
lnopen	-0.011 (-0.59)	-0.036** (-2.07)	-0.058*** (-3.33)	-0.057*** (-3.23)	-0.024 (-1.27)	-0.037** (-2.06)	-0.056*** (-3.15)
lnmanu	0.039 (1.17)	0.070** (2.22)	0.097*** (3.02)	0.139*** (4.56)	0.100*** (3.28)	0.085*** (2.67)	0.129*** (4.26)
cons	-9.118*** (-32.77)	-8.669*** (-33.46)	-8.698*** (-31.46)	-8.448*** (-32.64)	-8.644*** (-33.15)	-8.715*** (-32.81)	-8.424*** (-32.39)
N	810	810	810	810	810	810	810
Adj.R-sq	0.773	0.765	0.759	0.758	0.763	0.762	0.757

*Note: Standard errors in parentheses, *p<0.1; **p<0.05 and ***p<0.01.*

Table 4. Estimation result of model (2)

	(1)High-income	*(2)Middle-high*	*(3)Middle-low*
fid	0.437*** (0.118)	-0.834*** (0.168)	-0.103 (0.484)
fia	-0.122 (0.106)	0.332*** (0.122)	0.017 (0.465)
fie	-0.164 (0.107)	-0.906*** (0.158)	0.154 (0.222)
fmd	-0.042 (0.072)	-0.006 (0.122)	0.166 (0.152)
fma	-0.001 (0.065)	0.349*** (0.123)	0.128 (0.176)
fme	-0.034 (0.039)	-0.063 (0.069)	0.068 (0.055)
lncarbper	-0.177*** (0.063)	0.117 (0.174)	-0.587*** (0.149)
lnpgdp	0.0381 (0.092)	-0.031 (0.206)	0.488** (0.222)
lnener	0.182 (0.111)	-0.099 (0.206)	0.156 (0.192)
lnopen	-0.007 (0.042)	-0.104** (0.042)	-0.175*** (0.058)
lnmanu	-0.111* (0.066)	-0.117 (0.090)	0.183 (0.139)
Constant	1.155 (0.876)	1.937 (1.445)	-2.264 (1.630)
Observations	432	189	189
R-squared	0.091	0.343	0.267
Number of id	16	7	7

*Note: Standard errors in parentheses, *p<0.1; **p<0.05 and ***p<0.01.*

From the point of view of control variables, no matter for high-income or low-income countries, the increase in carbon emissions per capita will clearly contribute in bringing down the efficiency of carbon emissions. For countries, the increased opening up will definitely bring down the efficiency of carbon emissions. As a result of the transfer of industries to these countries, the increase in GDP per capita will improve the efficiency of carbon emissions to a certain extent, so for low and middle-income countries, development is the last word.

3.3. Robustness test

Let fdr epresent financial development variable, fi represent financial 355 institutions variable and fmr represent financial market variable. The robustness results are shown in Table 5.

As it can be seen, when using lncarbper as the dependent variable, the overall and sub-variable variables were estimated. Compared with the previous estimation results, Among the factors that affect carbon emissions from financial development, according to the overall estimates, financial development led to a reduction in per capita carbon emissions, which is consistent with the previous results. When it have been estimated, however, as being divided into financial development, financial institutions and financial markets, the reduction of carbon dioxide emissions per capita has become very significant, which indicates a robust estimate.

Using fd as the main explanatory variables and effval as the dependent variable, a robustness test was conducted for countries with different incomes, and it was found that the financial development of low-and middle-income countries significantly improves the carbon emission efficiency at 1% level, while the financial development of high-and middle-income countries significantly reduces the carbon emission efficiency at 1% level. Well, that could be the reason the financial development of middle-low income countries is generally backward, and the statistics broken down into financial institutions and financial markets cannot provide more comprehensive information. As shown in Table 6, for high-income countries, financial development has already brought down carbon emission efficiency.

Apparently, in the robustness test where carbon emission efficiency plays as the dependent variable, due to that potential reverse causality between carbper and fd, endogenous problems need to be solved, and 2SLS and GMM tests need to be carried out. In the various factors that constitute fd, fi, fm, fia, fid, fie, fma, fmd and fme, fi and fie are taken as instrumental variables, because of the over-identification test， p value is 0.1734, fi and fie are exogenous, which are not related to the disturbance term. At the same time, Wold test shows that the minimum eigenvalue is 611.675> 19.93, which can accept a significance level of no more than 10%, can accept no more than 10% significance level, can reject the null hypothesis of instrumental variable “weak”. For robustness, we found that the limited information maximum likelihood method (LIML) less sensitive to weak instrumental variable, and very close to the results of 2 SLS. Instrumental variables cannot be used without endogenous explanatory variables existing. Using the traditional Hausman test, the results show that fd is an endogenous variable.

Table 5. Robust test result carbper as dependent variable

	(1)	*(2)*	*(3)*
fd	-0.160*** (0.0582)		
fm		-0.0787** (0.0340)	
fi			-0.200** (0.0884)
lngdper	1.074*** (0.0247)	1.059*** (0.0232)	1.078*** (0.0270)
lneneint	0.962*** (0.0385)	0.957*** (0.0385)	0.966*** (0.0388)
lnopen	-0.0227 (0.0186)	-0.0247 (0.0187)	-0.0331* (0.0180)
lnmanuratio	0.106*** (0.0328)	0.120*** (0.0318)	0.103*** (0.0342)
Constant	-7.844*** (0.267)	-7.777*** (0.264)	-7.817*** (0.268)
Observations	810	810	810
Number of id	30	30	30

*Note: Standard errors in parentheses, *p<0.1; **p<0.05 and ***p<0.01.*

Table 6. Robust test result (effval as dependent variable)

	(1)High-income	*(2)Middle-high*	*(3)Middle-low*
fd	-0.0879 (0.0952)	-0.717*** (0.210)	0.548*** (0.207)
lncarbper	-0.204*** (0.0638)	0.0481 (0.193)	-0.575*** (0.136)
lnpgdp	0.117 (0.0847)	0.208 (0.222)	0.454** (0.184)
lnener	0.161 (0.106)	0.188 (0.220)	0.135 (0.173)
lnopen	-0.0131 (0.0392)	-0.126*** (0.0454)	-0.178*** (0.0413)
lnmanu	-0.143** (0.0626)	-0.00203 (0.0896)	0.196 (0.133)
Constant	0.694 (0.828)	-1.145 (1.487)	-2.019 (1.432)
Observations	432	189	189
R-squared	0.044	0.149	0.264
Number of id	16	7	7

*Note: Standard errors in parentheses, *p<0.1; **p<0.05 and ***p<0.01.*

Heteroskedasticity robust DWH test was used, Durbin (score) chi2(1) = 30.2642 (p = 0.0000)， Wu-Hausman F(1,802) = 31.1283 (p = 0.0000). It shows that fd is an endogenous explanatory variable. Perform white test to determine whether there is heteroskedasticity. If there is heteroskedasticity, GMM is more efficient than 2SLS, After white test, chi2(27) = 123.77 Prob > chi2 = 0.0000. The P value is equal to 0.0000, so it is considered that there is heteroskedasticity, so the optimal GMM estimation is conducted. The results of various comparisons can be found in Table 7. The results show that when fi and fie are used as instrumental variables, the coefficients of 2SLS, LIML and GMM are relatively similar, and the conclusion is that financial development can be said to have shown a positive and significant effect on carbon emission efficiency. Further robustness test, since carbon dioxide emissions will be affected by the emissions of the previous period, we establish a dynamic panel model. Since there are many factors affecting carbon emissions, there may be omissions, so a first-order lag is introduced. The term can overcome the endogenous problem to a certain extent.

The square term of the financial development variable was added. Hu and Wang (2018) further confirmed the non-linear relationship between financial development and the scale and efficiency of carbon emissions model as given by Eqs. (5-6):

$$carbper_{it} = \beta_0 + \beta_1 carbper_{it-1} + \beta_2 fd_{it} + \beta_3 fd_{it}^{\,2} + \beta_4 X_{it} + \nu_i + \eta_t + \varepsilon_{it} \tag{5}$$

$$effval_{it} = \alpha_0 + \alpha_1 carbper_{it-1} + \alpha_2 fd_{it} + \alpha_2 fd_{it}^{\,2} + \alpha_3 X_{it} + \nu_i + \varphi_t + \varepsilon_{it} \tag{6}$$

For model (5), OLS, 2SLS, LIML, GMM estimation are taken, and in Table 8, the results obtained are can be seen. For model (6), OLS、2SLS、LIML, GMM estimation are taken, and the results obtained are shown in Table 9.

Table 7. Robust test result (effval as dependent variable)

	(1)	*(2)*	*(3)*	*(4)*
	ols	***2sls***	***liml***	***gmm***
lncarbper	-0.0954***	-0.0945***	-0.0945***	-0.0922***
	(0.0162)	(0.0169)	(0.0169)	(0.0169)
fd	0.411***	0.663***	0.664***	0.681***
	(0.0599)	(0.0752)	(0.0754)	(0.0742)
lngdper	0.196***	0.166***	0.166***	0.165***
	(0.0127)	(0.0136)	(0.0136)	(0.0136)
lneneint	-0.0707**	-0.0803***	-0.0803***	-0.0899***
	(0.0290)	(0.0295)	(0.0295)	(0.0288)
lnopen	-0.257***	-0.262***	-0.262***	-0.265***
	(0.0143)	(0.0146)	(0.0146)	(0.0143)
lnmanuratio	0.146***	0.125***	0.124***	0.129***
	(0.0302)	(0.0296)	(0.0296)	(0.0293)
Constant	-0.490***	-0.256**	-0.255**	-0.246**
	(0.115)	(0.119)	(0.119)	(0.119)
Observations	810	810	810	810
R-squared	0.628	0.619	0.618	0.617

*Note: Standard errors in parentheses, *p<0.1; **p<0.05 and ***p<0.01.*

Table 8. Robust test result (carbper as dependent variable)

	(1)	*(2)*	*(3)*	*(4)*
lncarbper	***ols***	***sls***	***liml***	***gmm***
L.lncarbper	0.978***	0.980***	0.980***	0.980***
	(0.00741)	(0.00731)	(0.00731)	(0.00730)
fd	0.0118	-0.335	-0.337	-0.345
	(0.0967)	(0.355)	(0.356)	(0.354)
fd2	-0.0360	0.252	0.253	0.261
	(0.0751)	(0.294)	(0.295)	(0.294)
lngdper	0.00585	0.0108	0.0109	0.0108
	(0.00495)	(0.00769)	(0.00771)	(0.00769)
lneneint	0.0305***	0.0385***	0.0386***	0.0375***
	(0.0114)	(0.0142)	(0.0142)	(0.0140)
lnopen	0.00621	0.0105	0.0105	0.0121
	(0.00732)	(0.00954)	(0.00955)	(0.00894)
lnmanuratio	0.00544	0.0112	0.0112	0.0122
	(0.00906)	(0.00942)	(0.00942)	(0.00920)
Constant	-0.0381	-0.0449	-0.0449	-0.0496
	(0.0478)	(0.0495)	(0.0495)	(0.0485)
Observations	780	780	780	780
R-squared	0.996	0.995	0.995	0.995

*Note: Standard errors in parentheses, *p<0.1; **p<0.05 and ***p<0.01.*

Table 9. Robust test result (effval as dependent variable)

	(1)	*(2)*	*(3)*	*(4)*
effval	***ols***	***Sls***	***liml***	***gmm***
L.lncarbper	-0.0751***	-0.102***	-0.102***	-0.0980***
	(0.0151)	(0.0230)	(0.0233)	(0.0223)
fd	-0.692***	3.936***	4.025***	3.781***
	(0.224)	(1.104)	(1.130)	(1.077)
fd2	1.024***	-2.822***	-2.895***	-2.679***
	(0.200)	(0.916)	(0.937)	(0.890)
lngdper	0.191***	0.125***	0.123***	0.124***
	(0.0129)	(0.0211)	(0.0214)	(0.0209)
lneneint	-0.0624**	-0.169***	-0.171***	-0.171***
	(0.0294)	(0.0417)	(0.0422)	(0.0413)
lnopen	-0.243***	-0.300***	-0.301***	-0.299***
	(0.0152)	(0.0226)	(0.0229)	(0.0224)
lnmanuratio	0.155***	0.0779**	0.0765**	0.0823**
	(0.0311)	(0.0369)	(0.0372)	(0.0360)
Constant	-0.358***	-0.268*	-0.267*	-0.257*
	(0.118)	(0.148)	(0.149)	(0.145)
Observations	780	780	780	780
R-squared	0.643	0.452	0.445	0.465

*Note: Standard errors in parentheses, *p<0.1; **p<0.05 and ***p<0.01.*

Tables 8-9 suggest that the lagging period of carbon emissions has, apparently, significantly brought up the amount of carbon emissions by 1%, and it also has significantly reduced carbon emission efficiency on 1% level, and without doubt, it is reducing carbon Emission efficiency. The coefficient of the square term of financial development is positive, while at the same time, the coefficient of the first term is negative, indicating that the impact that financial development have on carbon emissions is U-shaped. Also, financial development brings down the amount of carbon emissions at the initial stage. The use of new energy technologies and environmental pollution control technologies to reduce carbon emissions, as mentioned above, is consistent with the previous finding. The coefficient of the square term of the effect of financial development on carbon efficiency is negative and the coefficient of the first term is positive, indicating that the two are inverted U-shaped. Financial development reduces carbon emission at the stage, and increases carbon emission efficiency. Therefore the results are robust.

4. Conclusions

Based on the cross-country non-equilibrium panel data from 1990 to 2016, this paper takes the depth, availability and efficiency of financial institutions and financial markets as an agent variable of financial development. When we studied the effect of financial development on carbon dioxide emission, we used SBM model to calculate carbon emission efficiency strictly, test the effect of financial development on emission, and draw the following conclusions:

In general, financial development will significantly reduce carbon dioxide emissions on capita level. Both financial institutions and financial markets are likely to increase investment in environmental protection and Energy Conservation and emission reduction, which will have a significant impact on carbon dioxide emissions.

Financial development has improved the efficiency of carbon emission to some extent, but the performance of financial institutions and financial markets is different. Financial institutions have more obvious efficiency gains for high-income countries, and financial markets can adopt more flexible methods to improve efficiency. For middle- high income countries, the availability of financial markets increases efficiency.

Increasing per capita carbon emissions will reduce the efficiency of carbon emissions, while if per capita gdp and financial development is increased, the efficiency of carbon emissions will go up as well. For middle-low income countries, financial development should be increased first. A high proportion of primary energy consumption plus a high proportion of industrial added value will improve carbon dioxide emissions. The higher the proportion of exports, you can reduce carbon dioxide emissions, but also reduce carbon emissions efficiency.

Because of the possible endogenous problems in the model, we use fi and fid as tool variables to test the 2SLS LIML and GMM. The comparison results are similar and different from those of OLS, and the U-shaped test is carried out by using the square term of fd. Different stages of financial development have different impacts on the scale and efficiency of carbon emissions. From the scale of carbon emissions, the effect shows a u-shaped curve, while from the efficiency, the effect shows an inverted u-shaped curve, which is verified in the robustness test. Financial development can reduce carbon emissions scale while improve carbon emissions efficiency at a certain stage.

As the conclusion reveals, the in-depth development of financial institutions in high-income countries will have higher carbon emission efficiency.

Improving the in-depth development of financial institutions, while strengthening the supervision of financial institutions is the way to maintain high carbon emission efficiency. For middle- high income countries, the availability of financial institutions and the availability of financial markets can improve carbon emission efficiency.

Therefore, considering the different stages of financial development, policy makers should take different measures to promote financial system reform and increase Financial institutions increase various channels of financing in the financial market. It is recommended to establish green banks, or focus on green credit investment in bank investment, explore the establishment of green finance incentive mechanisms, and encourage financial institutions to participate; boost the prosperity of the financial market, especially for the financing of energy saving and emission reduction projects, using green stocks, Green bonds, green funds, green insurance and other green financial products and methods have made the financial market the main channel and way to increase carbon emission efficiency, establish a carbon emission trading market, and use market methods to effectively bring down carbon emissions and increase its efficiency.

For middle-low income countries, since the influence that financial development brings to carbon emission efficiency is significant, increasing per capita GDP can increase carbon emission efficiency. Therefore, economic development and financial development can improve carbon emission efficiency.

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