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# THE ROLE OF FINANCIAL DEVELOPMENT AND ECONOMIC GROWTH IN REDUCING $CO_2$ EMISSIONS: EVIDENCE FROM CHINA

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## Abstract

Based on the dynamic panel data from 29 administrative regions in China over the period of 2003-2013, we applied GMM system method to the analysis of the relationship between financial development, economic growth and $CO_2$ emissions. Empirical analysis indicates that economic growth is usually accompanied by higher $CO_2$ emissions, while the increasing level of final development is associated with a reduction in $CO_2$ emissions. Further analysis shows that the relationship between financial development and $CO_2$ emissions presents an inverted-U shape pattern. Only after the economic development has reached a threshold value will the promoting effect of financial development to the reduction of $CO_2$ emissions manifest. Moreover, industrial structure optimization and upgrading contribute to the reduction of $CO_2$ emissions. In other words, the increasing proportion of the secondary sector will weaken the promoting effect of financial development to the reduction of $CO_2$ emissions and intensify the negative impact of economic growth on $CO_2$ emissions. On the contrary, the increasing proportion of the tertiary sector will greatly facilitate the reduction of $CO_2$ emissions and mitigate the increase of $CO_2$ emissions due to economic growth. For less financially developed countries, market-oriented reform can reduce carbon emissions by promoting financial development. Moreover, industrial structure optimization and upgrading will contribute significantly to the reduction of $CO_2$ emissions.

*Key words:* $CO_2$ emissions, economic growth, financial development, industrial structure

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## 1. Introduction

In the past few decades, China and India, the two representative emerging markets, have experienced an impressive rate of economic growth. But the extensive economic growth featured by industrialization has led to dramatic rise of carbon emissions and a growing burden on the environment. After the global financial crisis in 2008, many developed economies have sunken into recession. At the same time, emerging economics like China contributes over 20% to global economic growth. However, China contributes about as high as 10.6% to the world's total carbon emissions (Jia, 2016). The major concern facing the emerging economies today is how to reduce carbon emissions in the context of fast economic growth.

The early literature report that the level of national development determines the impact of economic growth on carbon dioxide emissions. Developing countries are trying to use new material or investigate different environmental protection models to enhance the energy efficiency and to control the pollution (Choi et al., 2017; Hua et al., 2016; Genco et al., 2018; Kigpiboon, 2013; Luong et al., 2017; Marino et al., 2017; Massoud et al., 2017; Ordouei et al., 2018). However, the effects of the above attempts on prevent inequitable share of national economic development are limited (Danbaba et al., 2016). In an early study, Zomorrodi and Zhou (2016) find that developing countries suffer from high carbon dioxide

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emissions while the developed countries benefit with the economic growth. That means that better environmental quality can be achieved only after the level of development reaches a threshold level. Considering the different factor endowments in different countries, globalization, foreign direct investment and less stringent public policy, the developing countries should take responsibility for the cross-border pollution (Al-Fatlawi, 2018; Henry, 2014; Hofman, 2014; Zhou, 2014; Zomorrodi and Zhou, 2017). As environmental value is not only the concern of firms, the government of developing countries should find the balance between the environment and sustainability (Adebambo et al., 2014; Baran and Yilmaz, 2018; Torretta and Capodaglio, 2017).

Despite the inadequacy of the literature on a direct examination of the financial development-$CO_2$ emissions nexus, a large strand of literature has discussed the role of economic growth in $CO_2$ emissions. Ali et al. (2014) show an inverted U-shaped relationship between economic growth and environmental degradation in case of Pakistan. Similarly, Li et al. (2015) analyze the relationships between environmental quality and economic growth based on cross-country data using the generalized method of moments (GMM) estimation. Their results show that both financial development and environmental quality have a significant impact on economic growth and there is an "inverted U-shaped" relationship between economic growth and energy consumptions. Furthermore, Zhang (2017) examined dynamic interactions among population growth, wealth accumulation, and environmental change. Recently, there has been a shift of attention from the influence of economic growth on carbon emissions to the role of finance and industrial structure in the reduction of carbon emissions. For example, Halicioglu (2009) argues that financial development confers superior financial services for eco-friendly programs at decreased costs thus reducing environmental pollution.

Tamazian et al. (2009) suggest that an effective financial sector is helpful in offering greater funding at lower cost by establishing a link between financial development and environmental performance. In the study of Zhang (2011), financial development is found to be an important driver for carbon emissions in China. In another study, however, Jalil and Feridun (2011) examine the impact of financial development and economic growth on $CO_2$ emissions in China and their results suggest that financial development in China has not taken place at the expense of $CO_2$ emissions. Muhammad et al. (2013) examines the linkages between economic growth, energy consumption, financial development, trade openness and $CO_2$ emissions over the period of 1975Q1–2011Q4 in case of Indonesia using Zivot–Andrews unit root test and the ARDL bounds testing approach. The authors find that economic growth and energy consumption increase $CO_2$ emissions, while financial development and trade openness compact it. Shahbaz et al. (2013) apply the bounds testing approach to study whether financial development reduces $CO_2$ emissions in case of Malaysia. They find significant long-run relationships between $CO_2$ emissions, financial development and economic growth. The empirical evidence also indicates that financial development reduces $CO_2$ emissions while economic growth adds in $CO_2$ emissions. In a recent study, Ali et al. (2015) find that both financial development and economic growth have a significant negative impact on fossil fuel consumption in the short run. In another paper, Omri et al. (2015) study how financial development, $CO_2$ emissions and trade affect economic growth using panel data from 12 countries from 1990 to 2011. Their results not only imply a bidirectional causality between $CO_2$ emissions and economic growth but also identify the neutrality hypothesis between $CO_2$ emissions and financial development.

Based on a literature review, a large body of literature have discussed the role of ecnomic growth in $CO_2$ emissions, very few have directly investigated the relationship between financial development and $CO_2$ emissions. This study attempts to fill this gap partially by providing empirical evidences on the relationships between financial development and $CO_2$ emissions. This helps to establish a direct link between financial development and $CO_2$ emissions, which in turn extends our understanding of the role of finance and industrial structure in the reduction of carbon emissions. We analyze the relationship between financial development, economic growth and $CO_2$ emissions using dynamic panel data from 29 administrative regions in China over the period of 2003-2013. Innovations are made in the following 4 aspects: first, carbon emissions are estimated for each district of China over the years; second, besides the linear relationship between financial development and carbon emissions, the potential non-linear relationship between the two is also noted, which is consistent with the early literature. This enriches the existing literature on finance-environment nexus.

Third, the factor of industrial structure is introduced when discussing the influence of financial development and economic growth on the reduction of carbon emissions, which produces some interesting conclusions; fourth, system GMM method is employed for regression, so as to deal with the endogeneity problem in regressors. We find new evidences showing that there exist a U-shaped relationship between financial development and $CO_2$ emissions

The major contents of the present article are arranged as follows. Part 2 is the estimation of carbon emissions for different districts of China from 2003 to 2013. Part 3 is the use of system GMM for the analysis of relationship between financial development, economic growth and $CO_2$ emissions. Part 4 is an analysis of the turning point in the non-linear relationship between financial development and carbon emissions as well as the elasticity coefficient. The article concludes with policy implications.

## 2. Estimation of carbon emissions in China

China has no official statistics of carbon emissions so far and carbon emissions are usually estimated by the scholars. The estimation method by Li et al. (2011) is used in this study. Carbon emissions are mainly contributed by the combustion of fossil fuels (Li et al., 2011; Ma et al., 2017). The amount of energy used is transformed into a standard value and then multiplied by the coefficient of carbon emissions to calculate the respective carbon emissions contributed by each type of energy. Finally, the carbon emissions contributed by all forms of energy are summed up to obtain the total carbon emissions (Eq. 1):

$$C_{it} = \sum E_{ijt}\theta_j\eta_j \quad (1)$$

where $C_{it}$ is total $CO_2$ emissions of district i in the year t; $E_{ijt}$ is the consumption amount of energy $j$ in district $i$ in the year $t$; $\theta_j$ is the conversion coefficient from energy $j$ to standard coal; $\eta_j$ is the coefficient of carbon emissions for energy $j$. The conversion coefficients from different energy to standard coal and the coefficients of carbon emissions for the energy are shown in Table 1 and Table 2, respectively.

Using China Statistical Yearbook (2003-2013), China Energy Statistical Yearbook (2003-2013) and Wine database, total carbon emissions of each province in China in 2003-2013 are estimated. The results are shown in Fig. 1.

An obvious increasing trend of carbon emissions can be seen from 2003 to 2013 according to the estimated carbon emissions in each province. The national total carbon emissions in 2003 amounted to 143844.6kg in 2003, and the figure rose by 2.31 times in 2013. The increasing trend was most prominent in North-eastern China. In 2003, the top five provinces in terms of carbon emissions were Shandong, Shanxi, Liaoning, Hebei and Guangdong. In 2013, the top five provinces were Shandong, Jiangsu, Hebei, Inner Mongolia and Shanxi. Over the period of 10 years, the increasing rate of carbon emissions in Shandong, Inner Mongolia, Jiangsu, Hebei and Henan is higher than that of other provinces. The increasing rate of carbon emissions in Beijing, Hainan, Qinghai, Shanghai and Tianjin is much lower.

**Table 1.** Conversion coefficients from different energy to standard coal

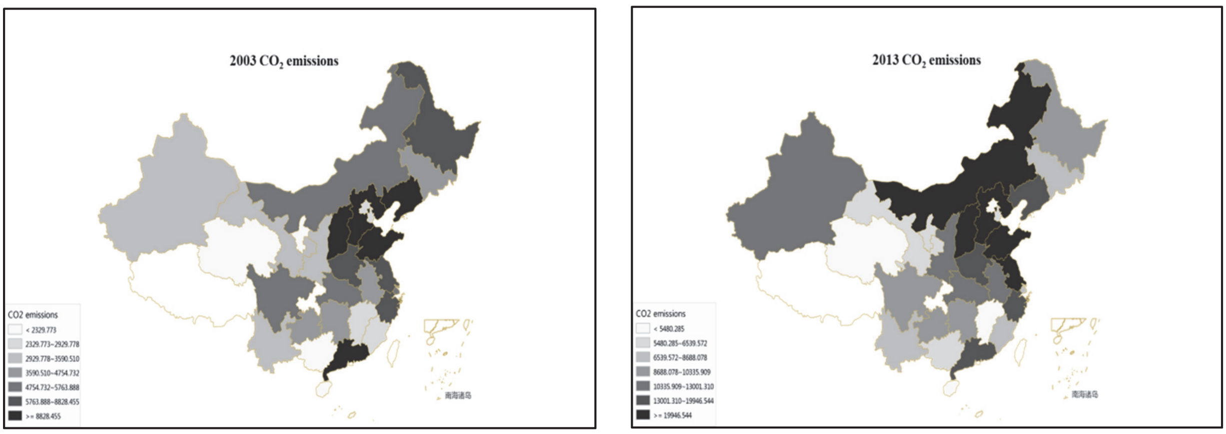
| *Type of energy* | *Conversion coefficient* | *Type of energy* | *Conversion coefficient* | *Type of energy* | *Conversion coefficient* |
|---|---|---|---|---|---|
| Coal (kg) | 0.7143 | Kerosene (kg) | 1.4714 | Coke (kg) | 0.9712 |
| Diesel (kg) | 1.4571 | Crude oil (kg) | 1.4286 | Electricity ( kW·h) | 0.1229 |
| Gasoline (kg) | 1.4714 | Fuel oil (kg) | 1.4286 | Natural gas ($m^3$) | 1.3300 |

*Data source: 2014 China Energy Statistical Yearbook*

**Table 2.** Coefficients of carbon emissions

| *Type of energy* | *Coefficient of carbon emissions* | *Type of energy* | *Coefficient of carbon emissions* | *Type of energy* | *Coefficient of carbon emissions* |
|---|---|---|---|---|---|
| Coal | 0.7476 | Kerosene | 0.3416 | Coke | 0. 1128 |
| Diesel | 0.5913 | Crude oil | 0.5854 | Electricity | 2. 2132 |
| Gasoline | 0.5532 | Fuel oil | 0.6176 | Natural gas | 0. 4479 |

*Data source: IPCC (1995)*




(a) (b)

**Fig. 1.** (a) Total carbon emissions of each province: 2003, (b) Total carbon emissions of each province: 2013

## 3. An empirical analysis

Regression is performed using dynamic panel data from 29 administrative regions from 2003 to 2013, in an attempt to examine the role of financial development and economic growth.

### 3.1. Model setting and sample data

The influence of financial development and economic growth on carbon emissions is estimated using the regression equation (Eq. 2):

$$CO_{2(i,t)} = \alpha_i + \beta_1 CO_{2(i,t-1)} + \beta_2 F_{i,t} + \beta_3 prate_{i,t} + \beta_4 X_{i,t} + \varepsilon_{i,t} \tag{2}$$

The left side of the Eq. (2) is the carbon emissions of different district in different years, which is the explained variable. On the right side, $\alpha_i$ is the interception term; $CO_{2(i,\ t-1)}$ is the environment index with one-phase lag; $F_{i,t}$ is financial development, measured by the credit-to-GDP ratio (credit/GDP); $prate_{i,t}$ is the growth rate of GDP per capita, used for examining the effect of economic growth rate on carbon emissions; $X_{i,t}$ is other control variable, including consumer price index (CPI), capital formation rate representing capital accumulation of the district (investgdp), export-import ratio of the district (exgdp), and highway mileage representing the infrastructure construction level (road); $\varepsilon_{i,t}$ is residual.

Considering that unobserved province-specific effect is typically present in panel data models, we use generalized method of moments (GMM) for estimation. Panel data for each variable range from 2003 to 2013 and cover 29 administrative regions in China except Tibet and Chongqing. To smooth data and reduce heteroscedasticity, absolute value of highway mileage (road) is taken. The meanings and statistical descriptions of each variable are presented in Table 3.

### 3.2. Estimation method

Model (2) is a typical dynamic panel data model. Because the lag term of the dependent variable may be related to the error term even if is not serially correlated, the conventional OLS estimation will be biased. As for the commonly used fixed effects (FE) estimator, although the individual-level effect $\mu_i$ is discarded from the data within the groups that assume the form of deviations from individual means, there is a correlation between $\left(CO_{2(i,t-1)} - \overline{CO_{2(i,t-1)}}\right)$ and $\left(\varepsilon_{i,t-1} - \overline{\varepsilon_{i,t-1}}\right)$. Therefore, the fixed effects estimator would be inconsistent. In terms of the generalized least squares (GLS) estimator for the random effects model, after treating the variables with quasi-demeaning, because $\left(CO_{2(i,t-1)} - \theta\overline{CO_{2(i,t-1)}}\right)$ and $\left(\varepsilon_{i,t-1} - \theta\overline{\varepsilon_{i,t-1}}\right)$ are correlated, the estimation results will still be biased. To obtain robust estimates, we follow Arellano and Bond (1995) and Blundell and Bondi (1998) and use system GMM estimator to estimate Model (2).

In order to test the validity of the instruments used in GMM estimation, we follow the standard literature by using Sargan test. Another specification test is the test for the existence of second-order serial correlation of the residuals. To ensure adequate model specification, one should confirm the first-order serial correlation and reject the second-order serial correlation. The Sargan test is applied to ensure the overall validity of the instruments used in the estimation. It is given by Eq. (3):

$$Sargan = \hat{v}Z\left[\sum_{i=1}^{N} Z_i'\hat{v}_i\hat{v}_i'Z_i\right]^{-1} Z'\hat{v} \tag{3}$$

with: $v_i = \left(\varepsilon_{i,2\theta} - \varepsilon_{i,\theta}, \ldots\ldots, \varepsilon_{i,5\theta} - \varepsilon_{i,4\theta}\right)'$ the vector of errors in difference, where $\hat{v} = \left[\hat{v}_1', \ldots\ldots, \hat{v}_N'\right]$ is a vector of estimated residuals and $Z_i$ is the matrix instruments.

The AR(2) test is used to test the hypothesis that there is no correlation among error terms in the differential Equation. Typically, we consider the following notations (Eqs. 4-5):

$$\hat{v}_{-2i} = \left[\hat{v}_{i,1}, \ldots\ldots, \hat{v}_{i,(T-2)\theta}\right]',\ \hat{v}_{*i} = \left[\hat{v}_{i,3\theta}, \ldots\ldots, \hat{v}_{i,T\theta}\right]' \tag{4}$$

$$\hat{v}_{-2} = \left[\hat{v}_{-2_1}', \ldots\ldots, \hat{v}_{-2_N}'\right]',\ \left[\hat{v}_{*1}', \ldots\ldots, \hat{v}_{*N}'\right] \tag{5}$$

**Table 3.** Statistical description of the variable

| *Variable* | *Meaning* | *Mean* | *Standard deviation* | *Maximum* | *Minimum* | *Observed value* |
|---|---|---|---|---|---|---|
| $CO_2$ | $CO_2$ emissions | 8.787 | 0.786 | 10.403 | 6.089 | 319 |
| F | credit/GDP | 1.073 | 0.367 | 2.585 | 0.537 | 319 |
| prate | Growth rate of per capita GDP | 15.790 | 6.119 | 42.520 | 0.070 | 319 |
| i2 | Secondary sector value added/GDP | 0.476 | 0.079 | 0.664 | 0.218 | 319 |
| i3 | Tertiary sector value added/GDP | 0.392 | 0.077 | 0.769 | 0.274 | 319 |
| cpi | | 103.057 | 2.059 | 110.090 | 97.650 | 319 |
| investgdp | | 0.532 | 0.139 | 1.151 | 0.310 | 319 |
| exgdp | | 0.344 | 0.421 | 1.680 | 0.030 | 319 |
| road | Highway mileage (km)* | 11.323 | 0.889 | 12.618 | 8.777 | 319 |

*Note: * is the variable whose natural logarithm is taken.*

The statistic is written as Eq. (6):

$$AR(2) = \frac{\hat{v}'_{-2}\hat{v}_{*}}{Q} \qquad (6)$$

It could be read as an average covariances of order 2 errors of the difference equation, $Q$ is a quotient appropriate standard. The Sargan statistic is assumed to be chi-squared ($\chi^2$) distributed under the null hypothesis, while the AR(2) statistic is assumed to follow the standard normal distribution (N (0,1)).

### *3.3. Result of empirical analysis*

Regression equations that contain no control variables are first plotted, and the equations with control variables are plotted next. The regression results are shown in Table 4, where 6 regression equations are displayed. Eq. (1) only considers the relationship between carbon emissions and financial development; Eq. (2) considers the relationship between carbon emissions, financial development and economic growth; Eqs. (3-6) control for the variables of cpi, investgdp, exgdp and road.According to the regression results, the following conclusions are drawn:

(1) At 1% confidence level, carbon emissions with one phase lag has a significant impact on carbon emissions of the current period. This indicates the persistence of environmental changes of a district and the environmental status of the previous period will have an impact on the environment of the current period.

(2) Economic growth does affect the environment negatively, whereas financial development will reduce carbon emissions. As shown by regression results in Table 4, the sign of coefficient of financial development (f) is negative and that of growth rate of per capita GDP (prate) is positive. During the course of rapid economic growth, more $CO_2$ emissions will be produced, but the environmental improvement will show with the deepening of financial development.

(3) As to the byproduct of control variables, Table 4 shows that the variable of inflation (cpi) has a significantly negative correlation with carbon emissions. However, other control variables, investgdp and exgdp, have a significantly positive correlation with carbon emissions. Thus higher capital accumulation and export-import ratio are detrimental to the environment.

All regression models in Table 4 pass the Sargan's test and AR (2) test, indicating that the instrumental variables chosen are valid. The residual is not affected by second-order sequence. Therefore, the estimation is reliable.

Next is the analysis of the influence of industrial structure. To that end, the interaction terms of financial development, economic growth, secondary or tertiary sectors are introduced into the regression analysis. The results are shown in Table 5. It can be seen that the coefficients of interaction terms of secondary sector, financial development and economic growth are all positive, indicating that the increasing proportion of the secondary sector will weaken the inhibitory effect of financial development on carbon emissions.

**Table 4.** Regression results

| | ***The dependent variable is the carbon emission : $CO_2$*** | | | | | |
|---|---|---|---|---|---|---|
| | *(1)* | *(2)* | *(3)* | *(4)* | *(5)* | *(6)* |
| L. $CO_2$ | $0.840^{***}$ | $0.899^{***}$ | $0.938^{***}$ | $0.941^{***}$ | $0.935^{***}$ | $0.962^{***}$ |
| | (26.29) | (43.81) | (52.75) | (39.90) | (30.97) | (25.39) |
| f | $-0.111^{***}$ | $-0.077^{***}$ | $-0.039^{**}$ | $-0.038^{**}$ | $-0.110^{**}$ | $-0.129^{***}$ |
| | (-2.70) | (-2.66) | (-2.05) | (-1.99) | (-2.04) | (-2.64) |
| prate | | $0.002^{***}$ | $0.008^{***}$ | $0.007^{***}$ | $0.008^{***}$ | $0.009^{***}$ |
| | | (2.73) | (4.01) | (4.68) | (3.92) | (4.69) |
| cpi | | | $-0.014^{***}$ | $-0.011^{***}$ | $-0.013^{***}$ | $-0.017^{***}$ |
| | | | (-3.19) | (-3.37) | (-3.01) | (-4.68) |
| investgdp | | | | 0.068 | $0.249^{*}$ | $0.280^{**}$ |
| | | | | (1.38) | (1.65) | (2.55) |
| exgdp | | | | | $0.096^{*}$ | $0.081^{*}$ |
| | | | | | (1.81) | (1.74) |
| road | | | | | | -0.031 |
| | | | | | | (-0.95) |
| _cons | $1.611^{***}$ | $1.011^{***}$ | $2.005^{***}$ | $1.671^{***}$ | $1.806^{***}$ | $2.335^{***}$ |
| | (5.36) | (5.09) | (5.89) | (8.61) | (4.42) | (6.42) |
| Wald chi2 | 912.145 | 2579.251 | 4946.182 | 7711.738 | 1939.614 | 2276.189 |
| Sargan | 25.607 | 27.169 | 25.901 | 23.006 | 25.547 | 24.837 |
| (p-value) | (0.109) | (0.455) | (0.631) | (0.999) | (0.598) | (0.687) |
| AR(2) | -0.701 | -0.612 | -0.590 | -0.569 | -0.387 | -0.517 |
| (p-value) | (0.483) | (0.541) | (0.555) | (0.570) | (0.699) | (0.605) |
| Observations | 290 | 290 | 290 | 290 | 290 | 290 |
| Regions | 29 | 29 | 29 | 29 | 29 | 29 |

*t statistics in parentheses, $^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$*

However, the coefficients of interaction terms of tertiary sector, financial development and economic growth are all negative, indicating that the increasing proportion of tertiary sector will enhance the inhibitory effect of financial development on carbon emissions and mitigate the increase of carbon emissions due to economic growth.

To further examine the non-linear relationship between carbon emissions and financial development, the quadratic term of financial development is introduced into the regression equation and the regression results are shown in Table 6. In Eq. (1), the coefficient for the linear term of financial development is positive at a significant level, while that for the quadratic term is negative at a significant level. This means financial development has a significant inverted U-shaped relationship with carbon emissions. Figure 2 present the invert U-shaped relationship between financial development and $CO_2$ emissions. At the beginning, carbon emissions will rise with the increasing level of financial development. But after the level of financial development has exceeded the threshold value, the carbon emissions will decrease.

As shown in Eq. (2), this inverted U-shaped relationship still holds after the introduction of control variables.

In Eq. (3), the coefficient for the interaction term of financial development and growth rate of per capita GDP is negative at a significant level, indicating that financial development mitigates the increase of carbon emissions due to economic growth. Moreover, in Eqs. (4-5), the coefficient for the interaction term of secondary sector and financial development is positive at a significant level, while that for the interaction term of tertiary sector and financial development is negative. This result confirms the conclusion made from Table 5. That is, the increasing proportion of secondary sector will weaken the inhibitory effect of financial development on carbon emissions; the increasing proportion of tertiary sector will enhance the inhibitory effect of financial development on carbon emissions.

To account for large variations of economic growth, financial development and environmental status across the districts, China is divided into three regions by the State Council of China: east, middle and west. East China includes Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Guangdong, Shandong and Hainan. Middle China includes Shanxi, Inner Mongolia, Jilin, Heilongjiang, Anhui, Jiangxi, Henan, Hubei, Hunan and Guangxi. West China includes Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia and Xinjiang.

**Table 5.** Influence of industrial structure on $CO_2$ emissions

| | ***The dependent variable is the carbon emission : $CO_2$*** | | | |
|---|---|---|---|---|
| | *(1)* | *(2)* | *(3)* | *(4)* |
| L.$CO_2$ | $0.836^{***}$ | $0.865^{***}$ | $0.910^{***}$ | $0.928^{***}$ |
| | (16.46) | (14.07) | (30.60) | (30.00) |
| f | $-0.468^{**}$ | $-0.303^{*}$ | $-0.079^{*}$ | $-0.094^{***}$ |
| | (-2.29) | (-1.66) | (-1.85) | (-2.66) |
| prate | $0.005^{***}$ | $0.006^{***}$ | $0.010^{*}$ | $0.017^{**}$ |
| | (3.01) | (3.91) | (1.90) | (2.09) |
| f*i2 | $1.118^{***}$ | | | |
| | (3.07) | | | |
| f*i3 | | $-0.802^{**}$ | | |
| | | (-1.98) | | |
| prate* i2 | | | $0.027^{**}$ | |
| | | | (2.49) | |
| prate* i3 | | | | $-0.032^{*}$ |
| | | | | (-1.65) |
| cpi | $-0.010^{***}$ | $-0.015^{***}$ | $-0.001^{***}$ | $-0.011^{***}$ |
| | (-2.59) | (-3.76) | (-3.30) | (-3.14) |
| investgdp | 0.152 | $0.617^{**}$ | 0.019 | $0.310^{**}$ |
| | (1.21) | (2.07) | (0.19) | (2.48) |
| exgdp | $0.138^{*}$ | $0.293^{**}$ | 0.012 | 0.058 |
| | (1.86) | (2.07) | (0.20) | (0.70) |
| road | 0.003 | -0.004 | -0.022 | $-0.054^{*}$ |
| | (0.12) | (-0.09) | (-0.69) | (-1.65) |
| _cons | $2.220^{***}$ | $2.331^{***}$ | $1.912^{***}$ | $2.316^{***}$ |
| | (5.14) | (3.64) | (6.06) | (5.61) |
| Wald chi2 | 1347.732 | 829.293 | 7019.272 | 3442.089 |
| Sargan | 23.572 | 25.461 | 22.574 | 21.683 |
| (p-value) | (0.828) | (0.327) | (0.997) | (0.865) |
| AR(2) | -0.284 | -0.504 | -0.694 | -1.094 |
| (p-value) | (0.776) | (0.615) | (0.488) | (0.274) |
| Observations | 290 | 290 | 290 | 290 |
| Regions | 29 | 29 | 29 | 29 |

*t statistics in parentheses * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$*

**Table 6.** Non-linear relationship between carbon emissions and financial development

| | *The dependent variable is the carbon emission : $CO_2$* | | | | |
|---|---|---|---|---|---|
| | *(1)* | *(2)* | *(3)* | *(4)* | *(5)* |
| L. $CO_2$ | $0.903^{***}$ | $0.917^{***}$ | $1.021^{***}$ | $0.819^{***}$ | $0.979^{***}$ |
| | (43.54) | (15.57) | (23.50) | (10.21) | (9.38) |
| f | $0.878^{**}$ | $1.287^{**}$ | $1.273^{***}$ | $1.873^{**}$ | $1.631^{***}$ |
| | (2.28) | (2.32) | (2.75) | (2.60) | (2.69) |
| f2 | $-0.342^{**}$ | $-0.550^{**}$ | $-0.336^{***}$ | $-0.641^{***}$ | $-0.819^{**}$ |
| | (-2.01) | (-2.21) | (-2.65) | (-2.69) | (-2.49) |
| prate | $0.004^{***}$ | $0.008^{***}$ | $0.039^{***}$ | $0.008^{***}$ | $0.007^{***}$ |
| | (3.02) | (3.98) | (3.00) | (3.31) | (4.12) |
| f*prate | | | $-0.031^{***}$ | | |
| | | | (-2.71) | | |
| f*i2 | | | | $0.911^{**}$ | |
| | | | | (2.12) | |
| f*i3 | | | | | $-0.852^{**}$ |
| | | | | | (-2.02) |
| cpi | | $-0.013^{***}$ | $-0.014^{***}$ | $-0.009^{*}$ | $-0.011^{*}$ |
| | | (-2.63) | (-3.61) | (-1.85) | (-1.86) |
| investgdp | | $0.368^{*}$ | $-0.157^{*}$ | -0.253 | -0.110 |
| | | (1.89) | (-1.65) | (-0.91) | (-0.72) |
| exgdp | | $0.218^{*}$ | -0.105 | $-0.508^{*}$ | -0.022 |
| | | (1.71) | (-1.20) | (-1.72) | (-0.23) |
| road | | -0.039 | $-0.057^{**}$ | -0.022 | -0.037 |
| | | (-0.90) | (-2.10) | (-0.42) | (-1.03) |
| _cons | 0.380 | $1.567^{*}$ | $1.038^{**}$ | $3.555^{***}$ | 0.535 |
| | (1.15) | (1.88) | (2.51) | (3.87) | (0.61) |
| Wald chi2 | 1991.041 | 1022.066 | 6393.117 | 762.938 | 2386.403 |
| Sargan | 28.152 | 22.640 | 17.980 | 20.745 | 19.506 |
| (p-value) | (0.351) | (0.422) | (0.877) | (0.292) | (0.772) |
| AR(2) | -0.790 | -0.977 | -1.911 | -1.181 | -0.842 |
| (p-value) | (0.430) | (0.329) | (0.056) | (0.238) | (0.400) |
| Observations | 290 | 290 | 290 | 290 | 290 |
| Regions | 29 | 29 | 29 | 29 | 29 |

*t statistics in parentheses, $^{*}$ $p < 0.10$, $^{**}$ $p < 0.05$, $^{***}$ $p < 0.01$*

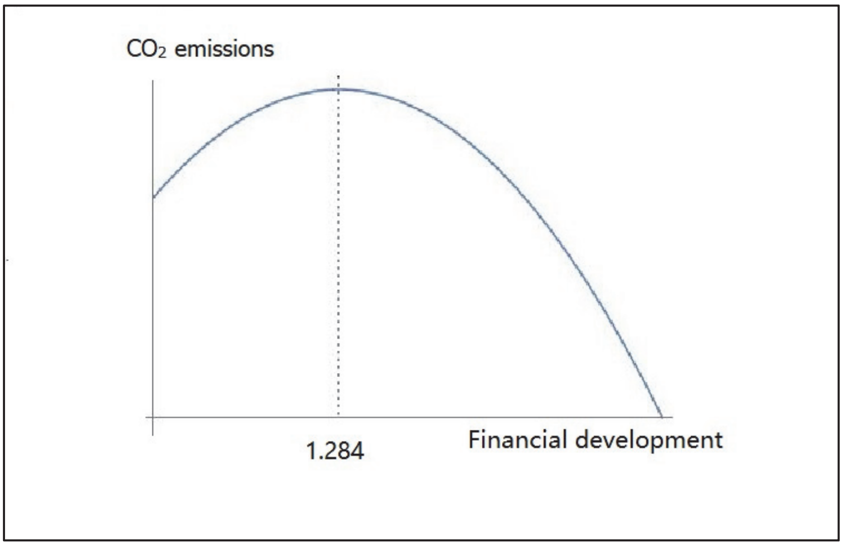



**Fig. 2.** The invert U-shaped relationship between financial development and $CO_2$ emissions.

Regression is performed for each region separately. The results are shown in Table 7. Eq. (1), Eq. (3) and Eq. (5) reflect the basic relationship between carbon emissions, financial development and economic growth in the three regions, respectively. Eq. (2), Eq. (4) and Eq. (6) contain the control variables on the basis of Eq. (1), Eq. (3) and Eq. (5). As shown in Table 7, the coefficients for growth rate of per capita GDP are all positive at a significant level, indicating that the faster the economic growth, the more severe the environmental deterioration will be. In Eq. (5) and Eq. (6), the coefficient for financial development is negative at a 10% significant level, indicating that financial development is favorable for environmental improvement in West China. In Eqs. (2-4), the coefficient for financial development does not reach a significant level, indicating that the improving effect of financial development on the environment for East and Middle China is not significant.

## 4. Further discussion: turning point and elasticity coefficient

Above is an empirical analysis of the non-linear relationship between environmental development and carbon emissions. The relationship between financial development and carbon emissions will be further evaluated quantitatively. Specifically, two problems are discussed here. One is the position of the turning point in the quadratic relationship between financial development and carbon emissions; the other is the value of elasticity coefficient beyond the turning point. Eq. (1) and Eq. (2) in Table 6 are used for the discussion.

Regressions with Eq. (1) and Eq. (2) in Table 5 indicate that (1) when no control variables are introduced, the turning point roughly occurs at the credit-to-GDP ratio of 1.28; (2) when control variables are introduced, the turning point occurs at the credit-to-GDP ratio of 1.17. With the turning point determined, the elasticity coefficient of financial development on carbon emissions is analyzed. Considering the quadratic relationship between the two and using Eq. (1) in Table 6, the following equation (Eq. 7) can be obtained:

$$CO_2 = 0.38 + 0.903CO_2(-1) + 0.878f - 0.342f^2 + +0.004prate \quad (7)$$

where $CO_2$ and $CO_2(-1)$ are carbon emissions of the current period and the previous period, respectively; $f$ and $f^2$ are the financial development and its quadratic term, respectively; $prate$ is growth rate of per capita GDP.

The first-order derivative of Eq. (7) is taken with respect to $f$ (Eq. 8):

$$\frac{\partial CO_2}{\partial f} = 0.878 - 0.684f \quad (8)$$

The simple elasticity coefficient is calculated using Eq. (4). Before reaching the turning point at 1.28, the elasticity coefficient is positive and declining gradually. The elasticity coefficients are calculated at 0.6, 0.8, 1.0 and 1.2, respectively, and the average is taken. Thus before the turning point, the elasticity coefficient is about 0.26. That is, for every increase of credit-to-GDP ratio by one unit, the carbon emissions will increase by about 0.26 unit. After the turning point, the elasticity coefficient is negative and increasing gradually. The elasticity coefficients are calculated at 1.4, 1.6, 1.8, 2.0, 2.2 and 2.4, respectively, and the average is taken.

The elasticity coefficient beyond the turning point is about -0.42. That is, for every increase of credit-to-GDP ratio by one unit, the carbon emissions will decrease by about 0.42 unit1. (The credit-to-GDP ratio ranges from 0.537 to 2.585).

**Table 7.** Regression for different regions

| | *The dependent variable is the carbon emission : $CO_2$* | | | | | |
|---|---|---|---|---|---|---|
| | *Eastern Region* | | *Central region* | | *Western Region* | |
| | *(1)* | *(2)* | *(3)* | *(4)* | *(5)* | *(6)* |
| L. $CO_2$ | 0.969*** | 1.101*** | 0.934*** | 0.976*** | 1.161*** | -0.107 |
| | (21.47) | (9.18) | (19.68) | (11.55) | (13.72) | (-0.18) |
| f | -0.224** | -0.036 | -0.012 | -0.057 | -0.103* | -2.664* |
| | (-2.49) | (-0.31) | (-0.08) | (-0.21) | (-1.76) | (-1.87) |
| prate | 0.008*** | 0.016*** | 0.005** | 0.007* | 0.005* | 0.016** |
| | (5.90) | (3.60) | (2.37) | (1.85) | (1.67) | (1.98) |
| cpi | | -0.017** | | -0.003 | | 0.008 |
| | | (-2.47) | | (-0.27) | | (0.61) |
| investgdp | | 0.148 | | -0.768 | | 6.264* |
| | | (0.22) | | (-0.97) | | (1.84) |
| exgdp | | -0.189** | | -0.741 | | 1.090* |
| | | (-2.03) | | (-0.55) | | (1.66) |
| road | | -0.129* | | 0.028 | | 1.601* |
| | | (-1.76) | | (0.32) | | (1.79) |
| _cons | 0.533 | 2.180*** | 0.593 | 0.820 | -1.215 | -9.010 |
| | (1.34) | (3.61) | (1.36) | (0.75) | (-1.53) | (-1.59) |
| Wald chi2 | 474.173 | 444.366 | 422.314 | 1370.11 | 493.785 | 1896.42 |
| Sargan | 9.677 | 1.887 | 7.158 | 3.816 | 1.873 | 7.719 |
| (p-value) | (0.883) | (0.999) | (1.000) | (1.000) | (0.966) | (0.999) |
| AR(2) | -1.199 | -1.105 | 1.131 | 0.873 | 0.309 | 0.878 |
| (p-value) | (0.231) | (0.269) | (0.258) | (0.383) | (0.756) | (0.362) |
| Observations | 110 | 110 | 100 | 100 | 80 | 80 |
| Regions | 11 | 11 | 10 | 10 | 8 | 8 |

*t statistics in parentheses, * p < 0.10, ** p < 0.05, *** p < 0.01*

Using the same method and Eq. (2) in Table 6, the elasticity coefficients of financial development on carbon emissions before and after the turning point are calculated. Before the turning point, the elasticity coefficient is about 0.40. That is, for every increase of credit-to-GDP ratio by one unit, the carbon emissions will increase by about 0.40 unit. After the turning point at 1.17, the elasticity coefficient is about -0.69. For every increase of credit-to-GDP ratio by one unit, the carbon emissions will decrease by about 0.69 unit.

**4. Conclusions**

This paper provides empirical support for the impact of financial development on $CO_2$ emissions. The relationship between financial development, economic growth and carbon emissions is examined by system GMM using panel data of 29 administrative regions in China from 2003 to 2013.

Empirical analysis shows that fast economic growth is accompanied by higher carbon emissions, and the increasing level of financial development is favorable for the reduction of carbon emissions. Further analysis shows that the relationship between financial development and $CO_2$ emissions presents an inverted-U shape pattern. Only after the economic development has reached a threshold value will the promoting effect of financial development to the reduction of $CO_2$ emissions manifest.

Similarly, early literature report that the level of national development determines the impact of economic growth on carbon dioxide emissions. This paper contributes to the existing literature for presenting an inverted U-shaped relationship between financial development and $CO_2$ emissions.

Moreover, we extend the model by distinguishing the impact of different industries on $CO_2$ emissions. As a result, industrial structure optimization and upgrading contribute to the reduction of $CO_2$ emissions. In other words, the increasing proportion of the secondary sector will weaken the promoting effect of financial development to the reduction of $CO_2$ emissions and intensify the negative impact of economic growth on $CO_2$ emissions. On the contrary, the increasing proportion of the tertiary sector will greatly facilitate the reduction of $CO_2$ emissions and mitigate the increase of $CO_2$ emissions due to economic growth.

Policy implications can be derived from two perspectives. First, financial development can reduce carbon emissions. For less financially developed countries, financial development can be promoted by market-oriented reform. Second, although $CO_2$ emissions will increase along with fast economic growth, industrial structure optimization and upgrading will contribute significantly to the reduction of $CO_2$ emissions.

For countries that are experiencing fast economic growth, the dependence on secondary sector for economic growth should be reduced, while the proportion of tertiary section in national economy should be increased.

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