ISSN:2790-1661 DOI: 10.56028/aemr.2.1.258

Fiscal Decentralisation, Economic Development, and Carbon Emissions: Empirical Analysis Based on the Provincial Static and Dynamic Panel Data

Yilong Chen

Department of Public Finance and Taxation, Central University of Finance and Economics

Central University of Finance and Economics, Changping District, Beijing

Corresponding author, E-mail: CYL20001226@163.COM

Abstract. The target 'Carbon Peak' and 'Carbon Neutral' in China is a key strategic choice to promote environmental regulation and high-quality economic growth. Public finance, as the bedrock and pillar of national governance, has a significant influence on China's macroeconomics and policy execution. This paper selects provincial panel data of China from 2010 to 2019, together with a two-way fixed-effect model and a Difference-GMM model, in order to conduct an empirical analysis of the impact of fiscal decentralisation and economic development on carbon emissions. The findings reveal that fiscal decentralisation has a considerable positive impact on carbon emissions, and that economic development and carbon emissions have an inverted U-shaped connection. Furthermore, economic development may reduce fiscal decentralisation's contribution to carbon emissions. In addition, there is a dynamic lag impact associated with carbon emissions. As a result, to achieve green and low-carbon transformation in China, advanced and long-term planning is required, as well as the optimisation of local government evaluation mechanisms and the application of fiscal funds.

Keywords: fiscal decentralisation; economic development; carbon emissions

1. Introduction

Since China's reform and opening up, the country's economy has grown significantly, and residents' living conditions have constantly improved. However, the extensive economic growth mode of 'high input, high energy consumption, and low quality' has irreparably destroyed China's natural environment. The Chinese model of fiscal decentralisation and the 'GDP-only theory', in which local governments prioritize economic growth above environmental control, is to blame for this issue (Fang Cai et al., 2008). At the 75th General Debate of the United Nations General Assembly, Jinping Xi, President of the People's Republic of China, suggested a 'Carbon Peak' target by 2030 and a 'Carbon Neutral' target by 2060, creating the 'Dual Carbon' Strategy as a cornerstone for China's eco-building efforts. As a result, the high levels of carbon emissions arising from a large economy have become a critical ecological challenge in China's quest for long-term growth.

Considering the above, this paper uses provincial panel data from 2010 to 2019 and builds a two-way fixed-effects model along with a dynamic panel model, in order to evaluate the three-way connection between fiscal decentralisation, economic development, and carbon emissions. The following is how the paper is organized: Part I, an overview of existing research; Part II, a research hypothesis based on the above review and theoretical analysis; Part III, Building static and dynamic empirical models; Part IV, Variable selection and relevant data processing; Part V, Empirical analysis and robustness testing of the model; Part VI, Conclusion and discussion.

2. Literature Review

2.1 The Relationship Between Fiscal Decentralisation and Carbon Emissions

In response to the rapid global economic growth and the rise in living standards, researches on fiscal decentralisation has steadily switched from the efficiency of the supply of public goods (Tiebout, 1956) to environmental sustainability.

ISSN:2790-1661 DOI: 10.56028/aemr.2.1.258

The link between fiscal decentralisation and regional environmental pollution is now separated into two academic perspectives: the first is relied on the first generation of fiscal decentralisation theory and is characterised by 'Environmental Federalism'. According to this theory, local governments strive to maximise the public interest, hence fiscal decentralisation encourages local governments to provide environmental management services, resulting in a boost in regional environmental quality (Stigler, 1957; Oates et al., 1988). Oates (2001) argued that local decentralisation could better exploit informational benefits and handle heterogeneity in the environmental preferences; Millimet (2003) claimed that decentralisation after the 1980s could enhance regional environmental quality through 'Race to the Top' local government competition; research by Tan and Zhang (2015) showed that fiscal decentralisation was inversely connected with environmental pollution emissions and that provinces with strong fiscal decentralisation could devote enough fiscal resources to environmental control.

The second point of view is based on the second generation of fiscal decentralisation theory, which is considered the 'Environmental Competition Theory'. In contrast to the 'Race to the Top' theory, this theory proposes that local governments grab attention from foreign investment and raise tax revenues by lowering environmental standards (Fredriksson et al., 2003), in order to support regional economic growth and satisfy their promotion incentives. Sigman (2007) stated that financial decentralisation allowed governments tax share incentives by waning the environmental governance practices; research by Zhang (2011) suggested provincial panels to determine that fiscal decentralisation increases carbon emissions, but the effect varies mainly between provinces with a variety of energy consumption levels, and Li (2016) used four fiscal decentralisation indicators in a study that evaluated the link between fiscal decentralisation and regional carbon emissions. As a result, fiscal decentralisation may be regarded a significant factor impacting regional environmental quality, and the link between fiscal decentralisation and carbon emissions has to be investigated further.

2.2 The Relationship Between Economic Development and Carbon Emissions

The environmental Kuznets curve EKC and the carbon emissions Kuznets curve CKC have dominated economic development and environmental quality studies to date. The classic EKC curve is concerned with pollutant emissions, such as sulfur dioxide, nitrogen oxides, and PM2.5, while the CKC curve is concerned with carbon emissions. Despite the fact that carbon dioxide is not a pollutant, it is an essential indicator of environmental quality and is mostly produced from fossil fuel consumption. As a result, the CKC curve can be explained by the EKC hypothesis.

The EKC and CKC curves have been examined both at home and abroad, with varying results: Grossman and Krueger (1995) proved the presence of an inverted U-shaped EKC curve, which has now been experimentally confirmed in the majority of countries; Xu and Song (2010) provided empirical evidence that the CKC curve in China conformed to an inverted U-shape; while Deng et al. (2014) considered a semiparametric generalized additive model, in order to verify that there is a direct relationship between economic development and carbon emissions in China; Shi (2017), however, confirmed that China's CKC curve was inverted N-shaped.

2.3 Other Factors Affecting Carbon Emissions

Most studies of the factors influencing carbon emissions consider energy consumption structure, environmental legislation, fixed-asset investment, industrial structure, and technological advancement as explanatory or control variables. Lin and Jiang (2009) showed that coal consumption had a significant impact on carbon dioxide emissions by impacting the energy consumption structure and energy intensity; research by He and Zhang (2012) found that the amount of fixed-asset investment, coal consumption in the energy consumption structure, and carbon emissions were all significant and positively related; Zhang and Wei (2014) argued that environmental regulations had an indirect impact on carbon emissions through the energy consumption structure, the industrial structure, technological innovation, and foreign direct

ISSN:2790-1661 DOI: 10.56028/aemr.2.1.258

investment; Hu et al. (2008) and Wang et al. (2010) also assessed the link between environmental regulations and carbon emissions.

In terms of empirical techniques, there are three main models for evaluating the causes of carbon emissions: the first is the STIRPAT model, which is extremely scalable and can concurrently validate non-linear correlations, such as the inverted U-shape. The LMDI model, on the other hand, has the benefit of having no residual term after factor decomposition and is suited for both additive and multiplicative decompositions. The third type of model is an input-output model, which is usually used to investigate multi-sectorial inputs and outputs in the national economic system, and may include environmental aspects, like energy, to build an empirical model of 'economic-carbon emissions'.

2.4 Summary and Innovation

In summary, scholars in the United States and abroad have performed several studies on the relationship between fiscal decentralisation, economic development, and carbon emissions, but the results are inconsistent due to a wide range of factors examined, and few studies have combined the two factors in a comprehensive framework for analysis. Moreover, when it comes to constructing indicators for economic progress, many studies consider GDP per capita indicators to validate the CKC curve, whereas just a few studies use total GDP indicators. Energy structure, environmental regulation, and fixed-asset investment serve as the foundation for the selection of control variables in this paper. For the empirical model, the STIRPAT model has clear benefits and can verify the inverted U-shape relationship, but it does not describe or control the lagged impact of carbon emissions.

As a result, the study introduces the following innovations: To begin, fiscal decentralisation and economic development are both considered as explanatory variables to evaluate their impacts on carbon emissions and mechanisms of action; second, instead of considering 'per capita GDP' to measure 'per capita income' to verify the CKC curve, this paper considers 'real GDP of each province' to assess the inverted U-shape relationship between economic development and carbon emissions; third, instead of using the mainstream static STIRPAT model, this paper uses the dynamic models for performing empirical analysis.

3. Research Hypothesis

3.1 Hypothesis I: Fiscal Decentralisation Is Positively Linked with Carbon Emissions.

This paper is set in the political framework of China, so it is important to explain the specifics of the Chinese fiscal decentralisation system. For one thing, China's 'fiscal decentralisation and political centralisation' style reflects the variation in the selection procedure for the local officials between China and the West: in contrast to the 'bottom-up' democratic elections in the West, China's selection mechanism is 'top-down', making 'voting by hand' is ineffective. Furthermore, the household registration system hinders people's free mobility between different areas of China, making 'vote with one's feet' impossible, resulting in local governments lacking effective control and healthy competition. Therefore, local governments have an incentive to maximise their own interests at the expense of the public in such circumstances, bringing about distorted behaviour that lowers regional environmental quality in pursuit of economic development (Ma, 2015), giving rise to the 'race to the bottom'.

Additionally, with the 1994 reform of China's taxation system, and under the constant fiscal revenues and expenditures, 'creating wealth from the land' has become the most significant source of revenue for local governments. Moreover, China’s decentralisation structure has resulted in political and fiscal rivalry among local governments, decreasing the effectiveness of central government environmental policies and the abatement impact of environmental governance initiatives (Cai, 2010; Yan, 2012). In summary, this paper suggests Hypothesis I.

ISSN:2790-1661 DOI: 10.56028/aemr.2.1.258

3.2 Hypothesis II: Economic Development and Carbon Emissions Have an Inverted U-shaped Connection.

Based on the EKC hypothesis, the CKC curve recommends an inverted U-shaped link between per capita income and carbon emissions, which is supported by the bulk of provincial panel studies in China employing GDP per capita measures. The implication is that: in the early stages of economic development, pulling economic development needs additional resources, which is linked with the rapid industrialisation and urbanisation, causing the large emissions of carbon; in the later stages of economic development, technology impacts and environmental regulations will boost the supply of environmental friendly resources or products, causing a reduction in emissions. Hypothesis II is provided based on the foregoing hypothesis and the use of real GDP as a measure of economic advancement.

3.3 Hypothesis III: Carbon Emissions Are Dynamically Lagging.

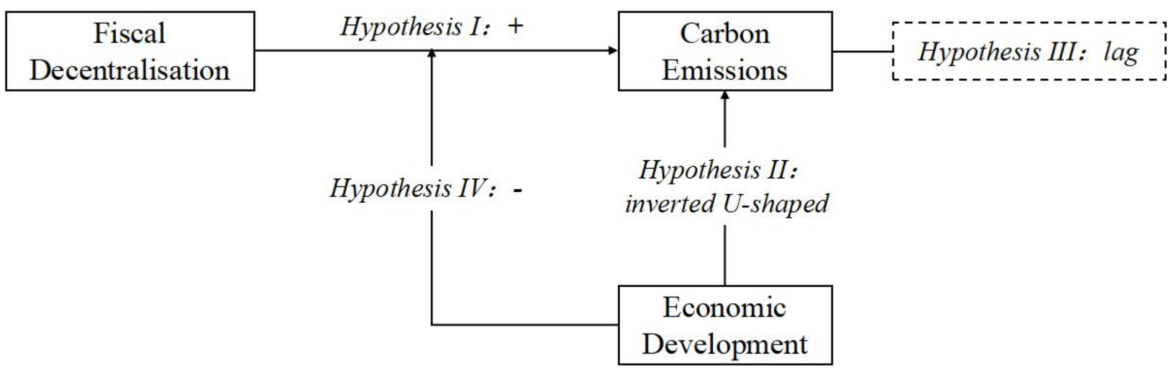
Carbon emissions are largely influenced by economic progress, energy consumption structure, and fixed-asset investment, according to the summary in the literature review section, all of which are difficult to modify considerably in a short period of time. As a result, this paper concludes that carbon emissions have long-term negative externalities, which is the basis for Hypothesis III.

3.4 Hypothesis IV: Economic Development Can Negatively Mitigate the Effects of Fiscal Decentralisation on Carbon Emissions.

Local governments with more fiscal funds are willing to respond to China's green transformation program and, to some extent, expand their efforts in contesting environmental pollution (Hu, 2018). In addition, in provinces where economic development has been accomplished, local governments are less inclined to chase GDP targets blindly and are more likely to devote financial spending to technical improvements, industry restructuring, and other carbon-reduction activities. Thus, Hypothesis IV is recommended in this paper.

To sum up, the research hypothesis suggested in this paper, and the mechanism by which it operates are reflected in Figure 1.

Figure 1. Hypothesis structure of this paper



4. Model Construction

4.1 Static Panel Data Model Setting

The STIRPAT model was proposed by York et al. (1998) on the basis of the IPAT model, which addressed the shortcomings of the initial model with limited influence factors and the inability to measure non-linear relationships. It is currently the most common method for analyzing the various

ISSN:2790-1661 DOI: 10.56028/aemr.2.1.258
factors that influence carbon emissions, and it is stochastic and scalable. Generally, the model is organized as follows:

$$I = aP^bA^cT^de$$

As shown in the equation above, I stands for the environmental factors; a represents the coefficient of the model; P, A, and T stand for population, assets, and technology, respectively; b, c, and d stand for the parameters to be estimated for each variable, and e is the error term.

The Kaya equation is a decomposition model of greenhouse gas emissions proposed by the Japanese scholar Kaya (1989), and the specific equation is as follows:

$$PC=POP \times \frac{GDP}{POP} \times \frac{EE}{GDP} \times \frac{PC}{EE}$$

PC, POP, GDP, and EE represent greenhouse gas emissions, total population, gross domestic product, and total energy consumption, respectively.

Based on the STIRPAT model and the Kaya equation, this paper identifies fiscal decentralisation, economic development, energy structure, environmental regulation, and fixed-asset investment as drivers of carbon emissions, and log arises them. To further test hypothesis II on the basis of hypothesis I, the quadratic terms of the economic development variables are added to the static panel data model, which is then set as follows:

$$lnpc_{i,t} = \alpha + \beta_1 lndec_{i,t} + \beta_2 lngdp_{i,t} + \beta_3 (lngdp_{i,t})^2 + \boldsymbol{\beta' Z} + \mu_i + \varphi_t + \varepsilon_{i,t} \quad (1)$$

i and t denote province and year respectively; $lnpc_{i,t}$ represents carbon emissions; $lndec_{i,t}$ denotes fiscal decentralisation, measured by the fiscal autonomy indicator of each province; $lngdp_{i,t}$ denotes economic development; β′Z represents the remaining control variables $lners_{i,t}$, $lnreg_{i,t}$,and $lninv_{i,t}$, which denote energy structure, environmental regulation, and fixed-asset investment respectively; μ_i denotes regional fixed effects; φ_t denotes time fixed effects; $\varepsilon_{i,t}$ is a random error term.

4.2 Dynamic Panel Data Model Setting

When studying persistent behaviour, a dynamic panel data model has better explanatory power than a static panel data model since it includes the lagged effects of the explanatory variables. In addition, this model can overcome the potential problems of omitted variables, reverse causality, and serial autocorrelation of the explained variables in model (1) through differential estimation. In order to test hypothesis III and enhance the robustness of the empirical results of hypothesis I and hypothesis II, the dynamic panel model is set up as follows:

$$lnpc_{i,t} = \alpha + \beta_1 lnpc_{i,t-1} + \beta_2 lndec_{i,t} + \beta_3 lngdp_{i,t} + \beta_4 (lngdp_{i,t})^2 + \boldsymbol{\beta' Z} + \mu_i + \varphi_t + \varepsilon_{i,t}$$

(2)

This equation adds a one-period lag of the explanatory variable lnpci,t-1 to the right-hand side of model (1), and the remaining variables are unchanged.

ISSN:2790-1661 DOI: 10.56028/aemr.2.1.258

4.3 Model Setting for Testing the Moderating Effect

To clarify the influence mechanisms between fiscal decentralisation, economic development and carbon emissions and to test hypothesis IV, this paper adds the interaction term of fiscal decentralisation and economic development to models (1) and (2), respectively, in the following manner:

$$lnpc_{i,t} = \alpha + \beta_1 lndec_{i,t} + \beta_2 lngdp_{i,t} + \beta_3 (lngdp_{i,t})^2 + \beta_4 lndec_{i,t} \times lngdp_{i,t} + \boldsymbol{\beta' Z} + \mu_i + \varphi_t + \varepsilon_{i,t} \quad (3)$$

$$lnpc_{i,t} = \alpha + \beta_1 lnpc_{i,t-1} + \beta_2 lndec_{i,t} + \beta_3 lngdp_{i,t} + \beta_4 (lngdp_{i,t})^2 + \beta_5 lndec_{i,t} \times lngdp_{i,t} + \boldsymbol{\beta' Z} + \mu_i + \varphi_t + \varepsilon_{i,t} \quad (4)$$

5. Variable Selection and Data Processing

For empirical analysis, This paper utilizes provincial panel data constructed from 2010 to 2019 for 30 provinces (cities and districts) in China (excluding Taiwan, Hong Kong, and Macau Special Administrative Region) , of which Tibet is not included due to a large number of missing data values. Data on energy consumption are obtained from the China Energy Statistical Yearbook; data on the main business costs of industrial enterprises above the designated size are obtained from the China Industrial Statistical Yearbook; data on fixed-asset investment are obtained from the China Fixed-Asset Investment Statistical Yearbook; the rest of the data are obtained from the China Financial Yearbook and the National Bureau of Statistics. Some of the missing data are filled in using linear interpolation.

5.1 Explained Variables

In this paper, carbon emissions are selected as the explained variable, and seven fossil energy sources are used in order to estimate it according to the Guidelines for the Preparation of Provincial Greenhouse Gas Inventories. The specific formula for calculating carbon emissions is as follows:

$$PC_{i,t} = \sum_{j=1}^{7} E_{i,t,j} \times CEF_j = \sum_{j=1}^{7} E_{i,t,j} \times H_j \times CH_j \times COR_j \times \frac{44}{12} \times 10^{-6}$$

According to the equation above, i, t, and j denote province, year, and the type of energy respectively; $PC_{i,t}$ denotes carbon emissions; $E_{i,t,j}$ denotes energy consumption; CEF_j denotes carbon emission factor of energy; H_j denotes average low-level heat generation of energy; CH_j denotes carbon content per unit calorific value of energy; COR_j denotes carbon oxidation rate of energy. The relevant data are shown in Table 1.

ISSN:2790-1661 DOI: 10.56028/aemr.2.1.258

Table 1. Carbon emission factors and related data for 7 fossil energy sources

Catogory	Average Low-Level Heat Generation	Carbon Content per Unit Calorific Value	Carbon Oxidation Rate	Carbon Emission Factor
Raw Coal	20908KJ/kg	26.37t-CO_2/TJ	0.94	1.9003kg-CO_2/kg
Coke	28435KJ/kg	29.5t-CO_2/TJ	0.93	2.8604kg-CO_2/kg
Fuel Oil	41816KJ/kg	21.1t-CO_2/TJ	0.98	3.1705kg-CO_2/kg
Petrol	43070KJ/kg	18.9t-CO_2/TJ	0.98	2.9251kg-CO_2/kg
Paraffin	43070KJ/kg	19.5t-CO_2/TJ	0.98	3.0179kg-CO_2/kg
Diesel	42652KJ/kg	20.2t-CO_2/TJ	0.98	3.0959kg-CO_2/kg
Natural Gas	38931KJ/m³	15.3t-CO_2/TJ	0.99	2.1622kg-CO_2/m³

Note. From General Rules for Calculating Comprehensive Energy Consumption (GB/T 2589-2008).

5.2 Explanatory Variables

The explanatory variables chosen for this paper are fiscal decentralisation and economic development. As there is no unified indicator for fiscal decentralisation, this paper takes into account the regional differences in panel data and refers to Jin et al. (2000) and Chen and Gao (2012) to choose the indicator of 'fiscal autonomy' to represent fiscal decentralisation. The specific formula is as follows:

$$\text{Fiscal autonomy} = \frac{\text{Provincial budgetary revenue}}{\text{Provincial budgetary expenditure}}$$

Provincial real GDP is used to characterise the level of economic development. For each provincial nominal GDP, the regional GDP index (2010=100) is used to remove the effect of inflation.

5.3 Control Variables

For balancing the estimation effect of the static panel and the validity of the instrumental variables, a total of three control variables are selected in this paper: energy structure, environmental regulation and fixed-asset investment. The 'coal-rich, oil-poor, gas-poor' energy endowment of China has led to a coal-based energy consumption structure that is responsible for high carbon emissions. This paper draws on a study by Zhong et al. (2007) to use the share of total coal consumption in total energy consumption (all in terms of standard coal) as an indicator of energy structure. And total coal consumption is calculated using the following formula:

$$CC_{i,t} = \sum_{j=1}^{7} CE_{i,t,j} \times SCC_j$$

In this formula, i, t, and j denote province, time, and type of energy respectively; $CC_{i,t}$ denotes total coal consumption; $CE_{i,t,j}$ denotes consumption of energy containing coal and SCC_j denotes the discount factor for energy, as shown in Table 2.

ISSN:2790-1661 DOI: 10.56028/aemr.2.1.258

Table 2. Coal-bearing energy and conversion factors

Category	Conversion Factor
Raw Coal	0.7143 tce/t
Coal Washing Concentrate	0.9000 tce/t
Other Coal Washing	0.2850 tce/t
Biquette	0.6000 tce/t
Coke	0.9714 tce/t
Coke Oven Gas	1.3000 tce/10^4m^3
Other Gas	6.1430tce/10^4m^3

Note. From General Rules for Calculating Comprehensive Energy Consumption (GB/T 2589-2008);

tce means tonnes of standard coal.

With the implementation of the 'dual carbon' policy, environmental regulation as an act of governance will have an impact on regional carbon emissions. The analysis in this paper uses an environmental regulation indicator derived from a study by Tan and Zhao (2021), which represents the ratio of industrial pollution control investment to the main business costs of industrial enterprises above the scale.

Fixed-asset investment is also used as a control variable in this paper. The amount of social fixed-asset investment is deflated by using the fixed-asset investment price index (2010=100) in order to eliminate the influence of price factors.

All of the above variables are logarithmized and the associated symbols can be found in Table 3.

Table 3. Variable attributes, names and symbols

Attribute	Variable	Symbol
Explained Variable	Carbon Emissions	$lnpc_{i,t}$
Explanatory Variable	Financial Decentralisation	$lndec_{i,t}$
	Economic Development	$lngdp_{i,t}$
Control Variable	Energy Structure	$lners_{i,t}$
	Environmental Regulation	$lnreg_{i,t}$
	Fixed-Asset Investment	$lninv_{i,t}$

ISSN:2790-1661 DOI: 10.56028/aemr.2.1.258

6. Empirical Analysis

6.1 Static Panel Data Analysis: Two-way Fixed Effects Model

Model selection is first carried out for the static panel: the p-value of 0.0000 for the F-test indicates that the data are not suitable for analysis by mixed regression; the results of the Hausman test strongly reject the random-effects model and suggest that a two-way fixed effects model should be used. Next, clustering robust standard errors are applied for estimation to correct for the heteroskedasticity and autocorrelation of the data. At last, to avoid serious problems of multicollinearity between variables, model (1) is regressed using stepwise regression, and the results are given in Table 4.

Table 4. Static panel data model estimation results

	(1)	(2)	(3)	(4)
$lndec_{i,t}$	0.503** (2.67)	0.508*** (2.87)	0.503*** (2.84)	0.552*** (3.20)
$lngdp_{i,t}$	5.553** (2.24)	3.463* (1.73)	3.418* (1.71)	3.375* (1.77)
$(lngdp_{i,t})^2$	-0.376** (-2.71)	-0.247** (-2.35)	-0.245** (-2.33)	-0.237** (-2.34)
$lners_{i,t}$		0.219*** (6.10)	0.220*** (6.19)	0.228*** (6.35)
$lnreg_{i,t}$			-0.180 (-1.01)	-0.213 (-1.18)
$lninv_{i,t}$				-0.052** (-2.16)
$\_cons$	-19.063 (-1.68)	-11.682 (-1.21)	-11.425 (-1.18)	-11.415 (-1.23)
R^2	0.313	0.405	0.407	0.419

Note. ***, **, * denote variables significant at 1%, 5%, 10% respectively, values in brackets are

t-statistics, same in later tables and not repeated.

As can be seen from the regression results, the significance levels and coefficients of variables are relatively stable throughout all four regressions, and the R2 of the model gradually increases from 0.313 to 0.419, which suggests that the variables are properly chosen, and model (1) has excellent explanatory validity.

A significant positive effect of fiscal decentralisation on carbon emissions can be observed with a significance level of 5% in the first regression and 1% in the remaining three regressions, supporting hypothesis I. For every 1% increase in local fiscal autonomy, carbon emissions will increase by 0.552%.

The primary term for economic development is significantly positive at the 10% level, and the secondary term is significantly negative at the 5% level, confirming the existence of an inverted U-shaped relationship between economic development and carbon emissions, so hypothesis 2 is valid.

The energy structure and carbon emissions are significantly and positively correlated at the 1% level, indicating that the higher the share of coal in the energy consumption structure, the higher the carbon emissions will be. Additionally, there is a negative impact of fixed assets on carbon

ISSN:2790-1661 DOI: 10.56028/aemr.2.1.258
emissions, suggesting that the amount of investment in fixed assets may be more heavily directed toward low carbon industries. Conversely, environmental regulation does not significantly reduce carbon emissions.

It can be concluded that fiscal decentralisation, economic development, and energy structure are the main factors affecting carbon emissions, as well as a correlation between fixed-asset investment and carbon emissions.

6.2 Dynamic Panel Data Analysis: One Step Difference-GMM with Robust Errors

As a means of removing heterogeneity such as unobserved characteristics of individuals, Difference-GMM is used to estimate the model (2), which can be divided into one-step and two-step estimations. Even though two-step estimation offers some efficiency improvements over one-step estimation, its weight matrix is dependent upon estimated parameters and its standard deviation is downward biased, resulting in unreliable estimates. For this reason, the one step Difference-GMM with robust errors is chosen in this paper to ensure the consistency of the estimates and the robustness of the conclusions, and the regression results are shown in Table 5.

Table 5. Dynamic panel data model regression results

	(1)	(2)	(3)	(4)
$L1.lnpc_{i,t}$	0.378*** (4.06)	0.599*** (9.49)	0.501*** (5.85)	0.498*** (5.73)
$lndec_{i,t}$	0.578* (2.03)	0.633*** (2.81)	0.715*** (2.78)	0.693*** (2.79)
$lngdp_{i,t}$	5.632*** (3.75)	3.641*** (2.79)	4.027*** (2.83)	4.019*** (2.79)
$(lngdp_{i,t})^2$	-0.333*** (-3.79)	-0.217*** (-3.04)	-0.249*** (-3.08)	-0.248*** (-3.04)
$lners_{i,t}$		0.080** (2.34)	0.109** (2.62)	0.110** (2.63)
$lnreg_{i,t}$			-1.107* (-1.89)	-1.145* (-1.85)
$lninv_{i,t}$				-0.012 (-0.62)
$AR(1)$	0.001	0.000	0.007	0.007
$AR(2)$	0.966	0.637	0.578	0.565
$Hansen\,Test$	0.157	0.270	0.238	0.282

Note. $L1.lnpc_{i,t}$ denotes the lagged period of $lnpc_{i,t}$, same in later tables and not repeated.

It appears that the p-values of the Hansen test range from 0.157 to 0.282, which does not reject the original hypothesis that the instrumental variable is selected to be valid. Moreover, according to David Roodman (2009)1, the instrumental variable in this paper can be deemed robust. The original hypothesis at the 1% significance level is rejected by AR(1), proving the existence of first-order autocorrelation. however, AR(2) does not reject the original hypothesis, denying the existence of second-order and higher autocorrelation. The significance levels of the variables in the dynamic

ISSN:2790-1661 DOI: 10.56028/aemr.2.1.258
panel data model are generally in line with that of the static panel data model. Therefore, the instrumental variables are suitably chosen, and the model identification is valid.

The first-order lagged terms for carbon emissions are all significantly positive at the 1% level, which works in favour of hypothesising Hypothesis III. In the full regression of model (2), the current period of carbon emissions will increase by 0.498% for every 1% increase in the first-order lagged term of carbon emissions.

At the 1% level, both primary and secondary terms of economic development are significant, and the outcomes are better than the static panel data model, verifying a stronger hypothesis II. To better explain this inverted U-shaped association: When GDP is low, the demand of the public for the quality of the environment is low and great amounts of resources have to be invested in speeding up economic development, which causes high energy consumption and high carbon emissions. In contrast, when GDP is high, the population's demand for environmental protection intensifies, and the government's focus on environmental regulation increases, along with the technological effect produced by a large population, therefore, high carbon emissions are gradually brought under control.

As control variables, energy structure and environmental regulation significantly impact carbon emissions at the 5% and 10% levels, respectively, whereas fixed-asset investment has no significant impact. The energy structure of China is still dominated by coal at this point, but as industrialisation moves into its mid-to-late stages, a clean energy transition has gained traction. Besides, in comparison to the static model, environmental regulations show better results in the dynamic model, providing evidence that environmental regulations are still having a dampening effect on carbon emissions as low-carbon policies proceed and green standards evolve. In the data, an increase of 1% in environmental regulations is associated with reductions of 1.107% to 1.145% in carbon emissions.

As a whole, model (2) is more effective than model (1), with the significance levels of the explanatory variables adjusted to 1% after taking into account of the lagged effect of carbon emissions. This implies that decarbonisation is a process that requires good long-term strategic planning, in which fiscal decentralisation and economic development can be the focus of policy.

6.3 Moderating Effect Tests

It has been argued above that economic development may moderate the relationship between fiscal decentralisation and carbon emissions. Therefore, this paper adds the interaction term of fiscal decentralisation and the primary term of economic development to two models, respectively. The results are presented in Table 6.

Table 6. Regression results for moderating effects

	_cons	$lndec_{i,t}$	$lngdp_{i,t}$	$(lngdp_{i,t})^2$	Interaction	$lners_{i,t}$	$lnreg_{i,t}$	$lninv_{i,t}$
(1)	-17.133 (-1.80)	2.163** (2.60)	4.402** (2.12)	-0.238** (-2.40)	-0.177* (-1.99)	0.223*** (6.17)	-0.218 (-1.20)	-0.053** (-2.11)
	R^2 =0.425							
	$L1.lnpc_{i,t}$	$lndec_{i,t}$	$lngdp_{i,t}$	$(lngdp_{i,t})^2$	Interaction	$lners_{i,t}$	$lnreg_{i,t}$	$lninv_{i,t}$
(2)	0.513*** (4.72)	4.461** (2.25)	4.552*** (3.34)	-0.172* (-1.88)	-0.486** (-2.22)	0.123** (2.08)	-1.516* (-1.79)	-0.032 (-1.08)
	AR(1) =0.012 AR(2) =0.171 Hansen Test =0.389							

Note. (1) refers to the regression on model (3) and (2) refers to the regression on model (4).

ISSN:2790-1661 DOI: 10.56028/aemr.2.1.258

Table 6 depicts that the interaction term is significant in models (3) and (4), respectively, at the 10% and 5% levels, and the significance levels and sign of the coefficients for the other variables are consistent with those reported early. In comparison to the model with no interaction term, the explanatory efficiency of the static panel data model with the moderating effect increased, with R2 rising from 0.419 to 0.425; the values for each test of the dynamic panel data model are also consistent with the results reported previously.

In both models, the coefficient on the interaction term is significantly negative while the coefficient on fiscal decentralisation is significantly positive, indicating that the contribution of fiscal decentralisation to carbon emissions is negatively affected by economic development, supporting Hypothesis IV. It might be interpreted that economic development can increase the fiscal space of local governments, making them more concerned with the efficacy of fiscal expenditures and directing fiscal resources to areas conducive to high-quality economic development.

6.4 Robustness Tests

To test the robustness of the conclusions and to eliminate the impact of outliers, this paper winsorizes each of the three important variables of carbon emissions, fiscal decentralisation, and economic development, which means removing samples below the 1% quantile and above the 99% quantile and estimating each model again. Table 7 contains the regression results for the processed static and dynamic panel models.

Table 7. Robustness Tests of Static and Dynamic Panel Data Model

	Carbon Emissions		Fiscal Decentralisation		Economic Development	
	Fe	Diff-GMM	Fe	Diff-GMM	Fe	Diff-GMM
L1. $lnpc_{i,t}$		0.570*** (6.79)		0.503*** (6.55)		0.539*** (7.03)
$lndec_{i,t}$	0.570*** (3.40)	0.607*** (2.87)	0.554*** (3.12)	0.948*** (2.94)	0.538*** (3.00)	0.556** (2.02)
$lngdp_{i,t}$	2.932 (1.62)	3.856** (2.65)	3.478 (1.52)	3.344** (2.38)	3.501 (1.41)	3.312** (2.21)
$(lngdp_{i,t})^2$	-0.215** (-2.21)	-0.235*** (-2.88)	-0.244* (-1.98)	-0.223** (-2.66)	-0.245* (-1.80)	-0.203** (-2.37)
$lners_{i,t}$	0.221*** (7.07)	0.094** (2.28)	0.226*** (5.94)	0.097*** (2.81)	0.227*** (6.04)	0.113** (2.33)
$lnreg_{i,t}$	-0.143 (-0.71)	-0.710 (-1.32)	-0.208 (-1.11)	-1.205** (-2.26)	-0.210 (-1.17)	-0.976* (-1.79)
$lninv_{i,t}$	-0.040* (-1.90)	-0.011 (-0.70)	-0.052** (-2.12)	-0.004** (-0.23)	-0.054** (-2.15)	-0.015 (-0.75)
_cons	-9.423 (-1.08)		-9.423 (-1.08)		-11.837 (-1.01)	
R^2	0.408		0.404		0.408	
AR(1)		0.001		0.021		0.003
AR(2)		0.848		0.764		0.713
Hansen Test		0.325		0.360		0.255

ISSN:2790-1661 DOI: 10.56028/aemr.2.1.258

The results show that, in the static panel data model, fiscal decentralisation and the quadratic terms of economic development are significant contributors to carbon emissions, with the direction of each variable consistent with the results without removing the extreme values. For dynamic data panel model, the p-values of the Hansen test, AR(1), and AR(2) are reasonable, the first-order lagged term for carbon emissions is significant at the 1% level, and all of the explanatory variables are significant at least at the 5% level. Accordingly, hypotheses I to III pass the robustness test. Aside from that, among the control variables, the energy structure performs better in both models, with a significant positive effect on carbon emissions at least at the 5% level, while the significance levels of environmental regulation and fixed-asset investment fluctuates.

Following this, Table 8 presents a test of the robustness of the moderating effects.

Table 8. Robustness tests for moderating effects

	Carbon Emissions		Fiscal Decentralisation		Economic Development	
	Fe	Diff-GMM	Fe	Diff-GMM	Fe	Diff-GMM
$L1.lnpc_{i,t}$		0.572*** (5.87)		0.578*** (5.94)		0.527*** (5.17)
$lndec_{i,t}$	2.423*** (3.06)	3.484** (2.09)	2.133** (2.58)	3.277* (1.99)	2.059** (2.55)	4.535*** (2.92)
$lngdp_{i,t}$	3.826** (2.08)	4.255*** (3.20)	4.018** (2.12)	4.149*** (3.13)	4.393** (2.15)	4.745*** (3.70)
$(lngdp_{i,t})^2$	-0.223** (-2.34)	-0.174** (-2.07)	-0.239** (-2.41)	-0.174** (-2.09)	-0.262** (-2.42)	-0.180** (-2.16)
Interaction	-0.208** (-2.45)	-0.374** (-2.05)	-0.174* (-1.96)	-0.359* (-1.93)	-0.166* (-1.92)	-0.492*** (-2.83)
$lners_{i,t}$	0.207*** (6.21)	0.100* (1.89)	0.223*** (5.98)	0.111** (2.04)	0.221*** (6.02)	0.127** (2.06)
$lnreg_{i,t}$	-0.176 (-0.86)	-0.844 (-1.50)	-0.217 (-1.15)	-1.121* (-1.73)	-0.215 (-1.18)	-1.310* (-1.87)
$lninv_{i,t}$	-0.039* (-1.71)	-0.021 (-0.95)	-0.053** (-2.13)	-0.018 (-0.81)	-0.053** (-2.13)	-0.032 (-1.13)
_cons	-16.658 (-1.79)		-17.063 (-1.80)		-18.521 (-1.85)	
R^2	0.408		0.413		0.428	
AR(1)		0.001		0.006		0.006
AR(2)		0.345		0.289		0.207
Hansen Test		0.218		0.284		0.453

From Table 8, the R2 of the model with the interaction term is 0.408~0.428 after the winsorisation, which is higher than the R2 of the model without the interaction term; the p-values of AR(1), AR(2), and Hansen test are as expected, thus supporting the validity of the model regression. The interaction term is significant in all models, with its absolute value of the t-statistic fluctuating between 1.92 and 2.83; the explanatory variables are all significant, and the sign of the coefficients is constant for each variable. Thus, hypothesis IV passes the robustness test also.

In conclusion, the empirical evidence presented in this paper can be regarded as robust, and the overall estimation of the dynamic panel model is more accurate.

ISSN:2790-1661 DOI: 10.56028/aemr.2.1.258

7. Conclusion and Discussion

7.1 Conclusion

This paper begins with a theoretical consideration of the relationship between fiscal decentralisation, economic development, and carbon emissions, followed by research hypotheses. After that, a two-way fixed effects model and a dynamic panel model consisting of provincial panel data spanning 30 provinces in China are considered for empirical analysis. The following are the conclusions:

To begin with, fiscal decentralisation has a significant positive impact on carbon emissions. By increasing the fiscal autonomy of local governments, local carbon emissions will gradually rise.

Secondly, there appears to be an inverted U-shaped relationship between economic development and carbon emissions, with the effect on carbon emissions shifting from facilitation to suppression as real GDP increases in each region.

Thirdly, there is a dynamic lag impact on carbon emissions.

Fourthly, economic development has an inverse moderating impact, which can reduce fiscal decentralisation's contribution to carbon emissions.

Furthermore, there appear to be certain flaws in this study, most notable the use of a small number of control variables to ensure as much validity of the instrumental variables as feasible in Difference-GMM estimation.

7.2 Discussion

Early planning to avoid the lagging cost of carbon emissions: According to the World Bank, China has surpassed the United States as the world's top carbon dioxide emitter since 2006. And it is worth noting that excessive carbon emissions cause long-term environmental issues that need early policy intervention. The research findings recommend that China's low-carbon policies should be implemented as soon as possible in terms of governance, energy consumption, and so on. Thus the risks of increasing pollution stocks and greater management costs with long-term high carbon emissions may be avoided.

Incorporating environmental governance into local government appraisals: Fiscal decentralisation not only contributes directly to an increase in overall carbon emissions, but it can also have an indirect effect by increasing competition among land finance agencies and local governments. In order to improve the incentive and responsibility of local environmental governance, the Chinese government's present performance rating system, which is based on GDP, should advocate for a more fair distribution of financial and administrative powers. Environmental indicators, such as carbon emissions intensity, can be used to gradually decrease economic indicators in the evaluation process. And, to some extent, limit and control the fiscal revenue earned by local governments through land concessions.

Investing in sectors that support the long-term economic viability: China, as the world's largest developing country, is still concentrated on economic development. While there is nothing wrong with attaining 'quantitative' GDP growth, we must focus more on 'qualitative' economic development. In terms of ecological development, the federal government should encourage the transfer of funds designed expressly for ecological and environmental preservation, and instruct local governments to invest in regions that support high-quality economic growth. The local governments can also make use of the information advantage to implement carbon reduction and low-carbon incentives based on local realities.

ISSN:2790-1661 DOI: 10.56028/aemr.2.1.258

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