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The Impact of Firm Productivity on Carbon Emissions: Evidence from Listed Companies in China

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Abstract: As climate change accelerates, carbon reduction is a global priority. China, as the largest emitter, faces the challenge of balancing growth and sustainability. The influence of productivity improvements on emission reduction remains a key question. This study aims to explore the impact of firm productivity on carbon emissions. By panel data regression method, the paper uses data from China's Shanghai and Shenzhen A-share listed companies from 2015 to 2022 to examine the relationship between enterprise productivity and carbon emission. The results show that increased productivity has significantly reduced the amount of carbon emitted per unit of output. In addition, heterogeneity analysis shows that regional characteristics play an important role on the relationship between productivity and carbon emissions, the impact in the eastern region is significantly stronger than in the central and western regions. Thus, enterprises should boost productivity through green innovation and energy optimization to reduce emissions and support sustainable development.

Keywords: Firm Productivity, Carbon Emissions, Listed Companies in China, Panel Data, Green Technology

1. Introduction

With the increasing severity of global climate change, reducing carbon emissions has become a top priority for governments worldwide. As the world's largest developing country and carbon emitter, China faces marked challenges in tackling climate change and transitioning to a greener economy. A major source to these emissions is the industrial and heavy industries sector, which, with its high energy consumption, is vital to the country's overall carbon footprint. In recent decades, driven by the transformation and upgrading of China's economic structure and technological advancements, many enterprises have made remarkable strides in improving productivity and optimizing resource allocation. Increased productivity is often linked by technological innovation, equipment upgrades, and improved management efficiency, improving energy efficiency and reducing carbon emissions per unit of output [1]. However, the link between business productivity and carbon emissions has not been extensively studied, particularly in China, where research on this topic is limited. In certain high-pollution industries, productivity gains may increase environmental pressures by expanding production capacity instead of reducing carbon emissions [2]. This study aims to explore the impact of firm productivity on carbon emissions, focusing on publicly listed Chinese companies. These companies are significant in both resource consumption and carbon emissions, while also leading in technological innovation and management improvements. Thus, the relationship between enterprise

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productivity and carbon emissions is studied, which provides important theoretical support and policy advice for China to achieve green and low-carbon transformation.

2. Theoretical framework and literature review

2.1. Relationship between carbon emissions and firm productivity

The relationship between firm productivity and carbon emissions is complex, and researchers have proposed various theoretical models and hypotheses from different perspectives. According to the Environmental Kuznets Curve (EKC) theory, in the early stages of economic development, carbon emissions increase as productivity rises. However, once a certain level of economic development is reached, further improvements in productivity lead to a decline in carbon emissions [3]. This view highlights the importance of technological progress, institutional innovation, and policy support in reducing emissions. Early empirical research supports this theory, showing that productivity gains, often driven by technological innovation and energy efficiency, reduce carbon emissions per unit of output [4]. However, some studies show that in highly polluting industries or low-tech enterprises, higher productivity may not always reduce emissions. Instead, it could exacerbate environmental pressures as production scales expand [2].

2.2. Related studies on productivity and carbon emissions in China

At present, research on the relationship between productivity and carbon emissions in China is still limited, with some exploring how environmental regulations contribute to economic transformation from a policy standpoint [5]. For example, studies on Chinese industrial firms suggest that strict environmental policies may drive technological upgrades, leading to higher productivity and lower carbon emissions [6]. However, other studies have indicated that China's heavy and high-polluting industries continue to face significant carbon emission pressures during economic growth, making substantial short-term emission reductions through productivity gains challenging [7].

In recent years, with the rise of green finance and innovation, researchers have focused on how enterprises can boost productivity and reduce carbon emissions through green technology [8]. For example, green technology innovation has greatly enhanced productivity in China's manufacturing sector, improved energy efficiency, and lowered carbon intensity [9]. Moreover, studies on Chinese listed companies show that investing in green technology R&D and refining production processes can significantly increase productivity while lowering carbon emissions [10]. Despite the numerous studies exploring the relationship between productivity and carbon emissions, there is still a lack of empirical analysis based on specific groups of listed companies in China. Most existing literature focuses on the overall economy or industry-level analysis, overlooking the unique micro-role of China's listed companies in the green transition. Moreover, many studies concentrate on a single industry or region, with a lack of systematic analysis covering a broad range of samples nationwide. Therefore, this study addresses this gap by analyzing data from Shanghai and Shenzhen A-share listed companies in China, aiming to reveal the impact of productivity gains on carbon emissions while also discussing the effects of regional differences.

3. Methodology

3.1. Data and sample selection

The research data in this study comes from A-share listed companies in China, covering panel data from 2015 to 2022. Productivity is calculated by integrating and weighting data on production tools and labor force. The data is sourced from CSMAR, the Wind database, corporate annual reports, and

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industry reports, providing insights into production tools, labor, and carbon emissions. The sample includes all A-share companies with complete data during this period, excluding those with missing or incomplete information, ensuring a representative and diverse sample across industries and company sizes.

3.2. Variable definition and measurement

The core explanatory variable is enterprise productivity, calculated by weighting production tools such as capital equipment and fixed assets against labor data like employee numbers and labor input. This indicator reflects production efficiency and is standardized for comparability across companies. The core explained variable is the carbon emission level of enterprises, measured according to the *Guidelines for Accounting and Reporting of Greenhouse Gas Emissions of Enterprises* issued by China's National Development and Reform Commission. The carbon emission data mainly comes from the greenhouse gas emission disclosures in corporate annual reports. All carbon emission data is standardized to per-unit carbon emissions for cross-company comparability. This method enables a comprehensive evaluation of carbon emissions across different industries and company sizes, as well as an analysis of their relationship with productivity.

To accurately analyze the relationship between carbon emissions and productivity, this study introduces several control variables. Specifically, the return on assets (ROA) is used to measure the profitability of an enterprise, calculated by dividing net profit by total assets; the proportion of fixed assets (Fixed) is obtained by dividing net fixed assets by total assets, reflecting the company's asset structure and long-term capital investment; the board size (Board) is measured by the number of board members, indicating the complexity of the company's governance structure; the proportion of ownership held by the largest shareholder (Top) represents the share of total capital held by the largest shareholder, which may affect strategic decisions, including those related to carbon emission management; cash holdings (Cash) are derived from the company's balance sheet, thus reflecting liquidity and fund management; the growth rate of total assets (Tagr) is calculated by subtracting the beginning period's total assets from the ending period's total assets, divided by the beginning period's total assets, indicating the asset growth of the enterprise; the rate of investment expenditure (Invt) reflects the company's attitude towards expansion and investment, calculated as the ratio of investment expenditure to total assets or total income; the number of employees (Noemp) is used to measure the scale of the company, based on the number of employees each year; and the number of independent directors (AD) serves as a measure of governance transparency and decision-making autonomy.

3.3. Descriptive statistical analysis

By summarizing the distribution, central tendency, and variability of the primary variables, Table 1 establishes a foundation for the subsequent regression analysis.

Table 1: Summary statistics of key variables

VarName	Obs	Mean	SD	Min	Max
CO2	22494	2.531	0.122	1.812	2.988
EP	29875	0.007	0.011	0.000	0.291
ROA	22494	0.042	0.064	-0.373	0.247
Fixed	22494	0.226	0.154	0.002	0.719
Board	22494	2.117	0.195	1.609	2.708
Top	22494	34.248	14.584	8.020	75.525
Cash	68697	0.195	0.155	0.000	1.000

Table 1: (continued).

Tagr	68697	0.194	0.902	-1.000	107.128
Invt	68697	0.050	0.055	-0.000	0.759
Noemp	68697	0.446	1.716	0.000	70.350
AD	68697	3.161	1.697	0.000	13.000

3.4. Model construction

To examine the relationship between enterprise productivity and carbon emissions, the following baseline regression model is developed:

$$CO_{2_{it}} = \alpha + \beta_1 EP_{it} + \beta_2 X_{it} + \mu_i + \gamma_t + \epsilon_{it} \quad (1)$$

where $CO_{2_{it}}$ represents the carbon emission level of enterprise i at time t, expressed as carbon emissions per unit; $\mathrm{EP}_{\mathrm{it}}$ represents the productivity level of enterprise$i$i at time t; X_{it} is a set of control variables used to control for other factors that may affect carbon emissions; μ_i is individual fixed effect, control all enterprise characteristics that do not change over time; γ_t is time fixed effect, control for all factors that change over time but are the same for all businesses; and ϵ_{it} is a random error term.

4. Results

4.1. Baseline regression

The impact of enterprise productivity on carbon emissions is presented in Table 2, with regression analysis conducted both without control variables (column 1) and with control variables (column 2). Productivity has a significant negative effect on carbon emissions, with a regression coefficient of -0.213 and significant at the significance level of 5% (T-value -2.45). This suggests that increases in firm productivity significantly reduce carbon emissions. After adding control variables, the effect of firm productivity on carbon emissions remains significant, with a regression coefficient of -0.166 and a t-value of -1.98, significant at the 5% level. Although the negative impact of firm productivity on carbon emissions weakens after the addition of control variables, it still remains significant. This finding indicates that improving production efficiency can be an important way for companies to achieve low-carbon development.

Table 2: Impact of enterprise productivity on carbon emissions

	(1) CO_2	**(2) CO_2**
EP	-0.213**	-0.166**
	(-2.45)	(-1.98)
ROA		0.158***
		(14.80)
Fixed		0.005
		(0.39)
Board		0.018***
		(3.67)
Top		-0.000
		(-0.59)

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Table 2: (continued).

Cash		-0.013**
		(-1.97)
Tagr		0.002
		(0.83)
Invt		0.023
		(1.25)
Noemp		0.010***
		(3.34)
AD		0.000
		(1.03)
Constant	2.533***	2.484***
	(3,588.19)	(202.44)
Observations	17768	17,768
R-squared	0.937	0.942
Enterprise FE	YES	YES
Year FE	YES	YES

4.2. Robustness test

Firstly, the firm-clustered robust standard errors in the baseline regression are substituted with industry-clustered robust standard errors to ensure the reliability of the regression results, as shown in Column (1). Under this adjustment, the regression results show that firm productivity continues to have a significant negative impact on carbon emissions, with a coefficient of -0.147 and a t-value of -2.19. This result suggests that when using industry-clustered standard errors, the suppressing effect of firm productivity on carbon emissions remains stable and is not affected by the change in the clustering method, indicating that firm productivity still exerts a significant negative impact after controlling for industry effects.

Next, the PPML method (Poisson pseudo-maximum likelihood regressions) is further employed, with results presented in Column (2). PPML models are especially suited for models with positive count (and non-count) outcome variables, where applying least-squares regression to outcome variables like log(y) could lead to inconsistent estimates due to heteroscedasticity. After applying this method, the regression results continue to show a significant negative effect of productivity on carbon emissions, with a coefficient of -0.066, which remains statistically significant at the 5% level (*t*-value = -1.96). The PPML method supports the findings of the original regression model, further strengthening its robustness. This indicates that the emission reduction impact of increased firm productivity remains significant even when using different estimation methods.

Overall, the robustness checks confirm the stable negative impact of productivity improvement on carbon emissions, which remains unaffected by changes in standard error clustering methods and estimation techniques.

4.3. Regional heterogeneity

The impact of firm productivity on carbon emissions was investigated for regional heterogeneity by categorizing firms into eastern, central, and western regions, as shown in Table 3. In column (3), regression results show that the impact of enterprise productivity on carbon emissions in the eastern region is -0.181, and it is significant at the significance level of 5% (T-value is -2.07). In column (4),

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the negative impact of firm productivity is 0.150, but not statistically significant (T-value = 0.66). Finally, column (5) presents the regression results for the western region, where the coefficient is -0.540, though it is not statistically significant (T-value = -1.61).

This result may reflect the more advanced technology and stronger environmental policy support in the eastern region, which enable firms to reduce carbon emissions more effectively. In contrast,in the central region, the impact of enterprise productivity on carbon emissions is weak, mainly due to the relatively insufficient technical and policy support in the central region. Also, the economic development level of the western region is lower than that of the eastern and central regions, and the implementation of environmental protection technologies and policies is more lagging, resulting in the improvement of western enterprise productivity has a weakest impact on carbon emissions.

Table 3: Impact of firm productivity on carbon emissions by region

	(1) Industry clustering	**(2) ppml**	**(3) Eastern**	**(4) Central**	**(5) Western**
EP	-0.147**	-0.066*	-0.181**	0.150	-0.540
	(-2.19)	(-1.96)	(-2.07)	(0.66)	(-1.61)
Constant	2.484***	0.911***	2.498***	2.504***	2.423***
	(204.51)	(186.62)	(170.20)	(91.52)	(69.52)
Observations	17,461	17,768	12,794	2,718	2,229
R-squared	0.942	-	0.945	0.949	0.938
Control	YES	YES	YES	YES	YES
Standard error clustering	Industry	Enterprise	Enterprise	Enterprise	Enterprise
Enterprise FE	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES

5. Conclusion

This study, using data from Chinese listed companies between 2015 and 2022, explores the impact of firm productivity on carbon emissions, focusing specifically on regional differences. The results indicate that improvements in enterprise productivity contribute to a reduction in carbon emissions, suggesting that productivity gains drive economic growth while also serving as an effective strategy for emission reduction. From the perspective of heterogeneity analysis, regional differences play a significant role in the results. In addition, it is found that improvements in enterprise productivity are more effective in reducing carbon emissions in the eastern region. In contrast, in the central and western regions, the relatively insufficient technical and policy support means that improvements in corporate productivity do not have a significant impact on curbing carbon emissions. Based on the research conclusions, this paper demonstrates that enterprises adopt advanced green technologies for energy conservation, clean production, and pollution control to promote low-carbon processes. Increased R&D and innovation will boost technical capabilities and competitiveness. Besides, using digital tools to optimize production reduces waste, while promoting a circular economy reduces costs and environmental impact through resource recycling. In short, Chinese enterprises should invest in green innovation to address climate change and achieve carbon peak and neutrality goals.

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