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Economic Growth and Carbon Trading Prices: An Empirical Analysis Based on the Chinese Market

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Abstract: This study explores the impact of macroeconomic factors, particularly GDP, on carbon trading prices in six major Chinese cities. Using a linear regression model, combined with province and quarterly fixed effects, it was found that the influence of economic scale on carbon trading prices exhibits significant regional differences. In the sample analysis, the economic growth in municipalities is positively correlated with carbon trading prices, whereas in other provinces, it is negatively correlated. The study controlled for province and quarterly fixed effects, ensuring the robustness of the results. This research fills a gap in the study of China's carbon market and provides theoretical support for formulating more effective carbon emission policies.

Keywords: Carbon Trading Prices, Macroeconomic Factors, Chinese Carbon Market, GDP Impact, Environmental Policies.

1. Introduction

1.1. Research Background

With the intensification of global climate change, controlling carbon emissions has become a focal point of international concern. As one of the world's largest carbon emitters, China plays a crucial role in achieving global greenhouse gas reduction targets. In recent years, the Chinese government has actively promoted the establishment of a carbon trading market to encourage carbon emission reductions through market mechanisms. Carbon trading, as a flexible market mechanism, allows emitters to optimize costs by trading carbon quotas while achieving reduction targets. Through carbon trading, the market can effectively allocate reduction resources, enhance reduction efficiency, and lower reduction costs, thus achieving the dual goals of environmental protection and economic development.

China's rapid economic growth has led to a significant increase in energy consumption, which in turn has resulted in higher carbon emissions. The economic situation directly and indirectly impacts carbon trading prices. On the one hand, economic growth drives increased energy demand, potentially pushing up carbon prices. On the other hand, economic instability and policy changes may increase uncertainty among market participants, affecting price fluctuations in the carbon market. Therefore, it is of great practical significance to investigate whether macroeconomic factors influence carbon trading prices. I believe that economic conditions significantly affect carbon trading prices. When the economy is robust, the government and enterprises are more capable and willing to invest in

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environmental projects and technologies, whereas during economic downturns, environmental investments may decrease, impacting the performance of the carbon trading market. For instance, the study by Zeng et al. found a long-term equilibrium relationship between macroeconomic factors such as the Air Quality Index and energy prices with carbon trading prices [1]. This indicates that macroeconomic factors indeed play a key role in the fluctuations of carbon trading prices.

1.2. Research Methods and Conclusions

In terms of research methodology, we first collected quarterly GDP data and carbon trading price data for six major cities, covering the period from the first quarter of 2014 to the first quarter of 2021. We selected these cities as samples not only because they are representative of the Chinese carbon market but also due to their varying levels of economic development and carbon market mechanisms, which help us analyze carbon trading price variations under different economic conditions.

Next, we employed a linear regression model to analyze the data. Specifically, we introduced province fixed effects and quarterly fixed effects into the model to control for province-specific and quarter-specific influencing factors. The application of fixed effects allows us to more accurately capture the marginal impact of GDP on carbon trading prices. Additionally, we conducted multiple regression analyses on the model to ensure the robustness and reliability of the results. This method enables us to uncover the specific impact of changes in economic scale on carbon trading prices. This is consistent with the microstructure pricing model proposed by Ibrahim and Kalaitzoglou regarding information asymmetry and liquidity [2]. The application of this model helps to better understand the impact of market behavior on carbon trading prices.

The research results indicate that cities with different levels of economic development exhibit distinct characteristics in the relationship between carbon trading prices and GDP. In the overall sample including the six cities, the impact of economic scale growth on carbon trading prices was not significant. However, in the sample that includes only the four municipalities—Beijing, Shanghai, Tianjin, and Chongqing—economic growth was found to be significantly positively correlated with carbon trading prices. This suggests that in more economically developed cities, the expansion of economic scale may drive up carbon trading prices. Conversely, in the samples from the provinces of Hubei and Guangdong, GDP was significantly negatively correlated with carbon trading prices, reflecting the differences in market mechanisms and policy environments across regions. This finding is similar to what Dechezleprêtre et al. observed in the EU Emissions Trading System, indicating that regional economic policies and market mechanisms significantly impact carbon trading prices [2]. The presence of this impact further underscores the necessity of studying regional markets.

1.3. Research Significance

The theoretical significance of this study lies in filling the research gap in the field of China's carbon market. While previous studies have indicated that macroeconomic factors affect carbon trading prices, most of these are based on the mature experiences of the EU market. This study, based on the relatively immature Chinese carbon market, reveals through empirical analysis the different patterns of impact that economic development has on carbon trading prices. This finding provides a new perspective for understanding the complexity of the Chinese carbon market and offers theoretical support for formulating more effective carbon emission policies. For example, Zeng et al. found a long-term equilibrium relationship between carbon trading prices and macroeconomic factors in China, and our research further elucidates the differences in this relationship across cities with varying levels of economic development [1]. This provides new theoretical grounds for policymakers.

Furthermore, the practical significance of this study lies in aiding policymakers and market participants in better understanding the influence of macroeconomic factors on carbon trading prices.

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By identifying the patterns of carbon trading price changes under different levels of economic development, this study offers reference points for the government when formulating carbon emission policies and economic development strategies. For instance, Xie et al. demonstrated that emission trading systems can reduce environmental risks for enterprises, and our study further provides specific data support from the Chinese market [3]. This data support helps in crafting policies tailored to the characteristics of the Chinese market. For enterprises, understanding the impact of macroeconomic factors on carbon prices aids in making better carbon trading decisions, optimizing carbon emission cost management, and enhancing competitiveness. This research not only provides new data and analytical frameworks for academia but also offers substantial support for policy-making and strategic planning in practical operations.

In summary, through this study, we not only uncover the uniqueness of the Chinese carbon market but also provide important theoretical and practical foundations for further exploring the development path of carbon markets. We hope that future research will continue to focus on this field, further improving the mechanisms and policies of carbon trading markets, and contributing to global climate change governance. Our research results offer important references for subsequent studies and policy formulation, as well as share China's experiences and lessons for the development of global carbon markets.

2. Literature Review

Globally, fluctuations in carbon trading prices reflect the dynamic changes in carbon trading markets. This paper comprehensively analyzes various factors affecting carbon trading prices, categorizing them into macroeconomic factors, technological advancements, and political factors. The following sections review and analyze relevant literature from these perspectives.

2.1. Macroeconomic Factors

Macroeconomic factors play a crucial role in the formation and fluctuation of carbon trading prices. According to the study by Zeng et al. , carbon trading prices (CTP) in China's carbon trading market are influenced by long-term macroeconomic factors [1]. They indicate that there is a long-term equilibrium relationship between China's carbon trading prices and factors such as the Air Quality Index (AQI), energy prices, and macroeconomic indicators. This suggests that economic development levels, energy demand, and supply conditions directly affect the volatility of carbon trading prices. Additionally, Dechezleprêtre et al. demonstrate that the European Union Emissions Trading System (EU ETS) significantly impacts carbon emissions and economic performance [4].

Market behavior and price formation, integral components of macroeconomic factors, also significantly influence carbon trading prices. Ibrahim and Kalaitzoglou propose a microstructural pricing model based on information asymmetry, considering that the response of prices to information and liquidity varies with each transaction [2]. Their research finds that the anticipated trading intensity of European carbon futures simultaneously increases the informational component of price changes, albeit at different speeds. Further, Kalaitzoglou and Ibrahim highlight that liquidity plays a dual role: higher relative liquidity introduces uncertainty, while higher absolute liquidity accelerates the resolution of uncertainty, thereby enhancing market efficiency [5].

Zhao et al. propose a hybrid carbon trading price prediction framework that combines multiple methods to improve prediction accuracy [6]. Zhao and Guo also present a carbon trading price forecasting approach based on a hybrid model, which integrates complete ensemble empirical mode decomposition with adaptive noise, sample entropy methods, an improved Salp Swarm algorithm, and a multi-kernel extreme learning machine method to enhance prediction accuracy [7]. These

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studies indicate that market behavior and price formation are crucial for the fluctuation and prediction of carbon trading prices.

2.2. Technological Advancements

Technological advancements play a critical role in the development of carbon trading markets and the reduction of carbon emissions. Lyu et al. from China emphasize that carbon trading policies have facilitated the decoupling of carbon emissions in China and have driven carbon reduction through both grey and clean technological innovations [8]. Their findings suggest that carbon trading policies can significantly promote the decoupling of carbon emissions in China, achieving carbon reduction targets through technological innovation. Further research by Wang and Qiu introduces an improved multi-scale nonlinear integration model for forecasting carbon trading prices [9]. These studies demonstrate that technological progress not only enhances the prediction capabilities of carbon trading prices but also provides market participants with more accurate information, thereby influencing market behavior and price volatility.

2.3. Political Factors

Political factors also play a significant role in the operation and price formation of carbon trading markets. Xie et al. investigate the impact of the Carbon Emission Trading Scheme (CETS) on the crash risk of heavily polluting listed companies in China [3]. They find that CETS can significantly reduce the crash risk of stock prices for heavily polluting companies by decreasing analyst attention to these firms. This research elucidates the relationship between climate risk and corporate financial risk from the perspective of stock price crash risk, highlighting the role of carbon trading systems. On the other hand, Zhao et al. from China demonstrate that the country's carbon emission trading policies can achieve carbon decoupling by encouraging and promoting low-carbon technological innovations [7]. These findings indicate that political carbon trading policies can influence corporate stock prices and market performance by mitigating environmental risks.

In summary, carbon trading prices are influenced by a variety of factors, including macroeconomic factors, technological advancements, and political factors. In-depth research into these factors not only aids in understanding the operational mechanisms of carbon markets but also provides theoretical support for formulating more effective carbon emission policies.

3. Research Design

3.1. Data and Summary Statistics

This study aims to analyze the relationship between carbon trading prices and local GDP in six major Chinese cities (Beijing, Guangdong, Hubei, Shanghai, Tianjin, and Chongqing) from the first quarter of 2014 to the first quarter of 2021. Given that carbon trading prices are a key indicator affecting regional economic development and the implementation of environmental policies, this paper collects quarterly data from these six cities over the specified period for analysis. The GDP data represent the economic scale of each city, while the carbon trading prices reflect the market's evaluation of emission reduction efforts. By comparing these two variables, we can gain insights into the dynamic relationship between economic development and environmental policy.

Table 1: Descriptive statistics of carbon trading prices and GDP from the first quarter of 2014 to the first quarter of 2021.

Variable	Obs	Mean	Std. Dev.	Min	Max
Carbon Trading Prices	171	29.39586	18.70567	2.15	92.96333

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Table 1: (continued).

GDP	174	9276.892	6622.55	-1152	32363.9
Year	174	2017.138	2.10242	2014	2021

Table 1 provides descriptive statistics of carbon trading prices and GDP for Beijing, Guangdong, Hubei, Shanghai, Tianjin, and Chongqing from the first quarter of 2014 to the first quarter of 2021. There are 171 observations for carbon trading prices, which is three fewer than the 174 observations for GDP. This discrepancy is due to missing carbon price data for Hubei and Chongqing in the first quarter of 2014, and for Chongqing in the second quarter of 2014. The unit of carbon trading prices is yuan, with an average value of 29.40 yuan and a significant volatility, indicated by a standard deviation of 18.71 yuan. This suggests considerable differences in carbon trading prices among the different cities during the study period, possibly due to varying levels of market maturity, policy differences, or changes in supply and demand. The lowest price recorded is 2.15 yuan, and the highest is 92.96 yuan, reflecting extreme market variations over different periods.

There are 174 GDP observations in Table 1, with an average value of 9276.89 billion yuan and a standard deviation of 6622.55 billion yuan. The range of GDP values spans from -1152 billion yuan to 32363.9 billion yuan. This range suggests that some cities may have experienced economic contractions (negative growth) in certain quarters, or there may be data entry errors involving negative signs. However, the presence of the highest value indicates that some cities may have experienced significant economic growth in certain quarters.

3.2. Model Specification

This study employs a linear regression model, taking into account province fixed effects and quarter fixed effects, to investigate the impact of different quarters and provinces on carbon trading prices. The model is specified as follows:

$$Carbon\ \ Price_{w,t,i} = \alpha + \gamma_i + \tau_t + \delta GDP_{w,t} + \varepsilon_{w,t,i} \tag{1}$$

$Carbon\ \ Price_{w,t,i}$ is the carbon trading price in province i during quarter t, γ_i represents the fixed effects for province i, τ_t represents the fixed effects for quarter t, $\delta GDP_{w,t}$ is the GDP adjusted by equivalent weight, α is the constant term, $\varepsilon_{w,t,i}$ is the error term.

Fixed effects γ_i and τ_t capture the effects in the model that are specific to provinces and quarters but are not explicitly included as variables. Province fixed effects control for province-specific, time-invariant unobservable factors such as culture, policies, and economic structures. Similarly, quarter fixed effects control for common influences that affect all provinces during specific quarters, such as seasonal fluctuations, macroeconomic trends, or national policy changes.

By incorporating these fixed effects, the model allows us to understand how province and quarter variables independently influence carbon trading prices, while also considering the effect of GDP adjusted by equivalence weights. The application of fixed effects helps to address unobserved heterogeneity, enabling more accurate estimation of the marginal impact of GDP on carbon trading prices.

4. Empirical Results

Table 2: The comparison of results from three different models.

VARIABLES	1	2	3
gdpw	-0.0009*	0.0022*	-0.0017*

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Table 2: (continued).

	(0.0005)	(0.0012)	(0.0009)
Constant	44.7047*** (5.8019)	19.2634** (9.4178)	83.3353*** (14.4439)
Observations	171	114	57
R-squared	0.758	0.812	0.764
Province FE	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

4.1. Analysis Overview

Table 2 reports the comparison of results from different models. Models 1, 2, and 3 respectively demonstrate the impact of GDP on carbon trading prices while incorporating province fixed effects and quarter fixed effects.

When exploring the relationship between GDP and carbon trading prices, we constructed three models to analyze the effects across different types of cities. Model 1 includes data from six cities: Beijing, Guangdong, Hubei, Shanghai, Tianjin, and Chongqing. Model 2 focuses only on the data from four municipalities: Beijing, Shanghai, Tianjin, and Chongqing. Model 3 specifically examines data from the provinces of Hubei and Guangdong.

4.2. Model 1 (Full Sample Analysis)

The results of Model 1 in Table 3 indicate that the relationship between GDP and carbon trading prices is not statistically significant (coefficient of -0.0009, p-value = 0.088). This suggests that the economic scale's growth does not have a statistically significant impact on carbon trading prices across the six cities in the overall sample. The model's R-squared value of 0.758 indicates that the model explains approximately 75.8% of the variation. The introduction of fixed effects ensures control over province and quarter-specific factors.

4.3. Model 2 (Municipality Analysis)

In Model 2, when limiting the sample to municipalities, as shown in Table 4, the relationship between GDP and carbon trading prices becomes positive and significant (coefficient of 0.0022, p-value = 0.071). This suggests that in economically developed cities, an increase in economic scale is positively correlated with carbon trading prices. The R-squared value of Model 2 increases to 0.811, indicating an improved explanatory power of the model.

4.4. Model 3 (Province Analysis)

For the data from the provinces of Hubei and Guangdong, Model 3 in Table 5 shows results different from Models 1 and 2. Here, GDP is negatively and significantly correlated with carbon trading prices (coefficient of -0.0017, p-value = 0.045), revealing a reverse relationship between economic growth and carbon trading prices in the provincial carbon markets. The R-squared value of Model 3 is 0.764, slightly higher than that of Model 1.

These models provide insights into how GDP independently affects carbon trading prices across different city types, considering the economic scale's role. By applying fixed effects, the models account for unobservable heterogeneity, allowing for a more accurate estimation of GDP's marginal impact on carbon trading prices in various regional contexts.

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4.5. The Conclusion for Empirical Results

These findings demonstrate that the relationship between GDP and carbon trading prices is indeed influenced by the economic development level of cities and the type of market. The positive relationship between economic growth and carbon trading prices observed in municipalities may reflect higher market efficiency and strengthened environmental regulations. Conversely, the inverse relationship at the provincial level may indicate different market dynamics and policy impacts. This discovery provides an important perspective on the complexity of regional carbon markets and offers data support for the formulation of targeted environmental policies and economic strategies.

5. Conclusion

5.1. Study Overview

This study conducts empirical analysis to explore the relationship between carbon trading prices and macroeconomic factors, particularly GDP, across six major cities in China. Quarterly data from the first quarter of 2014 to the first quarter of 2021 are collected and analyzed using linear regression models incorporating province fixed effects and quarter fixed effects. The findings reveal significant differences in the relationship between GDP and carbon trading prices across cities with different levels of economic development. Specifically, economic scale growth does not significantly impact carbon trading prices in the overall sample. However, in municipalities, economic growth correlates positively with carbon trading prices, whereas in provinces, GDP shows a negative correlation with carbon trading prices. This study not only fills gaps in research on China's carbon market but also provides new insights into the complexity of regional carbon markets.

5.2. Policy Recommendations

Based on the research findings, we propose the following policy recommendations to strengthen the development of the carbon trading market and promote green development in impoverished areas:

Firstly, the government should increase support for carbon trading markets in impoverished regions by providing policy incentives and financial support to help establish and enhance carbon trading mechanisms. Specific measures include establishing special funds to support carbon emission reduction projects in these regions, thereby increasing their participation and capacity in the carbon trading market.

Secondly, the government should strengthen the regulation and management of the carbon trading market to ensure fairness and transparency. Establishing a robust market supervision system will prevent market manipulation and excessive price fluctuations, thereby enhancing market stability and credibility.

Additionally, the government should enhance training and guidance for participants in the carbon trading market, including enterprises and institutions, to increase their understanding and participation. This effort will encourage more enterprises to actively engage in carbon trading.

Finally, the government should increase support for green development in impoverished areas through the carbon trading market to promote sustainable development. Encouraging and supporting green energy projects such as solar and wind energy will reduce reliance on traditional energy sources and lower carbon emissions. Simultaneously, by using the carbon trading market, the government can transfer emission reduction costs from developed regions to impoverished areas, thereby increasing economic income in these regions and promoting dual benefits for the economy and the environment.

These policy measures can effectively promote the development of the carbon trading market, better serving the green development goals of impoverished areas and providing strong support for achieving national carbon reduction targets. We hope that in the future, governments and stakeholders will continue to focus on and promote the development of the carbon trading market, contributing China's efforts to global climate change governance.

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