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Article

Analysis of the influencing factors of emission trading price in China

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Abstract: China established pilot carbon markets in 2013. In 2020, it set targets for carbon peaking in 2030 and carbon neutrality by 2050. China's national carbon market officially commenced operations in 2021. Based on the national market and seven pilot markets, this study established the factors influencing carbon trading prices by examining market participants, macroeconomics, energy prices, carbon prices in other markets, etc. Asymmetrical development among the seven pilot cities, for which the study employed a mixed-effects model, was the primary factor impacting carbon prices. The carbon prices in the pilot cities cannot be extrapolated to the entire country. In the national carbon market, where the study employed a multiple regression lag model, the SSE index was positively correlated with carbon prices, whereas the Dow Jones index had no significant effect on carbon prices in terms of macroeconomics. Coal and natural gas prices were negatively correlated with carbon prices, whereas oil prices were positively correlated with energy prices. The EU market prices have a positive correlation with prices in other markets. The significance of this study is that it covers the largest national Emissions Trading System (ETS) in the world and allows for comparing the characteristics of the Chinese market with those of other ETS markets. Additional studies, including more sectors, should be conducted as China's ETS coverage increases.

Keywords: carbon trading market; China; carbon trading price; influencing factors

1. Introduction

China's rapid economic development during the past four decades has garnered significant global attention. However, this development has come at massive costs in terms of carbon emissions. Thus, the Chinese government has increasingly prioritized the development of a green economy, culminating in a proposal to establish a green and low-carbon development system. During the Fifth Plenary Session of the 19th Central Committee of the Communist Party of China, ambitious targets were set to reduce carbon emissions and improve the ecological environment. Similarly, the 14th Five-Year Plan aims to improve the ecological environment and strengthen ecological security. General Secretary Xi Jinping has emphasized the significance of preserving the environment, stating that "green water and green mountains are golden mountains". To achieve these goals, China established a national carbon trading market in 2021. If it matures, it could boost China's competitiveness in the global carbon trading market.

The European Union (EU) established the carbon emissions trading system in 2005 to fulfill the Kyoto Protocol agreement. China's carbon trading market was established relatively late. However, it has witnessed significant progress in recent years. Since 2011, China has implemented local carbon trading pilot work in seven provinces and cities, namely Beijing, Chongqing, Guangdong, Hubei, Shanghai, Shenzhen, and Tianjin—Fujian was added later—all went online for trading in 2014. Subsequently, the Interim Measures for the Management of Carbon Emissions Trading were issued in 2014, and the National Measures for the Management of Carbon Emissions Trading (Trial) were issued in 2016. In December 2017, China commenced construction of the national carbon trading market, identifying the twin centers of Wuhan and Shanghai. The Ministry of Ecology and Environment issued the "Measures for the Management of Carbon Emission Trading (Trial Implementation)" and the "Implementation Plan for Setting and Allocating the Total Amount of National Carbon Emission Trading Quotas for 2019–2020 (Power Generation Industry)" in December 2020, launching the first compliance cycle of the national carbon trading market on 1 January 2021. By the end of December 2020, the spot carbon market in the eight pilot provinces and cities in China had traded a total of 445 million tons of carbon emission allowances, with a turnover of 10.431 billion yuan. By the end of 2022, the cumulative volume of carbon emission allowances traded in the national carbon market was approximately 230 million tons, with a cumulative turnover of approximately 10.4 billion yuan. China's carbon trading market is the second largest in the world in terms of quota turnover. The development of China's carbon trading market during the 14th Five-Year Plan period is of immense significance and is expected to achieve smooth operation from its start-up.

Carbon trading prices play a crucial role in developing the carbon trading market. China's carbon trading price is volatile and complex, making a study of it essential for the smooth operation of the national carbon trading market. Therefore, this thesis investigates the determinants of carbon emission rights prices during the first year of trading in the national carbon market, with a particular focus on the impact of macroeconomic variables and energy prices. This study aims to facilitate the sustainable development of China's carbon emission rights market and contribute to the achievement of China's carbon peak and neutral targets.

2. Materials and methods

2.1. Methods

This study employed both qualitative and empirical quantitative methodologies. The qualitative analysis methodology primarily adopted an inductive approach. First, we analyzed China's carbon trading market. For the pilot carbon markets, this study focuses on the development background, current development status, etc. For the national market, to have a clearer understanding of China's carbon market, the study introduces in detail each participating entity, its main activities, and objectives according to the three phases of carbon trading: "before", "during", and "after". The next part of the qualitative analysis analyzes the factors influencing the price of carbon trading. This study discusses the basic characteristics of China's carbon market factors and their impacts on Chinese carbon trading prices from both the supply and demand sides. On the demand side, the present study focuses on the contexts of energy, macroeconomics, international carbon markets, and climate factors. The supply side factors influencing the carbon emission trading price mainly include the total amount of allowances and the division of allowances.

In the empirical analysis, we selected the national carbon market and the average price of carbon trading in seven pilot cities in 2021 as the dependent variables. For the national carbon trading market, a multivariate autoregressive distributed lag model (ADL) was formulated to delineate the dynamic causal influences of three determinants on the current and future prices of carbon trading: the CSI 300 index, Bohai Sea oil price, and coal price.

$$yt = \beta 0 + \sum_{i=1}^{n} \beta i\ L(xi, t - m) + \varepsilon t$$

t = number of periods, y = carbon price, x_i = (sz, dqs, hbh, trq1, oil, EU Allowance [EUA], quota), and L(x_i, $t - m$) denotes lagged nth order.

This study employed a linear mixed model with a random intercept for the pilot carbon trading markets. Initially, the data from all seven pilot cities were utilized to build a single multivariate model, which ignored the differences between different cities and violated the principle of data independence. To address this issue, a random intercept mixed-effects model was applied, which accounted for the differences in the average carbon price levels in different pilot cities, considered the nested structure of the data, and made better use of the information. Compared with the multivariate model built by individual cities, the mixed model is more concise and requires only one model to represent the multivariate model built by seven cities individually.

$$\text{price}i = \alpha_{j[i]} + \beta 1\text{sz}i + \beta 2\text{trq}1i + \beta 3\text{oil}i + \beta 4\text{EUA}i + \beta 5\text{quota}i + \varepsilon i$$

The intercept of the multivariate linear model for the different carbon trading markets can vary freely, where j denotes the jth carbon trading market.

2.2. Data and variables

In this study, the indicators selected for each influencing factor were treated as daily data (**Table 1**). Data were collected from the China Carbon Emissions Trading Network and the official websites of the pilot carbon exchanges. The time range selected for analysis is the entire year of 2021. The dependent variables include the carbon prices in the national carbon market and the seven pilot carbon markets. Sample data were obtained after removing missing values and carbon values with zero trading volume on a given day. The independent variables are discussed below.

Table 1. Variable selection and data sources.

	Indicators	Symbols	Data sources
Dependentvariables	Average price of carbontrading in 7 pilot carbonmarkets National carbon marketcarbon trading closing price	Price	Each pilot carbon emissions trading The official Website of the Institute and the China Carbon Emissions Trading Website
Independentvariables	SSE Composite Index	Sz	Shanghai Stock Exchange
	Dow Jones IndustrialAverage	dqs	Sina Finance
	Bohai Sea Power Coal: Composite Average Price (5500K)	hbh	Qinhuangdao Coal Network

Table 1. (*Continued*).

	Indicators	Symbols	Data sources
Independentvariables	Production Materials Price: Liquefied NaturalGas (LNG)	trq1	National Bureau of Statistics
	Market Price: LNG	trq2	100ppi.com
	Spot Price: Brent CrudeOil	oil	100ppi.com
	CSI 300 Index	hs	Shanghai Stock Exchange
	S&P 500 Index	bp	Shanghai Stock Exchange
	EUA	EUA	European Carbon EmissionsTrading Network
	Carbon emissionallowances	quota	Each pilot carbon emissions trading The official Website ofthe Institute and the China Carbon Emissions Trading Website

Macroeconomics: Macroeconomics, which can be categorized as domestic or international, exerts a significant impact on the stock market. In this study, the Shanghai Stock Composite Index and the CSI 300 Index were selected as indicators of domestic macroeconomics. The Dow Jones Index and S&P 500 Index were selected as indicators of international macroeconomics.

Fossive energy prices The combustion of fossil fuels is the primary contributor to carbon dioxide emissions. The interplay between the supply and demand of fossil fuels affects their combustion in emission control enterprises, thereby influencing the demand for carbon emission rights. Coal, oil, and natural gas are the principal fossil fuel sources in China. Hence, this study employed the Bohai Ring power coal price, natural gas production price and market price, and Brent crude oil price as indicators to gauge the impact of fossil fuel prices on the demand for carbon emission rights.

Foreign carbon trading price: The EU carbon emissions trading system (EU-ETS) is a widely recognized mandatory allowance market with a mechanism similar to that of China's carbon pilot market. However, the EU-ETS was established earlier and has many participating countries, making it more mature in terms of development scale, trading mechanisms, and product development. The European Union Allowance (EUA) price of carbon allowances significantly impacts carbon prices in many global carbon markets. Additionally, futures play a crucial role in risk avoidance and price discovery and can predict the future development direction of spot prices. Therefore, the EUA daily carbon quota trading price was selected as an essential indicator in this study.

3. China's carbon emissions trading market

3.1. China's pilot carbon markets

China actively participated in the international carbon market as early as 2005, mainly by developing certified emissions reduction (CER) and voluntary emissions reduction (VER) projects. China simultaneously gained substantial benefits as a seller of emission reductions. China has been exploring the possibility of establishing a carbon market since 2011 and has launched pilot projects in seven places: Beijing, Chongqing, Guangdong, Hubei, Shanghai, Shenzhen, and Tianjin. After two years of practice, the seven pilot sites built a regional carbon market with precise subjects, explicit rules, and regulations in 2013.

In 2011, the National Development and Reform Commission (NDRC) published the "Official Notice on the Pilot Project of Carbon Emission Trading". The document identified seven provinces and cities in China to conduct carbon trading pilots; the Fujian carbon market was later added to the list. According to the relevant NDRC regulations, each of those provincial governments formulated its regulations for the operation of their respective carbon pilot markets. They determined the carbon quota allocation method based on a survey of actual local carbon emissions. By 2021, five of the seven pilot markets (Beijing, Guangdong, Shanghai, Shenzhen, and Tianjin) had completed eight compliance periods. Chongqing and Hubei had completed seven compliance periods.

There are two types of carbon market transactions in China's pilot market. The first is the mandatory carbon market that takes the form of quota trading. During the early stage of the carbon market, to stimulate enterprises' enthusiasm, the government set the way for quota distribution: 95% of the quotas were allocated without compensation and 5% with compensation. The other type is the voluntary carbon market, where enterprises can voluntarily participate in carbon emission reduction projects and obtain China Certified Emission Reductions (CCERs). However, most enterprises cannot attain the ratio specified in the CCER offset management method. Thus, in March 2017, the NDRC suspended trading in CCER projects.

As of 31 December 2022, more than 3000 emitters and units have been included in the seven pilot carbon markets. The total cumulative amount of carbon emission allowances allocated was approximately 8 billion tons. The total cumulative amount of allowance transactions completed in the seven pilot carbon markets in 2022 was 43,860,000 tons. The total transaction amount was 2.546 billion yuan.

This study uses online trading data from the China Carbon Emissions Trading Network and seven pilot exchanges. The selected data were collected by 31 December 2022.

Table 2 presents the cumulative online quota transactions in each pilot carbon market since its opening.

Table 2. Pilot carbon markets transactions in China.

Pilots	Market opening date	Total transaction volume (Million tons)	Total transactionamount (BillionYuan)	Average transactionprice (Yuan/ton)
Beijing	2013.11.28	1643.78	10.728	6.53
Tianjin	2013.12.26	1871.88	4.298	2.30
Shanghai	2013.11.26	1781.74	5.634	3.16
Shenzhen	2013.6.18	4927.12	12.093	2.45
Guangdong	2013.12.19	17,616.74	37.269	2.12
Hubei	2014.4.2	7645.25	17.894	2.34
Chongqing	2014.9.19	975.61	0.82	0.84

Source: Raw data from each pilot carbon market exchange (calculated and compiled by the author).

The Guangdong carbon market has the highest cumulative transaction volume and turnover. It is the only carbon market with a cumulative transaction volume of over 100 million tons among the other pilot carbon markets in China. Although the Hubei carbon market started late, it ranked second in terms of cumulative turnover. Its market activity was second only to that of Guangdong. Although the Shenzhen carbon market was the first to start, its cumulative transaction volume and cumulative turnover were less than those of the Hubei and Guangdong carbon markets, but higher than those of other pilot carbon markets. Chongqing, the last pilot market to start, had a much lower total volume and turnover than the of the other pilot markets. Its average transaction price was also the lowest, at RMB 18.28 per ton. The average transaction price in the Beijing carbon market was the highest among the seven pilot carbon markets, reaching RMB 56.42 per ton, which is nearly twice the price in the other carbon markets. The Shanghai and Tianjin carbon markets were similar in terms of market opening times, total transaction amounts, and total transaction volumes. However, the average transaction price in the Shanghai carbon market was higher, reaching 30.71 RMB/ton, second only to that of the Beijing carbon market.

3.2. National carbon emissions trading markets

Based on the pilot carbon market experience, the country launched the national carbon market in 2021. The details are summarised in **Table 3**. In December 2020, the Ministry of Ecology and Environment (MEE) announced the Measures for the Administration of Carbon Emission Trading (Trial) and the Implementation Plan for Setting and Allocating the Total Amount of National Carbon Emission Trading Quotas (Power Generation Industry) for 2019 and 2020. Additionally, the MEE released the quota allocation scheme and the first list of crucial emission units. The first compliance cycle of the national carbon market was officially launched on 1 January 2021. The launch of the national carbon market is expected to maximize the market mechanism's effectiveness in reducing carbon emissions and help achieve China's carbon peaking and carbon neutrality objectives.

Table 3. Framework of National ETS in China.

Management Structure	Three-level management system "national-provincial-city". The Ministry of Ecology and Environment is responsible for formulating technical specifications, strengthening the supervision of local quota allocation and MRV, and supervising trading-related activities in conjunction with relevant departments of the State Council. Provincial-levelecological and environmental authorities are responsible for organizing quota allocation and cleanup, GHG MRV, and other related activities within their administrative regions. Municipal-level ecological and environmental authorities are responsible for cooperating with provincial-level authorities to implement relevant specific work.
Coverage	Enterprises or other economic organizations with annualgreenhouse gas emissions of 2.6 million tons of carbon dioxide equivalent First, start trading and compliance from the power generation industry, and then include other industrieswhen ripe conditions.
Total amount setting	Provincial ecological and environmental authorities approve the allowances for each key emission unit according to the allowance allocation method determinedby the Ministry of Ecology and Environment and sum upto form the total number of allowances for provincial administrative regions. Finally, each province's total allowances will be summed up to determine the total national amount of allowances.
Allocation of allowances	All allowances for 2019–2020 will be allocated free of charge. The benchmark method will account for the number of allowances for units owned by key emissionunits in the power generation industry.

Table 3. (*Continued*).

Allowance Trading	The trading product is allowances right now. The Ministryof Ecology and Environment is in due course to increase other products and institutions. Individuals in line with the relevant trading rules willparticipate in the transaction. The transaction methods are agreement transfer, one-waybidding, or other ways to comply with the provisions.
Compliance Clearance	The power generation industry will complete clearing allowances for compliance by 31 December 2021. When the shortage of allowance for power generation control enterprises accounts for more than 20% of their verified emissions, their obligation to clear their allowances is up to the number of free allowances they have received plus 20% of their verified emissions. At the same time, to encourage using gas-fired power generation, when the gas power plants are confirmed to emit not less than the approved free allowance, the enterprises' obligation to clear the allowance is the total amount of free allowanceobtained.
Regulatory Penalty	Key emission units that do not pay their carbon emission allowances in full and on time shall be ordered by the local ecological and environmental authorities at or above the municipal level where their production and operation sites are located to make corrections within a certain period and shall be fined not less than 20,000 yuan and notmore than 30,000 yuan; if the corrections are not made within a certain period, the unpaid portion shall be reducedby the provincial ecological and environmental authorities where the production and operation sites of the key emission units are located by an equal amount of carbon emission allowances for the following year.

Under the authorization of the State Council, the National Ecological Environment Department is responsible for the relevant work with the cooperation of the National Development and Reform Department. The responsibilities of the central authority include: first, collecting and analyzing the fundamental data reported by enterprises; second, formulating and implementing national carbon emission reduction targets according to national conditions; and third, clarifying the scale of emission reduction targets and quota allocation for each province in light of the actual situation. Furthermore, the National Ecological Environment Department will commission a third-party institution to monitor and verify the scale of emissions in the regional markets reported by the provincial governments.

Provincial governments designate provincial ecological and environmental departments (or provincial development and reform commissions) that are responsible for managing the regional carbon markets within their respective jurisdictions. These provincial departments or commissions, must organize enterprises in their region to report their respective carbon emission information. Third-party institutions must be organized to verify their reports. They can ensure data quality via a preliminary check, re-check, and expert review, and submit a report to the national authorities. Thereafter, they must allocate allowances to enterprises in the region (including determining or adjusting the number of free allowances for individual enterprises) based on the allowances issued by the state, local emission targets, and the allowance allocation scheme set by the State Council (or the carbon emission allocation mechanism determined by provincial governments).

Enterprises to be included in carbon emission quota trading: Currently, the target companies include power generation enterprises with coal consumption above 10,000 tons of standard coal (including self-provided power plants with an annual emission scale above 26,000 tons of carbon dioxide equivalent). Based on their carbon emission efficiency, these enterprises can be subdivided into those with higher and lower emission efficiencies. Enterprises within market coverage are required to maintain records of their emission data, manage their emissions, report their emission scale of the previous year in the prescribed format, and actively fulfill their emission reduction obligations. According to foreign practices and domestic pilot projects, with the gradual maturity of the carbon market, the number of enterprises included in emissions trading will be further increased, and the threshold for inclusion in emissions coverage will be further reduced.

Third-party verification agencies: These agencies are entrusted by provincial governments to verify the authenticity of the emission information reported by the participants in the regional carbon market and the compliance status of enterprises, and issue verification reports. They play supervisory and verification roles in the trading system.

In terms of specific regulations, the Ministry of Ecology and Environment issued the "Implementation Plan for the Allocation of CO_2 Quotas for Key Emission Units (including Captive Power Plants and Cogeneration) in the Power Generation Industry in 2019 (Trial Version)". According to the Plan, the baseline method was used for quota allocation. Using the 2018 power supply data to calculate the quota, each enterprise multiplied 70% of the 2018 power supply (MWh) by the relevant coefficient to obtain the pre-allocated quota for 2019. The final quota was adjusted according to the actual power generation in 2019 with more refunds and less compensation. The Ministry of Ecology and Environment and provincial ecological agencies were responsible for the quota allocation.

To better implement the carbon emission allowance and trading system, the Ministry of Ecology and Environment and the Development and Reform Commission made a series of preparations in terms of design and infrastructure in the early stage of market construction. In terms of essential systems, they issued the Interim Measures for the Management of National Carbon Emission Trading (hereafter referred to as the Interim Measures), Construction Plan for the National Carbon Emission Trading Market (Power Generation Sector) (hereafter referred to as the Construction Plan), Notice of the General Office of the National Development and Reform Commission on the Key Work for the Launch of the National Carbon Emission Trading Market, Notice on the Preparation of the 2019 Annual Carbon Emission Report and Verification, and Notice on the Preparation of the 2019 Annual Carbon Emission Report and Verification of Key Emission Units in the Power Generation Sector. and verification and the work related to the submission of the list of crucial emission units in the power generation industry", and the "Implementation Plan for the Allocation of CO2 Quotas for Key Emission Units (including Captive Power Plants and Cogeneration) in the Power Generation Industry in 2019 (Trial Version)" issued by the Ministry of Ecology and Environment, and other essential systems.

In terms of infrastructure, the country relies on the relevant agencies of the ecological and environmental system and the relevant agencies of the statistical system of nuclear facilities to build a nationally unified and hierarchically managed carbon emission data reporting system. According to the 2017 decision, the National Registration Center was established in Wuhan and the National Trading and Settlement Center was established in Shanghai. The 2019 National Public Resources Trading Catalogue Guidelines proposed the inclusion of carbon emission rights in the management of the public resources trading platform.

On 16 July 2021, China's national carbon emission trading market went online, with local pilot carbon markets operating in parallel with the national carbon market.

The trading center of the national carbon emission trading market was located in Shanghai, and the carbon allowance registration system was situated in Wuhan. Enterprises registered their accounts in Hubei and traded in Shanghai, with the two regions jointly assuming the role of the pillars of the national carbon emissions trading system.

The critical emission units currently encompassed by the national carbon market include power generation enterprises, with emissions reaching 26,000 tons of carbon dioxide equivalent (comprehensive energy consumption of approximately 10,000 tons of standard coal) in any year from 2013 to 2019. The power generation industry became the first industry to be included in the national carbon market, with more than 2000 critical emissions units. These were identified based on the power generation industry's emissions of 26,000 tons of carbon dioxide equivalent and above (combined energy consumption of approximately 10,000 tons of standard coal) in any year from 2013 to 2019, or by screening the results of carbon emission verification by other economic organizations.

The choice of the power generation industry as the breakthrough point for the national carbon market is based on two main considerations. On the one hand, this industry directly burns coal and emits significant amounts of carbon dioxide. The country can use the carbon market mechanism to improve its ability to control greenhouse gas emissions by this industry.

However, accurate and effective access to carbon dioxide emission data is a prerequisite for national carbon market trading. The power generation industry has a relatively sound management system and high degree of automation, with complete measurement facilities for emission data, standardized data management, and easy verification. This simplifies the allocation of the carbon emissions quota.

According to data released by the Ministry of Ecology and Environment, from the official launch of online trading on 16 July 2021 to 31 December 2021, the national carbon market had operated for 114 trading days, with a cumulative volume of 179 million tons of carbon emission allowances traded and a cumulative turnover of 7.661 billion yuan, at an average price of 42.85 yuan per ton. In terms of compliance volume, the compliance completion rate was 99.5%.

3.3. The unique characteristics of China's national carbon market compared to foreign carbon markets

Compared with foreign carbon emissions trading markets, the Chinese carbon emissions trading market has the following characteristics:

3.3.1. Low market activity

The total quota of the national carbon market was approximately 4.5 billion tons, and based on the current trading volume, the turnover rate of the national carbon emissions trading market was approximately 3%. The EU carbon market was at the time of this study the most active globally, with a turnover rate that increased from 4.09% in the early stages to 417%. Compared with the EU carbon market, China's national carbon market is still in its early stages of development, but there is significant potential for an increase in market activity.

3.3.2. A sharp increase in market trading volume when the first compliance period is approaching its end

Trading was relatively limited during the early stages of the national carbon market. However, starting in October 2021, the daily trading volume began to rise, spiking in November and December 2021. The "Notice on Doing a Good Job in the Clearance of Carbon Emission Quotas for the First Compliance Period of the National Carbon Emission Trading Market" requires that 95% of the key emitting units in this administrative region complete compliance before 5 p.m. on 15 December 2021, and all key emitting units complete compliance before 5 p.m. on 31 December 2021. In the early stages of the national carbon market, although trading volume was limited, the market became exceptionally active toward the end of the compliance period. The maximum daily trading volume of approximately 20 million tons for the entire year appeared in December, and the daily trading volume in December was mostly 50–100 million tons, which was much higher than that in other months.

3.3.3. Bulk agreement trading is currently the main trading method

Carbon emission agreement transfers include listed and bulk agreement trading. Transactions of less than 100,000 tons are performed via listed agreement trading and transactions of 100,000 tons or more are performed via bulk agreement trading. From July 2021 to the end of December 2021, the cumulative trading volume of bulk agreements was much higher than that of listed agreements, accounting for 83% and 17%, respectively.

In terms of monthly transactions, the total trading volume of listed agreements was higher than that of bulk agreements in July, with listed agreements accounting for 85%, and bulk agreements accounting for 15%. This may be because most companies adopted a cautious attitude and attempted small-scale transactions in the early stages of the national carbon market. Thereafter, from August to December, the total monthly trading volume of bulk agreements was significantly higher than that of listed agreements.

4. Influencing factors of carbon trading price in China's carbon market

4.1. Analysis of the influencing factors of carbon trading price from the perspective of demand

4.1.1. Analysis of the influence of the energy market on the price of carbon emission rights trading

The use of fossil fuels, such as coal, oil, and natural gas, generates a significant amount of carbon dioxide and creates a demand for carbon emission rights. Relative changes in the prices 11 various fossil fuels will lead to changes in the use of these fossil fuels by enterprises and residents—the substitution effect. This will impact total carbon emissions and thus affect the price of trading carbon emission rights.

Mansanet Bataller and Pardo Tornero (2007) identified a relationship between the EU carbon trading price and fossil energy use. Kim and Koo (2010) designed an autoregressive distributed lag (ADL) model for empirical analysis and showed that carbon trading prices are simultaneously influenced by several energy prices, such as those of natural gas, crude oil, and coal. Wang and Zhao (2021) found that the Brent crude oil and natural gas prices significantly influence the EU market's carbon trading prices. Hu et al. (2020) opined that coal and oil prices were the main factors influencing carbon trading prices in the Chinese pilot carbon markets. According to Zhang et al. (2019), the price of coal affected carbon trading prices in a few of those pilot carbon markets.

When the price of one energy source increases, companies and society may change to two alternative sources of energy consumption. Such change is influenced and constrained by the characteristics of production technology and duration and is an incomplete substitution. Assuming that the price of one energy source rises while the prices of the other two energy sources remain unchanged, enterprises are unable to switch to other energy sources in the short term because of the characteristics of fixed production equipment and production technology. Thus, an increase in the price of one energy source will adversely impact the price of carbon credits. In the long term, many companies will replace their production equipment and improve their production technologies and techniques, which will reduce the demand for carbon credit. However, in the case of natural gas, technological advances in production could eventually enhance the efficiency of natural gas use. Therefore, the expected impact of higher natural gas prices on the trading price of carbon credits is positive in the long run.

4.1.2. Analysis of the impact of macroeconomic factors on carbon trading price

Gronwald et al. (2011) identified that macroeconomic factors have a significant impact on the futures price of carbon allowances in the EU. Wang (2012) utilized panel data to analyze carbon emissions and GDP in several countries over the previous 30 years. Based on econometric analysis, Oberndorfer (2009) determined that changes in EU carbon allowance futures prices significantly impacted the share prices of power companies, whereas carbon trading prices were not significantly influenced by power companies' share prices. Girler Ulkii (2016) conducted an empirical analysis of EU carbon emissions allowance data from 2008 to 2012 that revealed that carbon allowance prices were influenced by global macroeconomic changes. Zhang (2015) utilized data from six Chinese pilots and found that a few economic activities have the most significant effect on carbon trading prices.

When the economy booms, the total demand for social consumer goods increases, and enterprises choose to expand their production and investment scales to boost their profits. The use of energy is essential in the production process; therefore, the demand for corporate carbon emissions and allowances will increase, and the carbon price will rise. Conversely, the demand for carbon allowances from enterprises increases during macroeconomic booms. To further develop the carbon market, the government will introduce relevant policies to promote carbon transactions on financial markets and increase carbon prices. Therefore, the impact of the improvement of the macroeconomic environment on carbon prices is formed in two ways: enterprises' production decisions and government policies.

However, when the economy is depressed, the total social consumption and demand decrease significantly. Enterprises' production and investment activities are sluggish, and carbon emissions decrease. The 2008 financial crisis is an extreme but typical example. After the outbreak of the financial crisis, many factories drastically reduced their production levels or even stagnated or closed down. The EU carbon price crashed from 30 to 7 and there was a downturn in consumer, financial, and carbon markets.

4.1.3. Analysis of the impact of the international carbon market on China's carbon trading price

The international carbon market was established earlier and has developed to a more mature level in terms of market mechanism, scale, and depth. The carbon price is more reasonable and reflects supply and demand more accurately. The Chinese government refers to foreign carbon prices when setting carbon prices, especially EUA prices. Therefore, changes in foreign carbon prices will affect carbon prices in China.

4.1.4. Analysis of climate impact on the price of carbon emission trading

Wei et al. (2020) examined the Chinese pilot carbon markets and disclosed the positive effects of the frequency of extreme weather on carbon prices. According to Voituriez and Wang (2011), extreme weather significantly affects carbon trading prices.

When the temperature deviates from the optimum range—when it is extremely cold or extremely hot—consumer demand for heating or cooling increases. Similarly, businesses consume more energy to maintain their production. Thus, energy demand and consumption have increased, resulting in increased CO2 production.

Lin et al. (2015) studied Chinese carbon trading price data and ascertained that temperature variables had a substantial impact on carbon quota prices. Ji et al. (2021) used a structural break test and an autoregressive distributed lag model to investigate the causes of changes in carbon trading prices: extreme temperatures significantly increased carbon trading prices in Beijing. Han et al. (2019) and Wen et al. (2022) found that temperature and the air quality index (AQI) had a considerable impact on carbon prices in the Shenzhen carbon emissions trading market. Dao's (2022) empirical study revealed that environmental quality is a crucial factor influencing carbon trading prices in China.

Recently, China has been plagued by hazy weather because of massive emissions of industrial waste gas and automobile exhaust. This phenomenon occurs frequently in first-tier cities. However, in recent years, it has gradually spread to second- and third-tier cities, severely disrupting the normal lives of residents and the production and operation of factories. To address this phenomenon, the government has implemented measures, such as restricting vehicular traffic and limiting production in factories. Industrial enterprises covered by the carbon market are mandated to reduce carbon emissions. All these measures will increase the demand for carbon quotas from enterprises and induce a hike in the price of carbon.

4.2. Analysis of the influencing factors of carbon trading price from the perspective of supply

Zhao et al. (2016) analyzed seven pilot markets in China and found that compliance date is a key factor affecting carbon price volatility. Anke et al. (2020) studied the role of policies on carbon trading prices in the EU carbon trading system and inferred that national policies play a crucial role. Zeng et al. (2023) utilize a panel model to analyze the factors influencing carbon prices in China's carbon trading pilot market. They identified significant differences in carbon price fluctuations among different exchanges, and found that information at the exchange level had a significant impact on carbon prices.

4.2.1. Analysis of the impact of the total amount of allowances on the carbon trading price

EUA prices fell twice between 2005 and 2007 in the EU ETS. The first drop was due to the overallocation of EUA allowances (Alberola, 2008; Chevallier, 2010). Chevallier (2010) indicated that in April 2006, the main cause of the plunge in EUA prices was not speculative arbitrage, but the over-allocation of emission allowances and the fact that allowances could not be used across time. When the total number of allowances is negligible, carbon credits become a scarce resource, thereby increasing their price. As noted by Aldy (2016), these experiences are policy lessons from the successes and failures of the countries that implemented the policy first.

4.2.2. Analysis of the impact of quota division on carbon emission trading price

The carbon trading market has two main types of allowances: the historical and benchmark methods. Because the historical method is more consistent with the actual carbon emissions of each enterprise in each industry, the trading of carbon credits will not be too active. This has a dampening effect on the trading prices of carbon credits. Implementing the benchmark method will cause certain enterprises to have a surplus of carbon allowances and other enterprises to experience a shortage. This promotes the trading behavior of carbon emission rights, which has a positive effect on the price of carbon emission trading rights. Overall, in the pilot market that primarily adopted the historical method, the carbon emissions trading price tends to decrease, while in pilot market that mainly adopted the benchmark method, the carbon emissions trading price tends to increase.

4.2.3. Analysis of the impact of carbon allowance allocation method on carbon emission trading price

As the carbon market continues to develop and improve, the proportion of unpaid allocations will gradually decrease, whereas the proportion of paid allocations will progressively increase. This adjustment will prompt enterprises with insufficient free quotas to actively seek trading, which will lead to a gradual increase in the price of carbon emissions trading rights. When the carbon market matures, the free allocation method disappears, and the paid allocation method assumes a dominant position, as noted by Ellerman et al. (2010). At this time, the carbon trading price gradually increases and then stabilizes. The carbon trading price is close to the social cost of one unit of carbon dioxide emitted by an enterprise.

4.2.4. Analysis of the impact of quota offset and over-penalty system on the price of carbon emission rights trading

A quota-offset system is one in which carbon dioxide emission reductions can be used instead of carbon allowances. When the percentage of allowance offset is high, carbon emission reduction enterprises have more ways to complete their carbon reduction tasks, which will negatively impact the carbon price. When the percentage of allowance offset is low, enterprises face a higher demand for carbon emission rights in the carbon trading market, which induces an increase in the price of these rights.

An enterprise that fails to complete the carbon reduction task on time should be appropriately penalized—the over-penalty system. Penalty methods primarily include fixed and floating mechanisms. The former refers to the imposition of a fixed fine amount on enterprises that fail to complete the carbon emission reduction tasks, while the latter penalizes enterprises depending on the carbon trading price. When the penalty is significant, carbon emission reduction enterprises increase their demand for carbon emission rights, which in turn increases the price of carbon emission trading. When the penalty is minor, the demand for carbon emission rights by carbon emission reduction enterprises decreases, which is not conducive to increasing the carbon trading price.

5. Empirical results

5.1. Correlation test

5.1.1. Multicollinearity test

Given the inclusion of macroeconomic variables, the presence of multicollinearity among variables or correlations between two variables can influence the degree and strength of the individual effects of the explanatory variables on the dependent variables. This study included tests to identify and mitigate these issues. The tests examined multiple correlations between the variables for both the national and pilot carbon markets. The results are presented in **Tables 4** and **5**.

Table 4. National carbon market lagged model dependent variable VIF values.

Variable	VIF_simple	VIF_full
L(sz, 4)	2.003	5.328
L(dqs, 4)	1.753	20.29
L(hbh, 4)	2.178	2.311
L(trq1, 4)	1.617	4.423
L(oil, 4)	3.489	4.616
L(EUA, 4)	1.447	3.651
L(quota, 4)	1.261	1.556
L(trq2, 4)	Removed	3.742
L(hs, 4)	Removed	10.692
L(bp, 4)	Removed	22.807

Based on the VIF values of the independent variables in the model, the correlation coefficients between variables, and whether they were significantly related to carbon prices, three variables were excluded from the analysis.

Table 5. Pilot carbon markets mixed effects model dependent variable VIF values.

Variable	VIF_simple	VIF_full
sz	1.302	5.838
trq1	1.274	9.958
oil	4.017	6.202
EUA	3.441	9.636
quota	1.031	1.074
dqs	Removed	34.833
hbh	Removed	9.871
trq2	Removed	10.001
hs	Removed	16.745
bp	Removed	55.309

The variables were iteratively removed based on the VIF values in the model until the VIF values of the final simplified model were less than 5.

5.1.2. Pairwise correlation test

This section presents a pairwise correlation analysis of the variables. The results are summarized in **Figure 1** and **Table 6**.

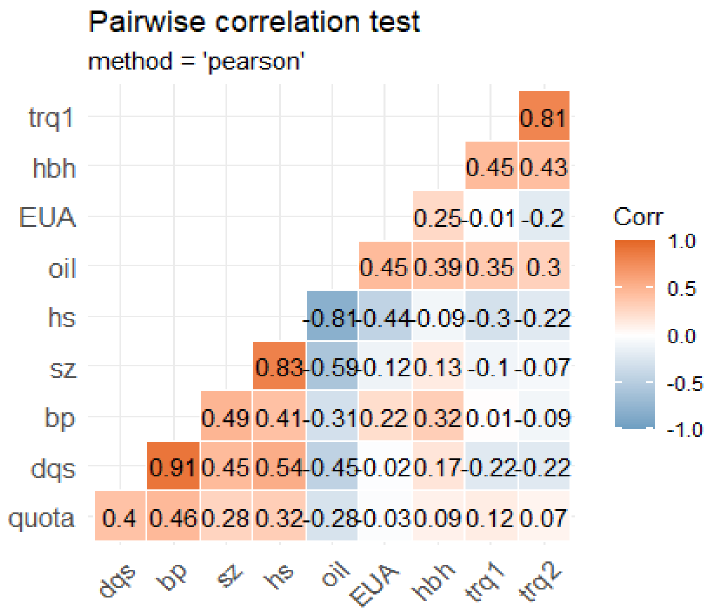

Figure 1. Pairwise correlation test-national carbon market lagging model (full).

Figure 1 shows a strong correlation between dqs and bp, sz and hs, as well as trq1 and trq2. Consequently, certain indicators were excluded from the model, leading to the creation of an optimized and simplified model.

Table 6. Pairwise correlation test-national carbon market lagging model.

Variables	sz	dqs	hbh	trq1	oil	EUA	quota
sz	1						
dqs	0.45*	1					
hbh	0.13	0.17*	1				
trq1	−0.1	−0.22*	0.45*	1			
oil	−0.59*	−0.45*	0.39*	0.35*	1		
EUA	−0.12	−0.02	0.25*	−0.01	0.45*	1	
quota	0.28*	0.4*	0.09	0.12	−0.28*	−0.03	1

Note: '*' shows significance at the 0.05 level.

Table 6 shows that the correlation coefficients among the variables are all below 0.7. This indicates a low level of correlation and insignificant covariance between the variables in the model.

5.2. Empirical results

5.2.1. National carbon market lagging model results

Initially, a multiple regression lag model was employed to analyze the carbon prices in the national carbon market. The first step was to determine the lag order of the model. Orders 1, 2, 3, 4, 5, and 6 were selected to this end, following which the lag models of different orders were evaluated. The evaluation results are listed in **Table 7**.

Table 7. Comparative evaluation of multivariate linear models with different lag orders.

Lag	R^2	Adj.R^2	AIC	BIC	RMSE
1	0.850	0.844	189.5032	218.3392	0.3857
2	0.852	0.846	186.7169	215.5033	0.3899
3	0.853	0.847	185.0634	213.8000	0.3933
4	0.858	0.852	179.7016	208.3881	0.3995
5	0.858	0.852	179.3038	207.9398	0.4122
6	0.853	0.847	184.1989	212.7842	0.4270

Table 7 shows that R^2 reaches its maximum at lag order 4, after which it decreases as the lag order increases. In the table, Adj.R^2 denotes the adjusted R^2 of the model. The smaller the AIC (Akaike information criterion), the better the model fits and explains the data. When the difference between the AIC of the two models is less than two, it implies that their goodness of fit is extremely close and that the complexity of the models is not significantly different.

The RMSE (root mean square error) is a key index for evaluating the magnitude of model prediction errors. The smaller the RMSE, the higher the prediction accuracy of the model. However, it has certain disadvantages, such as being sensitive to outliers, because the squared difference of the outliers has a considerable impact on the RMSE value.

Therefore, the evaluation of the model involved the consideration of several model evaluation indexes. Thereafter, the lagged 4th-order model was considered the optimal model. After determining the optimal lag order, the (simplified) estimation results of the model with a national carbon price lag of order four are listed in **Table 8** and **Figure 2**.

Table 8. Estimation results of the national carbon price lagged model.

Variable	Estimate	Std. Error	*t*. value	*p*. value	l_95	u_95	Sig
L(sz, 4)	−0.13	0.048	−2.777	0.006	−0.229	−0.039	**
L(dqs, 4)	0.06	0.039	1.631	0.105	−0.013	0.139	na
L(hbh, 4)	−0.49	0.043	−11.479	0	−0.572	−0.405	***
L(trq1, 4)	−0.49	0.038	−12.918	0	−0.563	−0.414	***
L(oil, 4)	0.65	0.056	11.555	0	0.539	0.759	***
L(EUA, 4)	0.30	0.035	8.673	0	0.234	0.37	***
L(quota, 4)	0.10	0.033	3.047	0.003	0.036	0.166	**
R-squared		0.8576		Sigma		0.3889	
Adj.R-squared		0.8518		RMSE		0.3995	
Df		7		AIC		179.7016	
F-statistic		147.1172		BIC		208.3881	
Prob(F-statistic)		0.000		Number of obs		179	

Notes: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, NA $p > 0.05$. L(variable,4) denotes the variable lagged by 4th order.

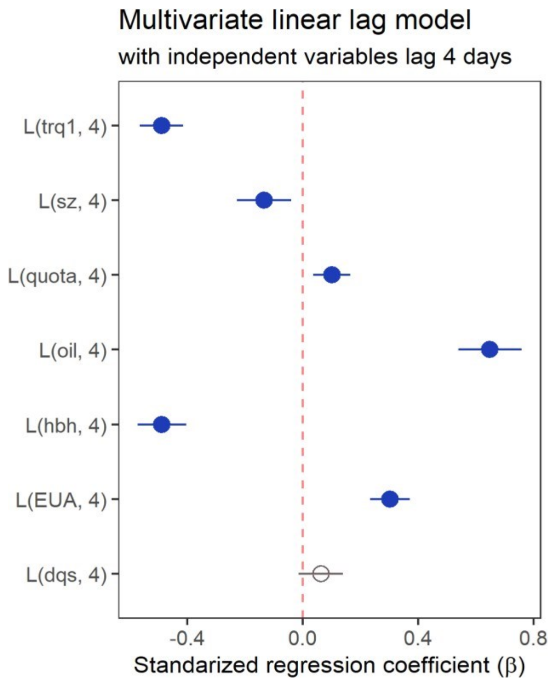

Figure 2. Estimation results of the national carbon price lagged model.

5.2.2. Pilot carbon market mixed model results

A mixed-effects model was developed to analyze the carbon markets of the seven pilot cities. The carbon price was the dependent variable (*y*), and the variables included oil as a fixed effect (x) and the carbon trading market as a random effect. **Table 9** and **Figure 3** present the estimation results of the model.

Table 9. Estimation results of the pilots' carbon price mixed model.

	Carbon Price		
Predictors	**Estimates**	**CI**	**p**
sz	0.02	−0.01 – 0.04	0.186
trq1	0.01	−0.02 – 0.03	0.575
oil	0.06	0.02 – 0.10	0.003
EUA	0.04	−0.00 – 0.07	0.064
quota	0.03	0.01 – 0.06	0.004
Random Effects			
	σ2 → 0.26 τ00 site → 0.85 ICC → 0.77 N site → 7		
	Observations → 2331 Marginal R^2/Conditional R^2 → 0.009 / 0.768s		

Note: Fixed effects explain only 0.9% of the carbon price variation; the mixed-effects model, which considers the differences between carbon trading markets,explains 76.8% of the variation in the carbon price.

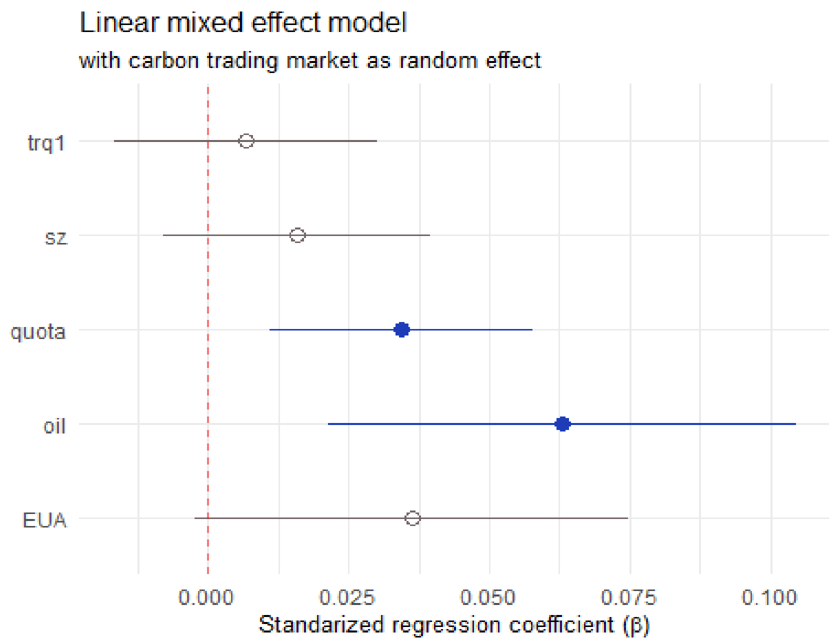

Figure 3. Estimation results of the pilots' carbon price mixed model.

5.3. Analysis of the results

The linear mixed model with a random intercept was utilized to analyze the seven pilot carbon markets, which include Beijing, Guangdong, Hubei, and Shanghai. In this model, the carbon price is regarded as the dependent variable, while variables such as oil serve as fixed effects (x) and the carbon trading market acts as a random effect. The mixed model is a conservative approach with fixed effects explaining only 0.9% of the carbon price in the pilot carbon markets. Nonetheless, it accounts for the variations between the pilot cities and shows a conditional R^2 of 0.768. This indicates that the differences among the pilot cities were the primary factors influencing the carbon prices. However, the reason for these variations remains unclear. The results of the analysis of the pilot cities are not representative of the influence of carbon prices throughout the country because of the asymmetrical development among the pilot cities. Additionally, the results of the model corroborate those of previous studies that have yielded widely disparate conclusions regarding the factors that influence carbon prices in different pilot carbon markets.

The findings from the lagged model for the national carbon market indicate that the Dow Jones Index does not exert a statistically significant impact on prices in the Chinese carbon market. Conversely, the SSE index, coal price, natural gas price, and EU carbon quota trading price significantly affect the carbon trading price of the national carbon market.

Macroeconomics: The results indicate that the Dow Jones Index does not have a significant impact on carbon prices, whereas the SSE index has a significant effect on carbon prices. This suggests that China's carbon market is influenced primarily by domestic rather than international economic factors. Notably, the negative relationship between the SSE index and national carbon prices deviates from theoretical expectations. A possible explanation is that, during periods of economic growth, companies increase their investment in emission-reduction technologies and practices to expand their operations, leading to a reduction in overall carbon emissions. However, due to the historically low carbon price in China, companies may prioritize production expansion over participation in the carbon trading market during periods of macroeconomic growth, resulting in a decrease in carbon trading prices.

Fossive energy prices: According to the findings, coal and natural gas prices have a negative impact on carbon prices, whereas oil prices have a positive impact. This finding is significantly inconsistent with our hypothesis. Combustion of fossil fuels, such as coal, is a primary source of carbon emissions. When the consumption of fossil fuels, especially coal, increases, it leads to an increase in CO_2 emissions and a rise in the demand for carbon credits, thereby increasing carbon prices. This, in turn, leads to an increase in the demand for fossil fuel raw materials from companies that use coal and natural gas as raw materials, inducing an increase in the carbon trading price. Therefore, coal and natural gas prices are negatively correlated with carbon trading prices. This result indicates that China continues to rely heavily on coal and natural gas as primary sources of energy. However, the oil price is positively correlated with the carbon trading price. One possible explanation for this is that when the price of oil rises, companies tend to shift their energy consumption toward coal, which has a higher carbon emissions factor. This shift leads to an increase in CO_2 emissions and a concomitant rise in the demand for carbon emission rights, thereby increasing the price of carbon.

International carbon price. These findings suggest that the carbon price in the EU carbon market is positively correlated with China's carbon trading price, supporting this hypothesis. One possible explanation for this is that China's carbon quota is significantly influenced by the European energy-trading quota, whereas the CER reflects the quota of the international market for developing countries. Therefore, when the international carbon trading price decreases, the domestic carbon trading price may move in the same direction because of the interdependence between the two markets.

6. Conclusion

This study applied market supply and demand theory to structure the logic of carbon price formation. It focused on demand-side factors influencing carbon prices, such as macroeconomics, energy prices, international carbon prices, and weather conditions, and proposed corresponding hypotheses.

The researchers collected the 2021 carbon trading prices of the national carbon market and seven pilot carbon markets as well as the SSE index, fossil energy prices, and international carbon prices as explanatory variables. First, a mixed-effects model was applied to analyze the factors influencing carbon prices in the seven pilot carbon markets. The findings indicate that asymmetrical development in the seven pilot cities was the primary factor influencing carbon prices, and that carbon prices in the pilot cities cannot be generalized to the entire country. Second, a multiple regression lag model was applied to analyze the factors influencing carbon prices in the national carbon market. The results demonstrate that, in terms of macroeconomics, the SSE index was positively correlated with carbon prices, whereas the Dow Jones Index had no significant influence on carbon prices in China. In terms of fossil energy prices, coal and natural gas prices were negatively correlated with carbon prices, whereas oil prices were positively correlated with carbon prices. Finally, regarding the international carbon market, a positive correlation exists between EU carbon prices and China's carbon prices.

Based on these analyses, this study concludes with the following recommendations for improving China's carbon financial trading development system:

6.1. Further expanding the national carbon market scale

Expanding the carbon market requires comprehensive coverage of carbon emissions, mandating the inclusion of key carbon-emitting sectors and reducing the entry threshold for enterprises into the carbon market. In the context of further improvement of the carbon market and the plan to achieve deep decarbonization, special attention should be paid to the key energy production and consumption sectors that emit carbon dioxide, such as transportation, construction, industrial production, land use, and materials. Additionally, enterprises constitute the main body of carbon market transactions and emission reduction. Therefore, the entry threshold for enterprises into the carbon market should be lowered. This will boost the trading volume of the carbon market, improve the efficiency of carbon price regulation mechanisms, and establish an influential carbon pricing center, thereby forming a mature world-class carbon market.

6.2. Improving China's energy use structure

China's energy use structure has room for improvement. To reduce the use of non-clean energy by enterprises and enable them to use clean energy independently, all levels of the government should provide the necessary energy subsidies or financial support to local governments and related control and emission reduction enterprises.

Promoting the construction of a clean energy infrastructure through government subsidies encourages enterprises to increase the use of renewable energy sources.

6.3. Maintaining the stability of the macro environment's impact on carbon prices

It is necessary to constantly monitor changes in the macro environment, prepare for them, and strengthen the government's reasonable and flexible regulation of carbon prices. Empirical studies have identified that both macroeconomic indicators and EU carbon emissions trading prices have affected carbon prices in China's national carbon market. Therefore, in terms of the macro environment, China should promote the internationalization of the renminbi, maintain the stability of the renminbi exchange rate, promote China's voice in setting carbon prices in the international market, and mitigate the impact of international environmental changes on China's carbon prices.

6.4. Developing a scientifically sound carbon emission quota allocation mechanism

China is currently in a critical stage of developing a national carbon-trading market. Therefore, it is necessary to establish a scientifically sound allocation mechanism for carbon emission quotas. By unifying quota allocation methods, determining appropriate carbon emission quotas for each enterprise, and increasing the participation of domestic enterprises in the carbon trading market, enterprises can be encouraged to reduce their carbon dioxide emissions.

6.5. Enhancing technological innovation in the carbon finance market

Companies must reduce their emissions by upgrading their emission control technologies. This is crucial because the increase in emissions due to expanding the scale of production will be greater than the reduction in carbon emissions resulting from increasing investments in emission-reduction technologies. The government must enhance technological innovation in the carbon finance market by providing research funding and encouraging the development of emission-reduction technologies through intellectual property innovation. Additionally, it is important to accelerate the conversion and application of emission reduction technologies developed by major research institutions to reduce the cost of emission reduction for enterprises, improve technical efficiency, enhance the timeliness of results, reduce air pollutants, improve the quality of emission reduction, and reduce the cost of purchasing carbon emission quotas. Finally, the government should formulate relevant policies, provide subsidies for technological R&D, and encourage companies to innovate and apply new technologies. This will promote the development of enterprises and help China achieve its emission reduction targets.

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