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An Empirical Study on China's Carbon Markets

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Abstract:
Using a dynamic linear unobserved effects panel data model, this study investigates how the production of thermal power affects China's carbon markets, while focusing on efficiency information about carbon price and trading volume, market activity, and market efficiency. Our results suggest that the production of thermal power has only increased the trading volume without raising the carbon prices, and that thermal power companies lose the motivation to reduce carbon emissions at low carbon price levels. Moreover, the production of thermal power has increased market activity in the carbon market, although this impact reduced after the announcement of the China National Emissions Trading System (ETS) because thermal power companies choose to trade carbon dioxide allowances, which are more flexible. Furthermore, the results indicate that market efficiency was increased in the Hubei and Shanghai pilots after the announcement of National ETS, and the impact especially significant in the first half of 2019. This implies that power companies participated actively in carbon markets in the Hubei and Shanghai pilots in the second phase of the National ETS. However, this impact disappeared in the latter half of the year because of the companies achieved their emissions reduction obligations before the end of compliance period.

Keywords: Carbon Market; National ETS; Thermal Power Sector; China

１． Introduction

To promote investments and reduce greenhouse gas emissions, the operation of eight pilot carbon markets was started before 2017[1]. Although China's emissions trading systems (ETS) are considered to be at the exploratory stage of marketization, more than 20 industries and nearly 3,000 key emissions enterprises were covered until the end of September 2017 (Zhang et al., 2020). Furthermore, to reaffirm China’s Nationally Determined Contribution for 2030 under the Paris Agreement, and the “13th Five-year Work Plan for Greenhouse Gas Emission Control,” the National Development and Reform Commission (NDRC, 2017) officially launched its national ETS “Program for the establishment of a national carbon emissions trading market (Power Sector) (Work Plan),” building on the experience of China's pilot markets in December 2017. It is worth noting that this plan only includes the power sector. One important reason for this is that thermal power companies are requested to trade in all carbon markets in China, because this sector is the single largest source of the discharge of carbon dioxide (CO_2) emission. The thermal power sector accounted for 30% of the total emissions in 2012 (Huang et al., 2017).

Being high-profile markets, China's carbon markets were the focus of a number of academic studies. Several studies have investigated the impacts of market efficiency and environmental costs on the industry in China's carbon markets. Wen et al. (2020) uses a difference-in-differences method to quantitatively analyze the impact of carbon emissions’ environmental regulation on stock returns of companies for the Shenzhen pilot. The results show that establishing China’s carbon emissions trading market has had a positive effect on the excess returns of companies participating in carbon emissions allowances trading. Besides, the carbon premium in stock returns increased after China's carbon emissions trading market was established. Liu et al. (2018) investigate the impacts of launching a national carbon trade market through the integrated model of energy, environment and economy for sustainable development / computable general equilibrium model between Shanghai and the rest of China. They find that launching a national carbon trading market could generate both economic and environmental benefits and help China achieve its Nationally Determined Contribution targets. Based on the carbon emissions trading price data from China’s Hubei Emission Exchange, Zhou and Li (2019) use a vector auto-regressive - vector error correction model to investigate the dynamic relationship between energy price, macroeconomic indicators, air quality, and carbon emissions trading price. The authors indicate that there is a long-term equilibrium relationship between carbon emissions trading price and these indicators. When the carbon emissions price is too high and deviates from the long-term equilibrium value, it slowly declines to eventually reach

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[1] The eight pilots are set in Shenzhen, Shanghai, Beijing, Guangdong, Tianjin, Hubei, Chongqing, and Fujian.

the long-term equilibrium value. The price of carbon emissions trading is largely affected by macroeconomic indicators among all these influencing factors. Liu and Zhang (2019) develop a corresponding indicator system to analyze and access the pilot carbon markets by using a maturity model. They indicate that the drivers to maintain market maturity is differ among the pilot markets, either with a good performance on market structure, scale, or efficiency could lead to a certain score. Downscaling the firm size, raising the legislation level, and increasing the participation of the third-party entities may help the carbon market grow and become healthier.

Furthermore, several studies focused on the relationship between carbon markets and the thermal power sector in China. Lin and Jia (2019) establish five counter-measure scenarios based on the recently launched China National ETS market and construct a dynamic recursive computable general equilibrium model to study the impact of the national ETS on the economy, energy, and environment. They find that the national ETS will have a negative impact on the gross domestic product by 0.19%-1.44%. The national ETS can significantly increase the price of electricity; however, the prices of other commodities will increase much less than that of electricity. As long as the mechanism of the ETS market remains unchanged, emissions reduction per year will increase linearly. Based on the data of CO_2 emissions from thermal power plants over the 2005 - 2010 period in China, Liu, Wang, et al. (2018) estimate the potential economic gains and potential carbon emissions reduction under three allocation strategies of carbon emissions trading allowance. Their results show that maximum potential gains can be obtained by the spatial allocation scenario for the combination of CO_2 and sulfur dioxide (SO_2) emissions trading, and the output growth ratio among the power plants varies significantly. The establishment of joint CO_2 - SO_2 emissions trading is usually highly beneficial to ensure optimal allocation of resources, increase potential gains, and reduce pollutant emissions. Tang et al. (2020) simulate the marginal abatement cost curves of different sectors in China National ETS and calculate the optimal carbon price of sector coverage scenarios based on criteria that involve eight sectors, indicating that the power sector undertakes the largest emissions reduction. All of these studies focus on the impacts of carbon trading on environmental benefits in the power sector.

As an immature market, the China National ETS decided to only cover the thermal power sector in trading activities. Estimating reaction of the market to changes in production characteristics of thermal power sector is essential for discussing how to improve the existing market and promoting further expansion of trading partners in the next stage. However, there is rarely any study has thus far conducted a thorough analysis of the impact of thermal power production on China's carbon markets. To fill this research gap, this study investigates how the production of thermal power affects China's carbon markets by focusing on the efficiency information of carbon price and trading volume, market activity, and market efficiency. Moreover, we construct terms of the dummies of launching the China National ETS and the two priority pilot markets as well as analyze how the announcement about the national ETS impacts thermal power production. A dynamic linear panel data model was used for the month-level analysis. The results of this study suggest that the supply of thermal power increases the trading volume, market activity, and efficiency.

Our empirical analyses contribute by identifying the impact of thermal power production on China's ETSs. First, in contrast with previous research that examines the relationship between the demand for CO_2 allowances and carbon prices (Tang et al., 2020), we find that thermal power companies lose the motivation to reduce carbon emissions, when the carbon price is maintained at a low level. Then, our study finds that the production of thermal power increases market activity because trading is more flexible in the carbon markets. We consider that marketization plays an important role in China's carbon trading, as the trading volume is restricted by the government. Finally, this study examines an interaction impact of thermal power production and China National ETS policy's implementation in the carbon markets over different periods, indicating that power companies have participated actively in the Hubei and Shanghai pilots. The results further show that the market activity is restricted by the institution of a compliance period. Thus, we suggest the government should incentivize thermal companies to complete trading initiatively, and thus activate the carbon market, by adopting more efficient policy instruments.

The remainder of this paper is organized as follows. Section 2 presents the background of this study by introducing the outline of China's thermal power sector and ETS. Section 3 describes the empirical methodology and data used in the analysis. The estimation results and discussions are provided in Section 4. Finally, Section 5 presents our conclusions, as well as implications of the research.

2. Background

The thermal power sector is the largest sector for energy production in China. Although China's government has been endeavoring to diversify energy supply, approximately 70%-85% of total electricity was still generated by the thermal power sector in recent years (Figure 1). Furthermore, the thermal power sector is the largest contributor to air pollution, and more than 49% of CO_2 emissions came from the power sector in 2017 (Xie et al., 2021). China's government not only issued numerous polices to control the discharge of air pollution in the thermal power sector, but it also attempted to reduce air emissions by using a market-based approach[2]. According to the simulation of Tang et al. (2020), the power sector undertakes the largest emissions reduction in the carbon markets. Therefore, introduction of an ETS for carbon emissions is an attempt in this context.

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[2] The command-and-control policies brought innovative technologies for emissions reduction and for increase in energy efficiency.

[Figure 1]

China's government has established several pilot carbon markets in recent years[3]. Unlike the market-based tools for emissions reduction in some developed countries such as the European Union ETS (2005), Switzerland ETS (2008), and the Regional Greenhouse Gas Initiative (2009), carbon emissions systems in China are highly controlled by the government (Lo, 2015). The allocation of CO_2 allowances and the design of most market operation paths are both government-led (Song et al., 2019)[4]. China's government looks forward to using all these experiences to introduce the national ETS (ETS in China, n.d.). Therefore, to encourage these cities and provinces to test different design options and explore best practices, all of the pilots were established based on their local circumstances and respective economic profiles (Table 1; Figure 2). The industrial companies which consume over 10,000 tonnes of standard coal equivalent in each year were requested to participate in carbon trading[5]. The intensity-based emission caps set by the reduction in carbon intensity, and the emissions coverage calculated by the reduction share of gross emissions (NDRC, 2017). Significantly, the thermal and power sectors are allowed to trade in all eight pilots. In 2014, more than 1,900 companies and services were involved in the seven of the pilots except Fujian, and the total amount of CO_2 allowances was about 1.2 billion tons. Up to the end of 2015, nearly 80 million tonnes were transacted in these pilot markets (Weng and Xu, 2018). Furthermore, there are trade barriers between all the carbon markets; that is, China's pilot carbon markets are still independent from each other (Lee et al., 2019). Therefore, inter-regional transactions among the provinces not allowed in China's carbon markets.

[Table 1]

[Figure 2]

From there, to contribute to the effective control and gradual reduction of carbon emissions in China, as well as to achieve green and low carbon development, the NDRC launched a three-

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[3] The State Council issued the "Decision of the State Council on Accelerating the Fostering and Development of Strategic Emerging Industries'" in October 2010 (Weng and Xu, 2018). "The Notice on Carrying Out the Work of Carbon Emissions Trading Pilot Program" was announced by the NDRC in October 29 of the next year. Based on this notice, seven regional carbon emissions trading pilots were determined in Shenzhen, Shanghai, Beijing, Guangdong, Tianjin, Hubei, and Chongqing. All of the pilots were allowed to provide emissions trading services to domestic companies within the province.
In September 2016, the eighth regional pilot ETS was mandated by the State Council with the endorsement of the ``National Ecological Civilization Pilot Area (Fujian) Implementation Plan" (ICAP, n.d.).

[4] Almost of all allocations were allocated based on different methodologies, and the final number might be updated based on actual output.Furthermore, a small share are allowed to be auctioned (ETS in China, n.d.).

5 The industrial companies are companies that belong to industrial sectors including petrochemicals (crude oil processing, ethylene), chemicals (calcium carbide, ammonia synthesis, methanol), building materials (clinker, plate glass), iron and steel (crude steel), non-ferrous metals (electrolytic aluminium, copper smelting), paper production (pulp manufacturing, machine made paper, cardboard), electricity generation (power, heat-power cogeneration, power grid), and aviation (civil aviation, passenger transportation, air cargo transport, airports).

phase work plan for its national ETS: "Program for the establishment of a national carbon emissions trading market (Power Sector) (Work Plan)" in December 2017[6,7]. Remarkably, the 2017 work plan only included power sector for the national ETS. This is because to systematically construct the national ETS, China's government designed a step by-step strategy to reduce the impact of CO_2 emissions discharge on macro-economy. That is, they introduced thermal power sector first and then progressively introduced other sectors to the ETS based on the experience from the power sector. The ETS was expected to regulate at most 1,700 companies, and more than 26,000 tonnes of annual CO_2 emissions discharge in the power sector[8] (ICAP, n.d.). In addition, the Hubei Emission Exchange (Hubei pilot) was selected to lead the development of the registration system for the ETS, and the Shanghai Environment and Energy Exchange (Shanghai pilot) was selected to lead the development of its carbon-trading platform[9].

3. Methodology and Data

3.1. Empirical model

To investigate the impacts of thermal power sector on China's carbon markets by focusing on the efficiency information of carbon price and trading volume, market activity, and market efficiency, we adopted the following four indicators of the carbon market: carbon price, trading volume, volatility of carbon price, and market liquidity. The carbon price and trading volume are well-researched topics for ETSs. Some studies focus on factors that affect carbon prices and trading volumes (Fan et al., 2017; Chang et al., 2017; Lu et al., 2020). In this study, we assumed that the demand on CO_2 allowances motivates thermal power companies to enter into carbon markets and, as a result, increase the carbon price. The volatility of carbon price is used to indicate market activity, and market liquidity is used to measure market efficiency in our study. Both these indicators are constantly used to evaluate market activity and efficiency by prior studies (Song et al., 2019; Liu et al., 2020). These indicators are used because of their two key functions in financial markets: price discovery and provision of liquidity (O'Hara, 2003). Since CO_2 allowances are a homogeneous good, the fundamental values about carbon emissions rights among different markets are the same. Even though there is no trading between different

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[6] This launch was in accordance with the "Outline of the 13th Five-Year Plan for National Economic and Social Development of the People's Republic of China" and the "Integrated Reform Plan for an Ecological Civilization."

[7] The three-phases areas follows: (1) period of basic infrastructure establishment focusing on the development of market infrastructures (roughly one year); (2) period of simulated operation carrying out simulated trading of CO_2 allowances in the power generation industry (roughly another year); and (3) period of deepening and perfecting of spot market trading for CO_2 allowances between participants in the power generation industry (roughly starting from 2020).

[8] Both the combined thermal and power and the captive power plants of other sectors were included in this program.

[9] The registration system is a crucial cornerstone of the ETS system; it is used for registry issues, and it tracks and verifies carbon emissions allowances and credits. The carbon-trading platform is where the buyers and sellers trade allowances and credits.

pilot markets in China, price information of carbon credit can still be transmitted rapidly among the markets, which causes the trend of similar prices. On the other hand, due to unobserved asymmetric information - such as imbalanced distribution of resources caused by information on supply and demand - the risk attitudes of investors, the overall economic and geopolitical environments of each region, and the microstructure of carbon markets may affect the process of price discovery. Therefore, this study used a linear unobserved effects panel data model to estimate such impacts. Furthermore, the Shenzhen pilot carbon emissions market is excluded from the analysis because of the absence of a thermal power sector in Shenzhen.

The dynamic models can be represented as follows:

$$\begin{aligned} Market\ Indicator_{im} =& \alpha + \gamma Lag\ Market\ Indicator_{im} + \beta Thermal_{im} + \delta ThermalShare_{im} \\ &+ \eta Control_{im} + \upsilon_i + \varepsilon_{im}, \end{aligned} \tag{1}$$

where *Market Indicator*$_{im}$ represents the indicators for China's carbon markets. Four indicators are used to estimate the carbon markets: carbon price (*Price*$_{im}$), trading volume (*TradingVolume*$_{im}$), volatility of carbon price (*Volatility*$_{im}$), and market liquidity (*Amihud*$_{im}$). *Price*$_{im}$ and *TradingVolume*$_{im}$ are respectively defined as the monthly average carbon price, and monthly accumulative trading volume in province *i* in month *m*. The variables were calculated by the arithmetic mean of daily carbon price and the summation of daily trading volume in each month. Furthermore, as volatile markets are usually characterized by wide price fluctuations and heavy trading, market volatility measured by the standard deviation of returns was used to reflect the market activity. The monthly volatility of carbon price is defined as the standard deviation of monthly logarithmic price change multiplied by the square root of the number of days in each month. We calculated the logarithmic price change by taking the natural log of the quotient of the intraday carbon price divided by the price a day before:

$$Price\ change_{it} = ln\left(\frac{P_{it}}{P_{i,t-1}}\right) \tag{2}$$

$$\begin{aligned} Volatility_{im} &= Standard\ deviation \times \sqrt{d} \\ &= \sqrt{\frac{\sum_{t=1}^{d}(Price\ change_{it} - \overline{Price\ change_i})^2}{d}} \times \sqrt{d} \end{aligned} \tag{3}$$

where *Price change*$_{it}$ represents the daily change of carbon price in pilot *i* on day *t*. *Price*$_{it}$ illustrates the daily transaction price in the carbon market in exchange \$i\$ on day \$t\$. *Volatility*$_{im}$ is the monthly price volatility in exchange *i* in month *m*. *d* shows the number of observations each month.

In addition, according to the conclusion of Ibikunle et al. (2016), we assumed that higher liquidity can enhance market efficiency through the impact of liquidity on the pricing process. The liquidity of carbon emissions markets was assessed by the Amihud (2002) measure. A lower value of Amihud indicates higher liquidity in the carbon market. The indicator is defined as the ratio of the absolute value of the daily return to the trading volume on the same day. The Amihud measure is estimated as follows:

$$Amihud_{i,m} = \frac{1}{d}\sum_{t=1}^{d}\frac{|Return_{it}|}{Trading\ volume_{it}} \tag{4}$$

where $Return_{it}$ is defined by the daily change in carbon price: $Price_{it}$-$Price_{i,t-1}$ for pilot market i on day t. $Trading\ volume_{it}$ represents the trading volume for pilot market i on day t. d is the number of non-zero trading volume days for pilot market i on day t.

The lag term $Lag\ Market\ Indicator_{im}$ represents the one-period lag term of market indicators. All of the indicators contain the information one month before since we consider the short-run dynamic process including the indicators one month before. $Thermal_{im}$ represents the thermal power generation in province i in month t, and $ThermalShare_{im}$ is the proportion of thermal power generation in the total electricity supply in each province[10]. $Control_{im}$ includes control variables indicating other factors that may affect the carbon price, including $VAI(YoY)_{im}$, $CO_2target_i$, $EmissionCoverage_i$, and $NETS_m$. $VAI(YoY)_{im}$ represents the real value of year-over-year increase for the value added of industry in province i in month t. $CO_2target_i$ is the CO_2 intensity reduction target for 2020 (Compared with the intensity in 2015) set by the the "13th Five-year Work Plan for Greenhouse Gas Emission Control."[11] $EmissionCoverage_i$ represents the the emission coverage of gross emissions in province i. $NETS_m$ is the dummy variable for the treatment period, which takes the value of 1 for the period from the date of announcement of the national ETS's launch by the NDRC (December 19, 2017) to the end of 2019, and 0 for otherwise. Furthermore, the cross-term $Thermal_{it} \times NETS_m$ is set to capture the effects of thermal power production on carbon price from the launch of China's National ETS. ν_i represents the individual effects in each province, and ε_{im} is an error term. By using the log-level specification equation, our results imply that the estimated coefficient of thermal power generation and other variables represent the elasticity of the carbon price and trading volume on China's pilot carbon markets.

Furthermore, as the national ETS plan only focuses on the thermal power sector, we assume that the announcement of the national ETS plays an important role in the impact of thermal power production on carbon markets. To estimate the interaction effect of the announcement of

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[10] The $ThermalShare_{im}$ is as $Thermal\ share = Thermal\ power\ generation\ /\ Total\ electricity\ supply$.

[11] The reduction target in Shenzhen was set by comparing the intensity in 2005.

the national ETS and the production of thermal power in carbon markets, the general form of the dynamic model is as follows:

$$\begin{aligned} Market\ Indicator_{im} =& \alpha + \gamma Lag\ Market\ Indicator_{im} + \beta Thermal_{im} + \delta ThermalShare_{im} \\ &+ \eta Control_{im} + \lambda Thermal_{im} \times NETS_{m} + \upsilon_{i} + \varepsilon_{im}, \end{aligned} \tag{5}$$

where $Thermal_{im}$ is used to represent the effects of thermal power generation in carbon markets before the announcement (December 2017), and $Thermal_{im} \times NETS_{m}$ represents the effects after the announcement.

3.2. Data

Carbon transaction data were collected from the websites of seven pilot markets (Shanghai Environment and Energy Exchange, n.d.; China Beijing Emission Exchange, n.d.; China Emissions Exchange (Guangdong), n.d.; Tianjin Climate Exchange, n.d.; China Hubei Emission Exchange, n.d.; Chongqing Carbon Emissions Trading Center, n.d.; Haixia Equity Exchange, n.d.). However, China Emissions Exchange (Shenzhen) was not included in our dataset because the data on electricity generation were absent for Shenzhen. The datasets included 10,535 observations on daily trading information, including daily transaction price and trading volume for each pilot market from the operated date to the end of 2019. Energy generation data for the electricity sector and data on the real value of year-over-year increase for the value added of the industry (VAI (YoY, real)) were acquired from the CEIC (n.d.) database. The dataset on electricity generation contains various electricity power sources, such as nuclear, thermal, solar, wind, and hydroelcetric power. All generation data and VAI (YoY, real) data were organized as month-level data for each month from June 2013 to December 2019. Information on the CO_2 intensity reduction targets and emissions coverage rate were obtained from the “13th Five-year Work Plan for Greenhouse Gas Emission Control” and the website of ETS in China (n.d.). Both the CO_2 intensity reduction targets and emissions coverage rate are time unvarying throughout the study period.

The descriptive statistics are shown in Table 2. Our sample covers all trading months from June 2013 to December 2019 across seven provinces, including 465 observations for each variable. Furthermore, our data are imbalanced due to the difference in the opening date of the pilots. The average carbon price ($Price_{im}$) is 27.35 RMB/ton in seven pilot carbon markets. While the average carbon price in each pilot market was at a higher level in the initial year (Figure 3), the price began to level off from 2015. The carbon price differences were also observed among seven pilot markets (Figure 4). Almost all carbon prices in the markets were lower than 40 RMB/ton, except in the Bejing pilot. The highest average carbon prices were observed in the Beijing pilot, higher than 40 RMB/ton. The average trading volume ($TradingVolume_{im}$) was 0.354 million tonnes, and the variance of this variable was large due to the differences in season and province (Figure 5). The average trading volume was higher in Guangdong and Hubei and lower in Chongqing and Tianjin (Figure 6). The average price volatility ($Volatility_{im}$) is 0.205%, and the average Amihud ($Amihud_{im}$) was 0.109 RMB. On the other hand, the production of thermal power showed a seasonal pattern and regional differences among seven provinces (Figures 7 and 8). The thermal power sector contributed more than 346.36 TWh electricity in Guangdong, but only 41.73 TWh in Beijing in 2019, because of differences in the industry sector scale in each province. However, the proportion of the thermal power sector was only 70.66% in Guangdong and 96.86% in Beijing in the same year (Figure 9). The proportion of thermal power was almost 100% in Beijing, Shanghai, and Tianjin, since the thermal power was the major power source in these provinces. The dependence on the thermal power sector was the lowest in Hubei (50.61%) because of large-scale hydropower supply, such as through the Three Gorges Hydroelectric Power Station.

[Table 2]

[Figure 3]

[Figure 4]

[Figure 5]

[Figure 6]

[Figure 7]

[Figure 8]

[Figure 9]

4.Results

Table 3-6 report results for the impacts of thermal power production on market indicators for the carbon markets. Standard errors are clustered at the pilot level. All columns (1) list the baseline estimations for the impacts of thermal power generation while eliminating the period dummies and interaction terms. The estimates including the period dummy variables are shown in columns (3) and (4), and those with interaction term $Thermal_{im} \times NETS_m$ added are reported in columns (2) and (4).

The results for carbon price are shown in Table 3. The coefficients of $Price_{i,m-1}$ are positive and statistically significant in all columns. The results suggest that carbon prices in the pilot markets are strongly dependent on the previous prices. The coefficients of $Thermal_{im}$ are positive in columns (1), (3), and (4) and negative in column (2). However the results are statistically insignificant, indicating that there were no notable impacts on carbon price from thermal power generation. $VAI(YoY)_{im}$ is positive and statistically significant in all columns, suggesting that strong industrial production leads to a higher carbon price. A 1% increase of the industry's value added leads to a 0.008% increase in carbon price. $CO_2target_i$ has positive and statistically significant coefficients, which means that a 1% increase in the CO_2 reduction target, leads to an approximately 8.51%-13.97% increase in carbon price. $EmissionCoverage_i$ is negative and statistically significant in columns (1) and (2), suggesting that if more industry sectors are covered in the CO_2 emissions trading, there is a reduction in carbon price, but this result is not robust.

$NETS_m$ has positive and statistically significant coefficients in all columns, meaning that the carbon price was higher after the announcement of the national ETS in all seven pilots we estimated. Furthermore, results for the trading volume are shown in Table 4. The coefficients of the lag terms of trading volume $TradingVolume_{i,m-1}$ are positive and statistically significant in all columns, suggesting that the trading volume is also dependent on the previous values. $Thermal_{im}$ is positive and statistically significant in columns (3) and (4), suggesting that a 1-million tonne increase in thermal power generation leads to a 0.05% increase in the trading volume. $ThermalShare_{im}$ has negative and statistically significant coefficients, indicating that a 1% increase in the proportion of thermal power production leads to an approximately 3.54%-4.56% decrease in the trading volume. $CO_2target_i$ has positive and statistically significant coefficients in all columns, meaning that a 1% increase in the CO_2 reduction target leads to approximately 170%-220% increase in the trading volume.

[Table 3]

[Table 4]

The results imply that thermal power companies prefer to buy CO_2 allowances rather than reducing CO_2 emissions, because the carbon price stays at a low price for a long time. Moreover, our finding is in line with Tang et al. (2020), who find that the demand for CO_2 allowances did not significantly increase carbon price since excessive CO_2 allowances are allocated in the carbon markets. In fact, in the long term, the carbon prices were less than 30 RMB/ton, while according to the estimation results of Tang et al. (2020), to achieve the target of reducing carbon intensity by 18% from the 2015 level by 2020, the carbon price should be at least 60 RMB/ton by 2020.

Table 5 shows the results for volatility. $Thermal_{im}$ has positive and statistically significant coefficients in all columns. The results suggest that a 1-million tonne increase in thermal power generation leads to a 0.006% increase in volatility. On the other hand, the interaction term $Thermal_{im} \times NETS_m$ is negative and statistically significant in columns (2) and (4), indicating that the impacts decreased to 0.004% after the announcement of the national ETS[12]. $ThermalShare_{im}$ is also positive and statistically significant, which means that a higher proportion of thermal power plays an important role in increasing volatility. $CO_2target_i$ has negative and statistically significant coefficients, implying that a higher CO_2 intensity reduction target reduces the scale for a single transaction. The estimation of liquidity results are shown in Table 6. $ThermalShare_{im}$ is positive and statistically significant in columns (1) and (2), suggesting that a higher proportion of thermal power leads to lower liquidity in carbon markets, but the result is not robust. Furthermore, the cross-term of $Thermal_{im} \times NETS_m$ has a negative and statistically significant coefficient in column (2), meaning that thermal power production began to increase liquidity in carbon markets after the announcement of the national ETS. $CO_2target_i$ has negative and statistically significant coefficients in all columns. The results imply that a positive correlation exists between the CO_2 intensity reduction target and liquidity in the markets.

[Table 5]

[Table 6]

These results are consistent with Reboredo, (2014) who finds that volatility is related to the rate of information flow in a market, and its changes reflect the arrival of new information. We consider that the impact of thermal power on price volatility reduced because the carbon credit trade changed into one that was more market oriented after the announcement. This is in line with Song et al. (2019) who find that about half of abnormal price volatility in China's carbon market stems from the impact of policy implementation. Lower volatility and higher liquidity after the announcement show that more frequent trading by thermal power companies in the carbon markets induces the reduction of extreme trading such as single transactions under a high level of carbon price or trading volume. Figure 10 shows a comparison of the daily trading volumes before and after the announcement. A single transaction higher than 90 RMB/ton or larger than 500,000 tonnes was rarely observed after the announcement.

[Figure 10]

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[12] Calculated by the coefficient of $Thermal_{im}$ - $Thermal_{im} \times NETS_m$ in column (4).

On the other hand, to establish the China National ETS, Shanghai and Hubei were selected as the priority pilots (host pilots) of the forthcoming national carbon markets. We assume that, the government's support and distribution of resources likely changed the balance between these host pilots and other pilots, as well as led to higher market activity and efficiency in the Shanghai and Hubei pilots. To investigate the impacts of thermal power production on carbon markets after the announcement of the China National ETS in the host pilots, the interaction of thermal power generation and the cross-term of host pilots and the announcement is used, as in Equation (6):

$$\begin{aligned} Market\ Indicator_{im} =& \alpha + \gamma Lag\ Market\ Indicator_{im} + \beta Thermal_{im} + \delta ThermalShare_{im} \\ & + \eta Control_{im} + \xi Host_i + \theta Host_i \times NETS_m + \lambda Thermal_{im} \times NETS_m \\ & + \sigma\lambda Thermal_{im} \times Host_i \times NETS_m + \upsilon_i + \varepsilon_{im}, \end{aligned} \tag{6}$$

where $Host_i$ is a dummy variable for the Hubei and Shanghai pilots, which takes the value of 1 for the Shanghai Environment and Energy Exchange and Hubei Emission Exchange, and 0 for otherwise. $Thermal_{im} \times Host_i \times NETS_m$ represents the effects of thermal power production in host pilots, and the coefficient of $Thermal_{im} \times NETS_m$ shows the effects of thermal power production in other pilots after the announcement.

The results are shown in Table 7. The results for carbon price, trading volume, volatility, and liquidity are shown pairwise in (1)-(8). The estimations including the period dummy variables are shown in columns (2), (4), (6), and (8). Standard errors are clustered at the pilot level. $Thermal_{im} \times NETS_m$ is negative and statistically insignificant in columns (7) and (8). The results suggest that thermal power production also leads to an increase in liquidity in other pilots after the announcement of the China National ETS, although a significant impact is not observed. Moreover, $Thermal_{im} \times Host_i \times NETS_m$ has negative and statistically significant coefficients in columns (7) and (8), indicating that thermal power production had a positive impact through increased liquidity in the Shanghai Environment and Energy Exchange and Shanghai Environment and Energy Exchange that compare with other pilots after the announcement.

[Table 7]

Furthermore, to investigate the monthly differences for liquidity, the interaction terms of thermal power production, host dummy, and period dummies are used, as in Equation (4):

$$\begin{aligned} Amihud_{im} =& \alpha + \gamma Lag\ Amihud_{im} + \beta Thermal_{im} + \delta ThermalShare_{im} + \eta Control_{im} \\ & + \xi Host_i + \sum_{j=-11}^{24} \tau_j PeriodDum_m + \sum_{j=-11}^{24} \theta_j Host_i \times PeriodDum_m \\ & + \sum_{j=-11}^{24} \lambda_j Thermal_{im} \times PeriodDum_m \\ & + \sum_{j=-11}^{24} \sigma_j Thermal_{im} \times Host_i \times PeriodDum_m + \upsilon_i + \varepsilon_{im}, \end{aligned} \tag{7}$$

where the excluded time category is December 2017 (j = -1) such that the effects are measured relative to the month before the announcement of the national ETS.

Figure 11 plots the points of estimations of the interaction coefficients of $Thermal_{im} \times Host_i \times PeriodDum_m$ over time. These coefficients in the pre-announcement period are almost not statistically significant, supporting that the impact of thermal power generation for liquidity in host pilots does not significantly differ from that in other pilots in these periods compared with December 2017. In addition, the figure shows that the interaction coefficients are negative and statistically significant in January 2018 and during the end of 2018 to the middle of 2019.

[Figure 11]

The results indicate that the interaction impact of being selected to become a priority pilot for the forthcoming national ETS and thermal power production was only significant for liquidity. We consider that the impact was not significant for other indicators, such as carbon price, trading volume, and volatility, because the 2017 work plan only included the power sector. The restricted companies (power plants) were allowed to trade in carbon markets, resulting in a restricted trading volume. On the other hand, the liquidity improved transitory appeared in the month after the announcement and immediately disappeared, suggesting that the impact of the announcement was extremely short and did not improve carbon trading. This is consistent with the conclusions of Song et al. (2019), who find that although prior policy adjustments rapidly stimulated market liquidity, they failed to mitigate price risks and then stabilize market operations in the long-term. This is because the lower operation efficiency of China's carbon markets is largely due to the lack of CO_2 allowances demand. Moreover, the significant improvement in liquidity during the first half of 2019 might be attributed to the effects of the beginning of the second phase of the China National ETS. The 2017 work plan for the China National ETS indicated that the ETS has had conducted simulated trading of CO_2 allowances in the power generation industry to test the effectiveness and reliability of the market in 2019 (NDRC, 2017). However, the impact disappeared during the latter half of 2019. We consider that this is because carbon trading is usually only performed actively during the first half of a year, to fulfill the emissions reduction obligations before the compliance period[13] (Figure 5).

5.Conclusions

This study examined the impacts of thermal power production on China's carbon markets. Our findings indicate that thermal power production has increased the trading volume, although it did not raise the carbon prices, because of the excessive CO_2 allowances in China's carbon markets, consistent with the description of Tang et al. (2020). When the carbon price is lower than the marginal abatement cost for thermal power companies, companies tend to buy CO_2 allowances over reducing emissions. Thus the actual reduction emissions become less than expected in the thermal power sector. Therefore, we consider that the government needs to reduce the allocation of CO_2 allowances to match the demand in the carbon market. When the allocated CO_2 allowances matched with the emissions reduction target, their demand would raise the carbon prices, and increase the motivation for reducing carbon emissions[14].

The results also show that the production of thermal power has increased market activity in carbon markets. After the announcement of the national ETS, thermal power companies tended to reduce the trading volume for single transactions and increase the number of transactions in the carbon markets. We consider that marketization plays an important role in China's carbon trading. Thermal power companies choose to trade carbon credit more flexibly, rather than passively following the government's instructions. However, the restricted national market (power sector) limits the trading volume. We consider that along with the market coverage, tradable products, and trading methods, the trading volume will increase rapidly.

On the other hand, this study not only evaluated the impacts of thermal power production on China's carbon markets, but also examined the interaction impact of thermal power production and the China National ETS policy's implementation on carbon markets in different periods. Our results show that only liquidity was increased in the Hubei and Shanghai pilots after the end of 2017. The results imply that power companies have participated actively in carbon markets in Hubei and Shanghai pilots. Especially, along with the beginning of the simulated national carbon trading, carbon trade has shown higher efficiency in Hubei and Shanghai pilots in the first half of 2019. The results further show that market was activity restricted by the institution of a compliance period. We consider that a considerable part of carbon trading occurred only because the thermal power companies needed to fulfill the emissions reduction obligations. Therefore, we suggest the government should incentivize thermal companies to complete trading initiatively, and thus activate the carbon market, by adopting more efficient policy instruments. For instance, requiring companies to finish their trade by a certain period, instead of before the compliance period in each year.

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[13] The end of compliance period is usually set as period from June to July in each year..

[14] A stricter emission cap regulation also leads thermal power companies paying attention on reducing carbon emissions, through increases abatement investment.

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Table 1: Overview of eight carbon emissions markets

Pilot ETS	Launch Date	2020 Reduction Target (CO_2 intensity [vs. 2015])	Emission Coverage (% of gross emissions)
Shenzhen	18 Jun 2013	45% (vs. 2005)	$>$ 40%
Shanghai	26 Nov 2013	20.5%	$>$ 57%
Beijing	28 Nov 2013	20.5%	$>$ 45%
Guangdong	19 Dec 2013	20.5%	$>$ 60%
Tianjin	26 Dec 2013	20.5%	$>$ 55%
Hubei	02 Apr 2014	19.5%	$>$ 35%
Chongqing	19 Jun 2014	19.5%	$>$ 40%
Fujian	30 Sep 2016	19.5%	$>$ 60%

Table 2: Descriptive statistics

Variables	Unit	N	Mean	Std. Dev.	Min	Max
$Price_{im}$	RMB/ton	472	27.35	17.01	1.614	86.77
$TradingVolume_{im}$	million ton	472	0.354	0.734	0	6.625
$Volatility_{im}$	%	472	0.205	0.197	0	1.556
$Amihud_{im}$	RMB	472	0.109	0.333	0	3.152
$Thermal_{im}$	TWh	472	9,398	8,060	1,550	34,630
$Other\ sector\ production_{im}$	TWh	472	4,219	5,171	20	21,451
$VAI(YoY)_{im}$	%	472	6.025	4.426	-10.43	15.90
$CO_2\ target_i$	%	472	0.201	0.00484	0.195	0.205
$EmissionCoverage_i$	%	472	0.498	0.0933	0.350	0.600
$NETS_m$	dummy	472	0.371	0.484	0	1
$Host_i$	dummy	472	0.305	0.461	0	1

Table 3: The impact of thermal power generation on carbon price for the carbon markets

$Price_{im}$	(1)	(2)	(3)	(4)
$Price_{i,m-1}$	0.922^{***}	0.921^{***}	0.922^{***}	0.922^{***}
	(0.025)	(0.025)	(0.025)	(0.026)
$Thermal_{im}$	-0.000	0.000	-0.003	-0.003
	(0.002)	(0.002)	(0.002)	(0.002)
$ThermalShare_{im}$	0.076	0.075	-0.112	-0.113
	(0.080)	(0.078)	(0.091)	(0.092)
$VAI(YoY)_{im}$	0.008^{***}	0.008^{**}	0.007^{***}	0.007^{***}
	(0.003)	(0.003)	(0.003)	(0.003)
$CO_2target_i$	8.512^{**}	8.559^{**}	13.938^{***}	13.966^{***}
	(3.907)	(3.954)	(4.278)	(4.346)
$EmissionCoverage_i$	-0.370^{*}	-0.370^{*}	-0.252	-0.252
	(0.204)	(0.205)	(0.199)	(0.199)
$NETS_m$	0.071^{***}	0.078^{**}	0.137^{**}	0.141^{**}
	(0.024)	(0.038)	(0.064)	(0.071)
$Thermal_{im} \times NETS_m$		-0.001		-0.000
		(0.002)		(0.001)
$Constant$	-1.420^{**}	-1.431^{**}	-2.392^{***}	-2.398^{***}
	(0.711)	(0.722)	(0.796)	(0.812)
N	465	465	465	465
$R^2_{between}$	0.997	0.997	0.998	0.998

Note: Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The robust option was used on all models. period dummy variables were used in columns (3) and (4). The cross-term $\text{Thermal}_{im} \times \text{NETS}_m$ was added in columns (2) and (4). The random effects method was selected for all models, since the results of the Hausman test > 0.05.

Table 4: The impact of thermal power generation on trading volume for the carbon markets

$TradingVolume_{im}$	(1)	(2)	(3)	(4)
$TradingVolume_{i,m-1}$	0.624***	0.624***	0.670***	0.670***
	(0.053)	(0.052)	(0.059)	(0.059)
$Thermal_{im}$	0.044	0.042	0.051*	0.049*
	(0.038)	(0.037)	(0.029)	(0.028)
$ThermalShare_{im}$	-4.568***	-4.560***	-3.544***	-3.537***
	(0.933)	(0.942)	(1.227)	(1.228)
$VAI(YoY)_{im}$	0.015	0.015	-0.023	-0.024
	(0.062)	(0.061)	(0.074)	(0.074)
$CO_2target_i$	220.3***	220.1***	170.6**	170.329**
	(49.30)	(49.93)	(68.54)	(68.65)
$EmissionCoverage_i$	-5.120	-5.120	-5.050	-5.052
	(3.518)	(3.520)	(3.173)	(3.174)
$NETS_m$	0.085	0.023	-2.610	-2.669
	(0.159)	(0.253)	(1.945)	(1.945)
$Thermal_{im} \times NETS_m$		0.006		0.005
		(0.011)		(0.007)
$Constant$	-35.18***	-35.11***	-25.91**	-25.84**
	(8.876)	(9.043)	(11.56)	(11.61)
N	465	465	465	465
$R^2_{between}$	0.951	0.951	0.966	0.966

Note: Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The robust option was used on all models. period dummy variables were used in columns (3) and (4). The cross-term $\text{Thermal}_{im} \times \text{NETS}_m$ was added in columns (2) and (4). The random effects method was selected for all models, since the results of the Hausman test > 0.05.

Table 5: The impact of thermal power generation on volatility for the carbon markets

$Volatility_{im}$	(1)	(2)	(3)	(4)
$Volatility_{i,m-1}$	0.299^{***}	0.296^{***}	0.311^{***}	0.308^{***}
	(0.068)	(0.066)	(0.074)	(0.071)
$Thermal_{im}$	0.003^{*}	0.004^{**}	0.006^{***}	0.006^{***}
	(0.002)	(0.002)	(0.002)	(0.002)
$ThermalShare_{im}$	0.167^{***}	0.164^{***}	0.340^{***}	0.338^{***}
	(0.043)	(0.042)	(0.090)	(0.090)
$VAI(YoY)_{im}$	-0.003	-0.002	-0.001	-0.001
	(0.003)	(0.003)	(0.004)	(0.003)
$CO_2target_i$	-8.921^{**}	-8.828^{**}	-13.867^{***}	-13.771^{***}
	(3.811)	(3.728)	(4.652)	(4.610)
$EmissionCoverage_i$	-0.141	-0.143	-0.241	-0.243
	(0.176)	(0.175)	(0.178)	(0.175)
$NETS_m$	-0.022	0.002	0.002	0.027
	(0.015)	(0.024)	(0.097)	(0.099)
$Thermal_{im} \times NETS_m$		-0.002^{**}		-0.002^{**}
		(0.001)		(0.001)
$Constant$	1.872^{**}	1.848^{**}	2.767^{***}	2.741^{***}
	(0.766)	(0.749)	(0.897)	(0.887)
N	465	465	465	465
$R^2_{between}$	0.848	0.845	0.898	0.895

Note: Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The robust option was used on all models. period dummy variables were used in columns (3) and (4). The cross-term $\text{Thermal}_{im} \times \text{NETS}_m$ was added in columns (2) and (4). The random effects method was selected for all models, since the results of the Hausman test > 0.05.

Table 6: The impact of thermal power generation on liquidity for the carbon markets

$Amihud_{im}$	(1)	(2)	(3)	(4)
$Amihud_{i,m-1}$	0.259^{*}	0.254^{*}	0.266^{**}	0.261^{**}
	(0.139)	(0.134)	(0.135)	(0.128)
$Thermal_{im}$	0.001	0.003	-0.001	0.001
	(0.003)	(0.003)	(0.004)	(0.004)
$ThermalShare_{im}$	0.356^{***}	0.348^{***}	0.248	0.241
	(0.138)	(0.134)	(0.161)	(0.153)
$VAI(YoY)_{im}$	-0.007^{*}	-0.007	-0.006	-0.006
	(0.004)	(0.005)	(0.004)	(0.005)
$CO_2target_i$	-19.870^{***}	-19.635^{***}	-15.511^{**}	-15.252^{**}
	(4.287)	(4.187)	(7.234)	(6.817)
$EmissionCoverage_i$	0.206	0.206	0.257	0.258
	(0.286)	(0.287)	(0.289)	(0.291)
$NETS_m$	0.050	0.107	0.504	0.567
	(0.049)	(0.076)	(0.467)	(0.502)
$Thermal_{im} \times NETS_m$		-0.006^{*}		-0.005
		(0.003)		(0.004)
$Constant$	3.716^{***}	3.655^{***}	2.837^{**}	2.767^{**}
	(0.850)	(0.843)	(1.380)	(1.314)
N	465	465	465	465
$R^2_{between}$	0.805	0.805	0.785	0.786

Note: Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The robust option was used on all models. period dummy variables were used in columns (3) and (4). The cross-term $\text{Thermal}_{im} \times \text{NETS}_m$ was added in columns (2) and (4). The random effects method was selected for all models, since the results of the Hausman test > 0.05.

Table 7: The impacts of market reaction from the launching of China’ s NETS

	(1) Price	(2) Price	(3) TradingVolume	(4) TradingVolume	(5) Volatility	(6) Volatility	(7) Amihud	(8) Amihud
$Price_{i,m-1}$	0.920***	0.920***						
	(0.028)	(0.027)						
$TradingVolume_{i,m-1}$			0.582***	0.627***				
			(0.054)	(0.058)				
$Volatility_{i,m-1}$					0.289***	0.302***		
					(0.059)	(0.068)		
$Amihud_{i,m-1}$							0.240*	0.241*
							(0.140)	(0.134)
$Thermal_{im}$	0.001	-0.002	0.069	0.080*	0.004**	0.007***	0.004	0.002
	(0.002)	(0.003)	(0.048)	(0.042)	(0.002)	(0.002)	(0.003)	(0.005)
$ThermalShare_{im}$	0.118	-0.076	-3.406**	-2.169	0.144**	0.321***	0.376***	0.251*
	(0.104)	(0.120)	(1.591)	(1.746)	(0.067)	(0.112)	(0.112)	(0.140)
$VAI(YoY)_{im}$	0.009**	0.008**	0.040	0.011	-0.003	-0.002	-0.007	-0.006
	(0.004)	(0.004)	(0.062)	(0.077)	(0.003)	(0.004)	(0.005)	(0.005)
$CO_2target_i$	7.559*	13.17***	193.0**	142.6	-8.619***	-13.57***	-21.71***	-16.93***
	(3.923)	(4.231)	(85.80)	(92.42)	(3.170)	(4.783)	(4.293)	(6.372)
$EmissionCoverage_i$	-0.371	-0.249	-5.687	-5.983	-0.208	-0.294	0.050	0.091
	(0.256)	(0.254)	(4.736)	(4.624)	(0.161)	(0.180)	(0.297)	(0.293)
$NETS_m$	0.082*	0.144**	-0.041	-2.517	-0.006	0.025	0.062	0.545
	(0.047)	(0.072)	(0.494)	(1.931)	(0.035)	(0.102)	(0.087)	(0.509)
$Host_i$	0.037	0.025	1.141**	1.035**	-0.033	-0.020	-0.044	-0.049
	(0.036)	(0.033)	(0.532)	(0.488)	(0.032)	(0.025)	(0.054)	(0.060)
$Thermal_i \times NETS_m$	-0.001	-0.000	0.013	0.010	-0.002	-0.002	-0.004	-0.004
	(0.002)	(0.002)	(0.020)	(0.013)	(0.001)	(0.001)	(0.003)	(0.004)
$Host_i \times NETS_m$	0.025	0.011	1.732	1.528	0.096	0.084	0.435***	0.487***
	(0.052)	(0.063)	(1.526)	(1.729)	(0.088)	(0.098)	(0.152)	(0.138)
$Thermal_{im} \times Host_i \times NETS_m$	-0.003	-0.001	-0.175	-0.159	-0.010	-0.009	-0.039***	-0.045***
	(0.005)	(0.007)	(0.136)	(0.162)	(0.008)	(0.009)	(0.010)	(0.009)
$Constant$	-1.281*	-2.281***	-30.67**	-21.28	1.870***	2.748***	4.134***	3.187***
	(0.711)	(0.788)	(15.287)	(16.143)	(0.617)	(0.876)	(0.840)	(1.177)
N	465	465	465	465	465	465	465	465
$R^2_{between}$	0.997	0.998	0.949	0.961	0.851	0.892	0.828	0.836

Note: Standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. The robust option was used on all models. Period dummy variables were used in column (2), (4), (6), and (8). The random effects method was selected for all models, since the results of the Hausman test > 0.05.

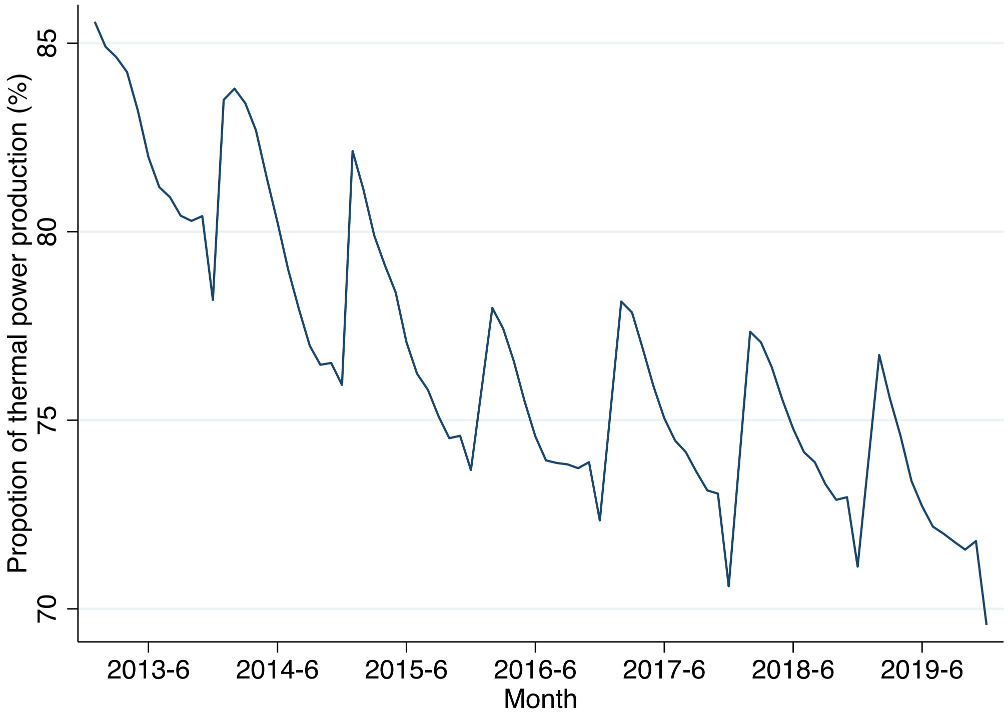


Figure 1: Trend in the proportion of thermal power production in China's electricity supply

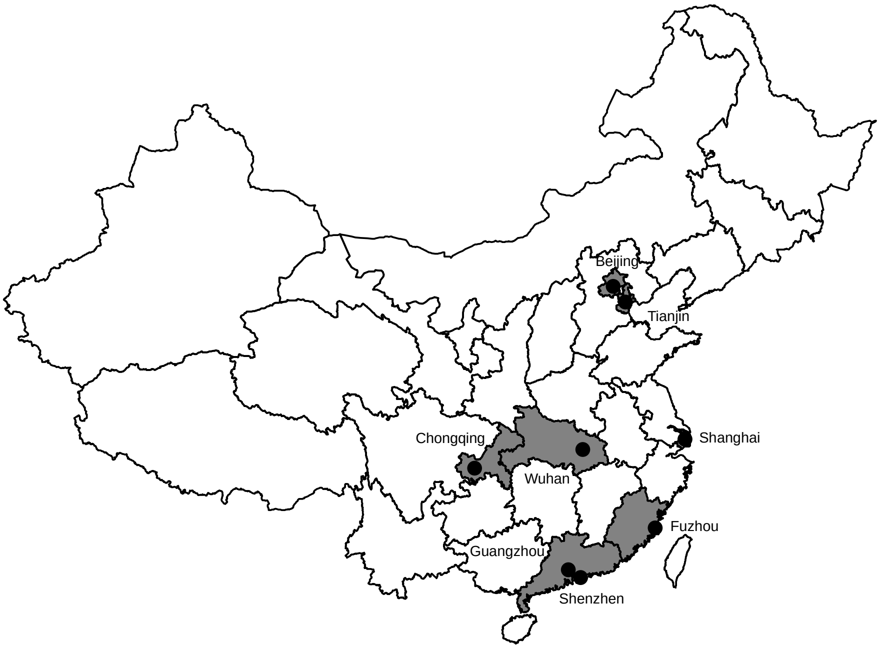


Figure 2: Eight carbon emissions markets in China

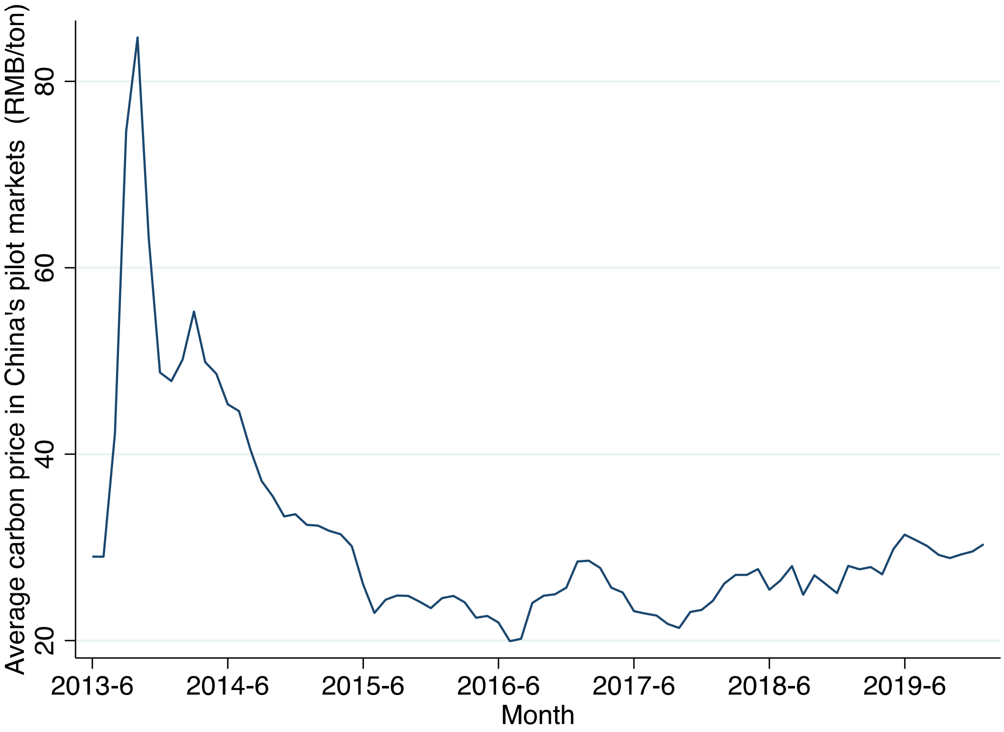


Figure 3: Trend in carbon price in China's carbon emissions markets

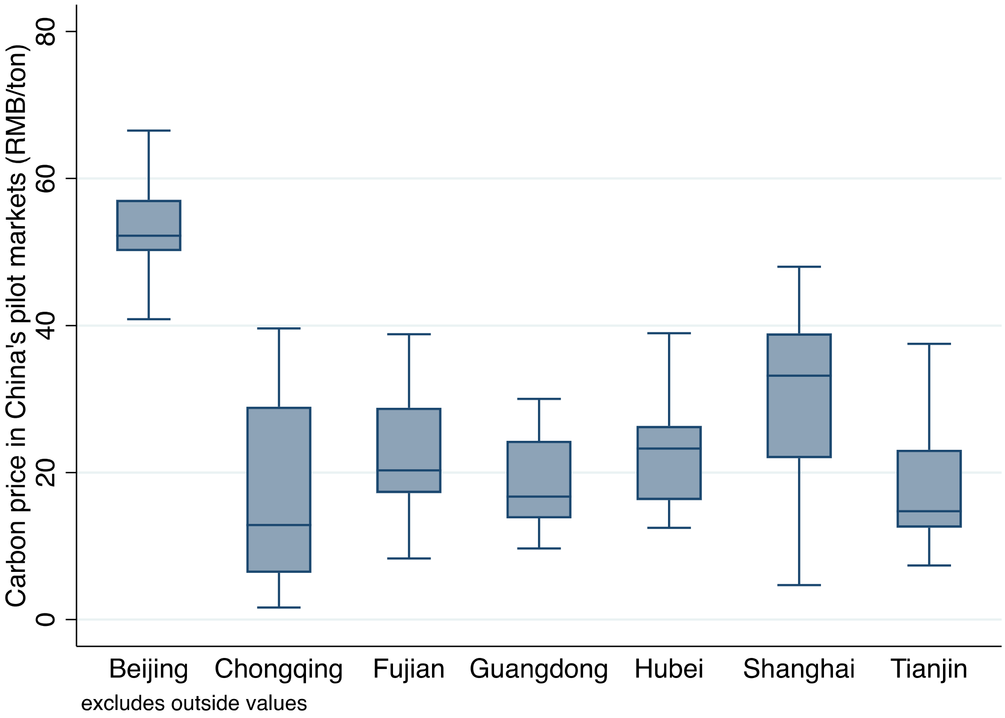


Figure 4: Carbon price in study project provinces

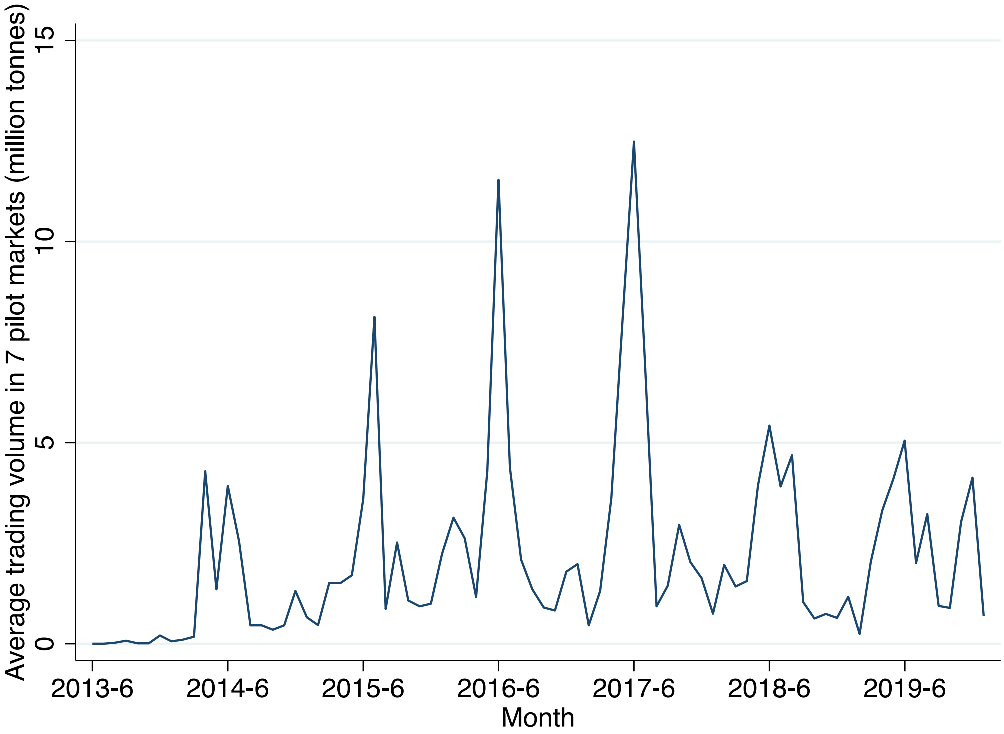


Figure 5: Trend in trading volume in China's carbon emissions markets

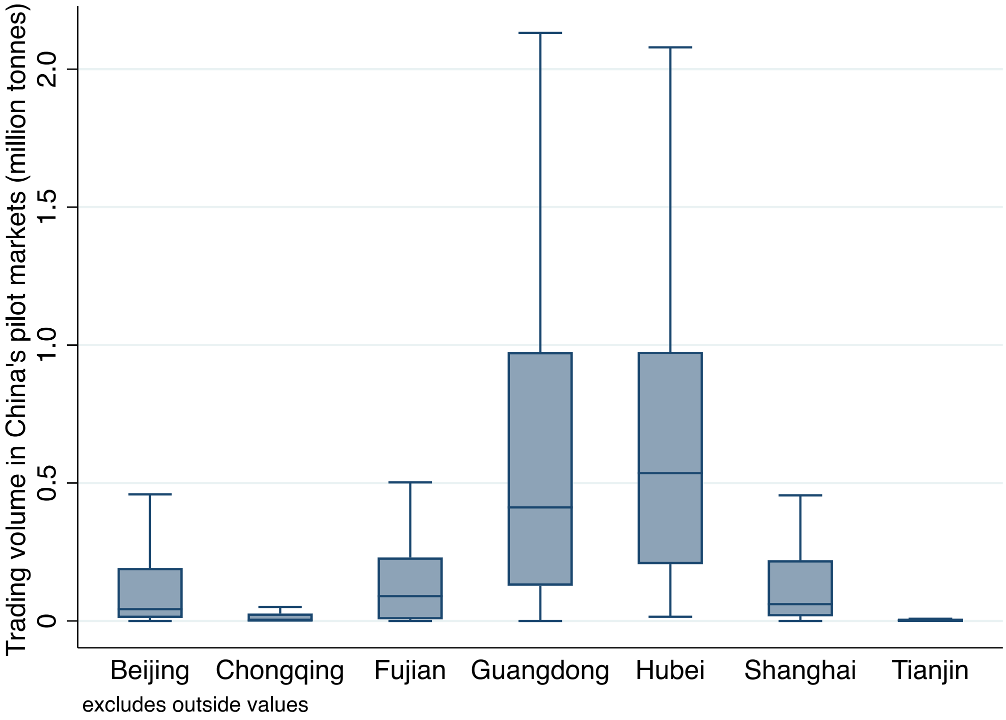


Figure 6: Trading volume in study project provinces

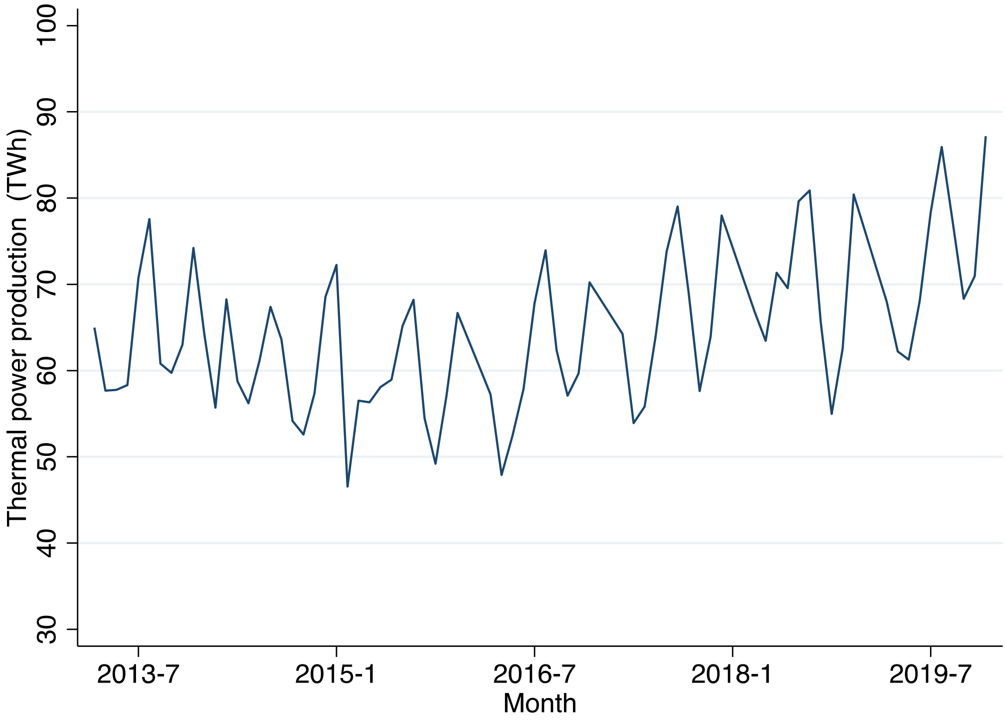


Figure 7: Trend in thermal power production in study object provinces

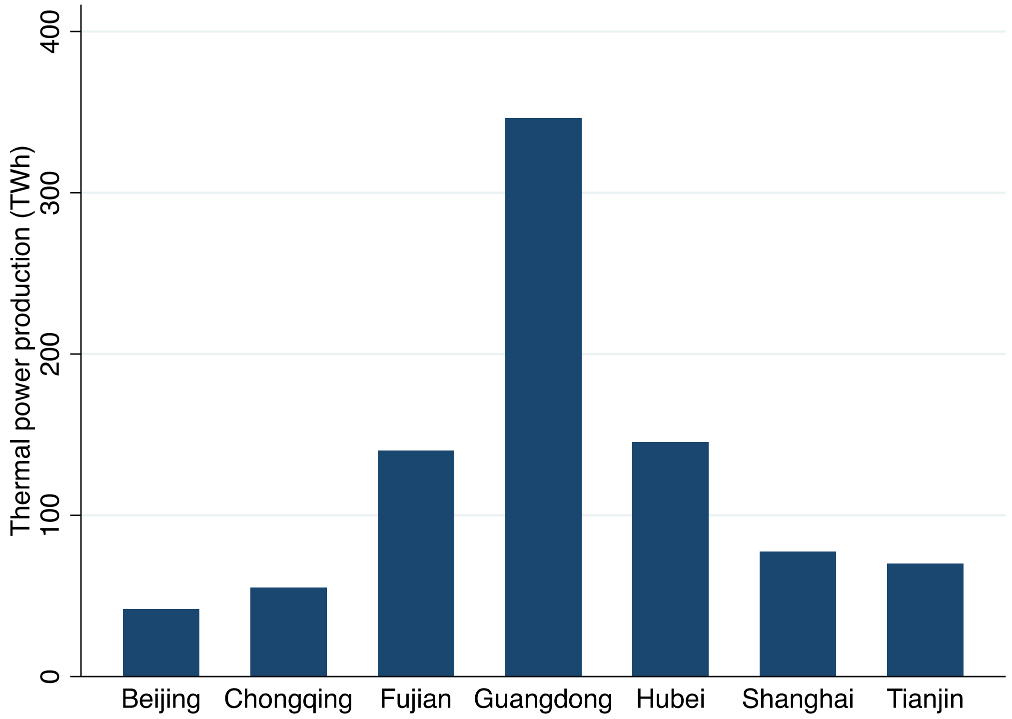


Figure 8: Thermal power production in study project provinces in 2019

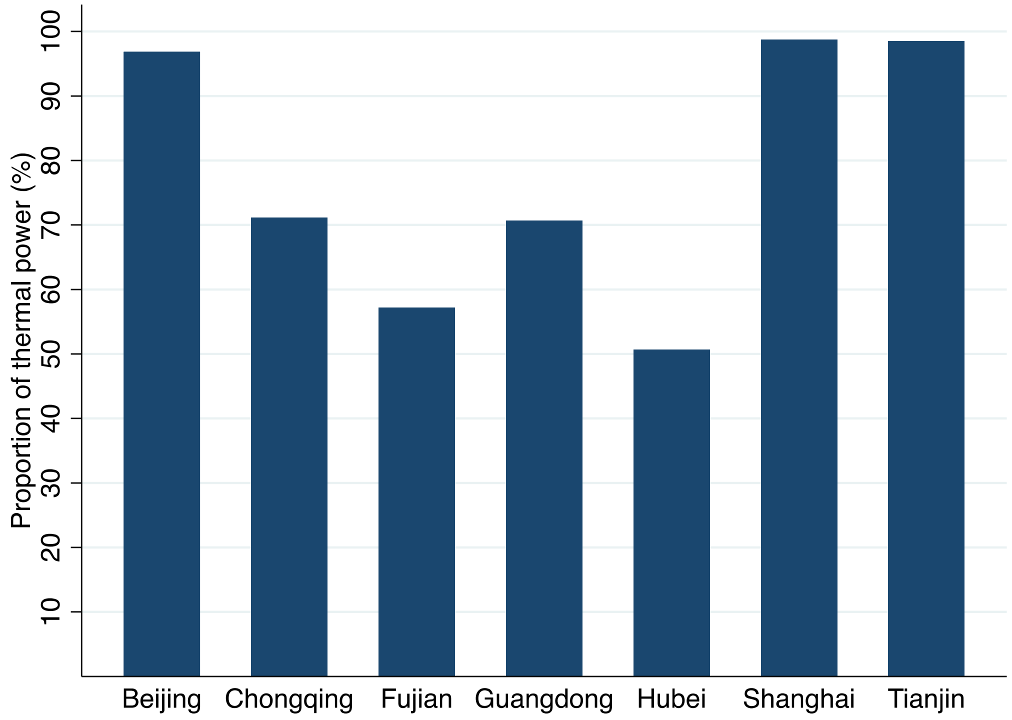


Figure 9: The proportion of thermal power production in 7 provinces in 2019

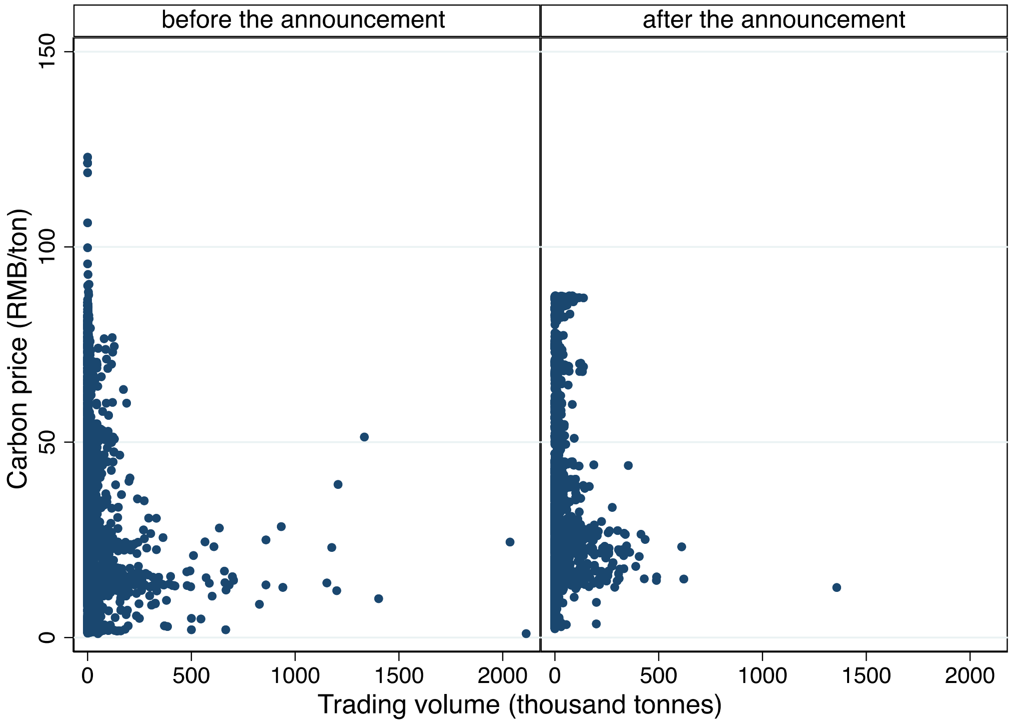
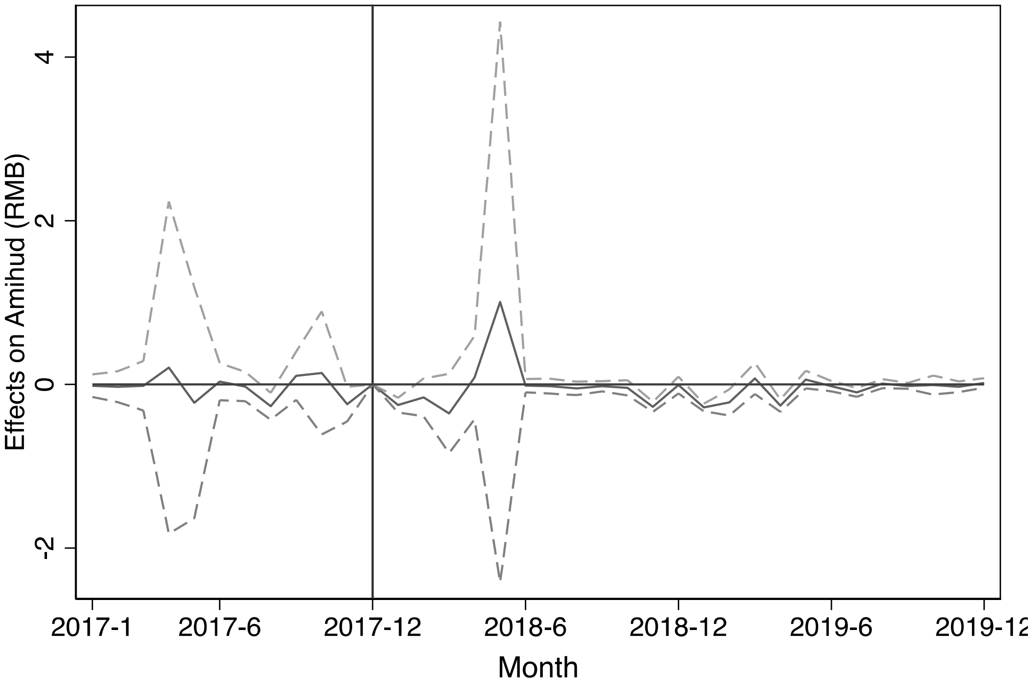


Figure 10: The comparison of daily trading volumes between the announcement of national ETS



Note: Dashed lines indicate 90% confidence intervals.

Figure 11: The effects of thermal power production on the liquidity of China's carbon market that under the announcement of China's national ETS