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Original Research

Free Trade Zone Policy and Carbon Dioxide Emissions: a Synthetic Control Group Approach

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Abstract

The international community has reached a consensus on preventing the global climate from deterioration. As the country with the largest carbon dioxide emissions, China has made a commitment to such prevention. Free trade zone (FTZ) established in 2013 is a designated area planned for promoting trade openness and investment facilitation. More importantly, it is a policy experiment aimed at establishing a green and low-carbon development model. Based on province-level data of China for the period 1997-2017, this study exploits the synthetic control method to explore the impact of FTZ policy on carbon dioxide emissions. The results show that, compared with the synthetic control regions, the carbon dioxide emission of the Shanghai FTZ has reduced by about 10% after the implementation of the FTZ policy. Moreover, the outcome holds with placebo tests and sensitivity analysis. Employing the difference-in-differences method, the results also demonstrate FTZ policy substantially reduces carbon dioxide emissions. Our findings provide institutional enlightenments for China and other developing countries to balance economic development and environmental protection with opening to the outside world.

Keywords: carbon dioxide emission, free trade zone policy, institutional innovation, synthetic control method

Introduction

Global warming has become a worldwide environmental problem that threatens the sustainable development of mankind. With the increase of cumulative carbon dioxide emissions, global warming will continue to intensify. Countries are aware of the need to do their utmost to reduce carbon dioxide emissions and thus avoid the negative effects of sea level rise and extreme weather events. As the largest carbon dioxide (CO_2) emitter in the world, China has identified the establishment and improvement of a green, low-carbon and circular economy system as a basic national development strategy as well as set

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clear targets for carbon dioxide emission reduction[1]. To achieve emission reduction targets, the Chinese government is looking for appropriate policy tools. Among these tools, the FTZ policy launched in 2013 may be an important attempt.

FTZs developed from free ports have a long history in many countries. In 2013, China established its first pilot FTZ in Shanghai, after that, Tianjin, Guangdong, and Fujian FTZs were added to the pilot list in 2015, and several other batches of FTZs were established after 2016. The policies of pilot FTZs in China include free entry and exit of goods, zero-tariff policies and other traditional policies that promote trade openness. More importantly, the "negative list" management model and "pre-entry national treatment" are adopted in FTZs to achieve expanding openness in service sector and finance sector. The measures rolled out in FTZs deepen trade openness, which will have a significant impact on environmental quality. Currently, the question of whether free trade intensifies or reduces carbon dioxide emissions fuels a controversial debate. Some studies indicated that free trade can reduce carbon dioxide emissions [1, 2]. The supporters believed that higher degree of trade openness may optimize environment resource allocation, boost eco-friendly technologies, and hence lower carbon dioxide emissions [3]. The antagonists who hold "Pollution Haven Hypothesis" supposed that free trade will shift emission-intensive goods from developed countries to developing countries and is hazardous to the host country's environment [4, 5, 6]. Considering the ambiguous relationship between free trade and carbon dioxide emissions, these conclusions may be biased by the possible measurement errors in trade openness and the reverse causality. This paper tries to complement the literature by analyzing China's FTZ policy represented by Shanghai FTZs – a plausibly exogenous policy shock – and its consequences for the carbon dioxide emissions that followed.

Different from the FTZs of other countries, the China FTZ policy has also carried out a series of fruitful institutional innovations in various fields such as transforming government functions and supporting emerging industries [7]. Some studies have found that the China FTZ policy has effectively improved the quality of intermediate goods imports and the entry of high-end foreign-funded manufacturing enterprises [8, 9], and promoted industrial structure upgrading and enterprise technological innovation [10, 11]. In fact, this positive advancement by the FTZ policies will have an impact on carbon dioxide emissions. The FTZ policy also includes strengthening environmental regulation, exploring the implementation of classified management of environmental impact assessment, improving the level and efficiency of environmental protection management, and reducing pollutants and greenhouse gas emissions[2]. For instance, the Shanghai FTZ has established a zero-carbon emission commercial center in the zone[3]. In this regard, FTZ may be beneficial to improving environmental quality and reducing carbon dioxide emission. However, the effect has not been empirically tested. Our work will fill the gap, and provide evidence that whether China's FTZ as an experimental field that deepens institutional innovations and strengthens environmental regulation has an effective effect on environmental quality.

This study uses synthetic control methods to analyze the causal impact of China's FTZ policy on carbon dioxide emissions. We treat the establishment of Shanghai FTZ as policy intervention that took effect in 2013 and construct a synthetic control unit for Shanghai which is good match for real Shanghai during preintervention period. The postintervention divergence in carbon dioxide emission between real Shanghai and Synthetic Shanghai suggest that the FTZ policy is conducive to reducing carbon dioxide emission. The finding is consistent across placebo tests and the sensitivity analysis. Further tests of Guangdong FTZ, Tianjin FTZ and Fujian FTZ also show that FTZ policy does have the effect of reducing carbon dioxide emissions.

The contribution of this paper to the literature is three-fold. First, our work contributes most directly to the long-standing debate over the impact of free trade on environment by setting a quasi-natural experiment based on China's FTZ policy, in doing this, we can effectively address the endogeneity bias. Our work also related to the literature on the evaluation of China's FTZ policy that illustrates China's FTZ policy promotes institutional innovations and drives industrial structure upgrading in the zones. We further shed light on the impact of FTZs on carbon dioxide emissions, which indicate a possible pattern that can deepen trade openness and implement innovative policy tools to minimize pressure on the environment.

Second, the present study applies the synthetic control method to avoid the problematic parallel trends assumption intrinsic to standard policy evaluations method such as Differences-in-Differences (DID) estimation. Indeed, carbon dioxide emissions in Shanghai implementing the FTZ policy may have unobserved time-varying determinants that lead to differences in carbon dioxide emissions time series with respect to provinces and municipalities not implemented the policy. The influence of unobserved time-varying determinants causes the parallel trends assumption to not be satisfied. To address the problem,

1 China's 'Strengthening Action to Combat Climate Change – China's National Independent Contribution' announced in 2015, proposed that by 2030, China's unit GDP CO_2 emissions would be 60%–65% lower than that in 2005.

2 These provisions are set forth in Article 50 of the Regulations of the China (Shanghai) Pilot Free Trade Zone.

3 See http://www.tanpaifang.com/ditanhuanbao/2015/0508/44315.html

we apply synthetic control method which can replicate the unobserved heterogeneity and allow it to have time-varying effects. Specifically, this method constructs Shanghai's counterfactual that would have experienced if it had not adopted the FTZ policy using a weighted sum of donor provinces and municipalities (untreated provinces and municipalities) with the highest possible accuracy. The post-FTZ policy divergence between Shanghai and its counterfactual reflect the causal impact of FTZ policy on carbon dioxide emissions.

Third, previous studies have typically used default emission factors released by the Intergovernmental Panel on Climate Change (IPCC) to calculate carbon dioxide emissions [12]. However, the total amount of CO_2 emissions measured based on this method is higher than China's official figures. Our work exploits the China carbon dioxide emissions data published by the China Emission Accounts and Datasets (CEADs) team on Scientific Data because the data has a more comprehensive accounting range, which enables us to get more accurate results that are in line with China's actual situation.

The rest of the paper is structured as follows. Section 2 reports the institutional background and literature review. Section 3 presents the material and methods. In Section 4, we present the results and discussion. Section 5 provides the conclusions and policy implications.

Institutional Background and Literature Review

Background

A few centuries ago, some European countries established free ports to allow free trade of goods. After the 20^{th} century, more developed and developing countries started to establish FTZs and built export processing industries in the FTZs. With its accession to the WTO, China has also implemented the FTZ strategy to promote economic globalization and regional integration. In 2013, the China (Shanghai) Pilot Free Trade Zone went into operation. In 2015, three FTZ pilots were established in Guangdong, Tianjin, and Fujian. And several other batches of FTZs were established after 2016.

According to the 'Overall Plan of China (Shanghai) Pilot Free Trade Zone', this pilot is responsible for accelerating the transformation of government functions, exploring innovations in management models, and promoting trade openness and investment facilitation, among many other functions. The FTZ implements several preferential policies, including applying the "negative list" management model and "pre-entry national treatment" in the fields of modern services industry, banking, insurance, capital markets and other fields. On the premise of complying with relevant regulations, qualified foreign-funded institutions and organizations are allowed to establish companies to conduct related business in the form of joint ventures or independent forms while enjoying various preferential policies. The FTZ policy also includes the deepening of institutional innovation. It is reflected in the simplified customs clearance procedures for commodities and the higher administrative efficiency. For example, the FTZs has changed the previous customs clearance process of "first declaring and then entering" but has implemented the "first entering and then declaring". The system innovation of pilot FTZs is also reflected in "batch entry and exit, centralized declaration[4]", simplified customs clearance documents and so on.

The above-mentioned measures have effectively promoted the development of modern service industry in the FTZ. In addition, the FTZ has some specific support measures to promote the development of low-carbon industries. For instance, Shanghai FTZ gives preferential income tax to some high-tech industries. To promote the development of financial services and high-tech industries, the Shanghai FTZ deepens the functions of the trading platform, establishes a comprehensive financial service platform, and reduces or removes restrictions on foreign investment access[5]. Similarly, the Guangdong FTZ encourages the development of high-end industries and characteristic industries that are compatible with the area, and promotes the agglomeration and development of high-end industries such as advanced manufacturing and service industries[6].

The FTZ policy also includes requirements for environmental quality. Article 50 of the Regulations of China (Shanghai) Pilot Free Trade Zone clearly stipulates that the environmental protection of the FTZ should be strengthened, the classification management of environmental impact assessment should be explored and advanced production techniques and technologies should be adopted to improve energy efficiency and reduce pollutants and greenhouse gas emissions. The policy is also required to make full use of the advantages of opening up and actively promote the application of an internationally accepted environmental and energy system standard certification by enterprises in the region. Therefore, the establishment of some relevant regulations on environmental protection in the pilot has strengthened environmental regulation, which

4 "Batch entry and exit, centralized declaration" means that when the goods are imported and exported in batches between enterprises in the special customs supervision area and other enterprises in the area, the actual import and export formalities of the goods may first be completed by relevant documents, after that, the customs formalities will be handled centrally.

5 These provisions are set forth in the Overall Plan of China (Shanghai) Pilot Free Trade Zone and the Further deepen the reform and opening up plan of China (Shanghai) Pilot Free Trade Zone.

6 These provisions are set forth in the Regulations on China (Guangdong) Pilot Free Trade Zone.

will directly suppress carbon dioxide emissions, and indirectly reduce them by promoting enterprises to make green technological innovations [13-16]. Therefore, FTZ may be an important institutional innovation to reduce carbon dioxide emissions.

Literature Review

Evaluation of the Effects of the Pilot Free Trade Zone

Numerous studies have discussed the impact of FTZ policies on free trade. FTZs have effectively reduced trade barriers, increased trade varieties and trade volume [17, 18]. In 2013, China began to implement the FTZ policy, which not only includes the implementation of zero tariffs and other policies commonly used in the FTZs of other countries, but also the liberalization of investment in the service sector through the negative list system, the deepening of opening to the financial sector and the innovation of administrative management system [7, 19, 20]. Chinese FTZ policy has effectively attracted foreign investment, promoted international capital flows, and promoted imports and exports [21, 22]. Moreover, Wang and Zheng [23] found that the policy has promoted the development of new trade methods such as service trade and cross-border electronic commerce.

Related research further explored the other effects of the China FTZ policy. The policy is conducive to enhancing the ability of enterprises in the FTZ to absorb advanced technologies from other countries, thus increasing the productivity of the industry [24], and helping promote innovation [11]. The FTZ has also promoted the upgrading of the manufacturing structure by improving the quality of intermediate goods imports and the entry of high-end foreign-funded manufacturing enterprises [8, 9]. FTZ policy also includes innovation of administrative management system, which effectively improves the institutional quality and reduce the transaction costs of enterprises [20]. However, the impact of the FTZ policy on carbon dioxide emissions has not received sufficient attention, and only Liu and Liu [25] have studied the environment impact of FTZ from the perspective of waste water, waste gas and solid waste emissions.

Research on Carbon Dioxide Reduction

The impact of free trade on carbon dioxide emissions has evolved a controversial issue in recent studies. One strand of the literature approved the existence of a positive free trade-carbon dioxide emission nexus [1, 26, 27]. For instance, Jayanthakumaran and Liu (2016) quantified the carbon dioxide emissions embodied in free trade between Australia and China and found that overall global emissions were reduced during 2010-2011 [1]. Using a sample of G-20 countries from 1990 to 2018, Ibrahim and Ajide (2021) exporters reduce carbon dioxide emissions. Employing a panel dataset regarding 46 African countries, Award (2019) also implied that free trade is good for carbon reduction [26, 27]. Conversely, another strand of the literature held that free trade is hazardous to the environment [5, 6, 28]. One important hypothesis - "Pollution Haven Hypothesis" argued that free trade will drive polluting industries relocate to low-income developing countries with less stringent environmental policies, due to this, trade openness may reduce environmental quality [29-32]. Some studies have provided empirical evidence to support it. For instance, He (2022) used exogenous geographic determinants of trade as instrumental variables, and found that increased trade openness leads to environmental degradation [32]. Examining 21 developed and developing countries with high carbon dioxide emissions throughout 1990-2016, Singhania and Saini (2021) proved that free trade enhances carbon intensity [30].

Several strands of literature have certified that institutional reform and institutional innovation are conducive to reducing carbon dioxide emissions [33]. For instance, The Emissions Trading System pilot program in China has been proven to effectively reduce total carbon dioxide emissions [34, 35]. In addition, from the perspective of the innovation of the financial management system, Zhang [36] believed that establishing an effective financial system by integrating banks and capital markets is conducive to reducing carbon dioxide emissions and promoting low-carbon development in China. The government can help improve the environment by establishing strong policy and institutional structures as well as consistently supporting and providing incentives to promote new technological innovation for the development of low-carbon economy [37]. The government can also significantly reduce emission through regulations and incentives, such as direct subsidies and preferential taxation rates [16, 38].

Technological innovation and industrial upgrading have important impacts on carbon dioxide emissions as well. Li et al. [39] confirmed that technological innovation can effectively suppress the growth rate of carbon dioxide emissions and improve the efficiency of carbon emission reduction. Wang et al. [40] found that carbon-free energy technology innovation has a significant contribution to the carbon dioxide emissions reduction process. Wang and Zhu [41] found that renewable energy technology innovation promotes emission reduction. In addition, the industrial structure rationalization, transformation, and upgrade are conducive to reducing carbon dioxide emissions [42-44].

By analyzing and summarizing the relevant research, we found that existing research has confirmed the significant role that the FTZ policy has played in trade and investment openness, innovation of administrative management system. However, the overall effect of the policy on climate and environment is largely unknown. Therefore, this paper tries to fill the gap and uses synthetic control method to study whether the implementation of FTZ policy is conducive to reducing carbon dioxide emissions, and if so, what level of carbon dioxide emission reduction can be achieved through FTZ policy.

Material and Methods

Synthetic Control Methods

Shanghai FTZ, established in 2013, was the first of its kind to be set up in China. Therefore, our work mainly aims to evaluate the impact of this policy event on carbon dioxide emissions. We need to estimate the counterfactual outcome that Shanghai would have experienced if it has not set up an FTZ, and then can infer the causal effect of the FTZ on CO_2 emissions which is the difference between Shanghai and its counterfactual. The synthetic control methods allow us to construct the counterfactual (i.e., the synthetic control group for Shanghai) which is a weighted sum of CO_2 emissions from a donor pool of untreated (no FTZ policy) jurisdictions and tracks CO_2 emissions in Shanghai before the implementation of the FTZ policy.

Following Abadie and Gardeazabal (2003), Abadie et al. (2010) and Abadie et al. (2015), we suppose there are $K+1$ municipalities or provinces, including one treatment unit (Shanghai) and K jurisdictions serving as potential donors [45, 46, 47]. The CO_2 emissions of $K+1$ provinces or municipalities during t periods have been given, for units $t = 1, ..., T$. Let C_{1t}^N be the CO_2 emissions that would be observed for Shanghai at time t before establishing the pilot FTZ. Let C_{1t}^F be the CO_2 emissions that would be observed for Shanghai at time t after establishing the pilot FTZ. We define that Shanghai is approved to establish FTZ at time $t=T_0$. Thus, for $t \in [1, T_0]$, the CO_2 emissions of Shanghai are not affected by the FTZ policy, and so we have $C_{1t}^N = C_{1t}^F$. After implementation of the FTZ policy, for $t \in [T_{0+1}, T]$, we use $\alpha 1t = C_{1t}^N - C_{1t}^F$ to show the carbon dioxide emission reduction effect of the pilot FTZ. During the postintervention period, we can only observe C_{1t}^F, but not C_{1t}^N. Based on the observed covariates and trends in CO_2 emissions prior to the implementation of the FTZ policy, it is possible to construct a synthetic control unit for C_{1t}^N.

Suppose that C_{it}^N is given by a factor model:

$$C_{it}^N = \lambda_t + \beta_t Z_i + \gamma_t \upsilon_i + \mu_{it}, \tag{1}$$

where λ_t is the time fixed effect of CO_2 emissions in all provinces or municipalities. Z_i is the observed covariate, that is, a control variable that is not affected by the FTZ policy, β_t is an unknown parameter vector. υ_t is unobserved provincial or municipal fixed effects, γ_t is an unknown common factor vector and μ_{it} is the unobserved short-term shock with mean zero. Define $W = (w_2, ..., w_{k+1})'$ as a $(K\times 1)$ vector of donor pool unit weights ($w_k \geq 0$ and $w_2 + ..., w_{k+1} = 1$). The value of the CO_2 emissions for each synthetic control indexed by W is

$$\sum_{k=2}^{k+1} w_k C_{ki} = \lambda_t + \beta_t \sum_{k=2}^{k+1} w_k Z_k + \gamma_t \sum_{k=2}^{k+1} w_k \upsilon_k + \sum_{k=2}^{k+1} w_k \mu_{kt} \tag{2}$$

Suppose there are $(w_2^*, w_2^*, ..., w_{k+1}^*)$ such that

$$\sum_{k=2}^{k+1} w_{k1}^* C_{k1} = C_{11}, \sum_{k=2}^{k+1} w_k^* C_{k2} = C_{11}, \dots \sum_{k=2}^{k+1} w_k^* C_{kT_0} = C_{1T_0}, \sum_{k=2}^{k+1} w_k^* Z_k = Z_1 \tag{3}$$

Abadie et al. (2010) have proved that under standard conditions [46], the $C_{1t}^N - \sum_{k=2}^{k+1} w_k^* C_{kt}$ will tend to be zero if the periods of time before the implementation of the policy is longer. Therefore, the estimate of the effect of the FTZ is as follows,

$$\hat{\alpha}_{1t} = C_{1t} - \sum_{k=2}^{k+1} w_k^* C_{kt}, t \in [T_{0+1}, \dots T] \tag{4}$$

We are interested in finding the optimal weights (W^*) of the donor provinces and municipalities that is a perfect fit for real Shanghai. The optimal weights (W^*) is selected to minimize the distance $\| X_1 - X_0 W \| = \sqrt{(X_1 - X_0 W)' V (X_1 - X_0 W)}$, where X_1 represents a $(J\times 1)$ vector of J predictors for Shanghai during the preintervention period, X_0 is the corresponding $(J\times K)$ matrix of J predictors for K donor pool units, V is a matrix that assign weights to linear combinations of the variables in X_0 and X_1. An optimal choice of V minimizes the mean square prediction error (MSPE)[7] of the outcome variable during the preintervention period. Given a V, $W^*(V)$ can be computed and a synthetic Shanghai that best approximate the real Shanghai can be constructed.

Following the lead set by Shanghai FTZ, Tianjin, Fujian, and Guangdong Province in 2015 were approved to establish FTZs. In 2017, seven provinces including Liaoning, Zhejiang, Henan, Hubei, Chongqing, Sichuan, Shaanxi were approved to set up FTZs. After that,

[7] According to Abadie et al. (2010), MSPE defined conventionally as $MSPE = \frac{1}{T_0} \sum_{t=1}^{T_0} (C_{1t} - \sum_{J=2}^{J+1} \omega_J C_{jt})^2$, measures the average squared difference between CO_2 emissions of Shanghai and synthetic Shanghai.

a series of FTZs have been established subsequently. Owing to limited data, our analysis range is from 1997 to 2017. Therefore, in addition to Shanghai, we can also explore the carbon dioxide emission reduction effect of Tianjin FTZ, Fujian FTZ, and Guangdong FTZ using the synthetic control method.

Predictive Variables

The predictive factors of CO_2 emissions include per capita GDP, industrial structure, development level of the service industry, industrial structure upgrading, energy consumption, population density and technological progress. Economic development increases CO_2 emissions through scale effects but reduces CO_2 emissions through technological and structural effects. Technological progress can reduce carbon dioxide emissions by improving energy efficiency. Technology market turnover is used as a proxy variable for technological progress. The descriptive statistics of variables are listed in Table 1.

At present, research institutions and scholars have widely used the IPCC default emission factors to calculate the CO_2 emission. These emission factors are higher than the survey values in China, which in turn leads to relatively high estimates. For example, in 2012, China's total CO_2 emissions estimated by the Emission Database for Global Atmospheric Research were 1.0057 billion tons while those estimated by the Carbon Dioxide Information Analysis Center were 1.02 billion tons, nearly 8% higher than the emissions estimated by Chinese officials (9.323 billion tons). Another limitation lies in that the above-mentioned data has only released the total amount of CO2 emissions nationwide in China, while has not extend to the provincial level.

Therefore, this study uses China's provincial CO_2 emissions data from 1997 to 2017, which is published by the CEADs team on Scientific Data [48, 49]. The CEADs calculated China's provincial CO_2 emissions data, which is an important supplement to the existing data. They calculated the provincial CO_2 emissions data based on the updated emission factors and most up to date energy consumption data. This data is calculated by a more comprehensive accounting scope that covers the relevant emissions data of energy-related emissions and process-related emissions [48, 49]. The changing trend of CO2 emissions of the four regions that we use the synthetic control method to evaluate the carbon emission reduction effect of the FTZs is shown in Fig. 1. We can see that the growth trend of CO_2 emissions decreased after 2013. To a certain extent, the trends show that the establishment of FTZs contribute to carbon reduction.

Data Resource

Given the data availability, we analyze 30 provinces of China (excluding Hong Kong, Macao, Taiwan, and

Table 1. Descriptive statistics.

Variables	Symbol	Description	N	Mean	SD	Min	Max
Economic development level	PGDP	Per capita GDP	630	11,857	13,858	202.1	89,705
Industrial structure	Secd	Added value of the secondary industry/regional GDP	630	0.458	0.0777	0.190	0.664
Development level of the service industry	Serv	Proportion of the tertiary industry	630	40.53	8.301	25.40	80.56
Industrial structure upgrading	Stru	Added value of the tertiary industry / added value of the secondary industry	630	0.946	0.465	0.494	4.237
Energy consumption	Enegc	Total energy consumption / regional GDP	630	10,114	7,656	390	38,899
Population density	Popu	Total population at the end of the year / province area	630	2,110	1,369	24	6,307
Technological progress	Tech	Technology market turnover	628	1261000	3807000	599	44870000

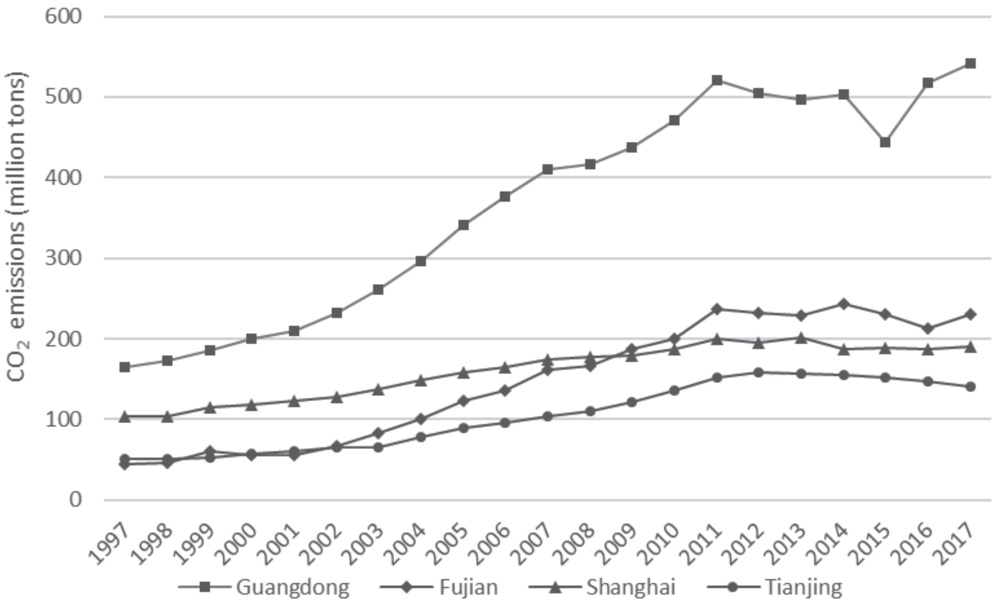

Fig. 1. CO_2 emissions in the Provinces and municipalities which established FTZs.

Tibet) as research objects for the period 1997 to 2017. The raw data of indicators such as output per capita, industrial structure, development level of service industry, industrial structure upgrading, energy efficiency, population density, and technology market turnover are all from the China Statistical Yearbook. The total fossil energy consumption data used in the calculation of CO_2 emissions come from the China Statistical Yearbook and the China Energy Statistical Yearbook.

Results and Discussion

Baseline Estimates

Based on pre-treatment CO_2 emissions and pre-treatment predictors, we can construct a Synthetic Shanghai that best approximates the Shanghai's pre-FTZ policy CO_2 emissions time series as a weighted average of untreated donor pool provinces and municipalities. One concern with the synthetic control analysis is that Synthetic Shanghai may be contaminated by a contribution from the donor jurisdictions which also introduce FTZ policy with CO_2 emission reduction effect among our analysis range. Because Tianjin, Fujian and Guangdong implemented the FTZ policies in 2015, we exclude these regions from the donor pool and estimate the effect of Shanghai FTZ policy from 2013 to 2016. Fig. 2 displays CO_2 emissions for real Shanghai and its optimal synthetic unit (Synthetic Shanghai) during the period 1997 through 2016. Table 2 displays the optimal weight matrix used to construct the Synthetic Shanghai, indicating that the pre-treated CO_2 emissions of Shanghai are reproduced by a weighted average of Beijing, Heilongjiang, and Shanxi.

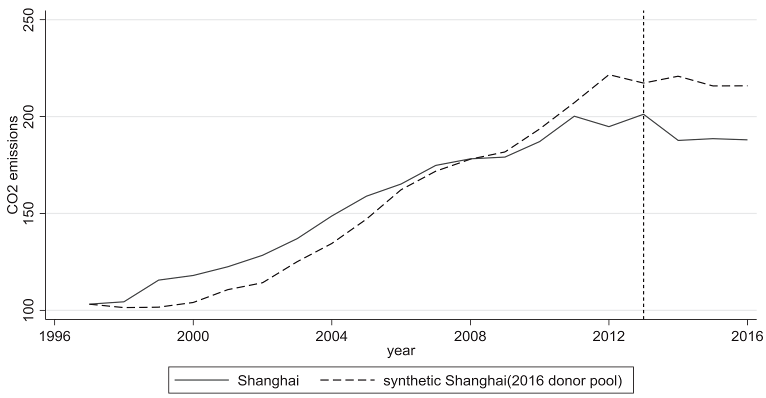

Fig. 2. Trends in CO_2 emissions: Shanghai vs. Synthetic Shanghai (2016 donor pool).

Table 2. Synthetic control group composition.

	Synthetic Shanghai Free Trade Zones prior to 2016	Synthetic Shanghai Free Trade Zones prior to 2017
Beijing	0.423	0.522
Heilongjiang	0.449	0.29
Shanxi	0.128	0.184
Hebei	0	0.004
Others	0	0

To extend the post-FTZ policy results period through 2017, seven additional jurisdictions that implemented the FTZ policy in 2017 must be removed from the donor pool. Fig. 3 displays this alternative version of Synthetic Shanghai constructed from the untreated donor jurisdictions that never implemented the FTZ policy from 1997 to 2017. The optimal weight matrix applied to construct this version of Synthetic Shanghai is also shown in Table 2.

Although the version of Synthetic Shanghai in Fig. 3 is constructed from the smaller donor pool compared to the version in Fig. 2, the fits before the vertical dashed line are quite similar. It suggests that real Shanghai (solid line) and its synthetic counterpart (dashed line) evolve on a shared path in the pre-FTZ policy period (from 1997 to 2012), in other words, the preintervention gap is small. The CO_2 emissions of Shanghai have been slowly increasing from 1997 to 2012. After the implementation of the FTZ policy, real Shanghai experiences a sharp decline in CO_2 as shown in the right side of the vertical dashed line in Fig. 1 and Fig. 3, and there is a discrepancy in the CO_2 emissions between real Shanghai and Synthetic Shanghai. The yearly post-treatment gaps indicate that the FTZ policy has effectively reduced CO_2 emissions. The average gap is approximately 20 billion tons, which represent an average decrease in CO_2 emission of approximately 10% relative to the counterfactual synthetic Shanghai.

Existing studies on free trade and environment quality mainly employed three measures to measure trade openness, including import, export, and total trade divided by GDP of a given country, respectively [50-52]. These studies mainly employed panel regression model in their empirical investigation, and there may be errors in the statistics of import and export, so the measurement of trade openness may be inaccurate. Moreover, it is difficult to deal with the reverse causality of carbon dioxide emissions and free trade using the panel regression model. This paper treats the establishment of Shanghai FTZ as an exogenous policy shock which promotes trade openness and exploits the synthetic control methods to examine the impact of FTZ on carbon dioxide emissions, effectively addressing the afore-mentioned estimation bias.

We find that the expansion of trade openness brought about by FTZs has a carbon dioxide emission reduction effect, which is consistent with past findings [3, 53, 54]. Based on the research of post-China countries, Arce et al., (2016) proved that free trade can reduce 15.2% to 18.2% on CO_2 emissions [53]. Muhammad et al., (2020) targeted 65 Belt and Road Initiative (BRI) Countries, and found that free trade export trade increased by 1%, CO_2 emissions decreased by 0.2%. [54] The evidence collectively indicate the conclusions of this paper that the establishment of Shanghai FTZ reduces CO_2 emissions by approximately 10% is valid. It is worth noting that China's FTZ policy also includes institutional innovations in various fields such as transforming government functions and developing low-carbon industries, which also play an important role in CO_2 emissions reduction [10, 11].

Placebo Test and Sensitivity Analysis

To evaluate the statistical significance of our Synthetic control estimates, we should verify that the postintervention gap between real Shanghai and Synthetic Shanghai was driven by the FTZ policy rather than other unobservable factors. Following Abadie et al. (2010), we conduct a placebo test [46]. First, we assume that other provinces or municipalities

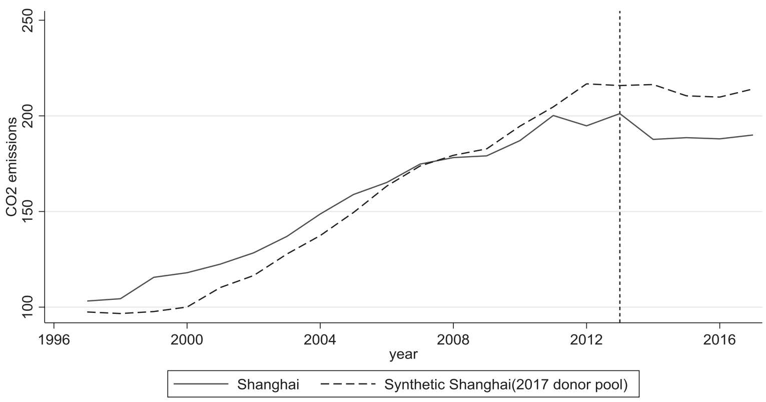

Fig. 3. Trends in CO_2 emissions: Shanghai vs. Synthetic Shanghai (2017 donor pool).

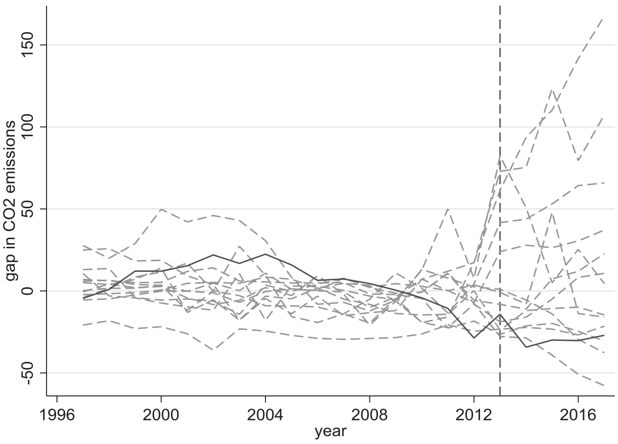

Fig. 4. CO_2 emissions gaps in Shanghai and placebo gaps in other control provinces or municipalities.

in the donor pool implemented the FTZ policy in 2013 and shift Shanghai in the donor pool. Second, applying the synthetic control methods to estimate the hypothetical policy effects. Third, compare the estimated gaps for the provinces and municipalities that did not implement FTZ policy with the postintervention gaps for Shanghai. Note that if the gap between the jurisdiction and its synthetic counterpart is too large in the years before the FTZ policy, suggesting that the combination of jurisdictions in the donor pool have poor fit for the real jurisdiction. Placebo runs that lack fit prior to the FTZ policy do not provide effective information, and the gap after the intervention could not be explained as a result of the policy effects [46]. Therefore, we exclude the provinces and municipalities whose MSPE is more than two times that of Shanghai before the policy was implemented.

Fig. 4 displays the CO_2 emissions gaps in Shanghai and the placebo gaps in other provinces and municipalities in the donor pool. After the implementation of the policy, the magnitude of the gap for Shanghai is the greatest (in 2014), and the second greatest is in 2015 and 2016. Therefore, we can draw the conclusion that the synthetic control analysis does provide evidence that the FTZ policy in Shanghai has a significant short-term effect on CO_2 emissions. There are three cases where the reduction effect associated with placebo runs exceed that in Shanghai in 2017. However, the data of CO_2 emissions after 2017 haven't been released, the long-term impact of the FTZ policy requires further study.

Following Xiang and Lawley (2019), we also compute 'placebo' estimates α that represents the change of CO_2 emission before and after the implementation of policies for all provinces and municipalities [55]:

$$\alpha_i = (Y_i^{post} - Y_{synth,i}^{post}) - (Y_i^{pre} - Y_{synth,i}^{pre}) \tag{5}$$

where Y_i^{post} is the average value of CO_2 emissions for jurisdiction i during the post-intervention period and $Y_{synth,i}^{post}$ is the average of synthetic CO_2 emissions. Y_i^{pre} and $Y_{synth,i}^{pre}$ are the corresponding value for the pre-intervention period. The value of $\alpha_{Shanghai}$ is -32.662, representing a 17.32% reduction relative to the counterfactual CO_2 emissions during the post-intervention period. $\alpha_{Shanghai}$ is the second highest among the 19 estimates, suggesting that Shanghai has the second most negative treatment effect.

We also perform a sensitivity analysis, that is, a 'leave-one-out' test proposed by Abadie et al. (2015), to ensure that our estimate is not produced as a consequence of one or a few influential donor pool provinces or municipalities [47]. We iteratively remove Beijing which has the largest weight in our original donor pool contributors and reconstruct Synthetic Shanghai. Fig. 5 shows that CO_2 emissions reduction effect of Shanghai FTZ remains the same in the leave-one-out alternative. We continue to exclude Beijing and the second-largest contributor (Heilongjiang) in our original model; the resulting Synthetic Shanghai comprises an entirely new donor pool composition. The policy effect also remains in this leave-one-out version of Synthetic Shanghai. These results suggest that our synthetic control estimate was not driven by the contributions from one or a few particular provinces or municipalities.

Analysis of other Pilot Provinces or Municipalities

In addition to Shanghai's implementation of the FTZ pilot in 2013, Guangdong, Tianjin and Fujian established pilots in 2015. The present study will also use the synthetic control methods to evaluate the impact of pilots in Tianjin, Fujian, and Guangdong on CO_2 emissions. Fig. 6 displays CO_2 emissions trends for real Tianjin and Synthetic Tianjin from 1997 to 2017. Before the implementation year of the policy, real Tianjin and Synthetic Tianjin evolve on a shared path. Beginning in 2015, Tianjin's CO_2 emissions continue to fall. Tianjin and its synthetic counterpart diverge noticeably. The post-intervention difference indicates that Tianjin's FTZ policy has effectively reduced CO_2 emissions.

Fig. 7 displays the CO_2 emissions of real Fujian and Synthetic Fujian. Similarly, the CO_2 emissions in Synthetic Fujian closely track those in real Fujian in the pre-intervention period. After the policy's implementation, the discrepancy between real Fujian and Synthetic Fujian suggests a negative impact of FTZ policy on CO_2 emissions. Indeed, in Fig. 6 and Fig. 7, the fits during the period before the implementation of the policy are better than that in Fig. 3. The possible reason is that Shanghai is the international economic, financial, trade, shipping, scientific and technological innovation center of China. The economic development level, energy technological innovation level and the environmental awareness of Shanghai have always been in the forefront of China. It is more difficult for Shanghai to be reproduced by other provinces or municipalities in the donor pool.

Fig. 8 displays CO_2 emissions for real Guangdong and Synthetic Guangdong between 1997 and 2017. Same as Tianjin and Fujian, Guangdong's CO_2 emissions have already fallen in the year that the FTZ was set up. This is mainly because the Tianjin, Fujian and Guangdong FTZs were set up in April 2015, so CO_2 emissions fell in the year they were set up. In 2015 and 2016, the CO_2 emissions of real Guangdong were lower than those of synthetic Guangdong. However,

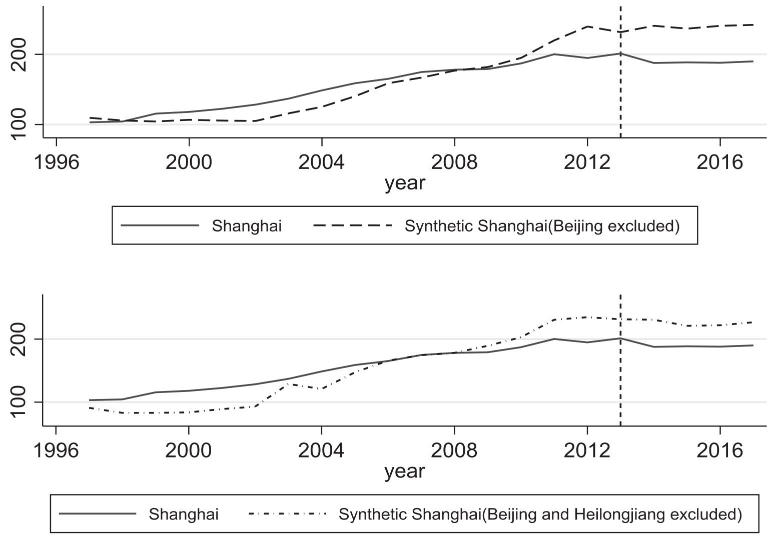

Fig. 5. Leave-one-out sensitivity analysis.

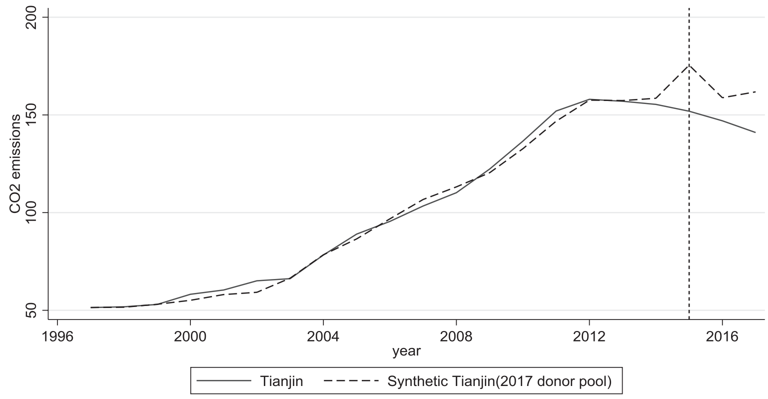

Fig. 6. Trends in CO_2 emissions: Tianjin versus Synthetic Tianjin.

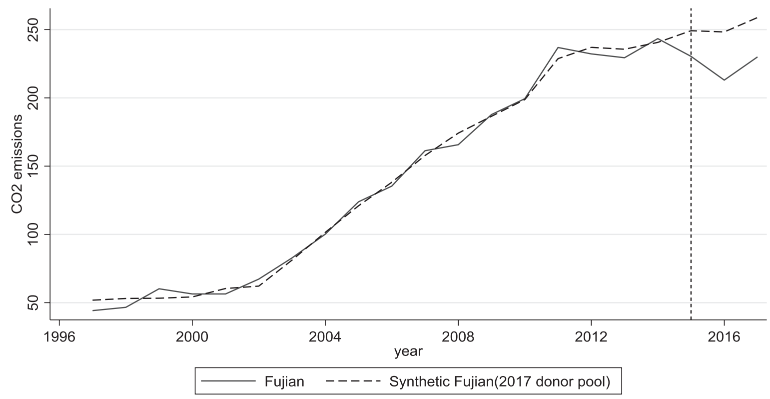

Fig. 7. Trends in CO_2 emissions: Fujian versus Synthetic Fujian.

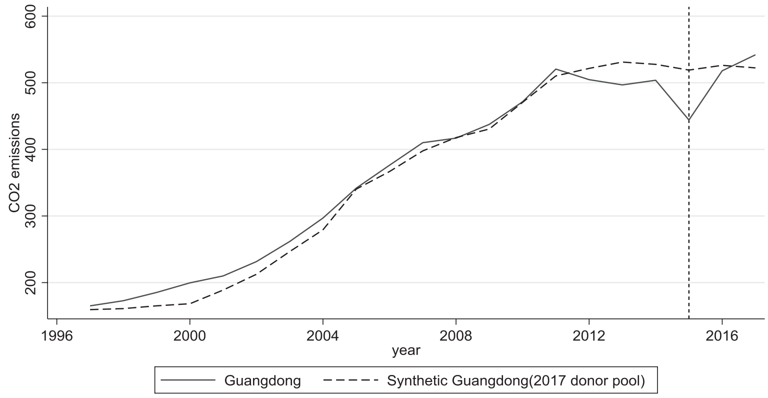

Fig. 8. Trends in CO_2 emissions: Guangdong versus Synthetic Guangdong.

in 2017, the CO_2 emissions of real Guangdong and Synthetic Guangdong were very close, with the CO_2 emissions of real Guangdong slightly higher than those of synthetic Guangdong. It is normal for CO_2 emissions to fluctuate to some extent. Due to the data after 2017 are not available, we also cannot observe the long-term differences between real and synthetic Guangdong. In summary, studies on Guangdong FTZ, Tianjin FTZ and Fujian FTZ also indicate that FTZ policy does reduce CO_2 emissions in the short term.

Robustness Test: Difference-in-Differences Model

To prove the effectiveness of the above empirical results, this study further employs the DID model to examine the impact of the FTZ policy on CO_2 emissions. The method can provide a unique opportunity to be able to avoid the occurrence of sample selection bias the potential endogeneity [56]. Given that the FTZs were randomly selected to be established in batches by the Chinese government, the policy conforms to the nature of quasi-natural experiments. Therefore, this paper refers to the practice of Liu and Sun (2019), the model specification takes the following form [57]:

$$C_{it} = \alpha + \beta dt_{it} + \sum \gamma_i X_{it} + \mu_i + \tau_t + \varepsilon_{it} \tag{6}$$

where *i* and *t* refer to provinces and years, respectively. The outcome of interest, denoted C_{it}, is the CO_2 emissions recorded in province *i* in year *t*. dt_{it} indicates whether the province set up an FTZ, which is a dummy variable that takes a value of 1 when and after the province set up an FTZ, and the others obtain a value of 0. The coefficient in which we are most interested is β, which reflects the carbon emission reduction effect of FTZs. X_{it} represents a set of control variables, including economic development level (*PGDP*), industrial structure (*secd*), development level of service industry (*serv*), industrial structure upgrading (*stru*), energy consumption (*enegc*), population density (*popu*) and

Table 3. DID estimation results.

	(1)	(2)	(3)	(4)
	C_{it}	$Ln(C_{it})$	C_{it}	$Ln(C_{it})$
dt	-62.383***	-0.220***	-94.735***	-0.141***
	(23.403)	(0.057)	(16.915)	(0.047)
Constant	98.591***	4.353***	112.872	3.401***
	(11.804)	(0.029)	(81.220)	(0.226)
Control variables	NO	NO	YES	YES
Time FE	YES	YES	YES	YES
Province/Municipality FE	YES	YES	YES	YES
Observations	597	596	595	594
Adjusted R^2	0.670	0.905	0.838	0.938
N	30	30	30	30

Note: *, **, and *** represent coefficients are significant at the 10%, 5%, and 1% levels, respectively.

technological progress (*tech*). μ_i is the fixed effect of province or municipality, τ_t is the fixed effect of year and ε_{it} is the error term.

The estimated results are presented in Table 3. In column (1) and (2), only the dummy variable (*dt*) is used as the independent variable for the regression analysis, and the estimated coefficient is negative and significant at the 1% level. This finding indicates that, compared to non-pilot cities, the FTZ pilots significantly lowers CO_2 emissions. In columns (3) and (4), when the control variables are added, the coefficient of FTZ pilots(*dt*) on CO_2 emissions is significantly negative. This result suggests that the carbon emission reduction effect of the pilot FTZ has strong robustness.

Conclusions and Policy Implications

Conclusions

In the context of global integration and increasing global warming, the impact of free trade on carbon dioxide emissions has been the subject of significant debates. In recent years, China has implemented an FTZ policy that includes greater openness to services, the transformation of government function and the optimization of regulatory system. We use a synthetic control method to investigate the effects on carbon dioxide emissions of the FTZ policy in China. Based on data-driven procedures to construct a counterfactual control group, the synthetic control method accounts for potential time-varying unobservable in DID and other policy evaluation methods. Results from our research suggest that Shanghai's FTZ policy has effectively reduced carbon dioxide emissions. The result of a placebo test shows that the gap between real Shanghai and Synthetic Shanghai appears higher than that for other provinces or municipalities, and the ratios of post/pre-FTZ policy MSPE in Shanghai are higher than that in all control provinces or municipalities. A similar decline in carbon dioxide emissions is observed for Tianjin, Fujian, and Guangdong coinciding with the timing of the FTZ policy and deviating from the trends for their synthetic counterparts. Further research through the DID method also suggests that the pilot FTZ has an obvious emission reduction effect, thereby proving the robustness of our results.

Policy Implications

Firstly, China's FTZ pilot has made considerable progress in improving administrative efficiency and the regulatory mechanism. On this basis, government efficiency and regulatory quality can be further improved. For example, scientific regulation and management means can be implemented to continuously reduce the cost of government regulations and improve the efficiency of government regulations and management. The government can also continue to explore institutional innovation, such as the third-party supervision system, to reduce the occurrence of over-emissions by enterprises. Moreover, the pilots have implemented policies to promote financial liberalization and internationalization, effectively promoting the development of the financial industry. Next, we must further promote financial products and service methods under the low-carbon concept, such as green credit and green securities. To create a good external financial environment for the green development of foreign-funded enterprises, the level of financial development must be improved continuously.

Secondly, during the construction of the FTZ, we should pay full attention to the role of environmental regulation. Although the policy contains some relevant regulations on environmental protection, the regulations on controlling carbon dioxide emissions are still incomplete. The government should formulate a reasonable level of environmental supervision intensity and effective measures, explore, and establish a statistical reporting system for greenhouse gas emission of key enterprises and a carbon dioxide emissions evaluation system for major projects, and strengthen the supervision of corporate carbon dioxide emissions. To ensure environmental regulation plays a role in suppressing carbon dioxide emissions, we must comprehensively use command-control and market-incentive environmental regulations. Apart from formulating emission standards to control carbon dioxide emissions from the source, we can also explore technology investment and subsidies for polluting enterprises to promote the transformation of the enterprises to green development.

Thirdly, the FTZ has created good conditions for the introduction of FDI. As FDI may cause environmental degradation, the environmental supervision mechanism for the introduction of FDI should be further perfected in the construction of FTZ. In particular, it is necessary to further improve the environmental protection negative list system of FDI import projects, improve the environmental entry threshold for FDI, and guide FDI with both quality and efficiency into the high-tech industry, thereby amplifying its pollution halo effect. In addition, the technology spillover effect of FDI should also be fully utilized to carry out independent innovation based on learning and imitating the advanced production technologies of foreign enterprises. Accomplishing this objective will accelerate the research and development of low-carbon technologies, achieve clean production, and reduce CO_2 emissions.

Fourthly, China's FTZ policy has attracted a large number of high-end service industry enterprises and high-tech enterprises by liberalizing the service industry and implementing preferential tax policies for high-tech industries. Relying on the advantages of the policy, low-carbon industries such as telecommunications and financial services industries in the Shanghai FTZ and the new energy and new materials industries in the Guangdong FTZ have all developed well. Next, we can further promote the development of other emerging low-carbon industries. At the same time, we can promote the development of low-carbon technologies to upgrade traditional industries, and give priority to supporting the development of low-energy consumption and environmentally friendly industries. In addition, we can strive to build a modern industrial system characterized by low emissions.

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Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

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