Carbon Trading Scheme in the People's Republic of China: Evaluating the Performance of Seven Pilot Projects

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The People's Republic of China (PRC) launched seven emissions trading scheme (ETS) pilot projects in 2013–2014 to explore a cost-effective approach for low-carbon development. The central government subsequently announced its plans for the full-fledged implementation of ETS in the entire PRC in late 2017. To ensure the success of ETS in the PRC, it is necessary to gain a better understanding of the experiences and lessons learned in the pilot projects. In this paper, we provide a policy overview of the seven pilot projects, including policy design, legislative basis, and market performance. We use the synthetic control method to evaluate the carbon mitigation effect of each of the seven ETS pilots. Our findings are that success has been limited and uneven across the pilot projects, which warrants deeper evaluation of the differences between them and caution in scheme expansion. Results from the analysis also shed light on policy improvements that can benefit the nationwide development of ETS.

Keywords: cap-and-trade, climate change, emissions trading schemes, synthetic control method
JEL codes: Q51, Q54, Q56

I. Introduction

The need to address climate change and reduce greenhouse gas (GHG) emissions has become the consensus of the world's major countries. Policy makers are employing or contemplating the use of market-based instruments for climate policy. In recent years, cap-and-trade schemes have commanded attention in discussions related to climate change. The theoretical attraction of cap-and-trade is its potential to reduce emissions at lower cost than conventional, direct regulations such as mandated technologies or performance standards.

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Asian Development Review, vol. 35, no. 2, pp. 131–152
https://doi.org/10.1162/adev_a_00117

In October 2011, the National Development and Reform Commission (NDRC) of the People's Republic of China (PRC) designated seven provinces and cities—Beijing, Chongqing, Guangdong, Hubei, Shanghai, Shenzhen, and Tianjin—as regional pilot projects in a carbon emissions trading scheme (ETS) that is consistent with the logic of a cap-and-trade system (NDRC 2011). The Government of the PRC also established a nationwide carbon emissions trading market at the end of 2017. While there is a wide agreement among economists as to the potential advantages of market-based instruments, there is much debate as to whether ETS is the best policy option for the PRC.

This article provides an overview and analysis of the PRC's carbon market based on 4 years of pilot testing. We introduce the background and market performances of ETS, along with a comparison of the seven pilot projects in different regions of the PRC. We use the synthetic control method to evaluate emissions reduction achievements at the regional level. Challenges that exist in the PRC carbon market are identified and policy recommendations to further improve the market are also provided.

The rest of this paper is organized as follows. The next section lays out the legislation that supports the PRC's ETS system and analyzes existing regulations. Section III focuses on the actual market performances of the seven pilot projects. Section IV evaluates the carbon mitigation effect of the seven pilot projects based on the synthetic control method. The final section provides highlights of key conclusions from the analysis, the main challenges to successful implementation of ETS, and policy recommendations to support the program's expansion nationwide.

II. Policy Overview

Theoretically, ETS affects total GHG emissions by creating a market for emissions permits allocated to individual emitters under an aggregate emissions cap. The regulatory authority stipulates the total allowable quantity of emissions. In doing so, the level of scarcity of allowable GHG emissions is determined; total allowable emissions are then divided into a certain number of emissions permits that are allocated to individual emitters based upon certain rules. Recognizing differences in marginal costs of implementing the permits by different individual emitters, the trading of permits is allowed and an equilibrium price for the permits emerges. This equilibrium price provides a signal as to the level of scarcity of the emissions permits, guiding individual emitters (firms most likely) to choose between reducing or increasing GHG emissions, and to identify technologies corresponding to their choices. Moreover, an effective ETS achieves the set cap with minimum social costs.

In 2009, the PRC pledged to reduce by 2020 the intensity of carbon dioxide (CO_2) emissions per unit of gross domestic product (GDP) by 40%–45% from

Table 1. **Legislative Basis of Seven Emissions Trading Scheme Pilots**

Pilot Province or City	Legal Document
Beijing	Resolution on Beijing to Carry Out Carbon Trade Pilot under the Premise of Strictly Controlling Total Carbon Emissions (Beijing Municipal People's Congress Standing Committee) (31 December 2013)
Shanghai	Shanghai Carbon Emission Management Interim Guidelines (Shanghai Municipal People's Government Order No. 10) (18 November 2013)
Guangdong	Guangdong Province Carbon Emission Management Interim Guidelines (Guangdong Provincial People's Government Order No. 197) (15 January 2014)
Shenzhen	Regulation on Carbon Emission Management for the Shenzhen Special Economic Zone (Shenzhen Municipal People's Congress) (30 December 2012)
Tianjin	Notice on Issuing the Interim Measures on Carbon Emissions Trading in Tianjin (General Office of Tianjin Municipal People's Government) (21 May 2013)
Hubei	Hubei Province Carbon Emissions and Trade Management Interim Measures (Hubei Provincial Government Order No. 371) (25 April 2014)
Chongqing	Chongqing Carbon Emission and Trade Management Interim Measures (Chongqing Municipal People's Government 41st Executive Meeting) (27 March 2014)

Sources: All data are from the following local municipal government websites. For Beijing, http://www.bjrd.gov.cn/zdgz/zyfb/jyjd/201312/t20131230_124249.html; for Shanghai, http://www.shanghai.gov.cn/nw2/nw2314/nw2319/nw2407/nw31294/u26aw37414.html; for Guangdong, http://zwgk.gd.gov.cn/006939748/201401/t20140117_462131.html; for Shenzhen, http://www.sz.gov.cn/zfgb/2013/gb817/201301/t20130110_2099860.htm; for Tianjin, http://qhs.ndrc.gov.cn/qjfzjz/201312/t20131231_697047.html; for Hubei, http://fgw.hubei.gov.cn/ywcs2016/qhc/zg_gzdt/bgs_wbwj/201404/t20140425_76918.shtml; and for Chongqing, http://www.cq.gov.cn/publicinfo/web/views/Show!detail.action?sid=3874934.

2005 levels. In December 2011, the PRC suggested for the first time in its 12th Five-Year Plan for National Economic and Social Development to "gradually establish a carbon emissions trading market" as a way to control GHG emissions. The GHG Emissions Control Work Schedule for the 12th Five-Year Plan specifically points to establishing a "carbon emissions trading pilot" and developing the PRC's "overall program for [a] carbon trading market." This indicates that the PRC's carbon trading policy will follow the principle of "first pilot at the local level, then scale up." In October 2011, a Notice on Conducting Carbon Trading Pilots by the NDRC confirmed seven designated pilots. The pilot provinces and cities established an institutional basis for carbon trading and officially launched trading in 2013–2014. Building on the pilot experience, the PRC accelerated the construction of a national carbon trading market, which began operation on 19 December 2017.

Establishing the legal basis of ETS is an important prerequisite for successful implementation. The legal documents listed in Table 1 carry different legal weight: some are resolutions passed by the local People's Congress Standing Committees, while others are government orders. In addition to legal tools, some pilot ETSs also use administrative methods such as confiscation of the following year's permits and public shaming to promote compliance among firms.

The science, rationality, and effectiveness associated with ETS design is also critical for the success of each pilot and of the future national carbon market. In addition to learning from existing markets globally, including the European ETS and the Regional GHG Initiative in the United States, the PRC has conducted in-depth studies into its own conditions in order to establish locally appropriate markets. Overall, the cap-and-trade schemes in the PRC's seven pilots have the following characteristics:

- **Executive entity.** In most cases, the executive entity is the local Development and Reform Commission, generally its department in charge of resources, environment, and energy. Local finance bureaus and other departments provide support to implementation.

- **Industries regulated.** Almost all energy-intensive industries are covered in the pilot trading schemes, including electricity, steel, cement, and chemicals. The Beijing, Shanghai, and Tianjin ETSs also include the construction and services industries.

- **Government intervention**. Government intervention in the carbon market includes emissions data collection, emissions permit allocation and auction, and interventions in market pricing when necessary. For example, the Beijing, Shanghai, and Shenzhen ETSs put forward market conditions and methodologies to regulate prices for emissions permits.

- **Permit allocation methodology**. All pilots adopted the historical emissions method to allocate permits, while the benchmarking method was used for new facilities and certain industries. The Guangdong, Hubei, and Shenzhen ETSs conducted auctions for emissions permit allocation. Other pilots generally distributed permits free of charge.

- **Transaction and reporting thresholds**. The pilots also set market access conditions for companies involved in the trading scheme and announced thresholds for emissions reporting for other large emitters that were not covered by the trading system (referred as "reporting companies"). These companies must report their emissions to the government on an annual basis so the latter can determine whether they should be included in the future carbon trading scheme or not. The emissions of companies involved in carbon trading (referred to as "emissions control companies") account for about 60% of total regional emissions in Guangdong and Tianjin, and for more than 40% in other pilot regions (Table 2).

Table 2. **Carbon Emissions Cap and Number of Covered Companies in Seven Pilots**

Pilot Province or City	Carbon Emissions Cap (CO_2 million tons/year)	Number of Covered Companies	Proportion of Allowance in Total Emissions
Beijing	70	490	40.0%
Shanghai	510	191	57.0%
Guangdong	350	202	58.0%
Shenzhen	30	635	40.0%
Tianjin	150	114	60.0%
Hubei	120	138	35.9%
Chongqing	100	242	39.5%

CO_2 = carbon dioxide.
Notes: Most pilots increased their number of covered companies each year. The information in this table is for the initial year of each pilot. All pilots were launched in 2013, except for Hubei and Chongqing, which were launched in 2014.
Source: Carbon Emissions Allowance Management Rules (Interim) published by the local government in each pilot region.

Table 3. **Trading Indicators of the Seven Emissions Trading Scheme Pilots**

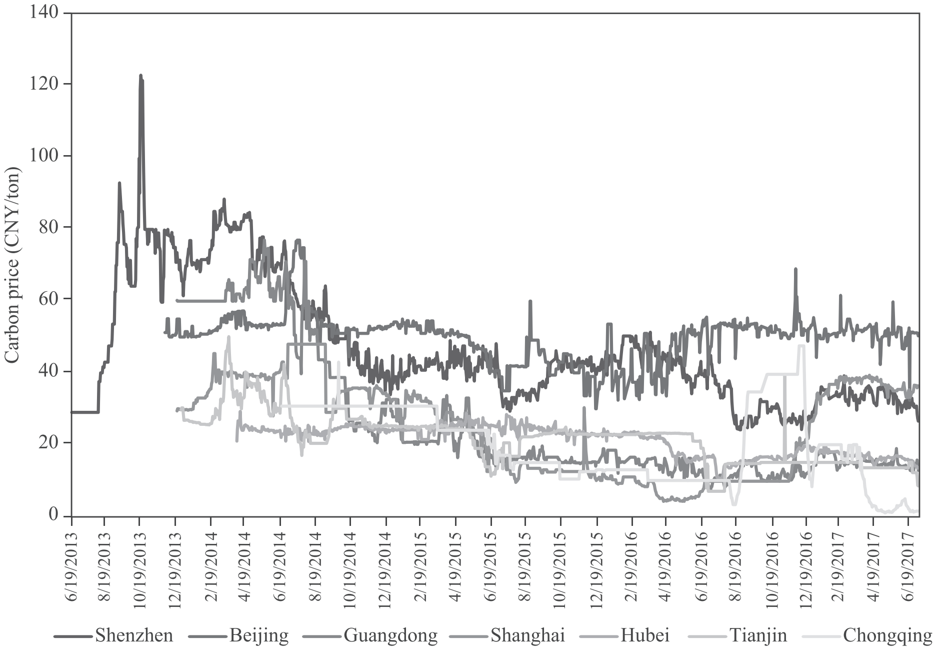
Pilot Province or City	Starting Date	Active Ratio[a]	Average Trading Price (CNY/ton CO_2)	Average Trading Volume (ton/day)	Share of Total Volume
Shenzhen	19 Jun 2013	90%	47	18,604	16%
Beijing	28 Nov 2013	69%	50	7,869	6%
Shanghai	19 Dec 2013	63%	25	11,819	9%
Guangdong	19 Dec 2013	71%	26	34,399	26%
Tianjin	26 Dec 2013	52%	22	3,450	3%
Hubei	2 Apr 2014	96%	21	50,163	35%
Chongqing	16 Jun 2014	18%	20	6,644	5%
Average	…	66%	30	18,992	…

CNY = yuan, CO_2 = carbon dioxide.
[a]Active ratio refers to the number of days that have trading volume divided by the total number of trading days.
Source: China Carbon Trading Platform. http://k.tanjiaoyi.com/ (accessed June 30, 2017).

III. Market Performance

The effectiveness of ETS pilots relies not only on institutional design, but also on the actualities of policy implementation. The intermediate effects of the carbon trading policy can be observed through the market performances of the seven ETS pilots. This study selected carbon price and trading volume to evaluate market performance of each of the seven pilots (Table 3).

Figure 1. **Historical Trend of Carbon Prices in the Seven Emissions Trading Scheme Pilots**



CNY = yuan.
Source: China Carbon Trading Platform. http://k.tanjiaoyi.com/ (accessed June 30, 2017).

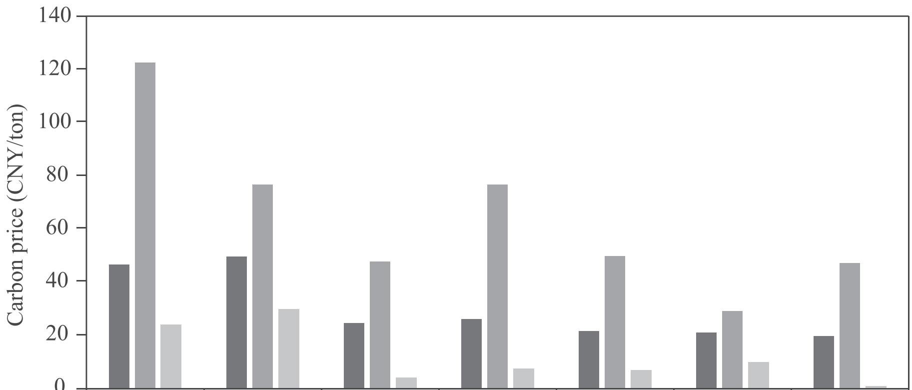
A. Carbon Price

Price fluctuations were observed to be normal in most ETS pilots. Overall, the price fluctuated wildly in 2013; subsequently, price fluctuations were smaller. This is because in the early stage of ETS in the PRC, there was only one pilot project (Zhao et al. 2016). With the subsequent launching of other ETS pilots, the price fluctuations moderated (Figure 1).

Price differences are obvious among the seven ETS pilots, with the overall average price in the review period (June 2013–June 2017) being CNY30 per ton. The average price was CNY50 per ton in Beijing, which ranks the highest, followed by Shenzhen at CNY47 per ton. The average price in Chongqing in June 2017 was CNY20 per ton, which ranks the lowest. The lowest price observed in Beijing during the review period was CNY44 per ton, which is still higher than the national average price and the peak price observed in Chongqing.

As can be seen from Figure 2, among the seven pilot ETSs, prices fluctuated the most in Tianjin and Shenzhen, while price movements in Hubei ETS were relatively small. However, when approaching the compliance deadline (mainly in

Figure 2. **Peak Price, Average Price, and Lowest Price of the Seven Emissions Trading Scheme Pilots**



	Shenzhen	Beijing	Shanghai	Guangdong	Tianjin	Hubei	Chongqing
Average price	46.88	49.87	24.73	26.27	21.73	21.20	19.87
Peak price	122.97	77.00	48.00	77.00	50.10	29.35	47.52
Bottom price	24.13	30.00	4.20	7.57	7.00	10.07	1.00

CNY = yuan.
Source: Authors' calculations based on data from China Carbon Trading Platform. http://k.tanjiaoyi.com/ (accessed June 30, 2017).

June or July each year), the carbon price always rose.[1] Although price fluctuations are common in the early stage of ETSs globally, excessive price fluctuations are not conducive to reflecting the actual cost of carbon emissions. They create huge risks for market participants and uncertainty for the covered companies.

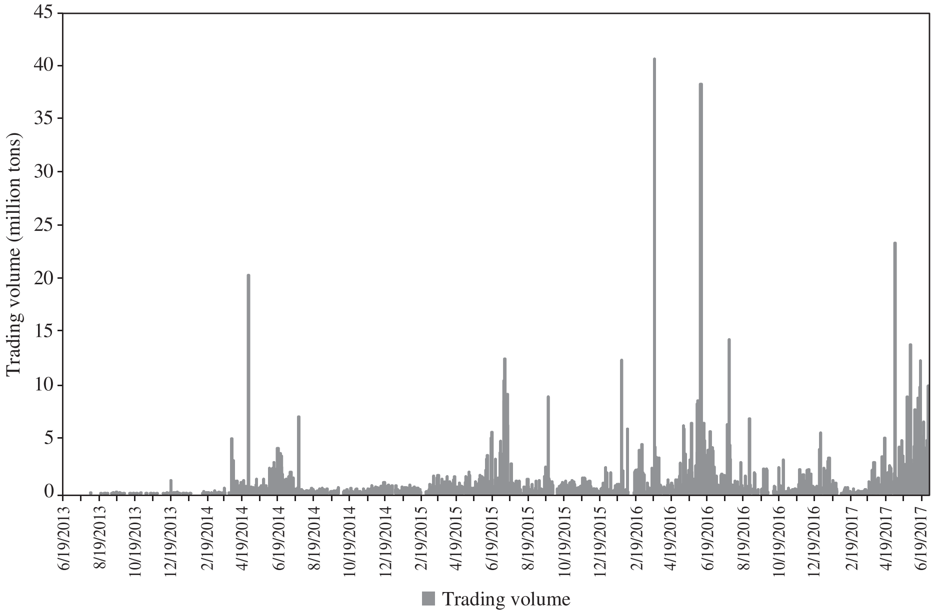
B. Trading Volume

Another characteristic of ETS pilots is their low trading volumes, which seems to be a big challenge for the PRC's carbon market. There is little or even no trading volume on most days. However, the trading volume of each ETS pilot increased sharply before its respective compliance period (Figure 3).

Although the overall size of the PRC's seven pilot carbon markets is substantial, companies were not enthusiastic in participating in carbon trading, as evidenced by the ratio of cumulative trading volumes to carbon emissions cap. Zhao et al. (2016) depicted this phenomenon: for the Shenzhen ETS, the cumulative trading volume only accounted for 5.6% of the carbon emissions cap, which is the highest among the seven ETS pilots. In the other six pilots, the ratios were

[1] When approaching compliance deadline, all participants must ensure that they have followed the procedural steps or they may get penalized.

Figure 3. **Historical Trend of Trading Volumes in the Seven Emissions Trading Scheme Pilots**

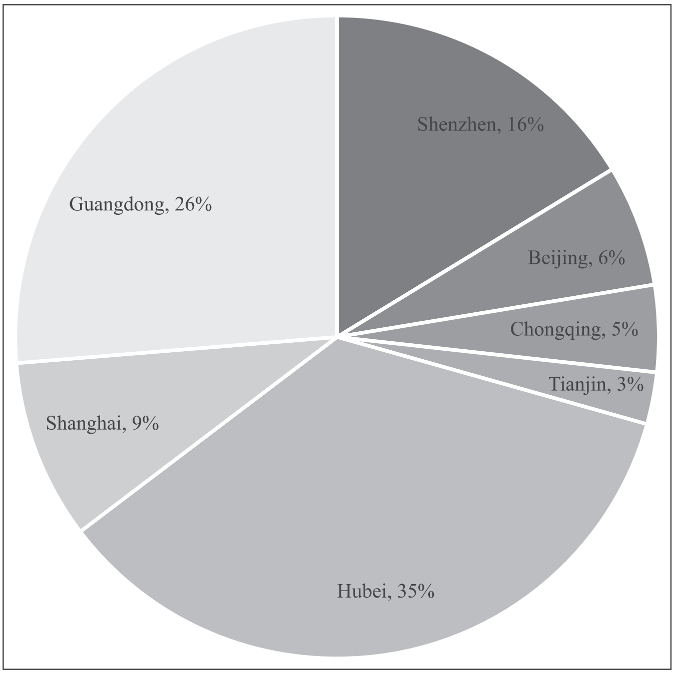


Source: Authors' calculations based on data from China Carbon Trading Platform. http://k.tanjiaoyi.com/ (accessed June 30, 2017).

4.9% in Hubei, 3% in Beijing, 2% in Shanghai, and less than 1% in each of the other three pilot locations. The total cumulative trading volume of seven ETS pilots only accounted for 1.4% of the total carbon emissions cap. Thus, the ratio is rather low and most of the allowances have not been traded. It is partly because of policy uncertainty during the pilot period of ETS, so it is difficult for covered companies to stay cautious. In addition, during the pilot period, covered companies are pressured by other existing energy conservation policies (e.g., energy saving targets) so ETS may not substantially influence companies' behavior.

Comparing compliance across the seven pilot ETSs—from the start date until the end date of the trading period—reveals that the Hubei, Guangdong, and Shenzhen ETSs had the most active trading. From the perspective of secondary market performance, the design and operation of the Hubei ETS has been successful. By 30 June 2017, cumulative nationwide trading volume was 114.6 million tons, among which the cumulative trading volume of the Hubei ETS was 40.4 million tons, or about 35% of the total. The Guangdong and Shenzhen ETSs also both had a larger trading volume than either the Beijing, Shanghai, Chongqing, or Tianjin ETSs (Figure 4). At the same time, Tianjin and Chongqing seems to be far behind the average level, reflected by fairly low market liquidity in the two places.

Figure 4. **Trading Volume Shares of the Seven Emissions Trading Scheme Pilots**



Source: Authors' calculations based on data from China Carbon Trading Platform. http://k.tanjiaoyi.com/ (accessed June 30, 2017).

IV. Emissions Reduction Achievements

With important implications for global climate change mitigation, the development of ETS in the PRC has attracted increasing attention in recent years. Before ETS was actually implemented, many researchers discussed the mechanism design and regional linkages from a theoretical perspective. With the establishment of ETS in the PRC, researchers began evaluating its emissions reduction achievements. In this section, we focus on the carbon mitigation effect of the seven pilot ETSs.

A. Research on Emissions Trading Scheme Impact Assessment

Perhaps because the PRC's ETS pilots only covered a short amount of time from preparation to commissioning, most attention has been paid to estimating the potential (ex ante) impacts of the regional ETSs and the hypothetical nationwide ETS (Jiang et al. 2016). There are few studies conducting an impact assessment from ex post empirical perspectives.

Many researchers have used computable general equilibrium (CGE) or CGE-based models to assess the PRC's upcoming national ETS. Tang and Wu (2013) established an interregional CGE model to simulate social welfare impacts of different climate policies. They found that ETS can moderate the economic and social welfare losses regardless of the allocation of emissions permits. Liu et al. (2013) used a Sino-TERMCO2 model to investigate carbon abatement effects of separated and linked markets. Their results showed that the linked market can improve social welfare and reduce carbon emissions intensity, but this system may distribute welfare more unevenly among different industries.

As current research mainly focuses on individual ETS pilots, a comprehensive comparison of all seven pilots is needed. For the Shanghai ETS, for example, Zhou (2015) simulated the economic impacts and cobenefits under alternative employment conditions. The results illustrated that a double dividend from carbon emissions trading is available if the labor released from ETS-affected sectors is absorbed immediately. Otherwise, GDP will decrease 1.5%–2.4% compared to the baseline. For the Guangdong ETS, Wang et al. (2015) used a GD_CGE model to simulate the effects of carbon mitigation through ETS under the carbon intensity target. The results show that with an abatement target, implementation of ETS can reduce abatement costs and decrease GDP losses, which constitutes a cost-effective way to achieve carbon reduction. Ren, Dai, and Wang (2015) used a dynamic two-region CGE model and the results showed that if a carbon trading policy is implemented in a low-carbon scenario GDP declines 0.8% relative to the baseline. For the Hubei ETS, Tan, Liu, and Wang (2016) used a multiregional general equilibrium model (Term-CO_2) to simulate economic and environmental impacts. The results showed that the carbon emissions of Hubei are reduced by 1% and GDP declines slightly by 0.06%. For the Tianjin ETS, Liu et al. (2017) simulated the impacts on the economy and environment using a Term-CO_2 model. The results showed that carbon emissions decrease by 0.62% and GDP declines a marginal 0.04%.

To sum up, these studies showed that ETS has the potential to lower the total economic costs and social welfare losses caused by carbon emissions abatement in the PRC, but its impact significantly varies by province and sector. Among these studies, however, only a small number of such impact assessments have been conducted and most of them have drawn qualitative conclusions. Empirical ex post impact assessments of the pilot ETSs are needed to guide the operation of the PRC's nationwide ETS (Jiang et al. 2016).

B. Method and Data

To estimate the effects of events and policy interventions at the aggregate level, researchers often use comparative case studies. In such studies, researchers estimate the evolution of aggregate outcomes (in this case, CO_2 emissions) for a unit affected by an occurrence of the event and compare it to the evolution of the same aggregates estimated for some control group of unaffected units. However, it is difficult to estimate the carbon mitigation effect of carbon trading because of the lack of solid control groups in this case.

The synthetic control method is used for effect estimation in settings where a single unit (e.g., state, country, or firm) is exposed to an event or intervention. The synthetic control method was first introduced and implemented in Abadie and Gardeazabal (2003). Other comparative studies include investigating the economic impacts of German reunification (Abadie, Diamond, and Hainmueller 2015) and the local impacts of nuclear power facilities (Ando 2015). There is also a series of research focusing on the PRC. Liu and Fan (2013) examine the economic impacts of the PRC's house property tax pilot program in Chongqing. Zhang, Zhong, and Yi (2016) used this same method to answer the question of whether the Olympic Games improved air quality in Beijing.

Based on Abadie, Diamond, and Hainmueller (2011), we use a simple model providing a rationale for the use of the synthetic control method. Suppose that we observe $J+1$ regions, and the first region is exposed to the intervention of interest, so that we have J remaining regions as potential controls. Suppose Y_{it}^N is the outcome that would be observed for region i at time t without treatment for units $i = 1, 2, \ldots J+1$, and time periods $t = 1, 2, \ldots T$. Let T_0 be the number of preintervention periods, with $1 < T_0 < T$. Let Y_{it}^I be the outcome that would be observed for region i at time t with treatment in periods T_0+1 to T. We assume that the intervention has no effect on the outcome before the implementation period, so for all i in period $t \in \{1, 2, \ldots T_0\}$, we have $Y_{it}^N = Y_{it}^I$. Let $\alpha_{it} = Y_{it}^I - Y_{it}^N$ be the effect of the intervention for unit i at time t, and let D_{it} be an indicator that takes a value of 1 if unit i is exposed to the intervention at time t and zero otherwise. The observed outcome for unit i at time t is

$$Y_{it} = Y_{it}^N + D_{it}\alpha_{it} \tag{1}$$

We aim to estimate $(\alpha_{1T_0+1}, \ldots \alpha_{1T})$. For $t > T_0$,

$$\alpha_{1t} = Y_{1t}^I - Y_{1t}^N = Y_{1t} - Y_{1t}^N \tag{2}$$

Because Y_{it}^I is observed, to estimate α_{1t} we just need to estimate Y_{1t}^N; suppose that Y_{it}^N is given by a factor model:

$$Y_{it}^N = \partial_t + \theta_t Z_i + \lambda_t \mu_i + \varepsilon_{it} \tag{3}$$

where Z_i is a $(r \times 1)$ vector of observed covariates (not affected by the intervention), ∂_t is an unknown common factor with constant factor loading across units, λ_t is a $(1 \times F)$ vector of unknown parameters, μ_i is a $(F \times 1)$ vector of unobserved factor loadings, and the error term ε_{it} represents unobserved transitory shocks at the regional level with zero mean.

We have to estimate Y_{it}^N. Consider a $(J \times 1)$ vector of weights $W^* = (w_2^*, \ldots w_{j+1}^*)$ such that $W_J \geq 0$ for $j = 2, \ldots, J+1$ and $w_2 + \cdots + w_{J+1} = 1$. Each value of the vector W^* represents a potential synthetic control, that is, a particular weighted average of control regions. The value of the outcome variable for each synthetic control indexed by W^* is

$$\sum_{j=2}^{J+1} w_j Y_{it} = \partial_t + \theta_t \sum_{j=2}^{J+1} w_j Z_j + \lambda_t \sum_{j=2}^{J+1} w_j \mu_i + \sum_{j=2}^{J+1} w_j \varepsilon_{it} \tag{4}$$

Suppose that there are $W^* = (w_2^*, \ \ldots \ w_{j+1}^*)'$ such that

$$\sum_{j=2}^{J+1} w_j^* Y_{jt} = Y_{11}, \ \ldots \sum_{j=2}^{J+1} w_j^* Y_{jT_0} = Y_{1T_0} \quad \text{and} \quad \sum_{j=2}^{J+1} w_j^* Z_j = Z_1 \tag{5}$$

If $\sum_{i=1}^{T_0} \lambda'_t \, \lambda_t$ is nonsingular, then

$$Y_{1t}^N - \sum_{j=2}^{J+1} w_j^* Y_{jt} = \sum_{j=2}^{J+1} w_j^* \sum_{s=1}^{T_0} w_j^* \lambda_t \left(\sum_{i=1}^{T_0} \lambda'_t \, \lambda_t \right)^{-1} \lambda'_s \left(\varepsilon_{js} \varepsilon_{is} \right) - \sum_{j=2}^{J+1} w_j^* \left(\varepsilon_{jt} - \varepsilon_{it} \right) \tag{6}$$

Abadie, Diamond, and Hainmueller (2011) proved that, under the general condition, the right-hand side of equation (6) will approach zero. As a result, $\sum_{j=2}^{J+1} w_j^* Y_{jt}$ is the unbiased estimation of Y_{it}^N, where $T_0 < t \leq T$. So $\alpha_{1t} = Y_{it} - \sum_{j=2}^{J+1} w_j^* Y_{jt}$ is the unbiased estimation of α_{1t}.

Take Hubei as an example. We construct the synthetic Hubei as a weighted average of potential control provinces, with weights chosen so that the resulting synthetic Hubei best reproduces the values of a set of predictors of CO_2 emissions in Hubei before the carbon trading system was implemented (i.e., before 2013). Because the synthetic Hubei is meant to reproduce the CO_2 emissions that would have been observed for Hubei in the absence of a carbon trading pilot, we discard from the donor pool provinces that adopted a carbon trading system during our sample period. Therefore, Beijing, Chongqing, Guangdong, Shanghai, and Tianjin are excluded from the donor pool. Finally, our donor pool includes the remaining 24 provinces.

Our outcome variable of interest is annual CO_2 emissions, calculated based on energy consumption at the provincial level. We use annual provincial-level data of energy consumption during the 1995–2015 period from the *China Statistical Yearbook* (National Bureau of Statistics of China 2016). Since seven pilots went into effect beginning in late 2013, we mark 2013 as the treatment year. This gives us 17 years of preintervention data. Our sample period begins in 1995 because it is the first year for which data on energy consumption are available for all our control provinces. It ends in 2015 because newer data have not yet been published. Based

Table 4. **Social and Economic Characteristics of Actual and Synthetic Emissions Trading Scheme Pilots**

Pilot Province or City		GDP per Capita (CNY)	Share of Secondary Industry in Total GDP (%)
Hubei	(real)	13,703.1	42.6
Hubei	(synthetic)	13,746.8	42.8
Beijing	(real)	42,862.0	29.9
Beijing	(synthetic)	17,454.5	33.5
Shanghai	(real)	47,094.2	46.5
Shanghai	(synthetic)	21,964.8	50.4
Tianjin	(real)	37,534.3	52.8
Tianjin	(synthetic)	14,944.7	48.9
Chongqing	(real)	13,678.4	44.2
Chongqing	(synthetic)	13,286.3	44.3
Guangdong	(real)	24,596.6	48.4
Guangdong	(synthetic)	24,505.5	49.0

CNY = yuan, GDP = gross domestic product.
Source: Authors' calculations.

on the method proposed by the Intergovernmental Panel on Climate Change, we calculate annual CO_2 emissions for all provinces. We choose our predictors of CO_2 emissions based on Auffhammer and Carson (2008): GDP per capita and share of secondary industry in total GDP.

Using the techniques described above, we construct a synthetic for each of Beijing, Chongqing, Guangdong, Hubei, Shanghai, and Tianjin that mirrors the values of the predictors of CO_2 emissions for themselves before the introduction of a carbon trading system. We estimate the carbon mitigation effect of carbon trading pilots as the difference in CO_2 emissions between Hubei and its synthetic version after 2013. We then perform a series of placebo studies that confirm that our estimated effects for carbon trading pilots are unusually large relative to the distribution of the estimate that we obtain when we apply the same analysis to the provinces in the donor pool. Then we repeat the process for Beijing, Chongqing, Guangdong, Shanghai, and Tianjin.

C. Results

As explained above, we construct the synthetic Hubei as the convex combination of provinces in the donor pool that most closely resemble Hubei in terms of prepilot values of CO_2 emissions predictors. The results are displayed in Table 4, which compares the pretreatment characteristics of the actual Hubei with that of the synthetic Hubei, as well as comparisons for the other five pilots. Table 5 displays the weight for each synthetic pilot.

Because social and economic characteristics vary substantially across provinces, different synthetic results emerge. Generally, the closer to the average

Table 5. **Synthetic Weight for Each Synthetic Pilot**

Province	Hubei_ weight	Beijing_ weight	Shanghai_ weight	Tianjin_ weight	Chongqing_ weight	Guangdong_ weight
Anhui	0.036	0	0	0	0.027	0.003
Fujian	0.025	0	0	0	0.030	0.008
Gansu	0.019	0	0	0	0.047	0.003
Guangxi	0.033	0	0	0	0.031	0.003
Guizhou	0.025	0	0	0	0.042	0.003
Hainan	0.096	0.682	0	0	0.080	0.133
Hebei	0.026	0	0	0	0.020	0.003
Heilongjiang	0.018	0	0	0	0.034	0.003
Henan	0.045	0	0	0	0.015	0.003
Hunan	0.059	0	0	0	0.023	0.004
Inner Mongolia	0.024	0	0.018	0	0.036	0.011
Jiangsu	0.057	0	0	0	0.012	0.052
Jiangxi	0.025	0	0	0	0.034	0.003
Jilin	0.017	0	0	0.566	0.040	0.003
Liaoning	0.024	0	0	0	0.026	0.007
Qinghai	0.013	0	0.352	0.381	0.301	0.003
Shaanxi	0.020	0	0	0	0.036	0.003
Shandong	0.027	0	0	0	0.010	0.005
Shanxi	0.017	0	0	0	0.039	0.003
Sichuan	0.322	0	0	0	0.020	0.003
Xinjiang	0.021	0	0	0	0.043	0.004
Yunnan	0.025	0	0	0	0.036	0.003
Zhejiang	0.029	0.318	0.629	0.052	0.020	0.734

Source: Authors' calculations.

level of the whole country, the better the synthetic result is. For example, Hubei, Guangdong, and Tianjin each have a better synthetic result than either Shanghai, Beijing, or Chongqing.

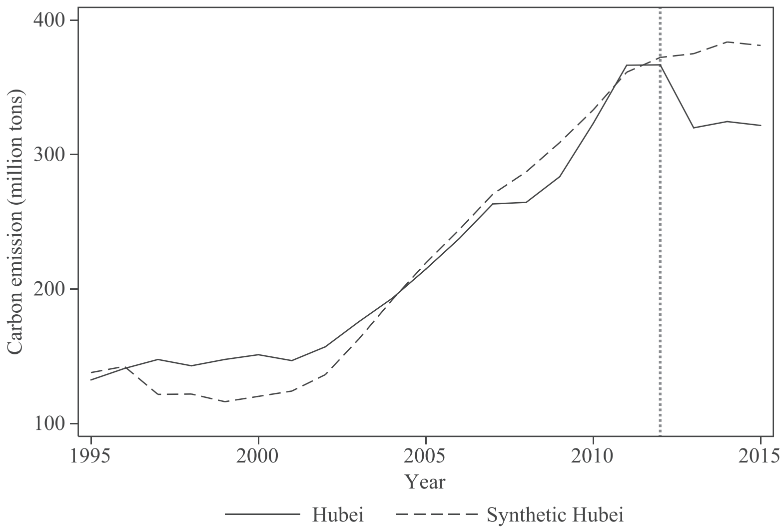
Figure 5 plots the trends in CO_2 emissions in Hubei and the synthetic Hubei. Since 2013, CO_2 emissions in Hubei and synthetic Hubei have differed notably, indicating Hubei reduced CO_2 emissions by about 59.5 million tons in 2015 due to the carbon trading scheme.

Figure 6 shows that before 2013 the synthetic data fit the actual data quite well for Guangdong. After 2013, the gap between the CO_2 emissions of Guangdong and that of synthetic Guangdong emerges, which shows a deviation from the synthetic data. Guangdong (including Shenzhen) reduced CO_2 emissions by 37.1 million tons in 2015.

From the perspective of trading indicators, Hubei and Guangdong (including Shenzhen) had more active trading than the other five pilots. The synthetic results support our expectation that more trading volume results in more emissions reduction.

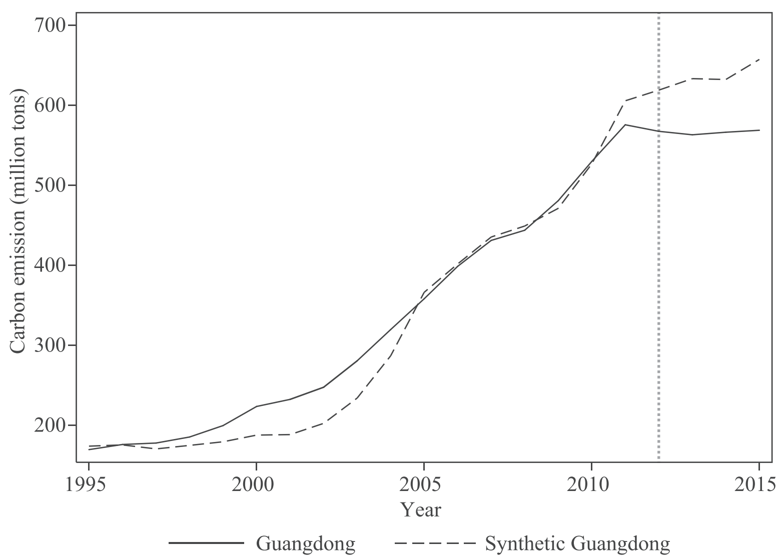
Figure 7 plots the trends in CO_2 emissions in Tianjin and synthetic Tianjin. Since 2013, CO_2 emissions in Tianjin seemed to have outpaced those in synthetic

Figure 5. **Carbon Dioxide Emissions in Hubei versus Synthetic Hubei**



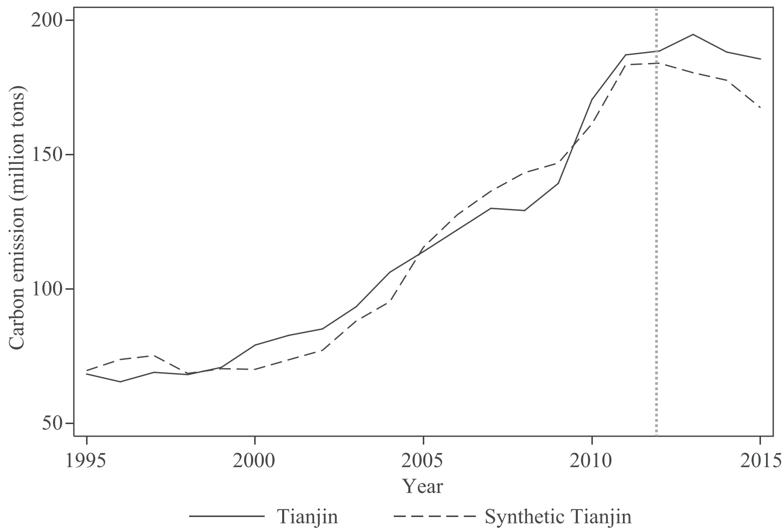
Source: Both actual emissions and synthetic emissions are authors' estimates based on data from the National Bureau of Statistics of China. 2016. *China Statistical Yearbook, 1995–2015*. Beijing.

Figure 6. **Carbon Dioxide Emissions in Guangdong versus Synthetic Guangdong**



Source: Both actual emissions and synthetic emissions are authors' estimates based on data from the National Bureau of Statistics of China. 2016. *China Statistical Yearbook, 1995–2015*. Beijing.

Figure 7. **Carbon Dioxide Emissions in Tianjin versus Synthetic Tianjin**



Source: Both actual emissions and synthetic emissions are authors' estimates based on data from the National Bureau of Statistics of China. 2016. *China Statistical Yearbook, 1995–2015*. Beijing.

Tianjin. The result is expected given the lack of liquidity in the Tianjin trading market.

However, we cannot get good synthetic results before 2013 for Beijing, Chongqing, and Shanghai. Therefore, we cannot say anything about their respective performances yet and are still searching for a better synthetic control strategy for these three municipalities. The existing results are included in the Appendix.

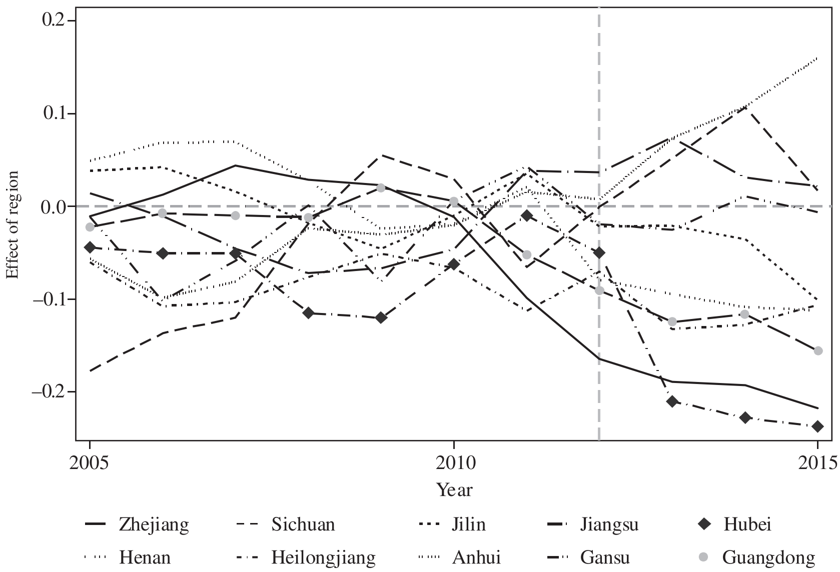
D. Robustness Test

The empirical results in the last section reveal a gap between the CO_2 emissions of Hubei and those of synthetic Hubei. In this context, we will use a placebo test to check the statistical significance of our results.

For example, are there any other provinces among the donor pool that show a gap between real CO_2 emissions and synthetic CO_2 emissions when these provinces are viewed as a treatment group? We iteratively apply the synthetic control method to estimate the impact of the carbon trading pilot on every other province. We can get the difference between real emissions and synthetic emissions, and then we divide the difference by real emissions.

Before doing this test, we need to exclude the provinces that do not fit the original CO_2 emissions data before 2012. The bad fit before the treatment means that the gap after the treatment may not be caused by the treatment itself. Therefore,

Figure 8. **Distribution of Carbon Emissions Forecast Changes in Guangdong, Hubei, and Other Provinces**



Source: Both actual emissions and synthetic emissions are authors' estimates based on data from the National Bureau of Statistics of China. 2016. *China Statistical Yearbook, 1995–2015*. Beijing.

we exclude the provinces whose mean squared prediction error before 2012 are larger than 100. Finally, we obtain nine provinces as a potential control group.

In Figure 8, each gray line represents the difference in CO_2 emissions between each province in the donor pool and its respective synthetic version. The estimated gap for Hubei is unusually large relative to the distribution of the gaps for other provinces in the donor pool. Similarly, Guangdong shows the same pattern since 2013, when its ETS went into effect.

V. Conclusions

Generally, the low trading volume in the PRC's carbon trading market shows that it is not liquid enough to be well functioning. The sharp increase in trading volume before the compliance period shows that the covered companies are unenthusiastic about ETS and view it as a routine government inspection that they must comply with. At the same time, the prohibition on cross-provincial trade reduces the attractiveness of the PRC carbon market to investors, especially institutional investors.

The awareness and participation of companies in the carbon market is still relatively low (China Emissions Exchange 2014). The high trading volume in the month before the compliance period shows that companies still treat carbon emissions trading as a means of compliance rather than an investment. Because the PRC's carbon market is still in an early stage of development, companies' views of carbon asset values will evolve with the development and maturing of the carbon market.

The seven pilot ETSs have achieved different emissions reduction results. Hubei stands out in many aspects as its ETS pilot has been very influential. Based on our synthetic result, Hubei reduced emissions by 59.5 million tons in 2015 through its carbon trading scheme. Guangdong (including Shenzhen) also performed reasonably well, reducing emissions by 37.1 million tons in 2015. On the other hand, Tianjin did not notably reduce its carbon emissions.

For policy recommendations, we suggest the following measures.

The expansion of coverage of the PRC's ETS is necessary. For now, most sectors covered by ETS are energy-intensive sectors such as petroleum processing, electricity, and steel. However, for Beijing, Shanghai, and Shenzhen, where energy-intensive sectors account for a low share of emissions, it is difficult to see an active market with a limited coverage. In these three pilots, the transport sector accounts for a large share of total emissions. According to China Emissions Exchange (2014), the transport sector accounted for 27.9% of Shenzhen's total emissions in 2010. Therefore, including the transport sector in the nationwide ETS is sensible.

Allowing multiple products to activate the ETS system. The PRC's seven ETS all use a single spot product, which may limit the liquidity of carbon markets. On the contrary, for the European Union ETS, forward trading accounts for 80%–90% of the shares traded while spot trading accounts for only about 10% (Aatola, Ollikainen, and Toppinen 2013). We suggest that authorities investigate the possibility to permit necessary derivative products in carbon trading markets. Shanghai and Shenzhen both have a stock exchange and therefore an advantage in promoting financial innovation compared with other pilots. Shanghai and Shenzhen should seize the chance to become the largest carbon futures exchange centers in the world.

Improving market transparency is the foundation to releasing market signals. Not all pilots clearly post information about each covered company. At the same time, although the carbon price and trading volume for each day are posted online, we find it difficult to know the exact trading parties. Improving market transparency would help enhance the efficacy of the system.

Despite the limited success of the ETS program, this has been extended nationwide, starting December 2017. There are two main differences between the nationwide scheme and the seven pilot programs. First, the supervision of the nationwide ETS program has shifted from NDRC to the newly established Ministry of Ecology and Environment. Second, the power generation sector is the only sector in the nationwide scheme, including 1,700 power companies. The coverage of only the power sector is due to two reasons. One is that the power sector is typically energy intensive and accounts for a large share of the PRC's carbon emissions. The other reason is that the power sector has better data. If the initial strategy to include only the power sector goes smoothly, the central authorities intend to extend the market to cover more sectors.

Finally, the PRC began implementing environmental taxes on 1 January 2018. The joint effects of the taxation system and carbon trading schemes on domestic pollution and carbon emissions warrant close monitoring and assessment. Analysis of the joint effects will shed light on needed policy changes and the country's prospects in the battle against pollution and climate change.

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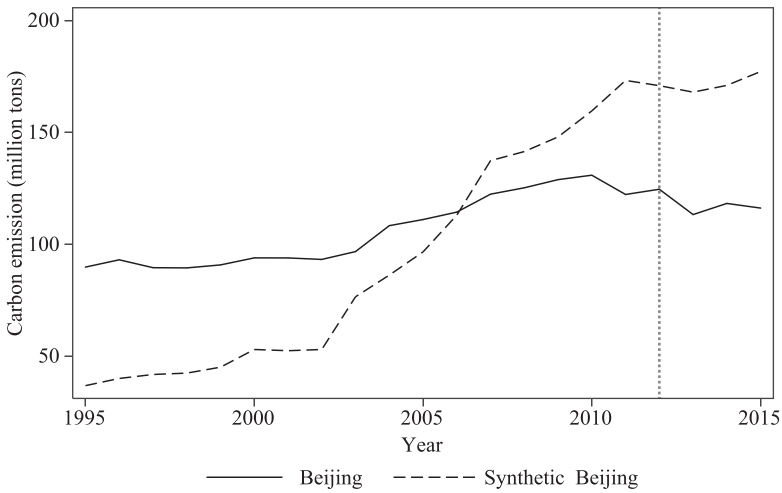
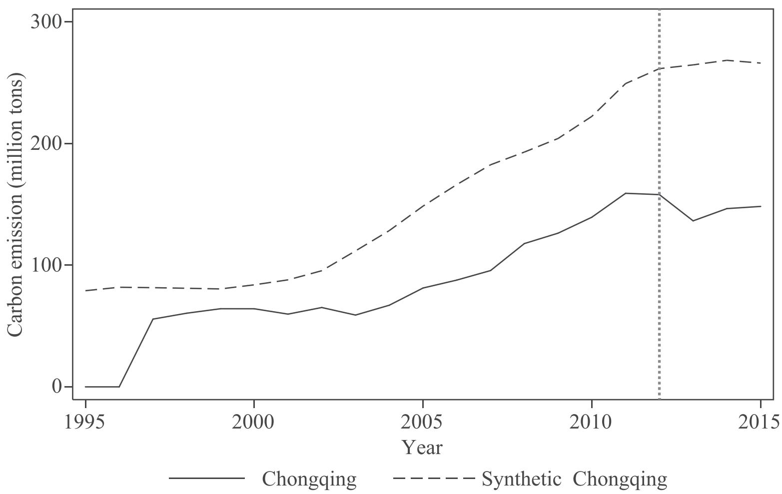
Appendix

Figure A.1. **Comparison of Emissions, Beijing**



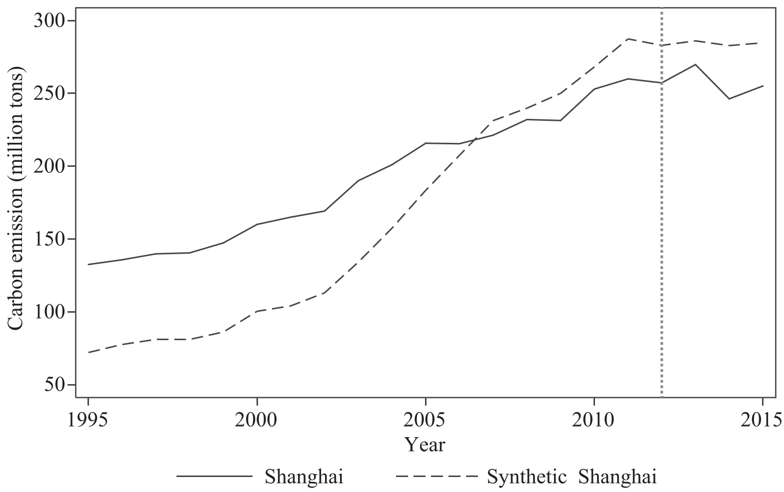
Source: Both actual emissions and synthetic emissions are authors' estimates based on data from the National Bureau of Statistics of China. 2016. *China Statistical Yearbook, 1995–2015*. Beijing.

Figure A.2. **Comparison of Emissions, Chongqing**



Source: Both actual emissions and synthetic emissions are authors' estimates based on data from the National Bureau of Statistics of China. 2016. *China Statistical Yearbook, 1995–2015*. Beijing.

Figure A.3. **Comparison of Emissions, Shanghai**



Source: Both actual emissions and synthetic emissions are authors' estimates based on data from the National Bureau of Statistics of China. 2016. *China Statistical Yearbook, 1995–2015*. Beijing.