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ORIGINAL PAPER

Can national forest city construction mitigate air pollution in China? Evidence from a quasi-natural experiment

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Abstract As air pollution in Chinese cities becomes a growing concern, measures to alleviate air pollution have attracted the attention of all sectors of society. By using the data for 283 prefecture-level cities from 2003 to 2016, we utilized the quasi-natural experiment of the national forest city construction (NFCC) and employed the difference-in-differences approach to examine the effects of NFCC on air pollution. The results show that the NFCC led to a 12.14% and 4.29% reduction in $PM_{2.5}$ concentrations and SO_2 emissions, respectively. A series of robustness tests such as instrumental variable estimates, placebo tests, and eliminating disturbing policies all supported these findings. In addition, we provided evidence that the environment benefits of the NFCC could be explained by increasing green spaces, strengthening environmental regulations, and forming green development models. Furthermore, the results from heterogeneity analysis indicate that the NFCC was more effective in smaller cities, southern cities, and western cities. Our findings are of significance to Chinese cities on the road to sustainable development and provide some insights for other developing countries and emerging markets to control air pollution.

Keywords National forest city construction (NFCC) · Air pollution · Quasi-natural experiment · Difference-in-differences (DID) · China

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Introduction

With the accelerated industrialization and urbanization, environmental problems such as air pollution are becoming more and more prominent in China. According to the Global Environmental Performance Index, jointly published by Yale University, Columbia University, and the World Economic Forum, China ranked 120th out of 180 countries and regions in 2018 and even ranked fourth from the bottom in air quality (Wendling et al., 2018). Increasing air pollution brings a series of socioeconomic problems such as endangering public health (Azizullah et al., 2011; Brunekreef & Holgate, 2002; Neidell, 2004), reducing labor productivity (Zivin & Neidell, 2012; Lichter et al., 2017), and inducing social risks (Deschenes et al., 2020; Ostro et al., 2014).

To address the air pollution problem, the Chinese government has implemented a series of policies, such as Air Pollution Prevention and Control Action Plan (APPCAP) (e.g., Cai et al., 2018; Feng et al., 2019; Huang et al., 2018; Ma et al., 2021), clean energy policies (Chen et al., 2017; Sheehan et al., 2014; Yuan & Zuo, 2011), "Two control Zones" policy (Cai et al., 2016; Hao et al., 2000), and driving restrictions (Han et al., 2020; Zhong et al., 2017). In addition, some previous studies concluded that some policies involving urban development and management could also improve air quality (Fang et al., 2014; Li et al., 2021; Yu, 2014; Yu & Zhang, 2021; Zhu et al., 2019). Different from previous studies, this paper sought to examine whether the national forest city construction (NFCC) helped mitigate air pollution.

The concept of forest cities was first proposed by scholars in the USA and Canada in the 1960s (Xu et al., 2020) and promoted in the USA, Europe, and Japan (Nowak et al., 2006; Tajima, 2003). In China, the national forest city is officially defined as a city whose ecosystem is dominated by forest vegetation and whose ecological construction has achieved integrated urban and rural development (Liao et al., 2021; Zhang et al., 2021). At the China Urban Forestry Forum, the national forestry authorities announce the annual list of national forest cities that meet related standards. Considering that the NFCC is a model centered on urban vegetation and green development in China (Zhang et al., 2021), it may become an important way to mitigate urban air pollution.

Specifically, the NFCC directly increased green spaces and improve vegetation coverage, which reduced the content of pollutants in the air (e.g., Escobedo et al., 2011; Lei et al., 2021; Nowak et al., 2006). In addition, to pass the assessment of NFCC, local governments further strengthened environmental regulation and indirectly improve air quality (Cole et al., 2005; Tanaka, 2015). More importantly, the concept of sustainable development caused by NFCC might give rise to green development models (Pérez-Campuzano et al., 2016; Wang et al., 2013). For example, the NFCC is more conducive to the development of eco-friendly related industries and promotes green innovation. Taken together, the NFCC employed more ecological means to improve the city environment, which is an important direction for sustainable development in Chinese cities.

Since 2004, China has established 192 national forest cities in 26 provinces. As the NFCC is in full swing throughout the country, three studies explored the environmental benefits of NFCC. Xu et al. (2020) took the Beijing–Tianjin–Hebei region, the most serious air pollution in China, as the case, finding that the NFCC effectively reduced $PM_{2.5}$ concentrations. Coincidentally, from the perspective of NFCC and residents' living environment, Zhang et al. (2021) reached a similar conclusion that NFCC had a positive impact on mitigating haze pollution. Yet these studies paid little attention to the direct causal relationship between the NFCC and air pollution mitigation and the indirect socioeconomic mechanisms. Moreover, Liao et al. (2021) concluded that the NFCC could help reduce carbon emissions and promote low-carbon development in Chinese cities.

By regarding the NFCC as a quasi-natural experiment and utilizing the difference-in-differences (DID) approach, we examined the impact of NFCC on air pollution in Chinese cities. This research contributed to the existing literature in the following ways. First, our findings enriched the research field on the environmental and ecological benefits of urban forestry (e.g., Escobedo et al., 2011; Fan et al., 2017; Lei et al., 2021; Margaritis & Kang, 2017; Nowak et al., 2006), and the positive effects of the NFCC on environmental quality improvement in China (Liao et al., 2021; Xiong, 2011; Xu et al., 2020; Zhang et al., 2021). Additionally, unlike previous policies that emphasized administrative and economic instruments (e.g., Cai et al., 2018; Feng et al., 2019; Fu et al., 2021; Li et al., 2021; Sheehan et al., 2014; Zhong et al., 2017; Zhu et al., 2019), we provided evidence that the NFCC, which concentrated on an ecological approach, is also effective in reducing air pollution in China.

Second, this study further supplemented the potential mechanisms that NFCC alleviated air pollution. The previous literature mainly believed that green spaces, forest coverage, urban sanitation and investment in environmental facilities were important ways for the NFCC to play a role (Liao et al., 2021; Xu et al., 2020; Zhang et al., 2021). We have innovatively increased the investigation on channels in terms of environmental regulations and green development models. Compared to afforestation and green spaces, the NFCC raised the government and public attention to environmental protection in cities and strengthening of environmental regulations, and the formation of green development models might bring long-term environmental benefits.

Third, our heterogeneous results showed that the NFCC worked better for less economically developed western regions and cities with relatively small populations, which provided insight into how some large cities could develop better measures to leverage the role of NFCC in improving air quality. Moreover, we found that compared to more polluted and sparsely vegetated northern cities, the NFCC played a more positive role in southern cities, which provided suggestive evidence that some Chinese northern cities promoted sustainable development by the NFCC.

The NFCC in China

The idea of forest cities in China originated in the 1980s, but it was not until 2004 that the official process of evaluating "national forest cities" was launched. In 2007, the National Greening Committee and the National Forestry Administration of China[1] promulgated the "National Forest Cities Evaluation Indexes" and the "National Forest Cities declaration methods", which further standardized the evaluation criteria and certification of national forest cities. The China Urban Forest Forum held every year announces the list of national forest cities and delves into various theoretical and practical issues of the NFCC. In 2013, the National Forestry Administration released the "Outline for Promoting Ecological Civilization (2013–2020)", which again emphasized the role of the NFCC in urban ecological restoration. In addition, "Thirteenth Five-Year Plan for National Economic and Social Development" also explicitly listed the NFCC as a national strategy for implementing China's ecological civilization.

Since Guiyang became the first national forest city in China in 2004, 192 cities (including municipalities, prefecture-level cities, districts, and counties) have been rated as NFCCs as of 2019. As shown in Fig. 1, national forest cities have spread across 26 provinces in China and are concentrated in the Shandong Peninsula, the Central Plains, the Yangtze River Basin, and the Pearl River Delta. Overall, there are more national forest cities in the southern and east-central provinces. At present, NFCC has become an important city brand, playing an active role in protecting forest resources, promoting green culture, creating livable cities, and improving the urban ecological environment (Liao et al., 2021; Xu et al., 2020).

Selection items of national forest cities include 7 aspects, namely comprehensive index, forest coverage, forest ecological network, forest health, public recreation, ecological culture, and green countryside, and each of them has relatively strict quantitative criteria.[2] In terms of forest coverage, the total forest coverage of the northern and southern cities should reach 40% and 30%, respectively, while the greening rate of built-up areas needs to be over 35% and the total public green space per capita ought to exceed 9 square meters. From the aspect of ecological network, greening rates of waterfront (rivers or lakes) and roads (roads or railroads) are required to reach 80% or more. For ecological culture construction, national forest cities need to hold various ecological science activities more than three times a year, and build more than two ecological science knowledge education bases or places. Furthermore, the public awareness rate of creating a national forest city is supported to reach above 90%, and the support rate should be at least 80%. The State Forestry Administration organizes expert to assess the national forest city designation after 3 years. Cities will be warned if do not meet the above requirements. After two years, these failed cities will be re-examined, and if they still do not reach the standards, the title of national forest city will be canceled.

Mechanism analysis

In this section, we discussed in detail the mechanisms of the NFCC on air pollution. We classified possible mechanisms into the following three categories: green spaces, environmental regulations, and green development models.

Green spaces

Forest cities focus on forest construction and forestry protection to reshape the city's ecosystem and environment by increasing green vegetation (Zhang et al., 2021). With the NFCC, the city became an effective

[1] In 2018, the National Forestry Administration was changed to the National Forestry and Grassland Administration.

[2] Information source: http://www.forestry.gov.cn/zlszz/4249/20190807/091811888773590.html.

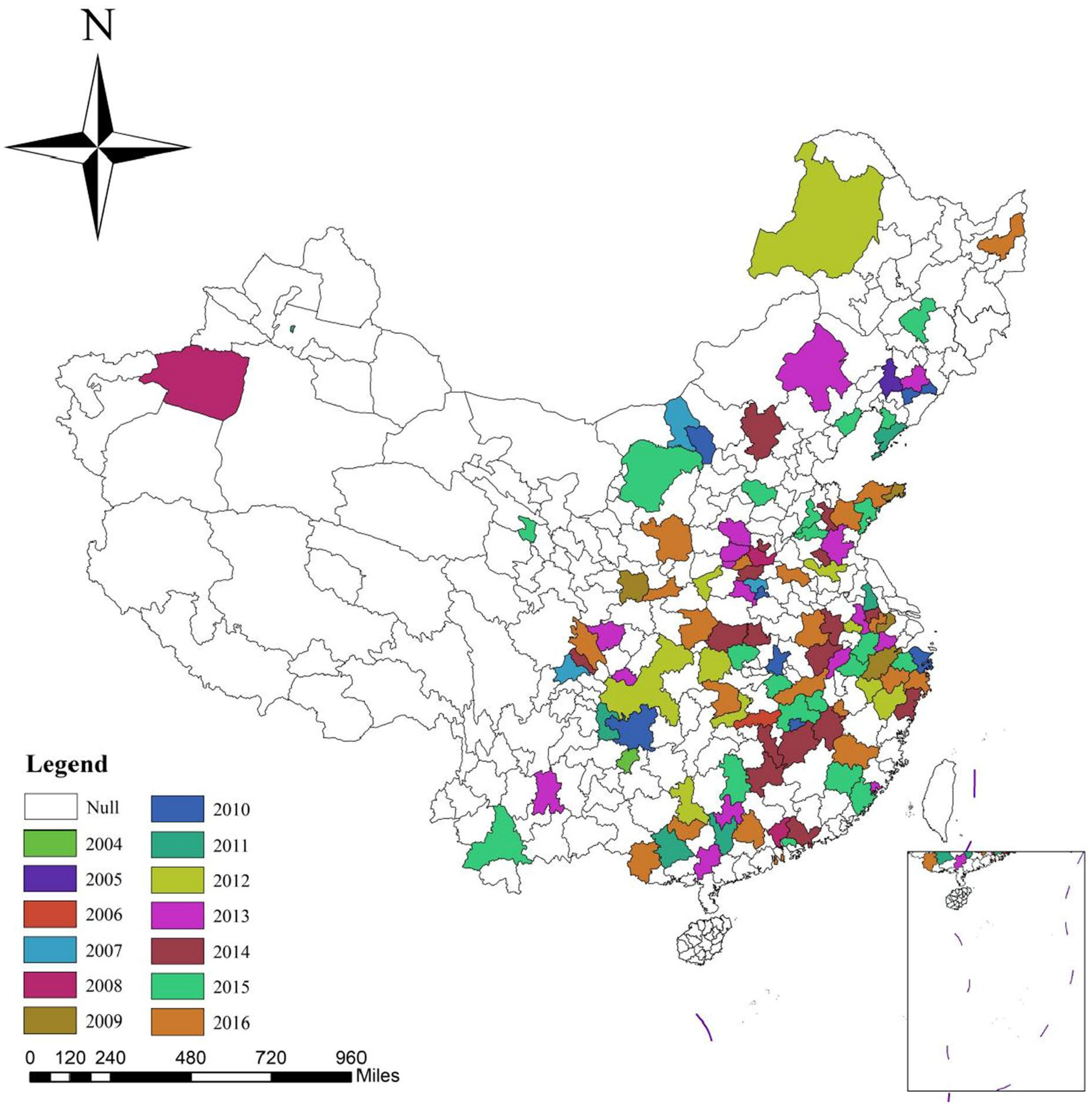

Fig. 1 Geographical distribution of China's National Forest Cities over the years

carrier of forestry resources. Also, plenty of recreational parks sprung up and the green area and vegetation cover increased (Xiong, 2011), bringing a better ecological environment and less pollution (Lei et al., 2021). In China, some cities have increased their green spaces and forest coverage after the NFCC by planting trees and creating urban forest parks (Xu et al., 2020). For example, from 2017 to 2019, the Baoding municipal government established 51 forest demonstration sites, with afforestation area of 933 square kilometers, which promoted the overall forest coverage to 38.1%.[3]

The positive role of urban greening on mitigating air pollution has been supported by many previous studies. On the one hand, some plants can absorb

[3] Data source: https://www.sohu.com/a/340348611_329129.

airborne pollutants such as $PM_{2.5}$, nitrogen oxides, and sulfides (Escobedo et al., 2011; Nowak et al., 2006). On the other hand, some urban greening plants can reduce and lower the airborne dust and particulate matter in large quantities (Lei et al., 2021; Liu et al., 2013; McDonald et al., 2007). For example, on average, a hectare of lawn can absorb more than 30 tons of soot per year in cities (Nowak et al., 2006). Since the trees in the city are cultivated and selected for years, in the context of NFCC, local governments should invest more special funds to improve the survival rate of trees and their positive effect on the environment. What's more, some artificially cultivated urban tree species have more significant purifying effect on urban waste gas compared to natural trees (Churkina et al., 2015).

To sum up, we considered that as a typical integrated urban ecosystem dominated by forest vegetation, the NFCC can be an effective approach to mitigate air pollution by enhancing forest cover and green spaces.

Environmental regulations

In addition to directly increasing forest cover, as one of the ecological and cultural brands of cities, the initial intention of NFCC is to establish an ecosystem with a good habitat and harmonious coexistence between the humans and nature (Xu et al., 2020). Therefore, to achieve these goals, the NFCC is likely to prompt local governments to increase environmental regulation, which contributes to reducing emissions and improving air quality.

As highlighted in "The NFCC in China" section, the NFCC is subject to periodic evaluations. If a city fails in two rounds of assessment, the national forest city designation will be revoked. Thus, under strict assessment criteria, similar to other city-level environmental policies (Wan et al., 2021; Yu & Zhang, 2021), the NFCC may evolve into an environmental regulatory tool for some cities. On the one hand, local governments in forest cities might impose mandatory interventions and constraints on some projects and enterprises that deteriorate air quality (Liao et al., 2021), inducing them to reduce pollutant gas emissions and upgrade pollutant purification technologies (Tanaka, 2015; Zheng et al., 2015). On the other hand, with NFCC, some special funds and fiscal stimulus programs helped some heavy polluters and industries to transform or shift (Sheehan et al., 2014).

Moreover, the NFCC promoted the application of public participation-type environmental regulation tools. Public participation tools rely mainly on individual consciousness, without the need for laws, regulations and monitoring systems (O'rourke & Macey, 2003). As mentioned earlier, the NFCC requires the dissemination of ecological knowledge to the public and the increasing awareness of environmental protection among citizens. As direct perceivers of air pollution information, citizens have a natural information advantage and are able to participate in environmental monitoring as a third-party force (Johnson, 2020; Tu et al., 2019). The public can monitor the policy implementation, provide timely feedback on environmental information, solve the information asymmetry between enterprises and governments (Martens, 2006), and improve the enforcement effectiveness of environmental regulations in national forest cities.

Given that the positive role of environmental regulations in improving air quality in China has been widely confirmed in previous studies (e.g., Cai et al., 2018; Du & Li, 2020; Tanaka, 2015; Xie et al., 2017; Zheng et al., 2015), the NFCC is likely to control air pollution by strengthening environmental regulations.

Green development models

Similar to other city-level energy and environmental policies (e.g., Chen et al., 2017; Pérez-Campuzano et al., 2016; Wang et al., 2013; Yu & Zhang, 2021; Yuan & Zuo, 2011), the NFCC may also construct green development models to enhance air quality and promote sustainable development.

First, the NFCC demands rational and scientific urban planning. On the basis of constructing a good living environment, it is necessary to realize the integration of ecology, culture, and modernization (Xiong, 2011; Zhang et al., 2021). The development philosophy of local governments is likely to change, with more emphasis on low-carbon economy and environmental quality. For example, the NFCC further optimized urban transportation networks and green transportation systems would be established (Li et al., 2005), such as green public transportation systems and introductions of new energy vehicles. Clearly, these measures keep expanding the environmental benefits of NFCC and alleviating air pollution.

Second, considering the advantages of national forest cities in forest tourism, forest ecology and greening technology, they can further develop industries related to environment and ecological protection based on their advantages (Han et al., 2019). These green industries brought about higher economic value added and less pollutant emissions (Guo et al., 2017; Hart & Ahuja, 1996). By funding green enterprises and developing green industrial parks, green innovation capabilities of national forest cities can be strengthened, which contributes to the creation of an environmentally friendly economic system (Ruiz-Pérez et al., 2001). Additionally, for some resource-based and heavy industrial cities, the NFCC provided them with new development directions. Taking Taiyuan, Benxi, and Xinyu as examples, they turned to develop ecological industries and green industries by NFCC and adjusting industrial structures to reducing pollution and improve the air quality (Xu et al., 2020).

In summary, the NFCC constructed conditions for cities to build green development models. Through the development of green transportation and green industries, the NFCC helped to promote innovative development and control air pollution.

Methodology

Considering the quasi-natural experiment of NFCCs in China, we used the DID model, which is widely used in environmental and ecological economics in recent years (e.g., Cheng et al., 2019; Fu et al., 2021; Tang et al., 2018; Wang & Watanabe, 2019; Yang et al., 2021; Zhong et al., 2017). By comparing the average treatment effects of the treatment and control groups before and after the policy, the DID approach could well exclude the effects of confounding factors to exclude endogeneity. Therefore, we first differenced the treatment and control groups and then differenced the treatment group before and after NFCC to obtain the causal effect. The baseline DID model used in this paper can be written as:

$$AP_{it} = \alpha_0 + \alpha_1 NFCC_{it} + \alpha_2 X_{it} + \delta_i + \lambda_t + \varepsilon_{it} \tag{1}$$

where the subscripts i and t represent the city and the year, respectively. δ_i and λ_t denate the city-fixed effect and year-fixed effect, respectively.[4] AP_{it} refers to the air pollution of city i in year t. $NFCC_{it}$ equals to 1 if the city i has implemented the NFCC policy and 0 otherwise. α_1 of $NFCC_{it}$ is the core coefficient we are most concerned about. X_{it} is a series of control variables for city characteristics and climate characteristics. ε_{it} is the random error term. Considering that the sample in this study is at the city level, we used the city-level clustered standard errors.

As mentioned earlier, the prerequisite for the use of the DID model is that the parallel trend assumption is satisfied. In other words, the air pollution status of the treatment and control groups needs to have the same trend before the NFCC policy implemented. Similar to the previous literature (Fu et al., 2021; Liao et al., 2021; Tanaka, 2015; Tang et al., 2018), we utilized the event study analysis method to test the parallel trends. The model is set as follows.

$$AP_{it} = \beta_0 + \sum \beta_t NFCC_{it} + \beta_2 X_{it} + \delta_i + \lambda_t + \mu_{it} \tag{2}$$

where $NFCC_{it}$ denotes the relative time t of city i from being implemented the NFCC policy. If t equals to 0, it means the year of being selected as a national forest city. Thus, a negative (positive) t indicates before (after) the implementation of the NFCC policy. For example, t equals to − 1 is the first year prior to the implementation of the NFCC policy; t equals to 1 involves the first year after being selected as an national forest city. The significance of coefficients β_t indicates whether there is a difference between the treatment group and the control group.

Since the theoretical analysis part of this paper has carried out in-depth analysis of the impact of various mechanism variables on sulfur dioxide and $PM_{2.5}$, we used the classic mechanism analysis method in environmental economics (Acemoglu et al., 2016; Almond et al., 2009; Li & Wang, 2022; Li et al., 2022). Models are constructed as follows.

$$MEC_{it} = \theta_0 + \theta_1 NFCC_{it} + \theta_2 X_{it} + \delta_i + \lambda_t + \sigma_{it} \tag{3}$$

[4] Since city- and year-fixed effects are added in the model, dummy variables measuring the time of NFCC policy and the treatment and control groups do not need to be controlled for again. That is, we can use the reduced form DID models (Duflo, 2001).

$$AP_{it} = \rho_0 + \rho_1 MEC_{it} + \rho_2 X_{it} + \delta_i + \lambda_t + \varphi_{it} \quad (4)$$

where MEC_{it} stands for mechanism variables. In Eqs. (3) and (4), θ_1 and ρ_1 are the core estimated coefficients we are concerned with. If they are significant and the sign is as expected, it indicates that the mechanism is working under are the core estimated coefficients we are concernedwith. If they are significant and the sign is as expected, it indicates that the mechanism is working under the DID framework. It should be noted that because of the excessive missing values for some of mechanism variables, we did not use the mediating effect model. Based on the existing theory and previous literature, analyzing the relationship between the mechanism variables and the explanatory variables can also provide convincing evidence for the mechanism tests (Almond et al., 2009; Chen & Zhao, 2021; Li et al., 2022; Zhao et al., 2022).

Data and variables

The explained variable is air pollution of cities. Haze pollution is one of the types of air pollution that the Chinese government and the public have recently paid close attention to. Consistent with some previous literature (e.g., Cai et al., 2018; Xu et al., 2020; Zhang et al., 2021; Zhao et al., 2021), we chose $PM_{2.5}$ concentrations (μg/m^3) to measure haze pollution. In addition, SO_2, as another typical air pollutants in cities, has also been the focus of scholars (Guo et al., 2017; He, 2006; Tu et al., 2019). We used SO_2 emissions (100,000 tons) of cities as proxies. The $PM_{2.5}$ data are from the satellite monitoring data by Dalhousie University, and the original data of SO_2 emissions come from the China City Statistical Yearbook.

It is worth mentioning that other pollutants of interest from previous studies, such as CO, PM_{10}, and NOx (e.g., Dong et al., 2019; Ebenstein et al., 2015; Feng et al., 2019; Han et al., 2020; Zhong et al., 2017), were not included in the explained variables. The main reason is that the Ministry of Environmental Protection of China has started to disclose statistical information on these pollutants since 2013 aFor climate-related control variablesnd only some major cities published them before (Ebenstein et al., 2015; Han et al., 2020). Due to the availability of data, we have to choose these two pollutants, $PM_{2.5}$ and SO_2.

As discussed in "Methodology" section, the core explanatory variable is a dummy variable for the NFCC policy. Similar to most policy evaluations based on quasi-natural experiments (Cheng et al., 2019; Duflo, 2001; Fu et al., 2021; Wang & Watanabe, 2019; Zhong et al., 2017), we assigned a city's year after implementation of the NFCC policy to 1, and 0 otherwise. The NFCC data come from the annual selection of the National Forestry and Grassland Administration since 2004.[5]

We further described the distribution of the two pollutants. We first calculated the proportion of the number of cities implementing NFCC in the eastern, central, and western regions to all cities,[6] as well as cities in the south and north.[7] We found that the proportion of cities implementing NFCC in the eastern, central and western regions was 36.44%, 36.11% and 18.63%, respectively; the proportion of cities that implement NFCC is 9.46% and 6.87% in southern and northern cities, respectively. We then observed the joint nuclear density distribution of SO_2 and $PM_{2.5}$ in different regions, as shown in Fig. 2. Clearly, compared with the central and western regions, the SO_2 emissions in the eastern region are larger and more concentrated. In terms of $PM_{2.5}$ concentrations, the western cities are also lower. In addition, compared with southern cities, northern cities have greater heterogeneity in $PM_{2.5}$ and SO_2 emissions. In general, the emission of environmental pollutants in the eastern region is relatively large, so the proportion of cities that implement NFCC may be also large.

The control variables mainly portray city characteristics and climate characteristics. According to related previous studies (e.g., Chen & Xu, 2017; Yang et al., 2021; Yu & Yang, 2021; Zhang et al., 2021), city characteristic variables include industrial structure (*Structure*), economic growth (*Growth*), fixed

[5] Information source: http://www.forestry.gov.cn/zlszz/4249/index.html.

[6] The eastern region includes eight provinces, namely Hebei, Shandong, Liaoning, Jiangsu, Zhejiang, Fujian, Guangdong, and Hainan. There are eight provinces in the central region, and they are Heilongjiang, Jilin, Shanxi, Jiangxi, Anhui, Henan, Hubei, and Hunan. The remaining 11 provinces or autonomous regions belong to the western region, namely Xinjiang, Inner Mongolia, Ningxia, Gansu, Qinghai, Tibet, Yunnan, Guizhou, Sichuan, Guangxi, and Shaanxi.

[7] The south and the north are divided by the Qinling-Huaihe line (Almond et al., 2009; Zhao et al., 2021).

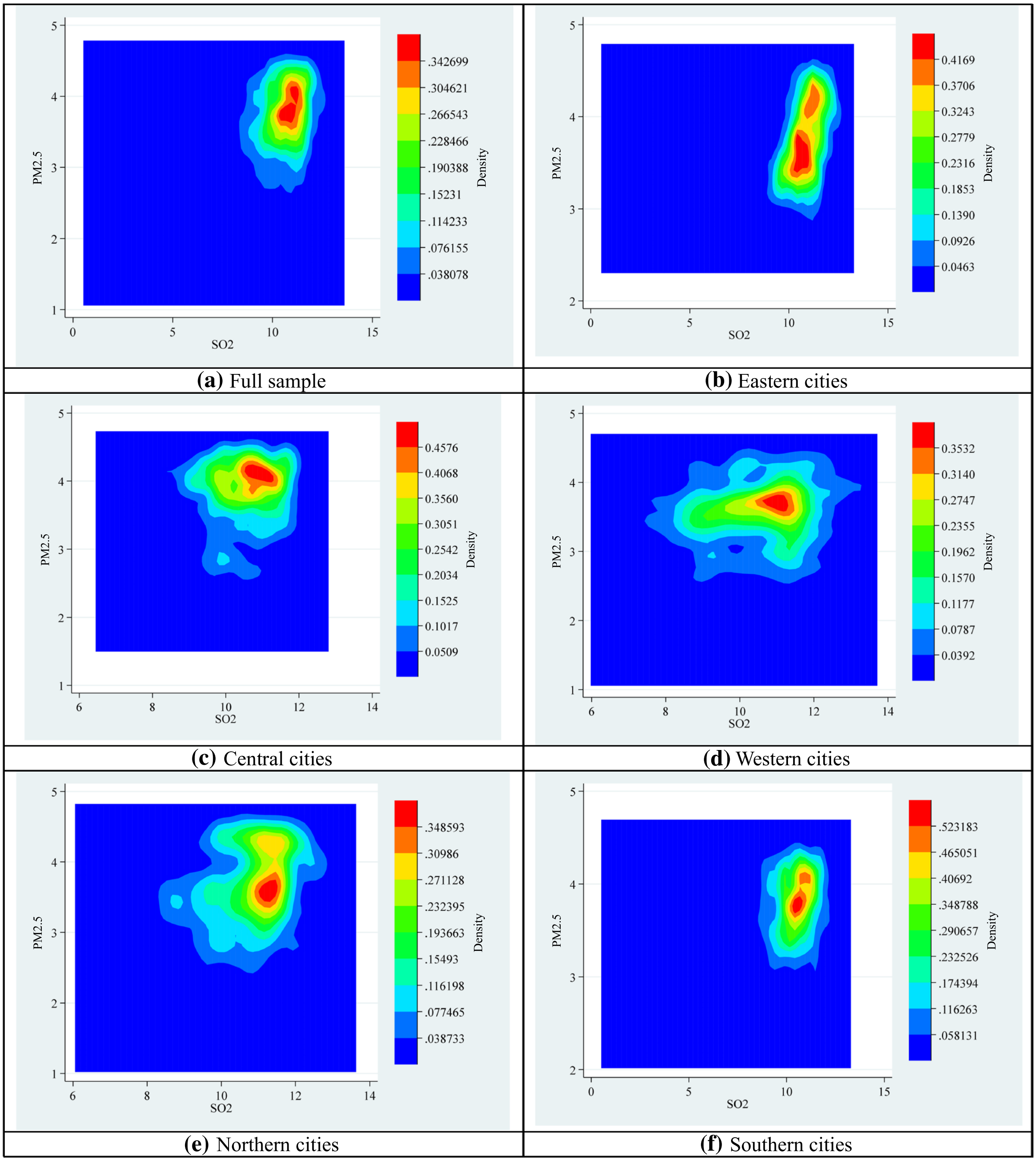

Fig. 2 Joint kernel density function plot of SO_2 and $PM_{2.5}$. *Note*: The kernel density function from a Gaussian product kernel

assets investment (*Investment*), city size (*Size*), energy consumption (*Energy*), industrial agglomeration (*Agglomeration*), and technological innovation (*Innovation*). Among them, *Structure* is measured by the percentage of employees in the secondary industry, and *Growth* refers to the annual growth rate of GDP (%). *Investment* is expressed by total investment in fixed assets (10 billion yuan), and population density (100 persons/km^2) is the proxy for *Size*. *Energy* and *Agglomeration* involve electricity consumption per

Table 1 Descriptive statistics

Variable	N	Mean	SD	Min	Max
$PM_{2.5}$	5180	39.728	20.612	3.5957	94.610
SO_2	4027	0.5741	0.52392	0.0028	3.3224
NFCC	5441	0.0811	0.2729	0	1
Structure	4032	0.4367	0.1416	0.1014	0.8008
Growth	4031	0.1209	0.0401	− 0.0380	0.2580
Investment	4032	9.0740	11.540	0.2825	69.827
Size	4031	4.1991	3.1669	0.1066	22.276
Energy	4024	0.7078	1.1575	0.0101	8.2144
Agglomeration	4031	0.9406	0.3014	0.2182	1.7107
Innovation	4698	7.9338	9.0034	0	11.097
Temperature	4671	14.356	5.5203	0.1000	25.200
Humidity	4671	0.6649	0.1074	0.3400	0.8465
Precipitation	4613	2.5876	1.5112	0.1000	7.4271
Sunshine	4655	5.6036	1.4987	2.2027	8.9414

capita (100 kWh) and the Herfindahl index calculated by the number of employees in the secondary industry, respectively. Lastly, we used the number of patent applications (logarithmic) to measure the technological innovation of cities.

For climate-related control variables, we mainly selected variables such as *Temperature*, *Humidity*, *Precipitation*, and *Sunshine*. Among them, *Temperature* is measured by annual average temperature (°C), *Humidity* refers to *the r*elative humidity (%), *Precipitation* is the average annual rainfall (mm), and Sunshine is expressed by average annual sunshine duration (hour). In terms of control variables, data on patent applications and climate variables come from the State Intellectual Property Office and National Weather Service, respectively, and original data of all other city characteristics are from the China City Statistical Yearbook.

Table 1 shows the descriptive statistics of above variables. The average $PM_{2.5}$ concentrations were 39.73 μg/m^3 and the SO_2 emissions were 5.74 million tons. The standard deviation of $PM_{2.5}$ and SO_2 indicates the large variation of $PM_{2.5}$ and SO_2 emissions in different cities, which provides sufficient heterogeneity for this study to employ the DID model to estimate. In addition, about 8.11% of the cities became NFCCs from 2003 to 2016.

Results

Baseline results

We employed the model (1) to examine the casual effect of the NFCC on air pollution, and the baseline results are shown in Table 2. To test the sensitivity of the estimates to different control variables, we included different kinds of control variables in different columns. Specifically, columns (1) and (4) controlled for city- and year-fixed effects only, columns (2) and (5) further added city characteristic variables, and columns (3) and (6) included all control variables and fixed effects. We found that the coefficients on *NFCC* are significantly negative in all columns, with statistical significance at the 1% level, indicating that the implementation of NFCC policy did mitigate air pollution.

Specifically, in columns (3) and (6), the coefficients on *NFCC* are − 0.1214 and − 0.0429, respectively, suggesting that compared to the control group without NFCC policy, the NFCC reduced $PM_{2.5}$ concentrations by 12.14% and SO_2 emissions by 4.29%. According to the back-of-the-envelope calculation (Deschenes et al., 2020), we found that during the sample period (2003–2016), the total environmental benefits of the NFCC in all cities were a 0.025 g/m^3 reduction in $PM_{2.5}$ concentrations and a 10.08 million tons reduction in SO_2 emissions. It is worth noting that the conclusions of this study are similar to Zhang et al. (2021), which both verify the inhibitory effect of NFCC on $PM_{2.5}$. To judge the economic significance of the estimates, we compared the effect of NFCC with other related policies. We found that the inhibitory effect of NFCC on the emission of environmental pollutants was less than that of the APPCAP, but greater than that of the carbon market pilot policy (Feng et al., 2019; Yu & Zhang, 2021). The possible reason is that the APPCAP are a mandatory policy issued by the Chinese government for areas with serious environmental pollution, and the pollution reduction efforts are quite strong (Huang et al., 2018; Li & Wang, 2022). The core of the NFCC is the increase of forest density, which is a subsidiary impact on pollution reduction (Liao et al., 2021; Zhang et al., 2021). The carbon market has the weakest ability to reduce pollution, which may be related to the imperfection of the market mechanism (Li et al., 2021).

Table 2 Baseline results

	$PM_{2.5}$			SO_2		
	(1)	(2)	(3)	(4)	(5)	(6)
NFCC	− 0.1476***	− 0.1318**	− 0.1214**	− 0.1078***	− 0.0493***	− 0.0429***
	(0.0496)	(0.0527)	(0.0530)	(0.0179)	(0.0176)	(0.0177)
Structure		− 0.0141	− 0.0144		0.0118*	0.0097
		(0.0122)	(0.0117)		(0.0069)	(0.0067)
Growth		0.0232	0.0022		0.0021	0.0055
		(0.0528)	(0.0457)		(0.0256)	(0.0254)
Investment		− 0.0054*	− 0.0047		0.0007	0.0003
		(0.0033)	(0.0032)		(0.0013)	(0.0013)
Size		0.0001**	0.0001*		− 0.0001	− 0.0001
		(0.0000)	(0.0000)		(0.0000)	(0.0000)
Energy		− 0.0007	− 0.0005		− 0.0012**	− 0.0012**
		(0.0005)	(0.0005)		(0.0005)	(0.0005)
Agglomeration		0.6730	0.6576		− 0.3740	− 0.2543
		(0.5676)	(0.5469)		(0.3260)	(0.3180)
Innovation		− 0.0438	− 0.0430		− 0.0179	− 0.0195
		(0.0395)	(0.0388)		(0.0267)	(0.0268)
Temperature			0.0874***			0.0042
			(0.0278)			(0.0104)
Humidity			− 0.0155***			0.0046*
			(0.0037)			(0.0026)
Precipitation			− 0.0013			− 0.0000
			(0.0022)			(0.0003)
Sunshine			− 0.0004***			0.0001
			(0.0001)			(0.0000)
City-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Constant	3.6065***	3.9616***	4.6757***	0.5356***	0.4559***	− 0.1294
	(0.0226)	(0.2261)	(0.5847)	(0.0131)	(0.1041)	(0.3417)
Adjusted R^2	0.3248	0.3865	0.4035	0.1884	0.2810	0.2894
Observations	5180	3990	3886	4027	4004	3900

The values in parentheses are the standard errors clustered at the city level

*, **, ***Represent the significant levels of 10%, 5%, and 1%, respectively. The following tables are the same

Parallel trend tests

By using the model (2), we tested whether the NFCC policy satisfied the parallel trends. The results are shown in Fig. 3, and we found that the coefficients β_t are all insignificant before being selected as a national forest city for both $PM_{2.5}$ and SO_2. These results indicated that there is no significant difference in the trend of air pollution change between the treatment group and the control group. However, SO_2 did not decrease significantly until the third year, which may be related to the timing of plant growth and technological progress afterward. In addition, these results suggested that the coefficient of two air pollutants decreased after implementing the NFCC policy, implying that NFCC reduced the air pollution in cities. In summary, our results provided supporting evidence that the NFCC policy met the parallel trends and it was valid and appropriate to employ the DID model in this study.

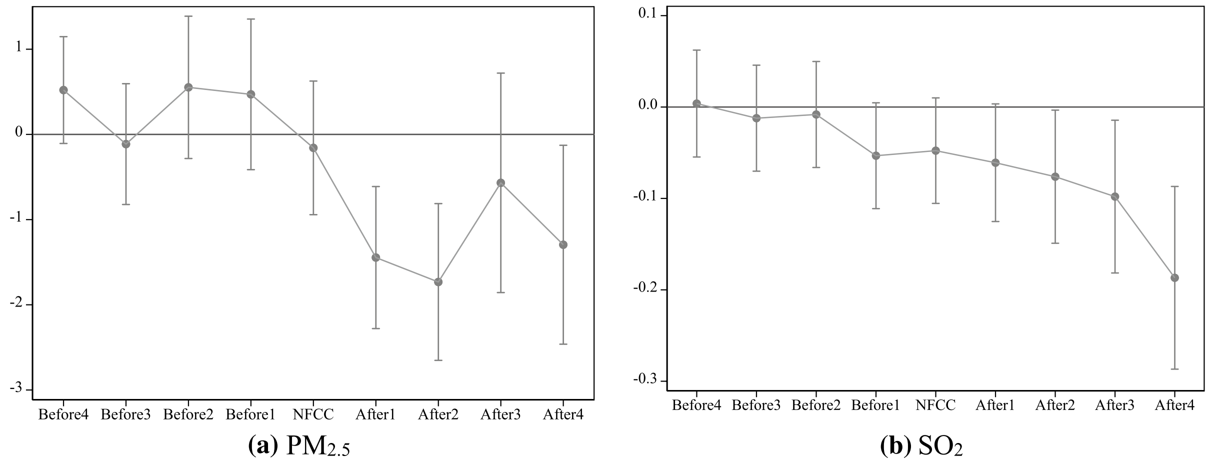

Fig. 3 Parallel trend tests. *Note*: The vertical axis represents the estimated coefficient, while the horizontal axis indicates the relative time node of the NFCC policy implementation

Robustness tests

The baseline results show that the NFCC mitigated air pollution; however, we preformed multiple robustness tests to ensure that these results were convincing.

Instrumental variable approach

Although the DID model is used in the main specifications, the issue of endogeneity deserves further consideration. On the one hand, since the selection of national forest cities was not random, some omitted variables that we cannot observe may affect the estimation results. On the other hand, the baseline estimates may also have the reverse causality problem. A city with severe air pollution will attract the attention of governments, and it is possible to alleviate severe air pollution by planting more trees or even implementing NFCC policies implementing NFCC policy. Therefore, we further employed an instrumental variable (IV) approach for robustness tests.

Specifically, we selected the average slope of each city as the IV (Qian, 2008). From the perspective of relevance, whether a city can become an *NFCC* has a lot to do with the amount and density of local forests, and the density of forests is closely related to the slope. For example, broad-leaved forest often appears on slightly sloped terrain, the distribution of young forests on different slopes is basically the same, and the proportion of over-mature forests increases with the increase of slope (Keim & Skaugset, 2003; Tsui et al., 2004). Some literature in forest science also confirmed that slope is closely related to tree survival and forest formation (Sharma et al., 2010; Stage & Salas, 2007). In terms of the exclusion restriction assumption, the slope of the city is formed by the movement of the earth's crust and unlikely to directly affect air pollution. In addition, the emission of air pollutants mainly depends on economic factors, such as economic development, industrialization, technological innovation, and mineral resources (Cai et al., 2018; Huang et al., 2018; Ma et al., 2021; Sheehan et al., 2014; Yuan & Zuo, 2011; Zhu et al., 2019). There is no direct evidence that slope is associated with air pollution. The slope data of Chinese cities are from You et al. (2018).

Table 3 reports the estimated results by using the IV approach. Although the coefficients on *NFCC* are insignificant in columns (1) and (4) of Panel B, estimated coefficients on *NFCC* are significantly negative at the 1% level in columns (3) and (6), indicating the robustness of our baseline results. Moreover, in Panel A, it is clear that the first-stage F values are well above the Stock-Yogo critical value for a weak IV (Stock & Yogo, 2005; Zhao et al., 2022) and other statistics (e.g., Kleibergen-Paap rk LM statistic) also suggest that this IV is strong.

Placebo tests

Similar to previous studies using the DID model (Cheng et al., 2019; Fu et al., 2021; Wang &

Table 3 Robustness checks: IV estimations

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: First-stage results	NFCC					
Slope	− 0.0125***	− 0.0029***	− 0.0472**	− 0.0133*	− 0.0027***	− 0.0455***
	(0.0001)	(0.0011)	(0.0203)	(0.0077)	(0.0008)	(0.0176)
City characteristics	No	Yes	Yes	No	Yes	Yes
Climate variable	No	No	Yes	No	No	Yes
City-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
F value of the first stage	16.38	26.69	15.22	13.73	27.82	30.84
Observations	4538	3990	3886	4013	4004	3900
Panel B: Second-stage results	$PM_{2.5}$			SO_2		
NFCC	− 1.6519	− 0.0814***	− 0.2369***	− 0.0072	− 0.0139***	− 0.0167***
	(1.8491)	(0.0261)	(0.0627)	(0.0075)	(0.0057)	(0.0062)
City characteristics	No	Yes	Yes	No	Yes	Yes
Climate variable	No	No	Yes	No	No	Yes
City-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes
Kleibergen–Paap rk LM statistic	1.845	33.850	19.852	17.426	34.132	20.031
Cragg–Donald Wald F statistic	1.348	26.761	15.223	14.841	27.029	15.397
Anderson–Rubin Wald test	759.46	35.26	160.27	0.98	10.73	13.33
Observations	4538	3990	3886	4013	4004	3900

The values in parentheses are the standard errors clustered at the city level. Panel A reports the first-stage results, where the explanatory variable is NFCC. Panel B presents the second-stage results, of which the explanatory variable in the first three columns is $PM_{2.5}$ and the explanatory variable in the last three columns is SO_2

Table 4 Robustness checks: placebo tests

	1 year in advance (1)	2 years in advance (2)	3 years in advance (3)
Panel A: $PM_{2.5}$			
NFCC	0.2188	0.2707	− 0.5011
	(0.6531)	(0.6629)	(0.5378)
Baseline controls	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes
Observations	3886	3886	3886
Panel B: SO_2			
NFCC	− 0.3246	0.0743	− 0.0455
	(0.6312)	(0.4558)	(0.5019)
Baseline controls	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes
Observations	3900	3900	3900

The values in parentheses are the standard errors clustered at the city level

Table 5 Robustness checks: eliminating disturbing policies

	APPCAP	Low-carbon cities	Carbon market pilots	Smart cities	Driving restriction policies	NLGC	"Two control Zones"
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Panel A: $PM_{2.5}$							
NFCC	− 0.9300**	− 0.1811***	− 0.1347***	− 0.1039**	− 0.1003**	− 0.0924**	− 0.0653***
	(0.3757)	(0.0527)	(0.0411)	(0.0420)	(0.0479)	(0.0425)	(0.0227)
Baseline controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3526	2560	3368	2271	2566	2016	1327
Panel B: SO_2							
NFCC	− 0.0353**	− 0.0509***	− 0.0489***	− 0.0322*	− 0.0402**	− 0.0512**	− 0.0377***
	(0.0172)	(0.0192)	(0.0199)	(0.0168)	(0.0185)	(0.0221)	(0.0106)
Baseline controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3540	2574	3382	2285	2580	2030	1341

The values in parentheses are the standard errors clustered at the city level

Watanabe, 2019), we further adopted some placebo tests. Specifically, we advanced the timing of NFCC policy implementation (treatment group) by one, two, and three years, respectively. Judging from the results reported in Table 4, the inhibitory effect of the NFCC on air pollution is no longer significant, indicating that the simulated treatment effect we constructed did not hold, and the main results have great credibility.

Eliminating disturbing policies

In further robustness checks, we considered some other disruptive policies that may have an impact on air pollution of cities. First, the APPCAP is the most important policy implemented by the Chinese government to control air pollution (Feng et al., 2019; Huang et al., 2018), especially in "2+26" cities in the North China Plain, which were implemented in the first batch. If this environmental policy in cities with severe air pollution was not ruled out, it should lead to an overestimation. In column (1) of Table 5, we excluded the "2+26" cities[8] and found that the coefficients on *NFCC* remained significantly negative in both two panels.

[8] Data source: http://www.gov.cn/xinwen/2019-08/23/content_5423736.htm.

Second, as a result of China's 2030 carbon peak and 2060 carbon neutrality targets, China's low-carbon city pilots and carbon market pilots have achieved carbon emission reductions while curbing air pollutant emissions (Fu et al., 2021; Yu & Zhang, 2021). Considering that most of the CO_2 and air pollutants are emitted from similar sources (Cheng et al., 2020; Lei et al., 2011), we eliminated these two city-level low-carbon policies. The results in columns (2) and (3) of Table 5 suggest that after controlling the effects of these disturbing policies, the NFCC still reduced air pollution.

Third, in recent years, the use of big data and artificial intelligence for monitoring and controlling pollution has become increasingly widespread (Honarvar & Sami, 2019), and the positive impact of smart cities with these information technologies at their core on air pollution has received attention from scholars (Liu et al., 2021; Zhu et al., 2019). China has been setting up smart city pilots since 2012, and there were more than 200 smart cities at all levels (including counties and towns) set up by 2016. We therefore excluded smart city pilot policy, and the results are presented in column (4) of Table 5. The estimates in two panels are qualitatively similar to the main estimates in Table 2, although somewhat smaller in magnitude.

Table 6 Robustness checks: using alternative specifications

	Deleting NFCC before 2007 and after 2017	Per capita indicators	PSM-DID (NNM)	PSM-DID (KM)
	(1)	(2)	(3)	(4)
Panel A: $PM_{2.5}$				
NFCC	− 0.1354***	− 0.0239**	− 0.1356***	− 0.1321***
	(0.0397)	(0.0108)	(0.0392)	(0.0438)
Baseline controls	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes	Yes
Observations	3595	3886	3568	3580
Panel B: SO_2				
NFCC	− 0.0457***	− 0.0175***	− 0.0424***	− 0.0446***
	(0.0166)	(0.0059)	(0.0182)	(0.0177)
Baseline controls	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes	Yes
Observations	3595	3900	3582	3594

The values in parentheses are the standard errors clustered at the city level

Fourth, to alleviate traffic congestion and air pollution problems, many cities in China have implemented driving restriction policies. Previous literature provided evidence that driving restrictions did help mitigate air pollution in China (Han et al., 2020; Zhong et al., 2017). Thus, we tried to exclude this driving restriction policies to conduct a robustness test. In column (5) in Table 5, we found that the results are virtually unchanged.

Fifth, we considered another program similar to the NFCC, National Landscape Garden City (NLGC). Since the Chinese Ministry of Housing and Urban-Rural Development declared Beijing the first NLGC in 1992, over 200 cities have become NLGCs. Clearly, NLGCs are also centered on urban ecology and may have an impact on urban air pollution. Therefore, in column (6), we removed the sample of NLGCs, fingding that the positive effect of NFCC on mitigating air pollution remains significant while considering the effect of NLGC.

Last, to reduce the formation of acid rain, the Law on the Prevention and Control of Atmospheric Pollution in China stipulates that, according to natural conditions such as weather, topography, soil, etc., areas that have produced or may produce acid rain or other areas with serious sulfur dioxide pollution may be designated as acid rain control areas or sulfur dioxide pollution, namely "Two control Zones" (Cai et al., 2016; Hao et al., 2000). The establishment of the "Two control Zones" can also significantly reduce SO_2 emissions, thus overestimating the effect of NFCC. After excluding the influence of "Two control Zones" in column (7) of Table 5, we found that NFCC can still significantly reduce SO_2 and $PM_{2.5}$.

Using alternative specifications

To exclude the bias of variable selection and model setting on the results, we tested the robustness by using alternative specifications. First, the specific selection criteria for NFCC were issued in 2007, so we excluded national forest cities before 2007. Moreover, we removed cities that were selected as national forest cities after 2017, as these candidates are different from the other cities in the control group. The results in column (1) of Table 6 indicate that this change has little effect on the results.

Second, considering the size differences, we utilized the per capita indicators as proxies for the explanatory variables. In column (2) of Table 6, the estimates of NFCC are quite insensitive to the variable measurement method adopted, suggesting that the main specification is satisfactory for capturing size differences.

Table 7 Mechanism tests: the NFCC and green spaces

	Green coverage area per capita in built-up areas		Green spaces per capita	
	(1)	(2)	(3)	(4)
NFCC	0.2965***	0.3404***	0.1473***	0.0355***
	(0.1092)	(0.1189)	(0.0156)	(0.0149)
Baseline controls	No	Yes	No	Yes
Year-fixed effect	Yes	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes	Yes
Observations	3999	3875	4000	3877

The values in parentheses are the standard errors clustered at the city level

Third, similar to some previous studies (Fu et al., 2021; Xie et al., 2017), we employed the DID approach on the basis of the propensity score matching (PSM) method. We used two matching methods, nearest-neighbor matching (NNM) and kernel matching (KM), and the estimation results from PSM-DID approach are reported in columns (3) and (4) of Table 6, respectively. Clearly, in two panels, the estimates are similar to the main results in Table 2.

Mechanism tests

Given the main finding that NFCC significantly curbed air pollution, we further examined the multiple potential mechanisms highlighted in "Mechanism analysis" section. These mechanisms included green spaces, environmental regulations, and green development models.

Green spaces

As a new urban ecosystem centered on forest vegetation and greening, the improvement of forest coverage and urban green spaces is the most significant feature of forest cities. Two variables are used to measure the green spaces in Chinese cities, green coverage area per capita in built-up areas and green spaces per capita, whose raw data come from the China City Statistical Yearbook. The results are reported in Table 7.

The DID estimates indicate that the coefficients of *NFCC* are significantly positive in all columns regardless of the inclusion of baseline control variables. These results are similar to findings in some previous studies (Xu et al., 2020; Zhang et al., 2021), suggesting that the NFCC increased green spaces in Chinese cities. Specifically, the NFCC increased green coverage area per capita in built-up areas by 34.04% and green spaces per capita by 3.55%. Considering that the positive role of urban green spaces in enhancing air quality has been widely confirmed in previous studies (e.g., Escobedo et al., 2011; Lei et al., 2021; Nowak et al., 2006), we found that urban green space is indeed negatively correlated with air pollutants in "Table 11 of Appendix". Thus, our estimates provided evidence that the NFCC could mitigate air pollution by increasing green spaces in China.

Environmental regulations

Next, we considered whether the NFCC affected environmental regulations. Two indicators, industrial soot removal rate and comprehensive solid waste utilization rate, were constructed to serve as proxies for environmental regulations. Previous studies on the measurement of environmental regulations were not uniform. One category used environmental policies and laws to analyze the role of environmental regulations (Cai et al., 2018; Tanaka, 2015; Wan et al., 2021; Xie et al., 2017), while the other focused on the measurement domain in terms of pollutant utilization and removal (Du & Li, 2020; Zhao et al., 2021). Since the NFCC has been considered as a

Table 8 Mechanism tests: the NFCC and environmental regulations

	Soot removal rate		Comprehensive solid waste utilization rate	
	(1)	(2)	(3)	(4)
NFCC	0.1391	0.3012	0.5538**	0.4870**
	(0.4627)	(0.3552)	(0.2251)	(0.2357)
Baseline controls	No	Yes	No	Yes
Year-fixed effect	Yes	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes	Yes
Observations	1689	1652	4008	3887

The values in parentheses are the standard errors clustered at the city level

Table 9 Mechanism tests: the NFCC and green development models

	Environmental employment	Green transportation	Green Inventions	Innovation index
	(1)	(2)	(3)	(4)
NFCC	0.0712**	0.0001	0.1190***	0.1370***
	(0.0337)	(0.0002)	(0.0466)	(0.0271)
Baseline controls	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes	Yes
Observations	3869	3834	2974	3895

The values in parentheses are the standard errors clustered at the city level

quasi-natural experiment, and it is difficult for us to construct environmental regulation variables through other policies or laws, the latter option is more suitable for mechanism testing in this study. The original data for these two indicators are also obtained from the Chinese City Statistical Yearbook.

The results of the mechanism analysis are reported in Table 8. We found that the coefficients on *NFCC* are positive but insignificant in the first two columns, which may be influenced by too many missing observations. Compared to the baseline results in Table 2, the number of observations is less than half. Additionally, the coefficients on *NFCC* are positive and significant at the 5% statistical level in columns (3) and (4), indicating that there is a positive association between the NFCC and the enhancement of environmental regulations. As highlighted in previous research that environmental regulations are one of core instruments for controlling air pollution in China (e.g., Cai et al., 2018; Du & Li, 2020; Tanaka, 2015; Xie et al., 2017; Zheng et al., 2015), the results in "Table 12 of Appendix" also show that environmental regulation variables are both negatively associated with air pollution in our sample. In sum, these results are suggestive of support for the environmental regulation-related mechanisms.

Green development models

With the deepening of the forest city concept, the NFCC gradually formed green development models to mitigate air pollution under the guidance of the government. We examined this mechanism from several perspectives, and the results are represented in Table 9.

In column (1), we adopted the number of employment related to environmental protection to measure city's green industry (Raff & Earnhart, 2019) and found that the coefficient on *NFCC* is statistically significant at the 5% level. These results imply that the NFCC is likely to promote the development of green industries. In column (2), we explored the government's guidance of green living for residents as characterized by per capita public transportation ownership (Mulalic & Rouwendal, 2020). Similarly, we found that the NFCC can significantly contribute to the development of green transportation in cities.

Moreover, given the positive role of technological innovation and green innovation in enhancing environmental quality (Popp, 2006; Zhao et al., 2021; Zhu et al., 2019), we further tested whether the NFCC inhibited air pollution through these mechanisms. Green innovation is expressed as the logarithm of green patent applications and technological innovation is measured by the city innovation index.[9] In columns (3) and (4), we found that the NFCC significantly contributed to the city's green innovation and technological innovation capacity, which are in line with our previous theoretical prediction.

In line with previous analysis in this paper, based on Eq. (4), we found that all four mechanism variables involving the green development model are significantly and negatively associated with air pollution in "Table 13 in Appendix". In summary, our findings confirmed that the NFCC can lead to green development models to reduce air pollution in Chinese cities.

[9] The original data of city innovation index comes from Kou and Liu (2017) and the data related to green patents are compiled in accordance with the "Green List of International Patent Classification" issued by the World Intellectual Property Office.

Table 10 Heterogeneity effects by cities

	Smaller cities (1)	Larger Cities (2)	Northern cities (3)	Southern cities (4)	Eastern cities (5)	Central cities (6)	Western cities (7)
Panel A: $PM_{2.5}$							
NFCC	− 0.9252**	− 0.1982***	− 0.8737	− 0.0698*	− 0.3618	0.3145	− 0.1562**
	(0.4644)	(0.0691)	(0.6244)	(0.0405)	(0.6256)	(0.8578)	(0.0649)
Baseline controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2971	915	1765	2121	1179	1085	1622
Panel B: SO_2							
NFCC	− 0.0614***	− 0.0423	− 0.0396	− 0.0676***	− 0.0412	− 0.0268	− 0.0664**
	(0.0195)	(3.6298)	(0.0684)	(0.0202)	(0.0411)	(0.0356)	(0.0322)
Baseline controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2985	915	1779	2121	1193	1085	1622

The values in parentheses are the standard errors clustered at the city level. Baseline control variables and fixed effects are added in all regressions

Heterogeneity analysis

The role of NFCC in mitigating air pollution may be heterogeneous. First, according to the State Council's criteria for classifying the size of cities,[10] we set cities with a resident population of more than 1 million as large cities, and the others as small cities. As reported in columns (1) and (2) of Table 10, the suppression effects of NFCC on $PM_{2.5}$ are both significant in different city sizes, while stronger in smaller city subsamples. Also, the NFCC is more beneficial to alleviate SO_2 emissions in smaller cities. To sum up, the NFCC is more effective in smaller cities and possible reason is that smaller cities could have more land for greening and forestry and better utilize the environmental benefits of NFCC.

Second, as mentioned above, southern and northern cities are not evaluated on the same criteria on the NFCC. For instance, the forest coverage rate of southern cities needs to be at least 40%, while northern cities only need to reach 30% or more. In addition, according to Figure 2, there are also some differences in air pollution between northern and southern cities in China. In columns (3) and (4) of Table 10, we compared and analyzed this difference and found that for both $PM_{2.5}$ and SO_2, the NFCC had greater inhibitory effects on air pollution in southern cities. However, the coefficients on NFCC are insignificant in northern cities.

Third, we analyzed the heterogeneity effects in the eastern, central, and western regions. Figure 2 tells us that SO_2 emissions and $PM_{2.5}$ concentrations in the different regions also show greater heterogeneity. In the last three columns of Table 10, the coefficients on *NFCC* are only significantly positive in column (7) for two panels, indicating that the NFCC had more effective in reducing air pollution in the western regions. In general, the western regions of China are dominated by plateaus and mountains, which are more suitable for the development of urban forest ecosystems. For example, Guiyang is the first national forest city in China. In addition, compared with central and eastern cities, the western cities are less industrialized and has relatively better air quality (Zhao et al., 2021; Zhou et al., 2019). The role of

[10] Data source: http://www.gov.cn/zhengce/content/2014-11/20/content_9225.htm.

NFCC with ecological means as the core is valid for reducing air pollution.

Conclusions

Air pollution has become a major challenge for most emerging market countries, and China has made great efforts to control air pollution. The NFCC, with the goal of ecological construction, is a key step for the Chinese government to create livable environment and sustainable cities. However, few studies have completely evaluated the effects of NFCC on urban environmental quality (Liao et al., 2021; Xu et al., 2020; Zhang et al., 2021), and the underlying mechanisms are poorly understood. By using data from 283 Chinese prefecture-level cities from 2003 to 2016 and regarding the NFCC as a quasi-natural experiment, we employed the DID model to examine the effects of NFCC on air pollution.

We found that the NFCC significantly reduced air pollution, which is supported by a series of robustness checks, including the IV approach, placebo tests, eliminating disturbing policies, and using alternative specifications. Specifically, the implementation of the NFCC policy resulted in an average reduction of 12.14% and 4.29% in $PM_{2.5}$ and SO_2, respectively. For all cities, these effects were equivalent to reducing the total $PM_{2.5}$ concentrations by 0.025 g/m^3 and the total SO_2 emissions by 10.08 million tons over the sample period (2003–2016). Moreover, we analyzed the potential mechanisms and found that the environmental benefits could be explained by increasing green spaces, strengthening environmental regulations, and forming green development models. Furthermore, the results from heterogeneity effects indicated that the NFCC was more effective in mitigating air pollution in smaller cities, southern cities, and western cities.

Our findings contributed to the literature on assessing environmental policies at the city level with a quasi-natural experiment of the NFCC. We found that the NFCC focused on ecological goal, helped to improve air quality as well, which distinguished it from previous policies on administrative and economic methods in China (e.g., Cai et al., 2018; Chen et al., 2007; Cheng et al., 2019; Fu et al., 2021; Huang et al., 2018; Ma et al., 2021; Tanaka, 2015; Zhong et al., 2017). Thus, we offered a new method of urban air pollution control from the perspective of the NFCC. Unlike traditional administrative-style policy measures that might have negative impacts (Lo, 2014; Tang et al., 2018), the use of softer ecological tools could also help achieve improvements in air quality.

More importantly, the NFCC provided directions for the formation of green development patterns in cities, not only in air pollution reductions, but also for the possible stable and long-term effects on promoting sustainable urban development. Our study had some insights not only for China but also for other high pollution countries, especially emerging market countries and developing countries. Specifically, some cities could utilize the NFCC opportunity to promote a green development model and reduce the cost of air pollution control. In addition, the NFCC played a lesser role in large cities, northern cities, and eastern. Therefore, local governments in these cities need to pay attention to the environmental benefits brought by NFCC, provide good public services, scientifically coordinate and plan green spaces and construction lands, and restore and build new urban forest elements according to local conditions.

Author contributions XL done conceptualization, supervision, formal analysis, supervision, and writing—original draft, writing—review and editing draft; CZ performed formal analysis, methodology, visualization, writing—original draft, and writing—review and editing draft.

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Data availability All data included in this study are available upon request by contact with the corresponding author.

Declarations

Conflict of interest The author declared that there is no conflict of interest.

Consent for publication All the authors consent to participate and consent to publish before reference in the manuscript.

Appendix

See Tables 11, 12 and 13.

Table 11 Green spaces and SO_2/$PM_{2.5}$

	SO_2		$PM_{2.5}$	
	(1)	(2)	(3)	(4)
Green coverage area per capita in built-up areas	− 0.4621***		− 0.3626***	
	(0.0595)		(0.0523)	
Green spaces per capita		− 0.1436***		− 0.1061***
		(0.0148)		(0.0153)
Baseline controls	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes	Yes
Observations	3875	3877	3875	3877

The values in parentheses are the standard errors clustered at the city level

Table 12 Environmental regulations and SO_2/$PM_{2.5}$

	SO_2		$PM_{2.5}$	
	(1)	(2)	(3)	(4)
Soot removal rate	− 0.5371***		− 0.8009***	
	(0.0532)		(0.0608)	
Comprehensive solid waste utilization rate		− 0.0701***		− 0.0676***
		(0.0159)		(0.0190)
Baseline controls	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes	Yes
Observations	1652	3887	1652	3887

The values in parentheses are the standard errors clustered at the city level

Table 13 Green development models and SO_2/$PM_{2.5}$

	SO_2				$PM_{2.5}$			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Environmental employment	− 0.9084***				− 0.1297***			
	(0.0810)				(0.0241)			
Green transportation		− 0.0750***				− 0.5703***		
		(0.0205)				(0.0718)		
Green Inventions			− 0.1540***				− 0.1734***	
			(0.0219)				(0.0234)	
Innovation index				− 0.1485***				− 0.1733***
				(0.0247)				(0.0269)
Baseline controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
City-fixed effect	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3869	3834	2974	3895	3869	3834	2974	3895

The values in parentheses are the standard errors clustered at the city level

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