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Impact of City Forests on Haze Reduction—Implementation of the National Forest City Policy in China

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Abstract: The construction and development of China's forest cities revolves around the goal of building an environmentally friendly society and achieving harmonious development between human beings and nature, which is essentially the implementation of the concept of green development and helps promote the sustainable development of sustainable cities. Based on the panel data of 263 prefecture-level cities in China from 2001 to 2020, the National Forest City Policy (NFCP) is used as a quasi-natural experiment to assess the effect of NFCP on haze pollution management and their heterogeneity using a time-varying DID (difference-in-differences) model, and a mediating effect model is used to analyze the mechanism of the effect of NFCP on haze pollution. The research found that (1) the NFCP can reduce urban haze pollution, and this finding remained robust after placebo tests and the replacement of explanatory variables; (2) the NFCP is more conducive to reducing haze pollution in the Pearl River Delta urban agglomeration, Type II large cities, cities in the eastern region, and cities east of the Hu Huanyong line; (3) the NFCP will improve urban green space coverage, raise residents' awareness of environmental protection, and promote the development of tertiary industries, thereby promoting urban haze reduction.

Keywords: national forest city; urban forest; haze pollution; PSM-DID; PM2.5; social environmental awareness

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1. Introduction

Air pollution, especially haze pollution, is one of the environmental problems that need to be addressed in China [1]. The construction of forest cities can alleviate the air pollution problems caused by rapid industrialization and urbanization, offset the CO_2, SO_2 and dust generated by industrial systems to a certain extent, help suppress haze pollution and improve the well-being of city residents [2]. In order to strengthen the construction of urban forests and rural greening, China implemented the National Forest City Policy (NFCP) in 2004, and the cumulative success of the NFC has reached 219 cities, with more than 400 cities in the NFC, which is expected to basically achieve the equalization of ecological services in forest cities by 2035 [3].

The purpose of the NFCP is to "let the forest come into the city, let the city embrace the forest", and really do a good job of "planting green for the people, planting green benefit the people". In terms of objectives, the NFCP seeks to achieve greening of the earth, greening of the heart and greening of the whole population. In terms of method, the NFCP emphasizes the use of artificial methods to create near-natural forests; in terms of function, the NFCP can enhance urban residents' awareness of green living and ecological civilization. The selection of national forest cities involves 36 indicators in 5 major systems, including the forest network, forest health, ecological welfare, ecological culture, and organizational management [4,5]. Only cities with all indicators meeting the required standards are eligible to be awarded the honorary title of national forest city [6]. With the maturity of the management system, the NFCP provides an important way for China's cities to follow the development path of production development, rich living and good ecology, and has received more and more extensive attention [7]. However, the social, economic and cultural impacts of the NFCP on local communities, especially the environmental aspects, have not been effectively assessed and empirical evidence on these aspects is still lacking. Therefore, research to assess the haze-reduction effect of the NFCP becomes significant.

Currently, studies related to the NFCP are divided into three main categories. The first category is concerned with the differences in the objectives of the NFCP in different types of cities. Highland mountain cities focus on improving the quantity and quality of forest city construction through the NFCP [8], Hilly cities hope that the NFCP can alleviate problems such as urban insularity [9]. In the case of the plain cities, the quality of urban life has been improved through the NFCP [10], Resource-depressed cities aim to take the NFCP as an opportunity to promote urban green development [11]. The second category is concerned with the functions of urban forests, fully affirming that the construction of urban forests has an important value for the local improvement of ecological connotation, enhancement of environmental carrying capacity, enhancement of carbon sequestration, emission reduction and oxygen release capacity, the improvement of residents' ecological well-being, and promotion of local green economic development [12,13]. The third category is a comprehensive evaluation of the construction results of the NFCP. The system construction involves indicators of forest status, forest benefits and forest development [14], and the object selection revolves around a single city [15] or a certain urban cluster [16].

The research on haze is mostly focused on the exploration of its hazards and management paths. Among them, the hazards brought by haze mainly include the following three aspects. One is that the chemical composition of haze directly damages the human respiratory and neurological life systems [17]. Second, haze reduces the quality of economic development. Haze pollution not only hinders local attraction of foreign direct investment and the gathering of highly qualified talents [18,19], but also has potential financial evolutionary risk effects that constrain high-quality economic development [20]. Third, haze brings many negative impacts on the production and operation of microeconomic agents such as enterprises. Haze pollution raises the labor costs of enterprises [21], reduces the confidence of business investors [22], causes a decrease in the productivity of enterprises [23], and so on. The analysis of haze management includes not only economic activities such as energy restructuring [24], industrial transformation and upgrading [25], and new infrastructure investment [26], but also economic phenomena such as population agglomeration [27], industrial agglomeration [28], and urbanization [29]; governmental decisions such as innovative city construction [30], smart city construction [31], and national-level integrated big data test areas [32] are also included in the study and become some of the hot spots.

The relationship between the NFCP and haze pollution has been less directly studied in the literature, mostly using natural experiments to study the combined effects of urban forest construction. In terms of the ecological environment, forest vegetation generally regulates the atmospheric environment by chemical dust removal and physical dust reduction, absorbing carbon dioxide and filtering air pollution particles, etc. [33,34]. Some scholars also believe that ozone and PM2.5 may be produced indirectly when trees in cities reach a certain density [35]. In terms of economic value, the construction of urban forests has a positive effect on the carbon storage of cities [36], green economic development [37], forest tourism and forest recreation development [38]. In terms of people's well-being, urban greening can enhance the quality of cities and relieve residents' stress [39,40]. Overall, in the vast majority of cases, China's urban forest construction can purify the atmosphere, reduce urban PM2.5 concentration and increase the concentration of negative air ions, while in some cities (such as Lanzhou and Kunming, etc.), the more green the area, the more serious the air pollution [41,42].

In summary, existing studies have explored the construction initiatives, roles and evaluation of urban forests as well as the hazards of haze pollution and its management, laying a solid foundation for further research in this paper. However, few in-depth studies have been conducted on whether the NFCP affects haze pollution and the variability of the impact, and there is a lack of positive answers to the question of how the policy affects haze pollution. The main marginal contributions of this paper are: firstly, the haze-reduction effect of the NFCP is explored in depth, and the ideas of NFCP research are broadened; Second, the heterogeneity of the haze-reduction effect of the NFCP is analyzed from the perspectives of urban population size, geographic and economic location, and urban clusters, which have an important practical significance for optimizing the layout of forest cities in China. Thirdly, we analyze the influence mechanism of the NFCP on haze pollution from the urban forest, social environmental awareness and industrial structure points of view, and provide reference for promoting high-quality construction of forest cities in China to effectively deal with haze pollution.

2. Theoretical Analysis and Research Hypotheses

The NFCP is to take forest vegetation as the main body, taking into account ecological construction and industrial development, and to improve the sustainable development ability of the city comprehensively through urban planning, combining policy guidance (pushing) and market incentives, reflecting the dual meaning of reducing haze pollutant emissions and improving the quality of urban green development [43]. On the one hand, the NFCP is guided by the concept of green development and covers numerous green development initiatives, which will have a direct positive impact on urban haze reduction [44]. On the other hand, the NFCP, as an external force to promote the green transformation of cities, provides a top-down impetus for urban green transformation and can also indirectly promote urban haze reduction [45]. The NFCP, as a kind of urban green infrastructure construction project, depends not only on the natural conditions in which they are located, but is also closely related to the economic status of the cities themselves [46]. In general, places with better economic development also have a greater ability to invest in urban environmental types of infrastructure. Accordingly, the following hypothesis is proposed:

H1: *The NFCP can reduce haze pollution, and there is regional heterogeneity in the haze-reduction effect of NFCP.*

The NFCP suppresses haze pollution by developing urban forests. As an important means of national forest city construction, urban forests are mostly configured with trees, irrigation and grass structures, with a large leaf area and complex spatial structures, which are not only conducive to absorbing carbon dioxide, nitrogen oxides, ammonia, sulfur dioxide and other substances, but also can effectively adsorb dust and suspended small particles through their own forest trees [47]. According to statistical data, urban PM2.5 mass concentrations are lowest within vegetated areas and highest in non-vegetated areas in urban areas [48]. The PM2.5 mass concentration inside the forest decreases faster than outside the forest, and the PM2.5 mass concentration on the roads protected by forests is smaller than the air PM2.5 mass concentration on the external roads [49,50]. This illustrates the ability of urban forest vegetation to combat pollution and reduce haze. Practice has shown that the large-scale construction of green infrastructure such as urban parks, nature reserves, and road forests is a low-cost and effective long-term way to reduce atmospheric particulate matter and clean the atmosphere [51]. Accordingly, the following hypothesis is proposed:

H2: *The NFCP can reduces haze pollution by developing urban forests and improving green coverage in built-up areas.*

The NFCP reduces haze pollution by raising social awareness of environmental protection. The State Forestry and Grassland Administration has included indicators related to cultivating public awareness of environmental protection, providing ecological culture sites, strengthening nature education for all, and promoting ecological culture in the Forest City Development Plan, so the NFCP will greatly increase society's awareness of environmental protection. For urban residents, it is conducive to the practice of a "green" lifestyle and the concept of ecological civilization [52]. For the government, it will increase investment in environmental protection and implement stricter environmental regulations [53]. The increase in social awareness of environmental protection will force enterprises to make technological innovations and stimulate them to develop and apply green production models, emission equipment, and pollution control technologies to reduce the cost of environmental pollution and thus achieve the goal of haze reduction [54]. Accordingly, the following hypothesis is proposed:

H3: *The NFCP reduces haze pollution by raising social awareness of environmental protection.*

The NFCP promotes urban haze reduction through industrial structure adjustment. Cities can take the opportunity of national forest city construction and implement the new development concept to effectively promote the optimization and upgrading of industrial structures, thus producing environmental improvement effects. On the one hand, many resource-based cities and old industrial bases have adopted green development strategies, the development of the green economy, to promote the transformation of industry from underground to above ground, from resource consumption to environmentally friendly transformation, as part of the "three high" enterprises in the "pollution sanctuary" driven by the initiative to transfer industry out of the national forest city construction area [55]. On the other hand, the NFCP has cultivated a number of forest-based green industries through planning guidance, project support, science and technology drive, and policy support, forming a forest ecological system and green industrial system that is compatible with urban and rural development, such as forest tourism, forest recreation, flower cultivation, green forest products, etc. [56]. The correlation and spillover effects of such industries can provide strong support for the green development of the city as well as reduce the haze pollution in the city. In addition, the success of the NFCP directly expands the green spaces of the city, improves the soft environment for regional investment and attracts investment from foreign enterprises [57]. A high-quality habitat environment will also attract high-end talents and intellectual capital to gather, which will not only promote the high-quality development of the city economy, but also lead to the upgrading of the industrial structure, which in turn will affect the level of haze pollution in the city [58]. Accordingly, the following hypothesis is proposed:

H4: *The NFCP reduces haze pollution by adjusting the urban industrial structure.*

3. Materials and Methods

3.1. Data and Variables

The data on urban economic and social indicators used in this paper were obtained from the China Urban Statistical Yearbook (2002–2021), the China Regional Economic Statistical Yearbook (2002–2021), the Wind database, and the work reports of each city government. For a small number of prefecture-level cities with missing data in some years, the average growth rate method was used to fill them in. Since this paper studies the haze-reduction effect of national forest cities at the prefecture level, four municipalities directly under the central government, including Beijing, Tianjin, Shanghai, and Chongqing, were excluded. In addition, cities with serious data deficiencies such as Hong Kong, Macao, Taiwan, and Tibet Autonomous Region, as well as cities such as Chaohu and Laiwu whose administrative divisions changed during the study period, were excluded from the study sample. The list of national forest cities was obtained from official documents published by the State Forestry and Grassland Administration and the National Greening Committee. The final study sample was determined to be 263 cities at prefectural level and above in China, including 157 cities in the treatment group and 106 cities in the control group. The value variables involved were converted to the actual values using the consumer price index with 2001 as the base period, and foreign capital was used to convert to RMB at the exchange rate of the year and then deflated. The results of the descriptive statistics of the relevant variables are shown in Table 1.

Table 1. Descriptive statistics of the variables.

Variables	Definition	N	Mean	S.D	Min	Max
Urban haze levels	Annual average urban PM2.5 concentration (μg/m^3)	5260	3.734	0.360	1.150	4.687
Development of NFCP	City is an NFC in that year = 1; otherwise = 0	5260	0.188	0.391	0.000	1.000
Urban economic development	Expressed in logarithmic GDP per capita (CNY)	5260	10.150	0.901	4.595	13.056
Development of secondary industry	Added value of secondary industry/GDP (%)	5260	0.471	0.112	0.107	0.910
Urbanization level	Non-agricultural employment population/total population (%)	5260	0.380	0.205	0.074	1.000
External openness	Total imports and exports/GDP (%)	5260	0.374	0.569	0.000	3.720
Technological innovation	The number of patent applications authorized per 10^4 people (pieces/10^4 persons)	5260	9.730	26.818	0.002	409.448
Energy intensity	Industrial power consumption/added value of secondary industry (KWh/10^4 CNY)	5260	0.317	0.596	0.013	14.125
Transportation intensity	Per capita freight volume (ton/person)	5260	32.169	38.605	0.089	483.247
Population density	Population per square kilometer (person/km^2)	5260	5.784	0.854	2.303	7.903

Given the purpose of this paper, our empirical estimation required haze data for each city, the development of national forest cities, and other explanatory variables.

(1) Annual average concentration of urban PM2.5. Haze is a collective term for the excess content of various suspended particles in the atmosphere, and PM2.5 is the main component of haze, which has the greatest impact on human health and the quality of the atmosphere; therefore, the key to managing haze is to solve the PM2.5 problem [59]. This paper used ArcGis 10.5 software to extract the raster data of global annual average PM2.5 concentration published by Columbia University to obtain the annual average PM2.5 concentrations of 263 cities in China, which were used to indicate the degree of urban haze pollution.

(2) Core explanatory variable: whether the NFC was created successfully or not (DID = treat∗time). Where treat is a group dummy variable, if the NFCP is successful, then treat will take the value of 1 and be included in the experimental group, otherwise treat will take the value of 0 and be included in the control group. time is a time dummy variable, and the value of NFCP is 1 in the year of success and the following years, and the value of the rest of time variables is 0. Since Guiyang succeeded in creating China's first national forest city in 2004, a total of 219 cities in China have succeeded in building national forest cities up to now. In view of the fact that the research subjects of this paper are prefecture-level cities, and some national forest cities are county-level cities or district and county-level cities, they are not taken into account, and the cities whose administrative levels have changed during the study period (such as Chaohu and Laiwu) and Hong Kong, Macao and Taiwan are also not included; 263 city samples were finally collated.

(3) Three mediating variables. First, we used the greening coverage of urban built-up areas as a proxy variable for urban forestry. Second, we used the harmless disposal rate of domestic waste to measure the social awareness of environmental protection. Third, we used the share of tertiary industry value added in GDP to describe the degree of industrial structure shift.

(4) In the empirical test of the impact of the NFCP on urban PM2.5 concentrations, a series of factors affecting urban PM2.5 concentrations were also controlled for, including: urban economic development (lnagdp), secondary industry development (indu), level

of urbanization (urb), external openness (fdi), technological innovation (te), energy intensity (en), transportation intensity (tra), population density (lnpopden) [60,61].

Table 1 gives the descriptive statistical analysis of each variable, including the name, definition, observed value, mean, standard deviation, minimum and maximum values of these variables.

3.2. The Benchmark Regression Model

The NFCP, which began in 2004, was born out of the policy shock of haze pollution, so the NFCP can be seen as a quasi-natural experiment. The standard DID requires that all individuals in the treatment group start to receive the policy shock at exactly the same point in time. Time-varying DID is applicable to the case where the processing-period time points of individuals are not exactly the same. Considering that the NFCP is promoted in batches year by year, this paper uses a time-varying DID model to identify the impact of NFCP on urban haze [62]. The time-varying DID regression model is as follows.

$$lnPM2.5_{it} = \alpha + \beta DID_{it} + \sum_{i=1}^{N} \gamma_j X_{it} + Cityfe + Yearfe + \delta_{it} \quad (1)$$

where $lnPM2.5_{it}$ denotes the annual average PM2.5 concentration in city i in year t. DID_{it} is the interaction term of two dummy variables treat and time, i.e., $DID_{it} = treat \times time$, and its coefficient β measures the net effect of NFCP on urban PM2.5, X_{it} denotes control variables, specifically including urban economic development, secondary industry development, urbanization level, openness to the outside world, technological innovation, energy emission intensity, transportation intensity, population density and other variables; N is the number of control variables. $Cityfe$, $Yearfe$, and δ_{it} denote city fixed effects, year fixed effects, and random disturbance terms, respectively.

3.3. Parallel Trend Test Model

The time-varying DID model requires the same trend of change between the experimental and control groups before the policy occurs, i.e., it satisfies the parallel trend test hypothesis [63]. To verify this, it is necessary to test whether there is a significant systematic difference in the trends between the experimental and control group cities before and after the NFCP. In this paper, parallel trend tests are conducted using the event study method with 2003 as the base period. The test formula is as follows:

$$lnPM2.5_{it} = c_0 + \sum_{k=-3}^{16} c_k P_{it}^{k} + \sum_{i=1}^{N} \gamma_j X_{it} + Cityfe + Yearfe + \sigma_{it} \quad (2)$$

In Formula (2), P_{it}^{k} is the core explanatory variable, $k \neq 0$ and k is an integer, and other variables are set in accordance with Formula (1); when $t - create\_year_i \geq 16$, $P_{it}^{9} = 1$, otherwise $P_{it}^{9} = 0$; when $t - create\_year_i \leq -3$, $P_{it}^{-3} = 1$, otherwise $P_{it}^{-3} = 0$; when $t - create\_year_i = k$, $P_{it}^{k} = 1$, otherwise $P_{it}^{k} = 0$.

3.4. Mechanism Test Model

Based on the previous theoretical analysis, to test the mechanism of the role of the NFCP in influencing the degree of urban haze pollution, we selected three mediating variables, urban forest, social environmental awareness and industrial transfer [64], and constructed the following mediating effect model.

$$Mediator_{it} = \alpha_2 + \beta_2 DID_{it} + \sum_{i=1}^{N} \gamma_2 X_{it} + \varepsilon_{2i} + \mu_{2t} + \sigma_{2it} \quad (3)$$

$$lnPM2.5_{it} = \alpha_3 + \beta_3 DID_{it} + \lambda Mediator_{it} + \sum_{i=1}^{N} \gamma_3 X_{it} + \varepsilon_{3i} + \mu_{3t} + \sigma_{3it} \quad (4)$$

Among these, the mediating variable $Mediator_{it}$ denotes the garden green area, social environmental awareness, and industrial structure of the city. To eliminate the effect of the magnitude, the index data are logarithmically processed. If the coefficient β_2 and the coefficient λ are both significant, the mediating effect holds. Further, if β_3 is also significant and has the same sign as $\beta_2 \times \lambda$, then $Mediator_{it}$ has a partial mediating effect, and its contribution to the total effect is $(\beta_2 \times \lambda)/(\beta_2 \times \lambda + \beta_3)$. In addition, to ensure the robustness of the empirical results, the bootstrap method is used to verify the existence of mediating effects.

4. Results

4.1. Benchmark Regression

In this paper, the DID model was used to identify the impact of NFCP on PM2.5, and the benchmark results are shown in Table 2. The coefficients of the core explanatory variable DID were found to be significantly negative regardless of whether fixed effects were included or not, indicating that the NFCP is conducive to reducing urban PM2.5 concentration. The coefficient of DID in column (4) was −0.023, which passed the 1% significance level test, indicating that the implementation of the NFCP can reduce the urban PM2.5 concentration by 2.30%, i.e., hypothesis H_1 is valid.

Table 2. Benchmark regression results.

Variables	***LnPM*2.5**			
	(1)	**(2)**	**(3)**	**(4)**
DID	−0.206 ***	−0.028 ***	−0.113 ***	−0.023 ***
	(0.009)	(0.007)	(0.0123)	(0.007)
lnagdp			−0.063 ***	−0.034 **
			(0.001)	(0.013)
indu			1.027 ***	0.013
			(0.065)	(0.044)
urb			0.084	0.050 *
			(0.053)	(0.029)
fdi			−0.074 ***	0.020 **
			(0.013)	(0.008)
te			−0.0025 ***	−0.001***
			(0.001)	(0.000)
en			−0.024 ***	0.009 **
			(0.008)	(0.004)
tra			−0.001 *	0.000
			(0.000)	(0.000)
lnpopden			0.107	−0.091 **
			(0.080)	(0.041)
_cons	3.772 ***	3.638 ***	3.322 ***	4.422 ***
	(0.002)	(0.005)	(0.432)	(0.251)
Time FE	NO	YES	NO	YES
Urban FE	NO	YES	NO	YES
N	5260	5260	5260	5260
R^2	0.196	0.750	0.409	0.756

Note: The values of ***, ** and * are significant at 1, 5 and 10%, respectively. The values of t are shown in brackets and are the same in the following tables.

The regression results in column (4) were used as a benchmark to observe the control variables. The estimated coefficient of lnagdp was negative and passed the significance test at the 5% level, reflecting that an increase in the level of economic development reduces PM2.5. The estimated coefficient of urb was positive and passed the significance test at the 10% level, reflecting that the increase in urbanization level brings about an increase in PM2.5, which is consistent with the fact that urbanization in China is in the medium-term acceleration stage. The estimated coefficient of te was negative and passed the test at the 1% level, indicating that cities with higher levels of technology will have lower PM2.5. The estimated coefficient of en was positive and passed the test at the 5% level, implying that the more energy is consumed, the higher its PM2.5 will be. The coefficient of Lnpopden was significantly negative, which means that population agglomeration is beneficial for reducing PM2.5 level. This indicates that the "clustering" effect of population in China's cities can effectively reduce urban haze pollution.

The parallel test is shown in Figure 1, It can be seen that the difference between urban PM2.5 in the control and experimental groups before the policy implementation was not significantly different from the difference between the two in the base period (2003), satisfying the prerequisites for using the DID model. In addition, although the coefficient of lnPM2.5 was not significant in the years after the successful creation of national forest cities, the magnitude of the coefficient decreases with time, which indicates that the creation of NFC has a significant negative effect on PM2.5.

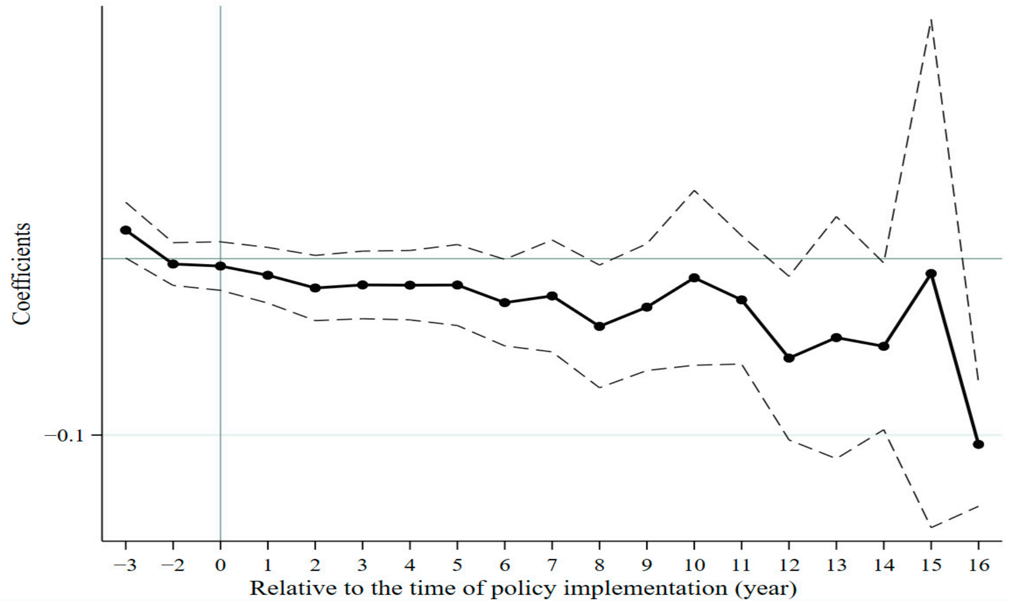

Figure 1. Parallel trend test. Note: the successive broken lines reflect the marginal effects created by national forest cities, and the dotted lines above and below are confidence intervals below the 95% level.

4.2. Robustness Tests

(1) Handling selection bias: PSM-DID. Since the NFCP is not a natural experiment in the strict sense, the haze-reduction effect of the NFCP separated by the double-difference method may still have the problem of self-selection, so this paper used the panel data transformation method and the period-by-period matching method in turn, to further test the robustness of the multi-time PSM-DID model. First, the level of urban economic development, secondary industry development, urbanization level, openness to the outside world, technological innovation, energy intensity, transportation intensity, and population density were set as matching variables. Then two new data sets were obtained according to cross-sectional PSM and period-by-period PSM, respectively, and the two data sets were tested for balance and analyzed for matching effects. In the cross-sectional PSM, the nearest neighbor matching method was used to generate the optimal control group satisfying the common support condition for all cities with successful NFC, and the non-common support part was excluded; while in the period-by-period matching method, the data obtained from year-by-year matching according to the characteristics of the city sample were combined vertically to generate the panel data required for regression. Finally, the haze-reduction effect of the NFCP was re-estimated using the time-varying DID method. The regression results of PSM-DID for both methods are shown in columns (1)–(2) of

Table 2, The coefficient of DID was still significantly negative, which is consistent with the conclusion that " NFCP can reduce urban PM2.5 concentration".

(2) Replace the low haze measurement indicator. In order to avoid the bias of the results caused by the way the explanatory variables are measured, this paper used PM10 and industrial sulfur dioxide removal as proxies to re-run the robustness test, and the results are shown in columns (3)–(4) in Table 3. It was found that the NFCP has had a significant negative effect on urban PM10 and a significant positive effect on industrial sulfur dioxide removal, indicating that NFCP significantly reduces urban PM10 concentration and has a positive effect on urban industrial sulfur dioxide removal, which also indicates the robustness of the baseline regression results.

Table 3. Robustness tests.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Cross-Section PSM	Year-by-Year PSM	PM10	Industrial Fume Removal	Energy Saving and Emission Reduction	Atmosphere 10
DID	−0.020 *** (−2.935)	−0.016 ** (−2.346)	−0.030 * (0.016)	0.107 ** (0.051)	−0.022 *** (0.005)	−0.020 *** (0.008)
fiscal_city					0.018 (0.0167)	
air						−0.140 *** (0.0305)
Control variables	YES	YES	YES	YES	YES	YES
_cons	—	—	6.617 *** (0.479)	11.19 *** (1.561)	4.435 *** (0.252)	4.422 *** (0.251)
Time FE	YES	YES	YES	YES	YES	YES
Urban FE	YES	YES	YES	YES	YES	YES
N	5217	4990	5260	5260	5260	5260
R^2	0.7567	0.7676	0.329	0.176	0.756	0.757

(3) Excluding other policy interference. During the study period, the construction of comprehensive demonstration cities for energy saving and emission reduction fiscal policies, which was carried out in three batches after 2011, and the Action Plan for the Prevention and Control of Atmospheric Pollution (the "Ten Atmospheric Articles") issued by the State Council in 2013 were closely related to urban PM2.5 concentrations. To control the impact of these two policies on the estimation results as much as possible, the dummy variables of the year of implementation of the two policies, namely, the comprehensive demonstration cities of energy-saving and emission reduction fiscal policies and the "Ten Atmospheric Articles", were added to the baseline regression model in turn. Columns (5)–(6) of Table 3 are the estimated results after excluding the above-mentioned policy interference. It was found that the core explanatory variable coefficient DID was still significantly negative after controlling for both types of policies, which indicates to some extent that the NFCP has a significant haze-reduction effect.

(4) Placebo test. Although the city characteristic variables have been effectively controlled in this paper, the assessment results of the haze-reduction effect of the NFCP may still be influenced by some unobserved city characteristic factors. Therefore, further placebo tests of the model were needed. A randomly selected number of cities equal to the number of successful NFC were selected from all sample cities as the experimental group for the placebo test [65]. The specific approach was as follows, using Stata software to randomly select 158 cities as the experimental group, and the policy time was randomly given, repeated 500 times, and the dummy variable $lnPM2.5\_Create^{randon}$ obtained from 500 groups was regressed, and the regression coefficients were distributed as follows. The distribution of regression coefficients is shown in Figure 2. It was found that the β^{randon} values generated during the randomization process showed a normal distribution with 0 as the mean, and the vast majority of coefficients had p-values higher than 0.1, while the estimated coefficient

of the actual policy was −0.023, which is significantly different from the placebo test results. This could also exclude to some extent that the baseline regression results above were caused by other unobservable factors.

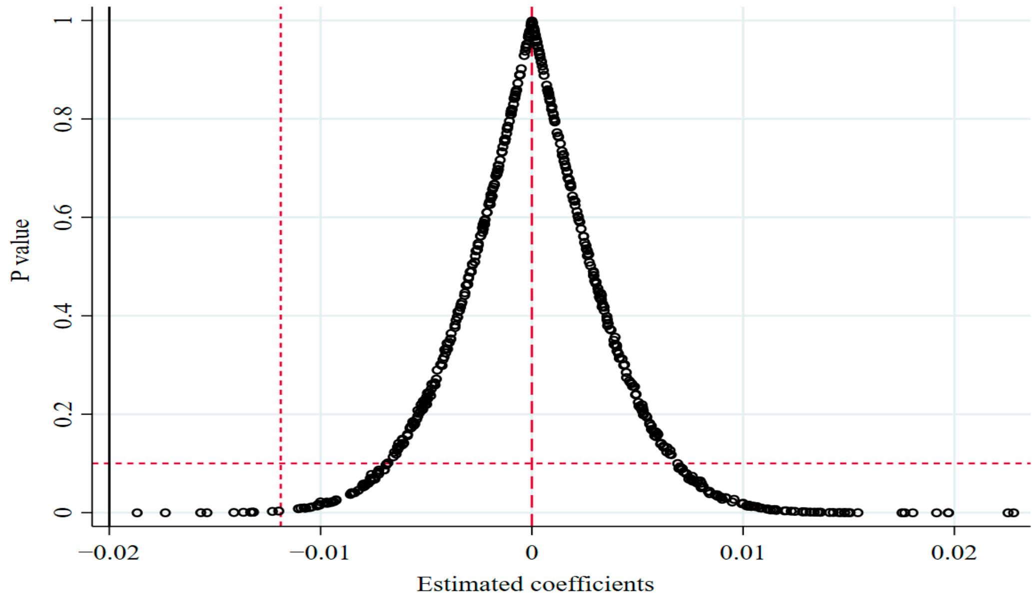

Figure 2. Distribution of estimated coefficients after random processing (500 samples). Note: the *X*-axis is the estimated coefficients generated randomly 500 times, the empty circle is the *p*-value of the estimated coefficients, and the left vertical line is the estimated coefficient of the actual policy.

4.3. Heterogeneity Analysis

The heterogeneity test in this paper focuses on answering the following questions: Does the haze-reduction effect of the NFCP differ significantly depending on the population size of the city? Does the effect of NFCP differ depending on the geographical location of cities? Is there any difference in the haze-reduction effect of NFCP in different forest city groups?

4.3.1. Urban Population Size Heterogeneity Analysis

The haze-reduction effects of NFCP in cities with different population sizes were investigated by dividing the sample cities into six groups according to their population sizes and conducting regressions on each of the six groups of sample cities based on China's 2014 Notice on Adjusting the Criteria for City Size Classification. Since the number of small-scale cities was small and the regression results unreliable, only the regression results for cities of medium scale or above are reported, as shown in columns (1)–(5) of Table 4.

Table 4. Heterogeneity analysis of urban population size.

City Type	(1) Medium City	(2) Large City	(3) Type II Large Cities	(4) Type I Large Cities	(5) Mega Cities and above
Population	0.5 M< and <1 M	≥1 M	1 M< and ≤3 M	3 M< and ≤5 M	>5 M
DID	−0.106 *	−0.108 ***	0.139 ***	−0.086 ***	0.055 ***
	(0.0551)	(0.00629)	(0.011)	(0.011)	(0.010)
Control variables	YES	YES	YES	YES	YES
_cons	3.216 ***	3.313 ***	3.493 ***	1.698 ***	3.580 ***
	(0.452)	(0.218)	(0.322)	(0.495)	(0.413)
Time FE	YES	YES	YES	YES	YES
Urban FE	YES	YES	YES	YES	YES
N	175	5013	1645	1551	1817
R^2	0.295	0.397	0.291	0.439	0.492

The coefficients of DID were all significantly negative, and the absolute values of the coefficients were larger for the sample group of large cities, indicating that the NFCP has a stronger inhibitory effect on haze pollution in large cities. The main reasons for this phenomenon are: firstly, that larger cities have economic agglomeration effects and relatively more efficient resource allocation and utilization, which, combined with stricter environmental regulations and a stronger willingness to improve the environment, make it easier to implement various environmental protection measures in large cities. Secondly, industries in large cities are dominated by service or high-end manufacturing industries, which are less polluting than those in heavy industrial cities. Thirdly, the role of selection of large cities is very significant; only those companies with high production efficiency, advanced technology, environmental protection to meet the requirements, stand firm in the locale, objectively playing a positive role in reducing the city's haze pollution. Further studies have shown that a larger urban population size is not better, and that the haze-reduction effect of the NFCP is strongest in large Type II cities, and relatively weak in mega cities and above. This is related to the function of the city, Type II large cities are mainly tourist cities, the rapid development of wholesale trade, in Type I large cities, manufacturing is more concentrated, and mega cities and above are mainly provincial capitals, the crowding effect of a large-scale concentration of population may offset part of the NFCP to reduce the haze effect. From this conclusion, it is clear that the key to combating PM2.5 does not lie in the size of the urban population, but in the innovation of urban governance, industrial upgrading and technological advancement.

4.3.2. Heterogeneity Analysis of Urban Geo-Economic Location

According to the geographic location of cities, the cities were divided into four groups of east, central, west and northeast for regression, so as to explore the geographic location heterogeneity of the haze-reduction effect of the NFCP, and the results are shown in columns (1)–(4) of Table 5.

Table 5. Heterogeneity analysis of urban geo-economic location.

Location	(1) Eastern Region	(2) Central Region	(3) Western Region	(4) Northeast Region	(5) Cities East of the Hu Line	(6) Cities West of the Hu Line
DID	−0.104 *** (0.011)	−0.097 *** (0.010)	−0.071 *** (0.013)	−0.051 ** (0.023)	−0.113 *** (0.013)	−0.080 ** (0.0334)
Control variables	YES	YES	YES	YES	YES	YES
_cons	4.094 *** (0.280)	1.467 *** (0.366)	3.268 *** (0.326)	−1.351 (1.083)	3.607 *** (0.468)	2.785 *** (0.644)
Time FE	YES	YES	YES	YES	YES	YES
Urban FE	YES	YES	YES	YES	YES	YES
N	1660	1580	1340	680	4880	380
R^2	0.447	0.561	0.394	0.215	0.430	0.281

The regression results of the subgroups show that the regression coefficients of DID were all significantly negative, and the NFCP had the greatest inhibiting effect on haze pollution in the eastern region, while the inhibiting effect on haze pollution in the northeastern region was relatively weak. The reason for this is that, as a kind of green infrastructure, the construction of an urban forest, in addition to relying on certain natural conditions, requires a large amount of capital investment for its construction and maintenance. Due to its waterfront location and long-term capital accumulation, the eastern region has traditionally been the center of economic development in China. Under the guidance of the new development concept, it is more capable and willing to improve the ecological environment of the city. As a heavy industrial base in China, the northeast region is subject to industrial transformation and places more emphasis on economic revitalization, which may cause a lack of investment in its green infrastructure and affect the construction efforts of urban forestry. The difference in the effect of the NFCP on haze reduction in central and western regions may be due to the fact that the Central Rising Strategy has promoted the upgrading and transformation of the industrial structure in the central region, thus reducing the degree of haze pollution in the central region, while the western region has taken over most of the polluting industries transferred from the east and central regions.

The Hu Huanyong line is a geographical dividing line between population development level and economic and social patterns in China, and there are obvious differences in population density, urbanization level and economic development level between its east and west sides. In this regard, this paper investigates the impact of NFCP on PM2.5 in cities on the east and west sides of the Hu Huanyong line. From the estimated results in columns (5)–(6) of Table 5, it is clear that the haze-reduction effect of the NFCP on PM2.5 in the cities east of the Hu Huanyong line was significantly higher than that in cities west of it. The reason for this is that the haze pollution is heavier in the eastern part of Hu Huanyong line and relatively less in the western part, while the difference in the level of economic development directly leads to the difference in the investment in the construction of NFCP on both sides, which is eventually reflected in the difference in the effect of haze reduction.

4.3.3. Heterogeneity of Forest City Clusters

China's "13th Five-Year Plan" forestry development plan clearly proposed the building of six national forest city clusters in Beijing-Tianjin-Hebei, the Pearl River Delta, the Yangtze River Delta, Chang-Zhu-Tan, Central Plains, and Guanzhong-Tianshui by 2020, and currently, the Pearl River Delta national forest city cluster has passed the national assessment and acceptance and is officially completed. In this context, this paper analyzed the haze-reduction effects of the NFCP in different forest city clusters, as shown in columns (1)–(6) of Table 6.

Table 6. Heterogeneity analysis of urban clusters.

City Cluster	(1) Pearl River Delta	(2) Beijing-Tianjin-Hebei	(3) Yangtze River Delta	(4) Chang-Zhu-Tan	(5) Central Plains	(6) Guanzhong-Tianshui
DID	−0.247 *** (0.033)	−0.044 (0.028)	−0.086 *** (0.016)	−0.029 (0.044)	−0.038 ** (0.016)	−0.049 (0.035)
Control variables	YES	YES	YES	YES	YES	YES
_cons	1.658 (1.031)	−0.462 (1.140)	2.237 *** (0.721)	−20.76 *** (6.184)	1.644 *** (0.566)	1.247 (1.487)
Time FE	YES	YES	YES	YES	YES	YES
Urban FE	YES	YES	YES	YES	YES	YES
N	180	240	500	60	520	140
R^2	0.594	0.669	0.572	0.826	0.554	0.489

The NFCP can significantly reduce the haze-pollution level in the Pearl River Delta, Yangtze River Delta, and Central Plains urban agglomerations, while the haze-reduction effect on the Beijing-Tianjin-Hebei, Chang-Zhu-Tan, and Guanzhong-Tianshui urban agglomerations is not obvious, and the haze control effect of the NFCP on the Pearl River Delta region is significantly better than other urban agglomerations. The possible explanation lies in the different effects of the NFCP on the effect of haze control within urban agglomerations, which is closely related to the leading industries and the state of urban forest construction in urban agglomerations. The modern service and manufacturing industries in the Pearl River Delta city cluster are very well developed, and it has a relatively low proportion of heavy industry, a high degree of urbanization and forest coverage, and relatively good urban greening work, so compared with other city clusters, the effect of the NFCP on haze-pollution suppression is most significant [66]. The Yangtze River Delta urban agglomeration is dominated by light industries such as textiles, electronics and foodstuffs, and the concentration of innovative resources has contributed to the improvement of the regional ecological environment by optimizing the industrial structure [67]. The Central Plains city cluster has taken over part of the industrial transfer from Beijing, Tianjin, Hebei, Shandong and other regions, but by building a "three screens and four corridors" ecological network, creating a "green ecological development demonstration area", and compiling urban air quality deadlines to meet the plan, the regional ecological environment has been effectively improved [68]. The Beijing-Tianjin-Hebei city cluster is China's influential heavy chemical industry base; the energy consumption structure is coal-based, coupled with more coal burning in the autumn and winter seasons, compared with other cities, The haze-reduction effect of the NFCP is not significant [69]. Despite the accelerated pace of regional integration development of the Chang-Zhu-Tan urban agglomeration, the degree of its economic development determines the low effect of industrial transfer, and the forest coverage rate is lower than the average level of Hunan Province, so there is much room for progress in the construction of national forest cities [70]. The Guanzhong-Tianshui Economic Zone is dominated by non-ferrous metal processing, building materials, coal and other industries, and lacks a coordinated policy for regional environmental protection and development, and the haze problem is more prominent [71].

4.4. Mechanism Test

Table 7 shows the test results of the mediating mechanism. The regression coefficient of NFCP was significantly positive when urban forest, environmental awareness and industrial structure were the explanatory variables, and the coefficient was significantly negative after including each mediating variable and the NFCP into the model regression at the same time. The confidence interval of the bootstrap test for each mediating variable did not include 0, which indicates that the NFCP can improve urban greenery coverage, enhance social awareness of environmental protection, promote industrial structure transformation, and thus reduce haze pollution. Hypothesis H2, Hypothesis H3, and Hypothesis H4 are all verified.

Table 7. Results of intermediate effect test.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	Urban Forest	**PM2.5**	**Environmental Awareness**	**PM2.5**	**Industry Structure**	**PM2.5**
DID	0.044 *** (0.016)	−0.023 *** (0.007)	0.192 *** (0.039)	−0.023 *** (0.007)	0.066 *** (0.009)	−0.023 *** (0.007)
Urban forest		−0.014 (0.010)				
Environmental Awareness				−0.003 (0.003)		
Industry structure						−0.039 (0.036)
Control variables	YES	YES	YES	YES	YES	YES
_cons	−4.310 *** (0.992)	4.379 *** (0.253)	−4.346 *** (1.588)	4.494 *** (0.270)	−2.065 *** (0.417)	4.344 *** (0.248)
Bootstrap test confidence interval	−0.1429269 < _bs_2 < −0.1056222		−0.1406999 < _bs_2 < −0.1034399		−0.1255899 < _bs_2 < −0.0853589	
Time FE	YES	YES	YES	YES	YES	YES
Urban FE	YES	YES	YES	YES	YES	YES
N	5259	5259	5063	5063	5260	5260
R^2	0.281	0.756	0.116	0.763	0.734	0.756

From the perspective of urban forest, the construction of NFC can promote the construction of urban forest, which is mainly reflected in the increase in forest area, recreational parks and urban green coverage. Urban forest can not only purify the air pollution, but also this effect will be more obvious as the trees grow or the forest area increases. In terms of environmental awareness, the construction of national forest cities helps strengthen the concept of ecological civilization among residents. Firstly, the construction of national forest cities requires cities to be equipped with a certain number of popular science places, such as science museums in parks or nature reserves that are open to the public for free; secondly, the construction of NFC requires ecology-related activities to be held at least five times a year, and voluntary tree planting activities to be organized for city residents at regular intervals. Finally, with the development of forest cities, the increase in green space per capita and the improvement of living conditions, the requirements for the environment will naturally become higher and higher. In terms of industrial structure, China does propose in the Forest City Development Plan to establish an ecological barrier and develop and expand forest-related green industries, such as forest farming and flower cultivation. On the one hand, stopping indiscriminate logging and continuing to expand ecological spaces; on the other hand, developing greening service industries such as forest tourism, recreation and oxygen bars according to the existing forest resources.

5. Discussion

This paper used a time-varying DID model to find out whether the NFCP could promote urban haze reduction, and whether there is regional heterogeneity in this haze-reduction effect. Further, using a mediating effect model, we found that the NFCP can promote urban haze reduction by increasing urban forest coverage, enhancing residents' awareness of environmental protection, and promoting the development of tertiary industries.

For the haze-reduction effect of the NFCP, we think the government management should actively play the guiding role in national forest city construction, and implement zoning classification and grading management for the cities according to the natural conditions, leading functions and economic location. The haze-reduction effect of the NFCP is heterogeneous, and each city needs to build a unique national forest city construction system by taking into account its own geographical features, location conditions and existing economic status, and formulate a forest city development plan that meets the actual local conditions. Relevant regulatory regulations are also essential, and the management department strengthens the supervision, inspection and guidance services for the NFCP through hard regulation and soft constraints, adjusts the NFC construction measures in a timely manner, and may adopt withdrawal mechanisms when necessary.

The development of an urban forest has a haze-reduction effect. As an important green infrastructure, urban forests should be incorporated into the planning and construction of cities along with urban buildings, brownfields, squares and other facilities. In the choice of urban greening methods, we can choose the urban greening mode of mainly trees, evergreen and native species, and actively explore three-dimensional greening methods in the form of roofs, walls and bridges to organically combine the forest and the urban space.

The improvement of social awareness of environmental protection can also promote urban haze reduction. With the development of the Internet, various new ways to use publicity have emerged. We can use new media such as Facebook and WeChat to carry out environmental protection publicity, making them important places to carry out environmental protection publicity. Residents themselves should develop a sense of ownership and realize that they are the ultimate beneficiaries of a protected urban environment.

For forest city construction, we should not only let it have the effect of haze reduction, but also bring about sustainable development of the urban economy. City managers should take the construction of a national forest city as an opportunity to continuously optimize the forestry industry structure in the region. On the one hand, local governments need to build an interconnected ecological forest network system according to the natural geographical conditions, create forest towns with urban cultural characteristics, forest parks, forest homes, forest oxygen bars and other bases, and on the other hand, they should develop ecological industries such as planting, breeding, tourism, vacation, leisure and recreation based on the forest resources in the region to promote the green growth of the urban economy.

In future research, we will focus on micro studies of the impact of national forest cities on the perceptions and behaviors of urban residents. For example, questions such as which aspects or types of forest city construction will affect the physical and psychological health of urban residents; and what kind of forest city (quantity, quality, and configuration of types and spaces) can accommodate the interests of different social groups in an urban society with changing demographic characteristics.

6. Conclusions

This paper used the NFCP as a quasi-natural experiment to estimate the impact and mechanism of action of the NFCP on urban PM2.5, based on the panel data of 263 prefecture-level cities in China from 2001 to 2020, using a time-varying DID model and a mediating effects model, and found that:

(1) Overall nationwide, the construction of NFC is beneficial in reducing urban PM2.5 concentrations, with an average decrease of 2.25% in PM2.5 concentrations in cities with a successful NFC; a finding that remains robust after placebo tests and replacement of explanatory variables, respectively.
(2) The haze-reduction effect of the NFCP is heterogeneous, and the haze-reduction effect of the NFCP is more significant for the Pearl River Delta urban agglomeration, Type II large cities, cities in the eastern region and cities east of the Hu Huanyong line.
(3) The NFCP promotes urban haze reduction by increasing the area of urban green spaces, raising residents' awareness of environmental protection, and promoting the shift of industrial structure to tertiary industries.

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