Spatiotemporal impact of major events on air quality based on spatial differences-in-differences model: big data analysis from China

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This is an author's accepted manuscript of an article published in the Natural Hazards DOI: 10.1007/s11069-021-04517-y, 2021.

The final definitive version is available online at:

https://doi.org/10.1007/s11069-021-04517-y

Spatio-temporal Impact of Major Events on Urban Air Quality Based on PSM-DID: Big Data Analysis from China

ABSTRACT

"Political blue sky" is a unique phenomenon in the emission control of air pollutants in China. In an attempt to investigate the impact of major events on urban air quality in terms of the extent, duration and spatial scope; data on the daily air quality index (AQI) and the concentrations of individual pollutants are collected in 140 cities of China from January 2nd, 2015 to November 28th, 2017. Based on the combination of differences-in-differences and propensity score matching, the impact of major events, such as political conferences, sporting events at the national level, on urban air quality in the dimensions of time and space are explored. The study shows a significant improvement (AQI decreases by about 10% on average) in the air quality of the cities involved in hosting major events. From the perspective of individual pollutant concentrations, there was a decrease in particulate matter, followed by nitrogen oxides, but less obvious in carbon monoxide and ozone. After a period of major events, an upward trend with varying degrees is presented in the air quality index and the concentration of each individual pollutant, even beyond the normal levels. It is concluded that major events not only affected the air quality of the host city, but also exercised influence on the air quality of the surrounding areas. The spatial scope affecting the urban air quality is about 800 km radius around the host city, and the farther away from the host city, the smaller the impact. Recommendations for mitigating the impact of major events on urban air quality have been proposed, such as establish regional atmospheric environment management system and formulate regional unified standards for pollutant discharge, industrial access and law enforcement.

Keywords: urban air quality, propensity score matching, differences-in-differences, major events

1. Introduction

According to the latest evaluation of WHO (2018), 90% of the world's population currently lives in areas where $PM_{2.5}$ levels exceed WHO limits (an average of 10ug/m^3 per year). In developed countries and regions such as North America, Europe, the haze-related problems are well controlled, but haze still poses a serious threat in undeveloped regions such as in East Asia, South Asia and Africa (Rafaj et al., 2018).

In China, with the global warming and increasing calm weather days in recent decades, the frequent occurrence of haze has attracted wide attention of the government and all sectors of the society. The effective prevention and control of air pollution and the guarantee of air quality are closely related to the image of the state and government, as well as the health of the people (Matus et al., 2012). When faced with major political conferences or events, governments at all levels take various measures to control air pollution. For example, during the 2008 Beijing Olympic Games, the Ministry of Environmental Protection laid down *Measures for Air Quality Guarantee in Beijing for the 29th Olympic Games*, and the General Office of Hebei Provincial Government formulated *the Emergency Measures for Air Pollution Control under Extremely Adverse Meteorological Conditions* during the Olympic Games in the Hebei Province.

These efforts were meant to ensure that the atmospheric environment quality during the Olympic Games met acceptable standards to ensure the normal progress of the competition. In addition, Beijing and its surrounding provinces implemented a series of temporary control measures for air pollution, including strengthening motor vehicle management, suspending part of a construction site operation, enhanced road cleaning, shutting down and limiting production of key pollution enterprises (Song et al., 2019, 2020). Other measure taken included the reduction in the discharge of organic exhaust and implementing emergency measures for pollution control under extreme adverse weather conditions. These measures achieved remarkable results. For example, from July 20th to September 20th in 2008, the total emission of air pollutants in Beijing dropped by 34.98%, the best level in 14 years after 1995 (Chen et al., 2013). The momentary "political blue sky" also appeared during the APEC meetings, the 70th anniversary parade of anti-fascist victory, the Nanjing Youth Olympic Games and the Hangzhou G20 Summit. Whilst it seems a common practice to conduct temporary air quality control during major events (Shi et al., 2016; Wu et al., 2018, 2019), little is known about the real impact of these major events on the quality of air in these cities and the surrounding towns. This study therefore seeks to address the following questions how much impact do major events have on urban air quality? How long does the impact last? What are the spatial characteristics of the impact?

Very limited studies on the impact of major events on air quality have been carried using quantitative methods. In this regard, this paper adopts a quantitative approach by using data on the daily air quality index (AQI) and the concentration of individual pollutants constituting air quality indices of 140 cities from 2015 to 2017, to analyse the impact of major events on air quality in China. The data included details on major competitions, important conferences, and urban air quality from two dimensions of time and space. The data was analysed using a combination of differences-in-differences (DID) and propensity score matching (PSM) methods.

The rest of this paper is arranged as follows. The second part deals with the literature review, followed by the data and empirical strategy, indicators and sources of data. The fourth section covers the empirical analysis, followed by the conclusion.

2. Literature Review

Some cities, both at home and abroad, endeavor to take temporary control measures to ensure air quality during major events, such as the Busan Asian Games in 2002, Delhi Federal Games in 2010, Beijing Olympic Games in 2008, Beijing APEC Conference in 2014, etc. Several authors have conducted thorough analyses and reported improvements in urban air quality during major events (Wang et al. 2012; Lee et al. 2005; Wang and Xie 2009; Beig et al. 2013; Liu et al. 2016; Huang et al. 2015; Zhao et al. 2016; He et al. 2016; Jia and Chen, 2019; Li et al. 2019). For example, Lee et al. (2005) investigated the significant concentration decrease of PM_{10}, CO, NO_2 and SO_2 in 13 air stations during the 24th Asian Games in Busan, Korea in 2002. Beig et al. (2013) found that Delhi adopted a series of measures, such as vehicle and traffic control, factory relocation and power plant emission reduction when the 2010 Commonwealth Games was held in India.

In addition, Wang and Xie (2009) evaluated the effect of environmental quality improvement by reducing traffic emissions during the 2008 Beijing Olympic Games. Based on the analysis of “Parade Blue” and “APEC Blue”, Liu et al. (2016) found that the concentration of NO_2 decreased by 43% in the military parade, compared with the normal level, whilst a decrease of 21% in concentration of NO_2 was reported during the APEC conference. Huang et al. (2015) analysed the regional emission control effects and found the “APEC Blue” phenomenon in China. Zhao et al. (2016) made a comparison between the air pollutant concentration data in Beijing from August 1, 2015 to September 18, 2015 and the monitoring data of the same period in 2014. Based on the comparison of NO_2 concentration in Hangzhou during and before the G20 Summit, Zhao et al. (2017) made a conclusion that the concentration of NO_2 decreased significantly during the G20 Summit. Ngo et al. (2019) gave an interesting research about the effects of transboundary air pollution following major events in China on air quality in the USA.

Towards the end of 2019, COVID-19 as a major event, has had a huge impact on industrial production and human life. Many scholars have studied the impact of COVID-19 on air pollution emissions. For example, He et al. (2020) analysed the short-term impact of China's lockdown measures on urban air governance during COVID-19. Fan et al. (2020) studied the impact of China's prevention and control measures on air pollution during COVID-19. Bera et al. (2020) studied the impact of the COVID-19 blockade on air pollution in Kolkata (India). Other studies include Dutheil et al. (2020), Bogdan (2020), Li et al. (2020), etc. However, these studies only focused on the impact of a single event not multiple events on air pollution. Based on the above considerations, this paper explores a number of events, and their impact on air pollution to supplement previous studies.

Despite the findings from available literature on urban air quality, this paper holds that the existing studies (e.g. list some of the studies - Lee et al. 2005; Wang and Xie 2009; Beig et al. 2013; Liu et al. 2016; Huang et al. 2015; Zhao et al. 2016; Ngo et al. 2019) did not exclude the influence of seasonal trend, year difference, and regional effect on urban air quality. In addition, existing studies did not assess the effect of major events on urban air quality, and also failed to reveal continuous changes and associated spatial characteristics before and after the major events. In order to address these shortfalls, this study posits that, the combined methods of propensity score matching, and differences-in-differences can address the current issues by providing a better estimation of the impact of major events on urban air quality. In this regard, the present study adopts the DID and PSM-DID models to investigate spatio-temporal impact of major events on urban air quality as new contribution to the current literature.

3. Data and Empirical Strategy

3.1 Variable and Data

3.1.1 The Air Quality Level

Air pollutants mainly include particulate matter, nitrogen oxides, carbon monoxide, sulfur dioxide, etc. (Li et al., 2019). In the present study, the daily average air quality index (AQI) and the concentration data of fine particulate matter ($PM_{2.5}$), inhalable particulate matter (PM_{10}), sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2) and ozone (O_3) are selected to measure the air pollution quality level.

3.1.2 Control Variable

In an attempt to exclude the influence of other factors (apart from major events) on air quality indicators, weather factors are added as control variables X_{it} in this paper. Weather variables mainly include the highest temperature (highest_t), lowest temperature (lowest_t), rainfall, density of snow and wind speed/direction, etc., to control the impact of weather changes on haze level. Furthermore, in propensity score matching, it is unreasonable to use control variables or to put control variables in logistic regression model in a certain period when no major activity occurs owing to the effect of long panel data. Therefore, the mean of control variables X_{it} is used in matching without the occurrence of major events.

3.1.3 Sample Selection

The major events in this paper are defined as international or national sporting events and important political conferences in China. The major events considered were from January 2, 2015 to November 28, 2017 (as shown in Table 1).

Table 1 Major events during January 2, 2015 and November 28, 2017

Major event	Start Date	End Date	Host Cities
The first youth movement of the people's Republic of China	October 18, 2015	October 27, 2015	Fuzhou
the Fifth Plenary Session of the 18th Communist Party of China (CPC) National Congress	October 26, 2015	October 29, 2015	Beijing

Fourth Meeting of China-Central and Eastern European Leaders	November 24, 2015	November 25, 2015	Suzhou
Fourteenth Meeting of the Council of Heads of Government of the Shanghai Cooperation Organization (SCO) Member States	December 14, 2015	December 15, 2015	Zhengzhou
Third Session of the Twelfth Chinese People's Political Consultative Conference (CPPCC) National Committee	March 3, 2015	March 13, 2015	Beijing
Third Session of the Twelfth National People's Congress	March 5, 2015	March 15, 2015	Beijing
Beijing International Association Of Athletics Federations (IAAF) World Track and Field Championship	August 22, 2015	August 30, 2015	Beijing
The 70th Anniversary Parade of the Victory of the War of Resistance Against Japan	September 3, 2015	September 3, 2015	Beijing
Boao Forum for Asia (BFA)	March 22, 2016	March 25, 2016	Haikou
Fourth Session of the Twelfth Chinese People's Political Consultative Conference (CPPCC) National Committee	March 3, 2016	March 14, 2016	Beijing
Fourth Session of the Twelfth National People's Congress	March 5, 2016	March 14, 2016	Beijing
Group of Twenty (G20) summit	September 4, 2016	September 5, 2016	Hangzhou
The Standing Committee of the Political Bureau of the Central Committee of the Communist Party of China (CPC)	January 10, 2017	January 10, 2017	Beijing

The Nineteenth National People's Congress of the Communist Party of China	October 18, 2017	October 24, 2017	Beijing
Five Sessions of the Twelfth Chinese People's Political Consultative Conference (CPPCC) National Committee	March 3, 2017	March 13, 2017	Beijing
Fifth Session of the Twelfth National People's Congress	March 5, 2017	March 15, 2017	Beijing
International Cooperation Summit Forum	May 14, 2017	May 15, 2017	Beijing
BRICS(Brazil, Russia, India, China, South Africa) Games	June 17, 2017	June 21, 2017	Guangzhou
Thirteenth National Games of the People's Republic of China	August 27, 2017	September 8, 2017	Tianjin
General Assembly of International Standards Organization	September 12, 2017	September 14, 2017	Beijing
BRICS(Brazil, Russia, India, China, South Africa) Summit	September 3, 2017	September 5, 2017	Xiamen
Thirteenth Hangzhou National Student Games	September 4, 2017	September 8, 2017	Hangzhou

The sample include 28 cities involved in these activities (9 host cities and 19 co-host cities). Based on the panel data of 140 cities over a span of 1094 days, 28 cities involved in major events (treatment group) were identified together with 112 control cities (control group) around them (as shown in Table 2). In addition, the persistence and spatial characteristics of the impact of the major events on urban air quality are discussed by using the PSM-DID model, with a thorough analysis of robustness.

Table 2 A list of cities involved in events and corresponding control cities

Cities involved in events (Treatment group)	Control cities (Control group)
Beijing、Changzhou、Foshan、Fuzhou、Guangzhou、Haikou、Hangzhou、Huzhou、Jinan、Jiaxing、Nanjing、Nantong、Ningbo、Quanhzou、Sanya、Xiamen、Shanghai、Suzhou、Taizhou、Tianjin、Wuzi、Wuhan、Xian、Zhenjiang、Zhengzhou、Zhongshan、Shenzhen、Shaoxing	Shijiazhuang、Zhangjiakou、Handan、Langfang、Baoding、Cangzhou、Xingtai、Chengde、Hengshui、Qinhuangdao、Tangshan、Xinxiang、Kaifeng、Jiaozuo、Hebi、Xuchang、Luoyang、Pingdingshan、Anyang、Puyang、Sanmenxia、Nanyang、Shangqiu、Xinyang、Zhoukou、Zhumadian、Luohe、Yancheng、Huaian、Suqian、Xuzhou、Lianyungang、Yangzhou、Nanping、Zhangzhou、Putian、Sanming、Longyan、Ningde、Wenzhou、Jinhua、Taizhou、Lishui、Zhoushan、Quzhou、Weinan、Tongchuan、Shangluo、Baoji、Ankang、Hanzhong、Yanan、Yulin、Taian、Liaocheng、Zibo、Dezhou、Binzhou、Qingdao、Weihai、Yantai、Dongying、Weifang、Zhizhao、Heze、Linyi、Zaozhuang、Jining、Xiaogan、Suizhou、Huangshi、Xianning、Jingzhou、Xiangyang、Yichang、Shiyan、Jingmen、Ezhou、Huanggang、Huizhou、Dongguan、Zhuhai、Jiangmen、Zhaoqing、Qingyuan、Shantou、Chaozhou、Jieyang、Shanwei、Zhanjiang、Maoming、Yangjiang、Shaoguan、Yunfu、Meizhou、Heyuann、Datong、Shuozhou、Taiyuan、Yangquan、Changzhi、Jincheng、Linfen、Suzhou、Bengbu、Chuzhou、Maanshan、Wuhu、Xuancheng、Huangshan、Qingyang、Changsha

3.1.4 Data Collection

In this paper, the daily AQI and the daily mean value of individual pollutant concentration are used as the object of analysis. AQI data was downloaded from the Environmental Protection Data Center of the People’s Republic of China (http://datacenter.mee.gov.cn/websjzx/queryIndex.vm), and the individual pollutant concentration data was obtained from the national real-time publishing platform of urban air quality of China Environmental Monitoring Station (http://106.37.208.233:20035/). In order to ensure the slight fluctuation of the city fixed effects in the short term, the time span of the samples was not too long. Besides, due to the missing data, the final time span of samples is from January 2, 2015 to November 28, 2017.

In addition, meteorological data such as rainfall, temperature and wind grade are derived from the historical weather data of the cities provided by “2345 Weather Network”. Specific indicators include the highest temperature (highest_t), lowest temperature (lowest_t), rainfall, density of snow and wind grade, etc. In terms of the wind scale, this paper adopts the mean treatment, such as 3.5 wind scales instead of 3-4 scales.

3.2 Empirical Strategy

During the major event of a city, other cities without such events become the control group. In this regard, a double difference is shown between the occurrence and non-occurrence periods in the same city, as well as the host and non-host cities in the same period, which lays the foundation of the idea of differences-in-differences.

Specifically speaking, the model is established as follows.

$$Y_{it} = \beta_0 + \beta_1 event_i dt_{it} + \lambda X_{it} + \mu_i + \nu_t + \varepsilon_{it} \tag{1}$$

Where subscript i represents the ith city, subscript t represents the date (year, month, day) of the data, ε_{it} represents the stochastic disturbance, and Y_{it} represents the air quality level of the ith city at the time t. $event_i$ denotes the cities involved in the major event. If $event_i=1$, the ith city is the one involved in the major event, otherwise $event_i= 0$. Owing to the different time of each major event, dt_{it} denotes whether the major event occurs in the i^th^ city at the time t. The occurrence should be taken as 1, otherwise as 0. The coefficient β_1 of $event_i dt_{it}$ describes the impact of the major events on air quality.

A set of control variables X_{it} is added to exclude the influence of other factors on air quality indicators. μ_i refers to the regional dumb variable, which reflects the city-fixed effects that will not change in a short time. v_t represents a set of time-fixed effects used to control the effects of seasonal factors and human working hours on air quality. Seasonal factors mainly include dumb variables of the year, month in the year and the week in the year, and the effects of human working hours on air pollution include the dumb variables of the day in a week.

In order to investigate the duration of the impact of major events on urban air quality, the values of “1-5 days after events” and “6-10 days after events” were added to dt_{it}. Given the occurrence of major events in the ith city at the time t, $dt_{it1} = 1$, otherwise 0; at the time t after 1-5 days of the major event in the ith city, $dt_{it2} = 1$, otherwise 0; at the time t after 6-10 days of the major event in the ith city, $dt_{it3} = 1$，otherwise 0. Besides, β_1、β_2 and β_3 are used to analyze the duration of the impact of the major events on urban air quality.

$$Y_{it} = \beta_0 + \beta_1 event_i dt_{it1} + \beta_2 event_i dt_{it2} + \beta_3 event_i dt_{it3} + \lambda X_{it} + \mu_i + v_t + \varepsilon_{it} \qquad （2）$$

In order to investigate the impact of major events on urban air quality, Model 1, after modification, is constructed as follows:

$$Y_{it} = \beta_3 + \beta_4 distance_{ij} dt_t + \lambda X_{it} + \mu_i + v_t + \varepsilon_{it}$$

（3）

Where $distance_{ij}$ is a grouping variable, representing the distance of the jth city from where the major event takes place (in ith city) at the time t. The values are “within 100 km”, “100-200 km”, “200-300 km”, “300-400 km”, etc. dt_t denotes whether a major event occurs within the time t. Accordingly, the coefficient β_4, is the estimation of the impact of spatial scope of each major event on urban air quality and the difference of its impact on different cities. The other variables have the same meaning as in model (1).

3.2.1 The Selection of Control Group

The impact assessment in this paper is mainly based on cities where major events occurred during the period under review. In this sense, cities with major events are defined as treatment groups, and the ones around which no major event takes place are defined as control groups. A double difference is made between the two groups of cities. However, due to the great heterogeneity in the development of different cities in China, it is difficult to satisfy the condition of time effect consistency. Therefore, before the application of DID method, it is necessary to make all aspects of the characteristics of the treatment group similar to those of the control group. In other words, with the characteristics similar to the treatment group, cities, where major events do not occur, are taken as the control group in order to eliminate the sample deviation as much as possible. On this basis, the present study further employs the PSM-DID method to assess the impact of major events on urban air quality. The propensity score value can be obtained through the logit regression of control variables based on the dummy variables of cities with or without major events, and the nearest value should be adopted as the control group of the city where the major events took place.

Before PSM-DID estimation, the rationality needs to be verified. If there is no significant difference in the co-variables between the matched treatment group and the control group, then the matching effect is great, which accounts for the rationality of PSM-DID estimation. If the results of PSM-DID are similar to those of DID, the robustness of the estimated results can also be demonstrated.

3.2.2 Robustness Test

In order to further prove the robustness of the estimated results, the methods adopted are as follows.

(1) Transform window. Samples of 20, 30 and 40 days before and after major events are retained. The retained similar results account for the robustness of results.

(2) Using different controls. Different cities are selected as the control group to investigate the consistency of the findings. The robustness of the estimated results can also be verified given the similar PSM-DID and DID results.

(3) Placebo test. Under the condition of fictitious event time, the change of regressive results from significant to insignificant verifies the robustness of the previous conclusion.

4. Empirical Analysis

4.1 Exploratory Analysis

The daily air quality data of the 28 cities involved in the events are divided into two parts according to dt_{it}=1 or 0, that is to say, whether the major events take place in the

i^{th} city at the time t. Descriptive statistics are made for the main variables, and longitudinal comparison is made with the sample data of the 28 cities. The average and maximum concentrations of AQI and individual pollutant during major events were found to be lower than those during non-major events (Table 3). Among them, the average AQI of the 28 activities involved in the urban major events is 64.26, which is 10.34 lower than that without major events, decreasing by about 13.9%. Besides, the maximum AQI during major events is 331, much lower than that without major events. From the perspective of individual pollutant, the average concentration of fine particulate matter ($PM_{2.5}$), inhalable particulate matter (PM_{10}), sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2) and ozone (O_3) in the 28 cities were lower than those during non-major events. Therefore, based on preliminary judgement, the air quality during major events is better than that during non-major events.

Table 3 Non-event period and event period for 28 cities involved in the events

Variable	Units	Non-event period			Event period			Difference		
		Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
AQI	index number	74.6	500	10	64.26	331	15	-10.34	-169	5
$PM_{2.5}$	μg□m^3	47.61	606	2	37.38	228	6	-10.23	-378	4
PM_{10}	μg□m^3	78.87	838	6	61.71	365	15	-17.16	-473	9
SO_2	μg□m^3	16.53	175	1	12.23	89	2	-4.3	-86	1
NO_2	μg□m^3	38.43	161	3	33.78	87	7	-4.65	-74	4
CO	μg□m^3	0.93	9	0	0.9	3	0	-0.03	-6	0
O_3	μg□m^3	112.24	363	2	106.8	270	29	-5.44	-93	27
highes_t	℃	22.96	41	-11	23.28	35	4			
lowest_t	℃	15.47	31	-16	15.6	27	-5			
rain	Dummy variable	0.39	1	0	0.33	1	0			
snow	Dummy variable	0.01	1	0	0	0	0			
wind	Ordinal number	3.1	11.5	1.5	2.99	6	2			

The samples with major events are divided into two parts. One part includes the samples of cities involved in the major events, and the other involves the ones without major events for a horizontal comparison. The average AQI of the cities involved was 65.84, which is much lower than that of the cities without major events (Table 4). In terms of individual pollutant, the mean concentration values of fine particulate matter ($PM_{2.5}$), inhalable particulate matter (PM_{10}), sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2) and ozone (O_3) in the cities with major events are lower than those without major events. On this basis, it can be preliminarily demonstrated that the occurrence of major events can improve the urban air quality.

Table 4 The cities involved and cities not involved at event period

Variables	Cities involved			Cities not involved			Difference		
	Mean	Max	Min	Mean	Max	Min	Mean	Max	Min
AQI	65.84	423	15	81.02	500	10	-15.18	-77	5
$PM_{2.5}$	37.7	316	6	49.76	537	3	-12.06	-221	3
PM_{10}	64.03	398	15	87.835	675	5	-23.805	-277	10
SO_2	12.49	112	2	21.39	551	1	-8.9	-439	1
NO_2	33.89	110	7	34.62	144	2	-0.73	-34	5
CO	0.92	4	0	1.1	13	0	-0.18	-9	0
O_3	105.66	264	29	114.45	407	2	-8.79	-143	27
highes_t	22.97	35	2	21.21	38	-9			
lowest_t	15.26	27	-6	12.45	29	-23			
rain	0.31	1	0	0.32	1	0			
snow	0	0	0	0.01	1	0			
wind	2.97	5.5	1.5	2.98	10	2			

Table 5 presents the mean values of air quality indicators and control variables in the 28 cities during major events, 1-5 days before and after major events, as well as 6-10 days before and after major events. It can be seen that except ozone, AQI and the average values of five other single pollutants show a sudden increase within 1-5 days after the end of major events, and then decrease slowly within 6-10 days. This indicates that local governments may improve air pollution quality by adopting temporary measures in advance (e.g. 7 days). However, after major events, the air quality index rebounds significantly, even higher than before. In this regard, it can be speculated that the temporary control has no long-term benefits for air quality. Therefore, the statistically significant difference needs to be further analyzed by establishing a model.

Table 5 The mean values of main variables in 28 cities involved during different periods

Variables	6-10 days before	1-5 days before	Event period	1-5 days after	6-10 days after
AQI	76.13	76.36	74.60	93.84	82.10
$PM_{2.5}$	45.59	47.32	47.61	60.37	54.03
PM_{10}	74.83	74.11	78.87	91.51	89.70
SO_2	15.00	13.92	16.53	19.02	16.07
NO_2	35.38	36.27	38.43	47.99	43.51
CO	0.99	0.96	0.93	1.05	1.00
O_3	113.34	104.89	112.24	106.51	92.83
highest_t	23.69	23.09	22.96	21.80	21.50
lowest_t	16.24	15.90	15.47	13.80	14.28
rain	0.31	0.36	0.39	0.28	0.39
snow	0.019	0.01	0.01	0.00	0.01
wind	3.01	2.99	3.1	2.74	2.9

The whole sample of 140 cities are classified by month to calculate the monthly mean of seven air quality indicators. Figure 1 shows the trend of the average air quality in the cities from January to December. For ease of observation, the carbon monoxide concentration is magnified 100 times. As the figure indicates, there are obvious seasonal characteristics in air quality. The AQI and most single pollutant concentration data in winter are higher than those in summer, while ozone concentration presents an opposite trend. In this sense, in order to eliminate the impact of other factors (excluding major events) on air quality, it is necessary to make some seasonal adjustments of air quality indicators, which accounts for the consideration of seasonal factors in the regression equation.

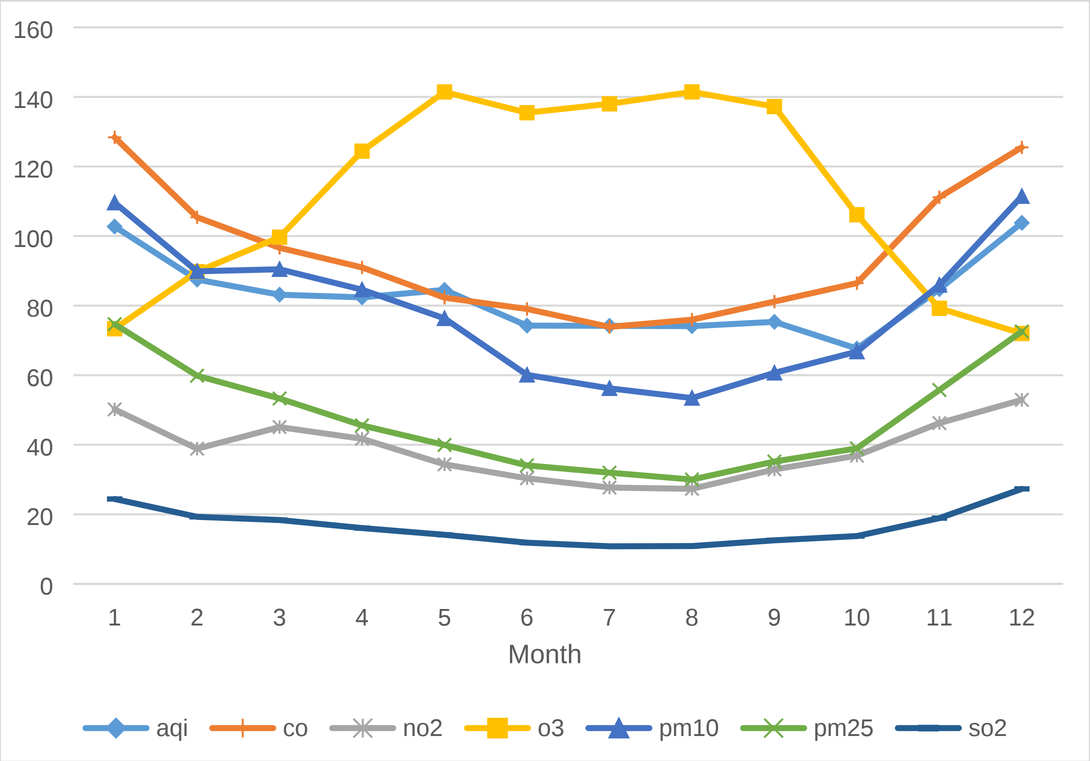

Figure 1 The trend of the average air quality in cities from January to December

Notes: Carbon monoxide concentration has been amplified 100 times to facilitate comparison with other pollutants.

To illustrate the impact of major events on air quality, the event “the Fifth Plenary Session of the 18th Communist Party of China (CPC) National Congress” which took place in Beijing in October 26-29, 2015 was chosen as a case. In order to reflect the comprehensive effect of air pollution, the daily data of AQI is selected. To make a comparison before and after the event, the data of 10 days before and after the meeting were selected. To carry out the comparison between cities, Baoding in Hebei province, which is close to Beijing, was selected as the comparison sample.

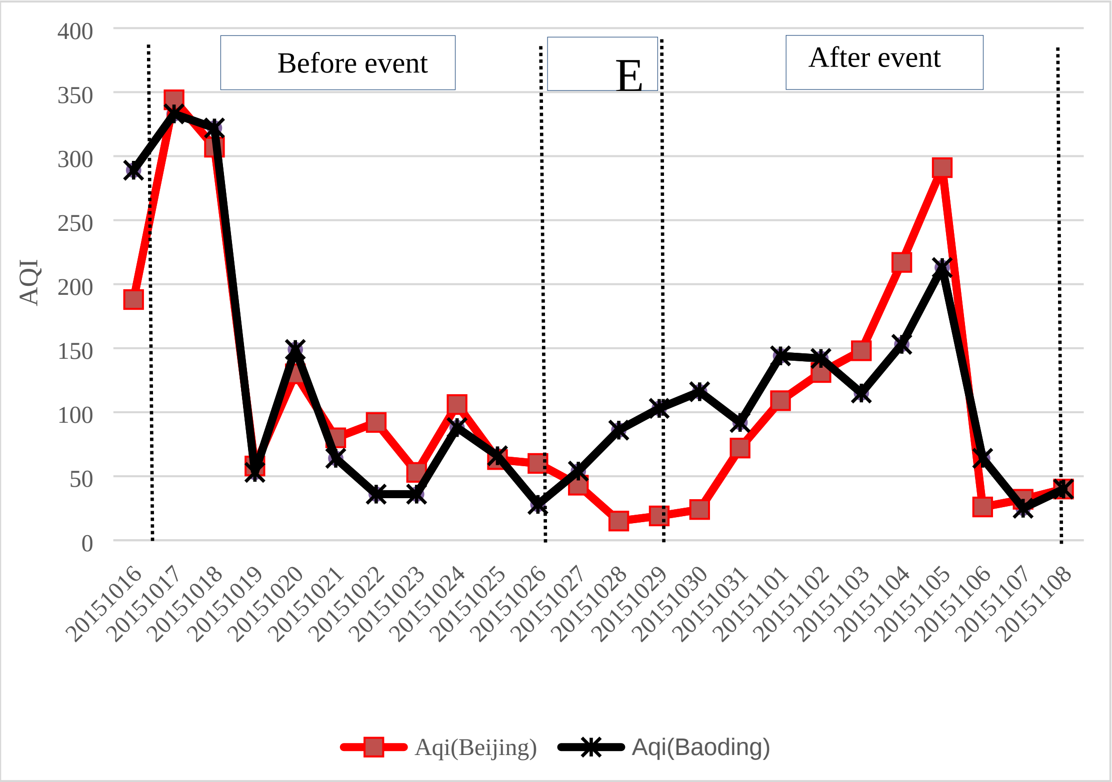

Figure 2 Comparison of AQI series in Beijing and Baoding

From the date comparison, AQI gradually decreases before the event and AQI is the lowest point in the event. After the event, AQI gradually rose. This shows that in order to hold the meeting, the government carried out air quality control, such as restricting the production of highly polluting factories, which gradually improved the air quality. But after the meeting, factories resumed production and air pollution rebounded in retaliation.

In terms of urban comparison, the daily air pollution data of Beijing and Baoding have followed roughly the same trend. But in the days and days after the meeting, Beijing's air quality was significantly better than Baoding's. Interestingly, by November 2, 2015, the level of air pollution in Beijing had surpassed that in Baoding, and the trend of retaliatory rebound is obvious.

The above is a statistical descriptive analysis. Did the event have a significant impact on air quality? Whether there is a statistically significant difference between the cities where the event occurred and the surrounding city requires further quantitative analysis.

4.2 Time Persistence Analysis of the Impacts of Major Events on Urban Air Quality

4.2.1 Empirical Analysis Based on DID

In this paper, the 28 cities involved in hosting major events from January 2, 2015 to November 28, 2017, were selected as the treatment group, and the 112 prefecture-level cities participating in major events in the very province and adjacent provinces were taken as initial control cities. This constitutes a double difference between the occurrence and non-occurrence periods in the same city, as well as between the cities with and without major cities. On this basis, a differences-in-differences model could be established directly. Regression based on Model 2 with AQI as the interpreted variable shows the remarkable effect of the model as a whole. An elaborate examination is made into the existence of inter-group heteroscedasticity, inter-group synchronous correlation and intra-group autocorrelation in the perturbation test of regression model. It is found that there are intergroup heteroscedasticity and intergroup synchronous correlation, but no intra-group autocorrelation. Therefore, the clustered standard error is used in the regression results in this paper. The regression coefficients of each variable are summarized in Table 6.

Table 6 Empirical results of AQI based on DID

Variables	Model 1	Model 2	Model 3	Model 4
Event period	-11.76***	-5.85**	-13.96***	-8.24**
	(2.78)	(2.71)	(2.64)	(3.24)
1-5 days after	4.12	7.05**	3.38***	5.51***
	(2.88)	(2.81)	(2.72)	(2.02)
6-10 days after	7.00**	4.85*	5.18***	1.84
	(2.89)	(2.83)	(2.74)	(5.01)
wind	-4.78***	-4.95***	-0.94***	-0.81**
	(0.17)	(0.18)	(0.18)	(0.39)
rain	-5.03***	-3.70***	-2.06***	0.61
	(0.32)	(0.32)	(0.31)	(0.44)
snow	2.21**	5.71***	0.04	5.27**
	(1.17)	(1.16)	(1.1)	(2.07)
highest_t	1.72***	2.26***	1.30***	2.06***
	(0.05)	(0.05)	(0.05)	(0.16)
lowest_t	-3.92***	-4.11***	-3.24***	-1.50***
	(0.05)	(0.05)	(0.05)	(0.25)

Time fixed effects	NO	YES	NO	YES
City fixed effects	NO	NO	YES	YES
R-square	0.19	0.24	0.29	0.36
Number of observations	17640	15120	13860	13490

Notes: (1) *, ** and *** are significant at 10%, 5% and 1% levels, respectively, with standard errors in parentheses, the same as in tables 7-15. (2) One of the reasons for the low value of R-Square is that PM is affected by many factors, such as energy consumption, industrial structure, economic conditions, etc. Since the focus of this paper is to analyze the impact of major events on PM, these factors are not included.

The observed coefficients during the major events are significantly negative, and the value of AQI is obviously lower than that of other periods at a significant level of 5% among the four models (Table 6). The model presents a better fitting effect with the addition of the city and temporal fixed effects. In terms of the dummy variables with city fixed effects, the significant coefficient of each region indicates that there are differences in air quality among the regions, and city-fixed effects should be added. However, the coefficients for most years, most months, most weeks of the year, and most days of the week are significant with respect to the dummy variables at each time (due to space limitations, the results are not reported), suggesting the existence of time-fixed effects, as well as more addition of dummy variables such as seasons and holidays. Therefore, the double fixed effect model is used for further analysis.

According to the double fixed effect model, the AQI value drops by 8.24% during major events, equivalent to 10% of the average AQI during non-major events. In other words, during the period of major events, AQI decreases by about 10% on average compared with that when events do not occur. After 1-5 days or 6-10 days of the major events, AQI presents a sharp increase, even much higher than usual. For the weather variables, the significant coefficients display the rationality of the variable addition. Of all the weather factors, wind scale is significantly correlated with air quality, which is also true of rainfall and air quality, but the highest temperature presents a negative correlation with air quality. In fact, considering the higher temperature, less rainfall, and lower wind scale, pollutants, discharged into the atmosphere, are not easy to diffuse, which leads to the poor air quality. In this regard, it can be seen that the conclusions of the study are consistent with common sense.

In order to further explore the specific impact of the major events on individual air pollutants, the differences-in-differences regression is carried out with each individual pollutant concentration as the explained variable in Regression Model 2. The regression results are shown in Table 7.

Table 7 Cross-term coefficient of single atmospheric pollutant

	$PM_{2.5}$	PM_{10}	SO_2	NO_2	CO	O_3
Event period	-9.15**	-8.52**	1.56	-6.61***	-0.01	-15.95***
	(3.53)	(3.73)	(0.88)	(1.60)	(0.06)	(2.05)
1-5 days after	3.59**	3.86***	2.59***	1.00	0.01	-5.00*
	(1.51)	(1.30)	(0.51)	(1.05)	(0.03)	(2.62)
6-10 days after	1.57	6.50	1.57	1.34	-0.01	-20.31***
	(3.90)	(4.46)	(1.04)	(1.15)	(0.01)	(2.29)
Control variable	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES	YES
R-square	0.40	0.44	0.46	0.54	0.47	0.45
Number of observations	17640	17640	17640	17640	17640	17640

The long-term impact of major events on individual pollutants revealed very interesting results (Table 7). Despite a concentration decrease in PM_{10} and $PM_{2.5}$, there is a rebound after 1-5 days of the major event, even much higher than in the normal period. However, a slight difference is shown between the normal period and 6-10 days after the major event. Thus, temporary air management had no long-term effect on air improvement, but a retaliatory rebound appears after the end of the temporary measures, then returning to the normal state. Besides, an obvious rebound is shown in SO_2 after the major events. As for NO_2, the concentration decreases significantly in the process of major events and returns to the normal level after events. Another individual pollutant, CO, presents a slight decrease during the major events, but not obvious. Ozone is an exception, since the content is neither an indicator of government performance appraisal nor a public concern. Therefore, Ozone is less affected by the major events, but to a larger extent by seasonal factors, and the specific reasons needs to be investigated further (Li et al., 2019).

4.2.2 Empirical Analysis Based on PSM-DID

In an attempt to overcome the bias of sample selection and reduce the estimation error caused by differences-in-differences method, the present paper further employs the method of propensity score matching, and then uses the matched samples to make a double difference. Specifically speaking, in the matching process, 140 cities are divided into two groups: one is the treatment group, which is made up of the 28 cities that have held major events from 2015 to 2017, and the other is the control group, which is made up of the 112 cities where no major events were held from 2015 to 2017. The matching method aims to find the samples from the control group with the closest control variables to the treatment group. In terms of the specific matching, the matching cities are found from the 112 cities for each host city, and then the matched samples are used to re-differentiate.

First of all, the propensity score is obtained by Logit regression of control variables with or without major events. The regression results show that the coefficients of each explanatory variable have significant effects on the outcome variables. Then the matching is carried out according to the value of propensity score, and the nearest neighbour matching in the caliper scope is adopted in this paper. The caliper is set to 0.01 to match the one-to-two playback nearest neighbour. Before the differences-in-differences estimation, it is necessary to check whether the matching results can balance the data well, that is to say, whether the mean value of the control variables of the two groups have a significant difference after matching. The remarkable effect can be better proved if no significant difference is presented. As shown in Table 8, the standard deviation of all variables is greatly reduced after matching, and the t-test results of all control variables do not reject the original hypothesis that there is no systematic difference between the treatment group and the control group, which indicates a favourable matching result.

Table 8 PSM-DID applicability test

Variables	Matched or not	Mean		Bias (%)	Bias reduction (%)	P-value
		Treatment group	Control group			
wind	unmatched	3.0660	2.9185	43.7	76.7	0.045
	matched	3.0525	3.0782	-10.2		0.796
rain	unmatched	0.4018	0.3464	51.3	61.5	0.025
	matched	0.3859	0.4161	-19.7		0.521
snow	unmatched	0.0085	0.0160	-69.2	90.5	0.004
	matched	0.0104	0.0093	6.6		0.841
highest_t	unmatched	23.321	21.823	49.9	64.5	0.020
	matched	22.757	23.492	-17.7		0.585

lowest_t	unmatched	15.829	12.876	70.8	79.5	0.002
	matched	14.982	15.833	-14.5		0.622

A second time of differences-in-differences is conducted based on the matched samples. Table 9 shows the long-term impact of the major events on air quality. Despite a decrease in AQI, PM_{10} and $PM_{2.5}$ during major events, the concentrations rebound 1-5 days after the major events, even much higher than those in the normal period. In this regard, the conclusion can be made that temporary air management has no long-term air improvement effect, since a retaliatory rebound appears after temporary measures. In addition, SO_2 concentration also presents a significant rebounding trend after the major events. As for NO_2, there is a sharp decrease during the major events. However, the improvement does not continue and the concentration returns to the normal level after the major events. CO concentration decreases slightly during major events and presents a subtle increase after the major events, but not significant. However, there is still no consistent trend in the change of Ozone. After propensity score matching, the differences-in-differences model with double fixed effect shows a high goodness of fit, which further expounds the rationality of the model.

Table 9 Empirical results based on PSM-DID

	AQI	$PM_{2.5}$	PM_{10}	SO_2	NO_2	CO	O_3
Event period	-10.30**	-11.35**	-11.22**	0.43	-6.96***	-0.04	-15.87**
	(4.20)	(4.30)	(4.44)	(0.93)	(1.92)	(0.07)	(2.19)
1-5 days after	5.97***	3.81**	3.65***	2.76***	1.39	0.01	-5.41**
	(2.12)	(1.80)	(1.41)	(0.73)	(1.14)	(0.03)	(2.65)
6-10 days after	4.38	4.10	10.95	2.09	1.88	0.01	-17.95**
	(7.10)	(5.62)	(6.34)	(1.52)	(1.13)	(0.06)	(2.00)
Control variables	YES	YES	YES	YES	YES	YES	YES
Time fixed effects	YES	YES	YES	YES	YES	YES	YES
City fixed effects	YES	YES	YES	YES	YES	YES	YES
R-square	0.37	0.41	0.45	0.50	0.55	0.46	0.43
Number of observations	12096	12096	12096	12096	12096	12096	12096

4.2.3 Further Investigation into Robust Test

Due to the short duration of the major events, the period without events had to be appropriately shortened in order to avoid other possible overlooked interference factors.

On this basis, the robustness of the results are tested by changing the sample window, and samples of 20, 30 and 40 days before and after the major events are retained respectively. After changing the different sample windows, the impact of the major events on air quality remains significant in the event-involved cities, and the air quality rebound after the major events. Moreover, this paper also assesses the robustness of the results with the help of a placebo that artificially sets the time for the major events. Specifically, one month ahead of schedule for the major events, it could be found that the cross-term coefficient was no longer significant, which indicates that the major events indeed contributed to the improvement in urban air quality. At this point, it is reasonable to believe that the above conclusions are robust and valid (Table 10).

Table 10 Empirical results in different sample windows

	Window	AQI	$PM_{2.5}$	PM_{10}	SO_2	NO_2	CO	O_3
Event period	20days	-9.15**	-10.42**	-10.89**	0.46	-6.90***	-0.01	- 15.00***
	30days	-9.92**	-11.08**	-11.32**	0.46	-7.36***	-0.04	-14.75**
	40days	-10.40	-11.32**	-11.71**	0.55	-7.24***	-0.04	-14.67***
Before event	20days	10.52***	7.56***	7.16**	3.37***	1.88*	0.04	-6.11**
	30days	5.89***	3.71***	4.70***	2.87***	1.03	0.01	-5.00**
	40days	5.81***	3.81**	3.31**	3.03***	1.17	0.02	-4.87**
After event	20days	8.68	6.79	13.88**	2.15	2.05**	0.02	-18.00***
	30days	6.41	5.50	3.45**	2.44	2.03	0.01	-16.04***
	40days	5.30	4.73	11.57**	2.27	1.81*	0.02	-16.58***

Notes: (1) In “Event period”, “20days, 30days and 40 days” means that the event period were extended to 20days, 30days and 40 days, separately. (2) In “Before”, “20days, 30days and 40 days” means that 20 days, 30 days and 40 days data prior to the event were collected, separately.

4.3 Spatial Characteristics of the Impacts of Major Events on Urban Air Quality

4.3.1 Empirical Analysis Based on DID

The analysis suggested that the occurrence of major events will significantly improve the air quality of host and co-host cities. However, owing to the continuous flow of air and spatial spillover effects of air quality, the question as to whether the impact of the major events on urban air quality was not only limited to host and co-host cities but also to the surrounding event sites naturally arose (Da et al., 2019). If any, how far can the scope stretch? Taking the cities 900 kilometers away from the host city as the control group, AQI and six individual pollution concentrations are used as the explanatory variables respectively. According to Model 3, the regression of the data on the 140 cities from January 2, 2015 to November 28, 2017 is carried out and the cross-terms coefficients are summarized in Table 11. Drawing on the AQI values and regression results of individual pollutants, it can be found that during the major events, the air quality of cities within 800 kilometers has been improved more or less, while the air quality within 500 kilometers presents an increasing trend. As the distance increases from the event-involved cities, a minor improvement is shown in the air quality until it is unnoticeable statistically, which is also in line with common sense. The impact of the major events on the concentration of individual pollutants in the cities became gradually obvious with the distance decreasing from the major events.

Table 11 Spatial scope of event impact based on DID

	AQI	$PM_{2.5}$	PM_{10}	SO_2	NO_2	CO	O_3
<100km	-11.76***	-10.23***	-12.21**	0.64	-4.63***	-0.07	-15.47***
	(3.14)	(3.79)	(5.41)	(0.79)	(1.08)	(-0.09)	(2.56)
100-200km	-9.55***	-10.09***	-11.11***	0.42	-3.36***	-0.07	-13.95***
	(2.32)	(2.58)	(3.39)	(0.95)	(0.86)	(0.05)	(1.83)
200-300km	-10.78***	-9.65***	-12.60***	-2.62***	-3.13***	-0.06**	-9.85***
	(2.41)	(2.13)	(2.68)	(1.01)	(0.61)	(0.03)	(2.05)
300-400km	-10.38***	-10.04***	-10.09***	-0.13	-1.10*	-0.05*	-10.05***
	(1.52)	(1.54)	(1.82)	(0.91)	(0.58)	(0.03)	(1.68)
400-500km	-10.21***	-9.31***	-9.05***	-2.10*	-0.76	-0.06**	-7.05***
	(2.03)	(1.86)	(2.53)	(1.08)	(0.58)	(-0.03)	(1.44)
500-600km	-4.80***	-4.62***	-2.26	0.87	-0.03	-0.03	0.06
	(1.43)	(1.14)	(1.51)	(0.78)	(0.46)	(0.02)	(1.50)
600-700km	-5.64**	-6.04***	-4.63	-1.71	0.41	-0.01	-1.91
	(2.50)	(1.82)	(2.99)	(1.95)	(0.66)	(0.03)	(1.72)
700-800km	-3.44**	-5.87***	-3.16	-0.65	-0.58	-0.01	1.23
	(1.70)	(1.43)	(2.45)	(0.84)	(0.45)	(0.02)	(1.77)
800-900km	-0.14	-1.81	1.20	-0.89	0.13	-0.01	0.06
	(1.27)	(1.26)	(1.61)	(0.55)	(0.40)	(0.14)	(1.87)

4.3.2 Empirical Analysis Based on PSM-DID

With an aim to eliminate the bias of sample selection, the method of PSM-DID is adopted for further analysis. During the occurrence of each major event, the cities within 900 km from the host city are treated as the treatment group and the others as the control group. The cities beyond 900 kilometers are searched to match the ones within 900 kilometers. It should be noted that altogether there were 9 host cities owing to the unfixed location of the major events and the matching process is carried out separately, nine in total. Furthermore, the equilibrium test should be conducted each time, and then the differences-in-differences method is applied in all successful matched cities. In this paper, the nearest neighbor matching in the caliper scope is used as the matching method, where the caliper is set to 0.01 with one-to-one playback matching. As the equilibrium test shows (Table 12), the standard deviation of almost all variables after matching decreases sharply, and the t-test results do not reject the original hypothesis that there is no systematic difference between the treatment group and the control group, which indicates a favorable result of matching.

Table 12 PSM-DID applicability test

Variables	Matched or not	Mean Treatment group	 Control group	Bias (%)	Bias reduction (%)	P-value
wind	unmatched	2.9629	2.9326	8.70	-74.8	0.609
	matched	2.9243	2.8713	15.20		0.250
rain	unmatched	0.0232	0.0056	197.8	87.3	0.000
	matched	0.0163	0.0140	25.10		0.870
snow	unmatched	19.988	24.319	-198.8	94.6	0.000
	matched	21.253	21.021	10.70		0.770
highest_t	unmatched	10.142	16.888	-226.9	95.1	0.000
	matched	12.381	12.048	11.20		0.470
lowest_t	unmatched	0.2564	0.4616	-358.3	96.0	0.000
	matched	0.3279	0.3197	14.20		0.260

After 9 times' matching, 120 cities were successfully matched and the regression results of the DID for the 120 cities, based on Model 3, are shown in Table 13. Combined with AQI and the regression results of individual pollutant concentrations, the major events significantly improved the air quality of cities within 800 km of the event-hosted cities. Moreover, as the distance increases, the improvement gets smaller and it is no longer significant beyond 800 km. The effect of the major events on the concentration of individual pollutants in cities becomes gradually apparent with the distance decreasing from major events, which is consistent with the results of DID and further verifies the robustness of the results to a large extent.

Table 13 Spatial scope of event impact based on PSM-DID

	AQI	$PM_{2.5}$	PM_{10}	SO_2	NO_2	CO	O_3
<100km	-12.48***	-10.80***	-13.31**	0.44	-4.63***	-0.09	-16.14***
	(3.26)	(4.00)	(5.60)	(0.81)	(1.19)	(-0.09)	(2.68)
100-200km	-10.11***	-9.90***	-9.90***	0.87	-2.79***	-0.06	-12.32***
	(2.82)	(3.27)	(4.13)	(0.94)	(0.86)	(0.06)	(1.74)
200-300km	-10.66***	-9.78***	-13.16***	-2.65**	-3.45***	-0.07**	-9.04***
	(2.50)	(2.29)	(2.81)	(1.03)	(0.70)	(0.03)	(2.42)
300-400km	-10.32***	-10.69***	-11.06***	-0.22	-0.95	-0.05*	-10.50***
	(1.91)	(1.86)	(2.18)	(1.07)	(0.76)	(0.04)	(2.04)
400-500km	-7.39***	-7.57***	-6.25***	-1.25	-0.74	-0.06**	-8.20***
	(2.58)	(2.35)	(2.56)	(1.08)	(0.71)	(-0.04)	(1.86)
500-600km	-4.90***	-4.93***	-2.48	1.08	-0.05	-0.03	0.07
	(1.57)	(1.23)	(1.61)	(1.37)	(0.50)	(0.03)	(1.59)
600-700km	-6.68**	-7.12***	-5.60*	-2.09	0.04	-0.02	-2.80
	(2.70)	(1.90)	(3.22)	(2.19)	(0.68)	(0.03)	(1.89)
700-800km	-3.29**	-5.99***	-3.16	-0.62	-0.57	-0.03	1.05
	(1.67)	(1.45)	(2.46)	(0.85)	(0.46)	(0.02)	(1.81)
800-900km	-0.00	-1.35	1.59	-0.89	0.18	-0.01	-0.25
	(1.34)	(1.27)	(1.67)	(0.57)	(0.41)	(0.01)	(2.03)

In addition, owing to the shorter period of the major events than that without their occurrences, the period without events should be appropriately shortened in order to avoid other possible interfering factors. After retaining the samples 30 days before and after the events and conducting the DID analysis of the 120 cities, conclusions can be drawn that the major events significantly improved the air quality of cities within 800 kilometers of the host city, and the improvement in cities within 500 kilometers is relatively remarkable. With regard to individual pollutants such as PM_{10} and $PM_{2.5}$, great improvement is presented in cities within 800 km of the event site, and the concentration of nitrogen oxides in cities within 300 km also improved significantly (Table 14).

Table 14 Empirical results in shorter sample window

	AQI	$PM_{2.5}$	PM_{10}	SO_2	NO_2	CO	O_3
<100km	-13.49***	-11.81***	-14.77**	0.35	-5.14***	-0.10	-16.40***
	(3.92)	(4.39)	(6.24)	(0.81)	(1.13)	(-0.09)	(2.64)
100-200km	-10.64***	-10.23***	-10.55***	0.98	-3.41***	-0.06	-12.63***
	(3.39)	(3.46)	(4.40)	(0.90)	(0.86)	(0.06)	(1.90)
200-300km	-10.37***	-9.62***	-12.32***	-2.36**	-3.80***	-0.08**	-8.08***
	(3.03)	(2.61)	(3.51)	(1.08)	(0.74)	(0.03)	(2.38)
300-400km	-12.29***	-11.76***	-12.95***	0.29	-1.40	-0.05*	-10.50***
	(2.18)	(2.02)	(2.89)	(1.26)	(0.87)	(0.04)	(1.93)
400-500km	-9.20***	-8.87***	-8.29***	-1.53	-0.98	-0.06**	-8.63***
	(3.08)	(2.61)	(2.89)	(1.13)	(0.73)	(-0.05)	(1.88)
500-600km	-6.27***	-5.91***	-3.82**	0.98	-0.68	-0.03	0.26
	(1.62)	(1.27)	(1.52)	(0.75)	(0.50)	(0.03)	(1.59)
600-700km	-7.88**	-8.31***	-7.26**	-1.91	0.48	-0.03	-3.38
	(2.64)	(1.89)	(3.21)	(2.03)	(0.67)	(0.03)	(2.01)
700-800km	-7.88**	-7.05***	-4.42**	-0.54	-0.92	-0.02	1.41
	(2.67)	(1.37)	(2.31)	(0.88)	(0.46)	(0.02)	(1.81)
800-900km	-0.56	-1.91	1.15	-0.78	0.16	-0.02	-1.23
	(1.51)	(1.39)	(1.78)	(0.57)	(0.44)	(0.01)	(2.15)

4.3.3 Further Analysis of Robustness

In order to identify whether the impact of major events on urban air quality in different areas is sensitive to the sample window, samples of 20, 30 and 40 days before and after major events are retained respectively. The regression results were insensitive to the different sample windows (Table 15) and these indicate the robustness of the conclusions drawn.

Table 15 Empirical results in different sample windows

	window	AQI	$PM_{2.5}$	PM_{10}	SO_2	NO_2	CO	O_3
<100k	20days	-12.06***	-10.16***	-13.11**	0.27	-4.42***	-0.04	-17.26***
	30days	-13.49***	-11.81***	-14.77**	0.35	-5.14***	-0.10	-16.40***
	40days	-13.59***	-11.63***	-14.90***	0.40	-4.90***	-0.10	-16.43***
	20days	-8.72***	-8.11***	-8.69**	1.75	-2.74***	-0.01	-13.16***

100-200km	30days	-10.64***	-10.23***	-10.55***	0.98	-3.41***	-0.06	-12.63***
	40days	-10.83***	-10.35***	-10.88***	0.96	-3.21***	-0.06	-12.58***
200-300km	20days	-7.84***	-7.10***	-9.43***	-0.96	-3.59***	-0.03	-8.50***
	30days	-10.37***	-9.62***	-12.32***	-2.36**	-3.80***	-0.08**	-8.08***
	40days	-10.65***	-9.73	-12.93***	-2.44	-3.57***	-0.08	-8.06***
300-400km	20days	-9.46***	-9.23***	-9.97***	2.72	-0.53	-0.00	-11.77***
	30days	-12.29***	-11.76***	-12.95***	0.29	-1.4	-0.05*	-10.50***
	40days	-12.10***	-11.53	-12.82***	0.05	-1.16	-0.06	-10.03***
400-500km	20days	-6.04***	-5.51***	-4.86**	-0.39	-0.46	-0.02	-10.35***
	30days	-9.20***	-8.87***	-8.29***	-1.53	-0.98	-0.06**	-8.63***
	40days	-8.95***	-8.75***	-8.31***	-1.71	-0.91	-0.08	-8.29***
500-600km	20days	-5.01***	-3.87***	-1.76	2.28	-0.70	-0.00	-1.88
	30days	-6.27***	-5.91***	-3.82**	0.98	-0.68	-0.03	0.26
	40days	-6.56***	-6.08***	-4.39***	0.66	-0.53	-0.03	0.08
600-700km	20days	-5.38**	-5.85***	-4.56	0.18	-0.34	0.00	-4.34**
	30days	-7.88**	-8.31***	-7.26**	-1.91	0.48	-0.03	-3.38
	40days	-8.16***	-8.28***	-7.46**	-2.26	-0.40	-0.03	-2.93
700-800km	20days	-2.81**	-4.93***	-2.11	-0.19	-0.99**	0.10	0.75
	30days	-7.88**	-7.05***	-4.42**	-0.54	-0.92	-0.02	1.41
	40days	-4.93***	-7.13	-4.89**	-0.69	-0.85*	-0.02	1.93
800-900km	20days	0.01	-1.05	2.34	-0.54	-0.41	-0.01	-1.12
	30days	-0.56	-1.91	1.15	-0.78	0.16	-0.02	-1.23
	40days	-0.98	-2.13	0.44	-0.89	-0.04	-0.01	-0.97

5. Conclusion

5.1 Research Findings

In this study, the daily air quality index (AQI) and the concentration of individual pollutants from January 2, 2015 to March 28, 2017 are empirically investigated. A summary of the research findings is as follows. The air quality of the cities involved in hosting the major events improved significantly during the occurrence, and it is warranted that the improvement is caused by the occurrence of the major events. From the perspective of individual pollutant concentrations, particulate matter exercises the most remarkable impact on the urban air quality, followed by nitrogen oxide, while less obvious impact is shown on the concentrations of carbon monoxide and ozone. After a period of the major events, the AQI value and the concentrations of individual pollutants present a rising trend with varying degrees, exceeding the normal level, which shows that the improvement of air quality brought by temporary control exhibits no sustained effect, even at the cost of retaliatory pollution. In this regard, the major events not only affected the air quality of the host city, but also affected the air quality of the surrounding areas. The spatial range of each major event, affecting the urban air quality, is within 800 km around the host city, and the farther away from the host city, the smaller the impact.

5.2 Countermeasures and Suggestions

China’s environmental management system should be innovated systematically based on the experience of developed countries but set within the context of China’s in air pollution joint prevention and control measures in recent years, such as during the Beijing Olympic Games, Shanghai World Expo, APEC, etc. On this basis, effective countermeasures should be taken as follows. First of all, a new system of atmospheric environmental management should be established with regional management as the main part and territorial management as the supplement, so as to avoid the “illusion” of governance effectiveness caused by local government “interference” (Yu et al. 2019). Secondly, great attention should be paid to the phenomenon of atmospheric transboundary transmission as a result of meteorological field factors, and a new mechanism of joint prevention and control of atmospheric pollution aimed at improving air quality in different regions should be comprehensively promoted (Xu et al. 2019). In addition, the total amount and proportion of the transboundary transport of atmospheric pollutants should be studied scientifically and reasonably for a further establishment of the regional ecological compensation management system of atmospheric environment. Fourthly, taking big data as the analysis resource, the early warning and emergency warning mechanism should be proposed (Yan et al., 2019). At last, taking China's ongoing current regional economic integrations (such as Beijing-Tianjin-Hebei integration, Yangtze river delta integration, Pearl river delta integration, etc.) as opportunities, regional unified standards for pollutant discharge, industrial access and law enforcement are proposed to be formulated to improve the urban air quality.

Conflict of interest: The authors declare that they have no conflict of interest.

References

Beig, G., Chate, D.M., Ghude, S.D., Mahajan, A.S., Srinivas, R., Ali, K., Ali, Sahu, S.K., Parkhi, N., Surendran, D., Trimbake, H.R., 2013. Quantifying the effect of air quality control measures during the 2010 Commonwealth Games at Delhi, India. Atmos Environ, 80, 455-463. https: //doi.org/10.1016/j.atmosenv.2013.08.012.

Bera, B., Bhattacharjee, S., Shit, P.K., Sengupta N., Saha S., 2020. Significant impacts of COVID-19 lockdown on urban air pollution in Kolkata (India) and amelioration of environmental health. Environment Development and Sustainability. https://doi.org/10.1007/s10668-020-00898-5.

Bogdan, E.A.2020. How a Deadly Pandemic Cleared the Air: Narratives and Practices Linking COVID-19 with Air Pollution and Climate Change. Space and culture. 23(3):293-300. https://doi.org/10.1177/1206331220938641.

Chen, Y., Jin, G., Kumar, N., Shi, G., 2013. The promise of Beijing: evaluating the impact of the 2008 Olympic Games on air quality. J Environ Manage, 66(3), 424-443. https: // doi.org/10.1016/j.jeem.2013.06.005.

Da, S.N., Boussauw, K., Sansen, J., 2019, Accessibility versus air pollution: A geography of externalities in the Brussels agglomeration. Cities, 84: 178-189. https://doi.org/10.1016/j.cities.2018.08.006.

Dutheil, F. □ Baker, J.S. □ Navel, V.2020. COVID-19 as a factor influencing air pollution? Environmental pollution. 263,114466.https://doi.org/10.1016/j.envpol.2020.114466.

Fan, C. , Li, Y. , Guang, J. , Li, Z. , & Leeuw, G. D., 2020. The impact of the control measures during the covid-19 outbreak on air pollution in china. Remote Sensing, 12(10), 1613. https://doi.org/10.3390/rs12101613.

He, G., Fan, M., Zhou, M., 2016. The effect of air pollution on mortality in China: Evidence from the 2008 Beijing Olympic Games. Journal of Environmental Economics and Management, 79, 18-39. https://doi: 10.1016/j.jeem.2016.04.004.

He, G.J., Pan, Y.H., Tanaka, T., 2020. The short-term impacts of COVID-19 lockdown on urban air pollution in China. Nature Sustainability, Jul. https://doi.org/10.1038/s41893-020-0581-y.

Heyman, F., Sjöholm, F., Tingvall, P.G., 2007. Is there really a foreign ownership wage premium? evidence from matched employer–employee data. J Int Econ, 73(2), 355-376. https:// doi.org/ 10.1016/ j.jinteco. 2007. 04. 003.

Huang, K., Zhang, X., Lin, Y., 2015. The “APEC Blue” phenomenon: Regional emission control effects observed from space. Atmos Res, 164-165:65-75. https: //doi.org/10.1016/j.atmosres.2015.04.018.

Jia, K., Chen, S.,2019. Could campaign-style enforcement improve environmental performance? Evidence from China's central environmental protection inspection. Journal of Environmental Management, 245,282-290. https://doi: 10.1016/j.jenvman.2019.05.114.

Kim, T. H., Koo, H., Han, E., 2018. Healthcare use among persons with visual impairment: difference-in-difference estimations. Disabil Health J. doi:10.1016/j.dhjo.2018.11.010.

Lee, B.K., Jun, N.Y., Lee, H.K., 2005. Analysis of impacts on urban air quality by restricting the operation of passenger vehicles during Asian Game events in Busan, Korea. Atmos Environ, 39(12), 2323-2338. https: //doi.org/10.1016/j.atmosenv.2004.11.044.

Li, B., Wang, F., Yin, H., Li, X., 2019. Mega events and urban air quality improvement: A temporary show? Journal of Cleaner Production. 217, 116-126. https://doi: 10.1016/j.jclepro.2019.01.116.

Li, K., Jacob, D.J., Liao, H., Shen, L., Zhang, Q., Bates, K.H., 2019. Anthropogenic drivers of 2013-2017 trends in summer surface ozone in China, Proc Natl Acad Sci USA, 116(2), 422-427. https://doi.org/10.1073/pnas.1812168116.

Li, L., Li, Q., Huang, L., Wang, Q., Zhu, A.S., Xu, J., Liu, Z.Y., Li, H.L., Shi, L.S., Li, R., Azari, M., Wang, Y.J., Zhang, X.J., Liu, Z.Q., Zhu, Y.H., Zhang, K., Xue, S.H., Ooi, M,C,G., Zhang, D.P., Chan, A.D., 2020. Air quality changes during the covid-19 lockdown over the Yangtze River delta region: an insight into the impact of human activity pattern changes on air pollution variation. Science of The Total Environment, 732, 139282. https://doi.org/10.1016/j.scitotenv.2020.138704.

Liu, H., Liu, C., Xie, Z., Li, Y., Huang, X., Wang, S., Xu, J., Xie, P., 2016. A paradox for air pollution controlling in china revealed by “APEC Blue” and “ParadeBlue”. Sci Rep, 6, 34408. https: //doi: 10.1038/srep34408.

Matus, K., Nam, K. M., Selin, N. E., Lamsal, L. N., Reilly, J. M., Paltsev, S., 2012. Health damages from air pollution in china. Global Environmental Change, 22(1), 0-66. https://doi.org/10.1016/j.gloenvcha.2011.08.006.

Ngo, N.S., Zhong, N., Bao, X.,2019. The effects of transboundary air pollution following major events in China on air quality in the U.S.: Evidence from Chinese New Year and sandstorms. J Environ Manage, 212(15):169-175. https://doi.org/10.1016/j.jenvman.2018.01.057.

Rafaj, P., Kiesewetter, G., Gül, T., Schöpp, W., Cofala, J., Klimont, Z., Purohit, P., Heyes, C., Amann, M., Borken-Kleefeld, J., Cozzi, L., 2018. Outlook for clean air in the context of sustainable development goals. Global Environmental Change, 53, 1-11. https://doi.org/10.1016/j.gloenvcha.2018.08.008.

Shao, S., Tian, Z., Fan, M., 2018. Do the Rich Have Stronger Willingness to Pay for Environmental Protection? New Evidence from a Survey in China. World Development, 105, 83–94. https://doi.org/10.1016/j.worlddev.2017.12.033.

Shi, Q., Guo, F., Chen, S., 2016. “Political Blue Sky” in Fog and Haze Governance ——Evidence from the Local Annual “Two Sessions” in China, China Industrial Economics, (5):40-56. https://doi:10.19581/j.cnki.ciejournal.2016.05.003. (in Chinese).

Song, M., Zhu, S., Wang, J., Wang, S. (2019). China's natural resources balance sheet from the perspective of government oversight: Based on the analysis of governance and accounting attributes. Journal of environmental management, 248, 109232.

Song, M., Zhu, S., Wang, J., Zhao, J. (2020). Share green growth: Regional evaluation of green output performance in China. International Journal of Production Economics, 219, 152-163.

Wang, H., Zhou, P., Wu, X., Nie,X., 2019. Can a carbon trading system promote the transformation of a low-carbon economy under the framework of the porter hypothesis? —Empirical analysis based on the PSM-DID method. Energ Policy, 129, 930-938. https://doi.org/10.1016/j.enpol.2019.03.007.

Wang, S., 2012. Efficiency of mitigation measures to reduce particulate air pollution—A case study during the Olympic Summer Games 2008 in Beijing, China. Science of The Total Environment, 427-428, 146-158. https://doi: 10.1016/j.scitotenv.2012.04.004.

Wang, T., Xie, S., 2009. Assessment of traffic-related air pollution in the urban streets before and during the 2008 Beijing Olympic Games traffic control period. Atmos Environ, 43(35), 5682-5690. https: //doi.org/10.1016/j.atmosenv.2009.07.034.

Wu, X., Cao, Y., Xiao, Y., Guo, J., 2018. Finding of urban rainstorm and waterlogging disasters based on microblogging data and the location-routing problem model of urban emergency logistics. Annals of Operations Research. 1-32. https://doi.org/10.1007/s10479-018-2904-1.

Wu, X., Xu, Z., Liu, H., Guo, J., Zhou, L., 2019. What Are the Impacts of Tropical Cyclones on Employment? An Analysis Based on Meta-Regression. Weather, Climate, and Society. 11(April): 259–275. https://doi.org/10.1175/WCAS-D-18-0052.1.

Xu, W., Sun, J., Liu, Y., Xiao, Y., Tian, Y., Zhao, B., Zhang, X., 2019. Spatiotemporal variation and socioeconomic drivers of air pollution in China during 2005–2016. J Environ Manage, 245 (1):66-75. https://doi.org/10.1016/j.jenvman.2019.05.041.

Yan, L.X., Duarte, F., Wang, D., Zheng, S.Q., Ratti, R.C., 2019. Exploring the effect of air pollution on social activity in China using geotagged social media check-in data. Cities, 91, 116-125. https://doi.org/10.1016/j.cities.2018.11.011.

Yang, Z., Fan, M., Shao, S., Yang, L., 2017. Does Carbon Intensity Constraint Policy Improve Industrial Green Production Performance in China? A Quasi-DID Analysis. Energy Economics, 68: 271–282. https://doi.org/10.1016/j.eneco.2017.10.009.

Yu, M., Zhu, Y., Lin, C., Wang, S., Xing, J., Jang, C., Huang, J., Huang, J., Jin, J., Yu, L., 2019.Effects of air pollution control measures on air quality improvement in Guangzhou, China, J Environ Manage, 244(15):127-137.https://doi.org/10.1016/j.jenvman.2019.05.046.

Zhao, H., Zheng, W., Xu, J., Wang, Z. Yuan, Y., Huang, J., Chu, Z., 2016. Evaluation of the improvement of the air quality during the parade in Beijing. J Environ SCI-China. 36(10), 2881-2889. https://doi:10.3969/j.issn.1000-6923.2016.10.001.

Zhao, J., Luo, L., Zheng, Y., Liu, H., 2017. Analysis on air quality characteristics and meteorological conditions in Hangzhou during the G20 summit. Acta Scientiae Circumstantiae. 37(10), 3885-3893. https://doi:10.13671/j.hjkxxb.2017.0195 (in Chinese).

Zheng, X., Wang, H., Zhao, Y., 2011. Can "Provincial Governance of Counties" Promote Economic Growth. Management World. 8, 34-65. https://doi:10.19744/j.cnki.11-1235/f.2011.08.005. (in Chinese).