Does Lockdown Improve Air Quality? Evidence from the blockade policy of county-level units in Hubei Province, China

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Abstract

Background The COVID-19 posed a great threat to the health of people all over the world. In response to the outbreak of COVID-19, Wuhan implemented the blockade policy on January 23, 2020. Subsequently, other cities in Hubei responded one after another. The flow of people, production and consumption activities were greatly reduced, and air pollution in some cities was obviously improved. Method We used the daily air pollution and weather data of 103 county-level units in Hubei Province from 2019 to 2020 to test whether the blockade policy affected the air quality. The method of regression discontinuity designs is adopted. And the blockade policy implemented by the government during COVID-19 is regarded as exogenous policy impact, so as to investigate whether the blockade policy will affect the air quality. Results (1) Lockdown has indeed brought about an improvement in air quality. During the lockdown period, the AQI decreased by 15.316%, and the concentrations of four air pollutants (PM10, NO2, PM2.5 and SO2) decreased by 19.607%, 12.395%, 11.448% and 1.278% respectively. (2) The improvement of air quality brought about by the blockade policy is not sustainable, and every index rebounded again about 30 days after lockdown. (3) RD estimation found that the concentrations of AQI, PM2.5, PM10 and NO2 decreased by 35.402%, 29.207%, 14.809% and 7.751% respectively. This is consistent with the change trend of the above results, but the change range is obviously larger than the previous one. Conclusion Although the study confirmed that most pollutant indexes decreased during the lockdown period, the blockade policy is not applicable to the prevention and improvement of air pollution. We put forward the policy suggestions from the following two aspects: Firstly, promote green travel and reduce traffic emission sources. Secondly, promote end-of-pipe governance and improve emission reduction efficiency.

1. Introduction

Looking back at the process of Reform and Opening Up, China's rapid economic growth is accompanied by serious environmental pollution. The economic development mode is too extensive, which leads to the continuous widening of the "scissors difference" between economic growth rate and environmental quality. In recent years, serious air pollution has caused great economic losses and health consequences, which has aroused widespread concern in academic circles and society(Chen et al. 2016, Han et al. 2016, Shuai et al. 2019, Xu et al., 2015). At present, China's economy has changed from high-speed growth stage to high-quality development stage. In order to promote the coordinated development of ecological environment and economy and society, it is required to resolutely fight a tough battle against pollution. It is extremely urgent to strengthen the effective control of air pollution, which is related to the successful transformation of China's economic growth mode in the new period and the effective satisfaction of people's needs for a better life. The outbreak of COVID-19 in early 2020 posed a great threat to the health of people all over the world. On January 23, the Wuhan government issued the blockade policy[1]. A few days later, other municipal governments in Hubei Province also announced lockdown one after another. In the next two weeks, 80 cities in 15 provinces of China were blocked and closed management was implemented in urban residential areas. Many enterprises have stopped production, and unless they get permission from the local epidemic prevention department, the company may not resume production, and almost all avoidable outdoor activities are prohibited. During this period, will the air quality be improved because of lockdown? Therefore, based on the fact of lockdown in Hubei province during COVID-19 period, this paper discusses the impact of the blockade policy on air environment.

Studies have shown that in some special periods, air pollution can be reduced by artificially controlling emissions. Some local governments have improved air quality by taking temporary control measures. Scholars found that AQI, $PM_{2.5}$, PM_{10} and other indicators in Wuhan were significantly reduced during the Military games, but this improvement was not sustainable(Fu et al. 2021). Some scholars collected the regional emission data during the parade in Beijing, and identified the main pollution sources and their temporal and spatial variation characteristics by using the positive matrix factorization (PMF). They found that the air pollution in Beijing was well controlled during the temporary control period. Collaborative emission reduction and meteorological conditions had a positive impact on environmental improvement in surrounding areas (Xue et al. 2018). Specifically, the local government controls the concentration of pollutants by temporarily closing the factory sites in the surrounding areas and prohibiting the operation of vehicles(Li et al. 2017). The daily concentration of $PM_{2.5}$ in Beijing was 47.53 g/m^3 during the "APEC Blue" period, and it dropped to 17.07 g/m^3 during the "Parade Blue" period(Lin et al. 2017).

Therefore, we think the problem that will COVID-19 lockdown also improve the air quality. Through case studies in specific countries, scholars compared the changes of air quality indicators before and after lockdown, and confirmed that the blockade policy led to a significant improvement in air quality(Dantas et al. 2020). Mahato (2020) pointed out that during the lockdown period, the decline of PM_{10} and $PM_{2.5}$ reached 60% and 39% respectively in Delhi, and the air quality was improved by 40%-50%. However, a few studies believed that the impact of COVID-19 was unclear, and may even reduce the air quality in Hubei Province, the center of China's epidemic situation(Almond et al. 2020). Wang(2020)found that serious air pollution incidents still occurred in the North China Plain during the COVID-19 period. Studies have shown that much transportation emission reductions and a small amount of industrial emission reductions cannot avoid serious air pollution in China, especially in unfavorable meteorological conditions. In addition, some scholars have investigated the global influence of COVID-19 by collecting global data(Dang and Trinh 2021). It was believed that the $PM_{2.5}$ of major cities in the world (New York, Los Angeles, Zaragoza, Rome, Dubai, Delhi, Mumbai, Beijing and Shanghai) has been reduced to a certain extent due to the reduction of personnel mobility during the lockdown period(Akshansha and Ramesh 2020)

At present, most of the related achievements are case studies of specific countries, which directly show the overall changes of air quality before and after the epidemic through data and charts., there are few results to verify the relationship between the blockade policy and the change of air quality by using the measurement method. However, it is worth noting that before the outbreak of COVID-19, China's air quality has been improving due to the government's continuous environmental governance policy(Greenstone and Schwarz 2018, Qiang et al. 2019). Studies have shown that during the Lunar New Year, China's air pollution will be greatly reduced(Q. et al. 2015). Therefore, directly comparing the changes of air quality data before and after the epidemic may exaggerate the influence of COVID-19 in reducing pollution(He et al. 2020). Also, most of the existing studies only consider the impact of COVID-19 on air quality, but ignore the reverse causal relationship that air pollution will aggravate the epidemic. The innovations of this paper are as follows: First, we study the change of air quality in county-level units and collect the daily average data of 103 county-level units in Hubei Province from 2019 to 2020. Second, the method of regression discontinuity (RD) designs is adopted. And the blockade policy implemented by the government during COVID-19 is regarded as exogenous policy impact, to investigate whether the blockade policy will affect the air quality. The research results can provide an important empirical reference for the formulation of relevant policies, and provide a basis for how to balance economic benefits and environmental losses in the post-epidemic era.

The remaining structure of this paper is as follows: the second part introduces the research methods and data sources. The third part is the empirical results. The fourth part further discusses the empirical results. And the fifth part is the conclusion.

[1] Notice of the Prevention and Control Command of Pneumonia Infected by novel coronavirus in Wuhan City (No.1): Since 10: 00 on January 23, 2020, the city's urban public transport, subway, ferry, and long-distance passenger transport have been suspended; For no special reason, citizens should not leave Wuhan, and the access roads from the airport and railway station to Han are temporarily closed.

2. Models

2.1 Methods

At present, many methods can be used to test the impact of the blockade policy on air quality. For example, the single difference method can simply compare the changes of air quality before and after COVID-19 lockdown (Sahraei et al. 2021). Double difference method selects other cities as the control group(He et al. 2020). And RD method is to study whether the air quality changes suddenly during the lockdown period(Bao and Zhang 2020). Simply using single difference method is too rough. On the one hand, it cannot distinguish the effects of the blockade policy and other policies, on the other hand, it cannot strip away the inherent trend of urban air quality change. And the double difference method can partially control the common air quality change trend in different regions, but it is difficult to solve the difference problem in different regions except the

COVID-19 lockdown. In addition, the double difference method cannot distinguish the impact of the blockade policy and other policies on air quality. The RD method can better solve the identification problem of the blockade policy, and analyze whether the air quality is suddenly impacted by the blockade policy in the gradual change with the date. RD analysis is considered as the closest test method to random experiment, which can alleviate the endogenous problem of parameter estimation, and has been used in more and more researches recently. Therefore, this paper uses RD method to estimate and analyze the air quality and its differences before and after the implementation of the blockade policy in sample areas.

First, we set the following panel fixing effect model:

$$A_{it}=\beta L_{it}+\gamma X_{it}+\alpha_i+\tau_t+\varepsilon_{it} \quad (1)$$

In the Equation (1), subscripts i and t represent the region and date respectively, A_{it} represents the air quality. L_{it} is a dummy variable, and its value is 1 when the blockade policy that it is implemented, otherwise it is 0. X_{it} is a group of weather control variables, including the highest temperature, the lowest temperature, precipitation, snowfall, and wind etc. Its coefficient γ reflects the influence of weather factors on air quality. The coefficient β is the focus of this article. α_i and τ_t represent the regional fixed effect and the time fixed effect respectively. τ_t is the regional fixed effect of i area, ε_{it} is the time fixed effect of t time. Also, we control the year, month, and Spring Festival respectively, to avoid the seasonal factors and the influence of Spring Festival holiday.

The Equation (1) cannot include the characteristic factors of sample areas that changed with time before COVID-19 outbreak, such as the degree of environment regulation and the public preference for environmental protection. At the same time, some studies pointed out that the higher the concentration of air pollutants, the higher the risk of infection with COVID-19(Zhu et al. 2020). This condition has led the government to implement a stricter blockade policy. If these possible reverse causal relationships are not controlled, the estimation results will be biased. Therefore, we use RD Design to treat the blockade policy against COVID-19 as exogenous policy impact.

$$A_{it}=\delta L_{it}+f(d_{it})+\theta X_{it}+\mu_i+\pi_t+\varepsilon_{it} \quad (2)$$

Where $f(d_{it})$ is a function of running variable (d_{it}), and running variable is set as the number of days after the blockade policy which it was implemented. Other settings are the same as Equation (1). Coefficient δ reflects the impact of the blockade policy on air quality. Coefficient θ reflects the influence of weather factors on air quality. μ_i, π_t are regional fixed effect and time fixed effect.

2.2 Data sources

As of December 31, 2020, Hubei Province has 12 prefecture-level cities, 1 autonomous prefecture (13 prefecture-level administrative regions in total), 39 municipal districts, 26 county-level cities, 35 counties, 2 autonomous counties and 1 forest region (103 county-level units in total). This paper collects the data of 103 county-level units in Hubei Province from 2019 to 2020[2]. Where, the air pollution data include *AQI*, $PM_{2.5}$, PM_{10}, SO_2, *CO*, O_3 and NO_2, which are often used to evaluate air quality(Kuang et al. 2018). Weather conditions can affect the formation and diffusion of air pollutants(Bao and Zhang 2020). Therefore, we collect the weather data of 2345 weather network, including the highest temperature (*TEMP_H*), the lowest temperature (*TEMP_L*), precipitation (*RAIN*), snowfall (*SNOW*), and wind (*WIND*) to control the impact of weather changes on air quality. The main explanatory variable of this paper is the blockade policy and the implementation date data of lockdown is from the official websites of local governments. We encoded a binary variable, which records the lockdown restrictions of 103 county-level units. If the government adopts the blockade policy, it is 1, otherwise it is 0. Figure 1 shows the detailed lockdown schedule of 103 county-level units.

Table 1 reports descriptive statistics of these variables. As shown in the table, during the lockdown period, the concentrations of *AQI*, PM_{10}, O_3, NO_2 and SO_2 were significantly lower than normal. For example, the average concentration of *AQI* is 72.815, lockdown period is 62.951, and normal days is 73.737. Moreover, the results of T-test also confirmed that there were significant differences between the values of all indexes during the lockdown and those at normal days. However, through the standard deviation, maximum value, and minimum value of each air index, it can be seen that the mean value conceals the huge difference of air quality in different areas and at different times. Therefore, it is necessary to further control the regional and time effects.

Table 1 Descriptive statistics.

Variable	Units	Full sample		Std. Dev.	Min	Max	Lockdown days		Regular days		T test	
		Obs.	Mean				Obs.	Mean	Obs.	Mean	t	p
AQI	Index	75,293	72.815	33.100	13	378	6,436	62.951	68,857	73.737	25.104	0.00
$PM_{2.5}$	Mcg	75,293	37.580	27.1931	1	328	6,436	39.861	68,857	37.367	-7.040	0.00
PM_{10}	Mcg	75,293	62.010	37.4928	1	416	6,436	58.989	68,857	62.292	6.761	0.00
O_3	Mcg	75,293	9.035	5.3238	1	292	6,436	82.930	68,857	94.157	20.215	0.00
NO_2	mg/m3	75,293	0.869	0.3405	0.1	4.6	6,436	13.266	68,857	22.884	52.859	0.00
SO_2	Mcg	75,293	93.198	42.7255	2	312	6,436	8.299	68,857	9.104	11.603	0.00
CO	Mcg	75,293	22.062	14.2166	1	140	6,436	0.999	68,857	0.856	-32.405	0.00
TEMP_H	°C	75,293	21.283	9.700819	-21	49	6,436	14.604	68,857	21.908	59.088	0.00
TEMP_L	°C	75,293	13.083	8.527284	-31	31	6,436	6.334	68,857	13.714	68.430	0.00
RAIN	Dummy	75,293	0.428	0.4948	0	1	6,436	0.362	68,857	0.434	11.119	0.00
SNOW	Dummy	75,293	0.022	0.1471	0	1	6,436	0.055	68,857	0.019	-18.691	0.00
WIND	Ordinal	75,293	1.845	0.7559	0	6	6,436	1.908	68,857	1.839	-6.948	0.00

Note: T test calculates two sets of data: Lockdown days and Regular days

[2] The air pollution data comes from Hubei air quality monitoring station. The weather data is collected from official website data of 2345 weather network by using crawler technology, http://tianqi.2345.com/.

3. Empirical Analysis

3.1 *Full sample regression*

Figure 2 shows the result of estimating equation (1). According to the results, *AQI*, $PM_{2.5}$, PM_{10}, NO_2, SO_2 are negatively correlated with the blockade policy, which means that the blockade policy can significantly improve air pollution. In addition, we find that there are great differences between different air pollutants. Among them, PM_{10}, *AQI*, NO_2, $PM_{2.5}$ decreased significantly by 19.607%, 15.316%, 12.395% and 11.448% respectively. SO_2 decreased by 1.278%, while *CO* increased by 0.046%. The change of these two pollutions is small. However, O_3 increased by 2.996%, showing a significant positive correlation with the blockade policy. This may be related to the formation conditions of each pollutant index. COVID-19 lockdown led to the shutdown of automobiles and factories, and the indicators such as particulate matter and nitrogen oxides showed a significant downward trend. Except *TEMP_H*, almost all the weather control variables are negatively correlated, while *TEMP_H* is positively correlated.

3.2 Event study analysis

In order to verify the conclusion, this paper selects event study method and uses air quality variables to carry out regression analysis on control variables, regional fixed effect, time fixed effect and a series of "event occurrence time". Specific practices are as follows. First, we divide the samples into a group every 10 days. B1, B2 and B3 represents 10 days, 20 days, and 30 days before lockdown. A1, A2 and A3 represents 10 days, 20 days, and 30 days after lockdown. The regression estimation results of air quality and various variables within 100 days before and after the implementation of the blockade policy are presented by grouping method.

The results are shown in Figure 3. The AQI, $PM_{2.5}$, PM_{10}, and NO_2 decreased obviously 10 days after lockdown (A1). The variation range of SO_2, CO and O_3 is small, which is roughly consistent with the estimated result of Figure 2. However, it is worth noting that after the COVID-19 lockdown for about 30 days, almost all indicators showed a rebound trend, which indicated that the blockade policy could not bring about continuous improvement of air quality. In addition, except for O_3, the values of all other pollutants in B2-A3 period (from January to February) are lower than those in other periods, which may be related to seasonal changes. Therefore, we added the monthly variable to control the influence of seasonal changes on air quality in this paper.

3.3 RD design

As the RD design needs to select the appropriate bandwidth to delimit the research window period, this paper takes the best bandwidth of AQI, $PM_{2.5}$, PM_{10}, O_3, NO_2, SO_2 and CO as the benchmark bandwidth for regression. According to Figure 4, before and after the release of the blockade policy, the absolute level of each pollutant index changed suddenly, and the time variation trend of the left and right sides of pollutants also showed obvious differentiation. Except for O_3, all other pollutants showed a downward trend after the implementation of the blockade policy, and AQI, $PM_{2.5}$, PM_{10} and NO_2 decreased significantly.

Table 2 shows the specific RD estimation results, and the regression controls the weather variables, time fixed effect and regional fixed effect. At the same time, parameter estimation will face the problems of bandwidth selection, fitting polynomial function setting and missing variables, and nonlinear fitting method can make up for its defects. Therefore, this paper selects three different forms of functions to estimate the air index. According to the results, AQI, $PM_{2.5}$, PM_{10}, NO_2, and CO are significantly negative no matter which running variable function is set. Among them, AQI, $PM_{2.5}$, PM_{10} and NO_2 changed greatly, reaching -35.402, -29.207, -14.809 and -7.751 respectively, while SO_2 and CO did not change significantly, reaching -0.393 and -0.099 respectively. While O_3 has a positive correlation with the blockade policy of 4.916. The change trend of RD is consistent with the above results, but the change range is larger than that of event study results. The reason may be due to the sample bandwidth selected by RD, which leads to the more obvious change trend of results.

Table 2 regression discontinuity

	AQI	$PM_{2.5}$	PM_{10}	O_3	NO_2	SO_2	CO
Liner	-35.402***	-29.207***	-14.809***	4.916***	-7.751***	-0.393	-0.099***
Model	(2.761)	(1.463)	(1.039)	(0.954)	(0.698)	(0.255)	(0.030)
R^2	0.519	0.362	0.343	0.590	0.737	0.422	0.407
)uadratic	-34.302***	-26.231***	-21.517***	6.376***	-7.730***	-0.407	-0.109***
Model	(2.680)	(1.391)	(1.082)	(0.920)	(0.692)	(0.265)	(0.027)
R^2	0.522	0.595	0.381	0.673	0.737	0.422	0.408
Cubic	-35.032***	-23.623***	-33.956***	4.930***	-9.634***	-0.928**	-0.094***
Model	(2.492)	(1.882)	(1.649)	(1.354)	(0.841)	(0.368)	(0.025)
R^2	0.522	0.595	0.390	0.673	0.738	0.422	0.408
ıate Controls	Y	Y	Y	Y	Y	Y	Y
Fixed Effects	Y	Y	Y	Y	Y	Y	Y
al Fixed Effects	Y	Y	Y	Y	Y	Y	Y
›servations	2,575	3,811	5,665	4,017	4,223	4,841	8,343

3.4 Robustness analysis

(1) Placebo test. This paper continues to set the placebo test to verify the robustness of the above estimation results, by artificially assuming the lockdown date. That is, selecting a value different from the discontinuity as the placebo discontinuity, and estimating it separately. In this paper, 5, 10, 15, 30 and 45 days before the real discontinuity are selected as breakpoints respectively. The results of placebo discontinuity are not the same as above, and the significance is not as good as above, which proves the robustness of above results.

Table 3 Placebo test

	5 Days	10 Days	15 Days	30 Days	45 Days
AQI	-7.263***	50.362***	-2.514 (2.832)	-9.011***	8.583**
	(1.810)	(2.234)		(1.931)	(3.415)
$PM_{2.5}$	-1.570	38.761***	0.051 (2.091)	-7.099***	5.309*
	(1.292)	(1.527)		(1.708)	(2.853)
PM_{10}	24.024***	51.327***	-0.587 (2.899)	32.534***	25.167***
	(1.293)	(1.800)		(2.433)	(4.606)
O_3	-3.108***	4.530*** (0.864)	5.145***	3.812**	-11.060***
	(1.061)		(0.801)	(1.490)	(1.205)
NO_2	3.820***	5.119***	-1.907***	11.047*** (0.685)	3.876*** (0.636)
	(0.724)	(0.519)	(0.520)		
SO_2	-0.225	0.461	-0.202	1.468*** (0.482)	-1.076***
	(0.215)	(0.434)	(0.564)		(0.213)
CO	0.360	0.031	-0.048*	0.051*	0.131
	(0.295)	(0.020)	(0.024)	(0.027)	(0.444)

(2) Sensitivity test of sample selection. The closer the sample is to the discontinuity, the more motivated it is to manipulate artificially, which is also called doughnut effect. Therefore, this paper deleted the samples of 1, 2, 3, 4 and 5 days before and

after the discontinuity respectively and tested the robustness. The results showed that the regression results of all indexes except SO_2 remained significant. It shows that even if there is artificial manipulation, the discontinuity effect still exists.

Table 4 Sensitivity test of sample selection

	1 Days	2 Days	3 Days	4 Days	5 Days
AQI	-43.739***	-43.418***	-38.484***3.189	-14.070***	-19.014**
	(3.041)	(3.452)		2.238	7.694
$PM_{2.5}$	-34.396*** (1.430)	-25.625***	-0.1131.025	-26.382***	-26.797***6.895
		1.368		3.270	
PM_{10}	-19.481***	-20.085***	-51.666***3.273	6.012***	-27.888***
	(1.434)	(1.911)		1.867	6.656
O_3	8.172***	6.903*** (1.046)	3.753**	19.528**	18.521***
	(0.851)		(1.503)	(1.278)	(2.407)
NO_2	-9.024***	-9.094***	-11.196***	-11.288***0.985	-6.141***1.916
	(0.731)	(0.797)	0.711		
SO_2	-0.552*	0.701*	-0.1890.417	0.4800.387	0.989**
	(0.314)	(0.379)			0.433
CO	0.099***	-0.091**	-0.002	0.098*	0.117***0.023
	(0.036)	(0.039)	0.038	0.023	

(3) Bandwidth sensitivity analysis. The bandwidth will affect the result of RD. Small bandwidth can effectively fit the distribution of samples near discontinuity, but too small bandwidth will lead to excessive sample loss and biased estimation results. A robust result requires that the bandwidth length cannot be too sensitive. Therefore, this paper manually sets the bandwidth to 25%, 50%, 75%, 150% and 200% of the optimal bandwidth for regression. According to the results, within the optimal bandwidth range of 25%-200%, all indexes except SO_2 show remarkable results, which shows that the above results are reliable.

Table 5 different bandwidth estimation results

	25%	50%	75%	150%	200%
AQI	-10.983***	-35.182***	-37.607***	-11.885***	-34.236***
	(3.508)	(2.574)	2.739	1.135	1.856
$PM_{2.5}$	-18.847***	-31.344***	-29.533***	-5.513***	-5.904***
	(2.469)	2.161	2.094	0.821	0.790
PM_{10}	-39.428***	-40.741***	-29.296***	-13.515***	-19.691***
	(2.267)	(2.155)	1.434	1.106	0.928
O_3	7.314***	7.118***	4.714***	6.524***	7.859***
	(1.649)	(1.571)	(1.291)	(0.763)	(0.757)
NO_2	-3.482***	-6.993***	-9.497***0.724	-9.275***0.621	-11.339***0.650
	(0.688)	(0.803)			
SO_2	-0.536	0.045	-0.549*	-0.886***0.225	-0.534**
	(0.335)	(0.371)	0.292		0.232
CO	-0.176***	-0.079***	-0.069**	-0.070***	-0.041**
	(0.027)	(0.024)	0.030	0.026	0.019

4. Discussion

In China, many studies have shown that air pollution has negative effects on health outcomes, such as life expectancy, mortality, and morbidity. It has also been found that air pollution can affect mental health, cognitive ability, productivity, and defense ability(He et al. 2020). Therefore, air pollution has obviously caused a considerable burden, and the improvement of environmental quality during COVID-19 lockdown may bring huge potential health benefits. According to the above results, we find that different air indexes have different changes during the lockdown period. The AQI, $PM_{2.5}$, PM_{10}, and NO_2 showed a significant downward trend after lockdown, while SO_2 and CO changed slightly, while O_3 showed an upward trend. Therefore, we further discuss the causes of different results.

As one of the main sources of air pollution is traffic mobility(Viard and Fu 2015), stricter policies may lead to lower mobility, thus improving air quality. According to the structural rules of AQI and the characteristics of air pollution in China, $PM_{2.5}$ and PM_{10} are the main factors affecting the change trend of AQI. The main sources of $PM_{2.5}$ and PM_{10} are burning smoke, industrial dust, building dust, ground dust and secondary pollutants produced by chemical reaction of other pollutants. NO_2 mainly comes from motor vehicle exhaust emissions, high temperature combustion (boiler, furnace) emissions, etc. Inhalable particulate matter and nitrogen oxides were all affected by traffic interruption and industrial activity reduction during the lockdown period, so AQI, $PM_{2.5}$, PM_{10} and NO_2 all showed a significant decline.

And SO_2 is often produced by the combustion of fossil fuels in power generation and heating furnaces. Therefore, its response to the blockade policy may be different. Apart from automobile exhaust, a large proportion of CO comes from various incomplete combustion products (such as boilers, industrial furnaces, internal combustion engines, household stoves, etc.). O_3 is a kind of secondary pollutants, mainly nitrogen oxides, volatile organic compounds, and other pollutants in the air, which produce photochemical reactions under the action of sunlight. According to the US Environmental Protection Agency (EPA), SO_2, CO and O_3 are "standard air pollutants", which will affect human health and the labor market(Hanna and Oliva 2015), and harm people's health(Deschênes and Shapiro 2017, Lleras-Muney 2010). To some extent, residents staying at home have increased the demand for residential electricity and heating resources, especially high-sulfur carbon. Therefore, the increase in residential demand offsets the decrease in industrial demand to a certain extent, resulting in a small change in SO_2 and CO during the lockdown period. The amount of O_3 is inversely proportional to the concentration of nitrogen oxides(Shi and Brasseur 2020). Therefore, when other variables remain unchanged, the reduction of nitrogen oxides leads to the increase of ozone concentration.

Studies have shown that human-related activities are closely related to air quality. However, the blockade policy is not applicable to the prevention and control of air pollution. The reduction of AQI, $PM_{2.5}$, PM_{10} and NO_2 is not enough to avoid serious air pollution. Although urban blockade has greatly reduced the air pollution level, the high economic cost of lockdown makes it an unsustainable choice to solve the pollution problem. Compared with other environmental laws and regulations implemented in China, we find that similar air quality improvement can be achieved at much lower cost. For example, the limitation of gasoline fuel standard alone may reduce the air quality index value by about 13%(Li et al. 2020). The regulations during the Beijing Olympic Games can reduce the concentration of PM_{10} in the host city by about 30%(He et al. 2016). In other words, it is very inefficient to use lockdown to reduce pollution, and there are many other more convenient ways to achieve the same environmental goals. The results also confirm that the decline of these indicators is only temporary and not sustainable. After the unsealing, the labor force gradually returned to work, and this temporary improvement is difficult to maintain. As far as China, especially Hubei, it is still too early to think that COVID-19 lockdown can improve the air weather and benefit people's health. However, it is feasible to reduce unnecessary personal trips and improve air quality by emphasizing the importance of green transportation and green production and life.

Our research still has the following limitations: due to the lack of some data, we cannot investigate the influence of all factors and the subtle reaction mechanism of air quality during the lockdown period. In the follow-up, we can also compare the air quality under the blockade policy in other middle and high-risk areas, such as Pudong in Shanghai and Hebei Province. In

addition, we can also consider the influence of the local government's decision-making autonomy on the blockade policy under the Chinese political system.

5. Conclusion And Suggestions

5.1 Main conclusions

In response to the impact of COVID-19, Hubei Province has adopted unprecedented blockade measures, including closing factories and suspending internal traffic in cities, which may bring about improvement in air quality. The exogenous impact of the epidemic enables us to test the impact of blockade restrictions on air pollution. By controlling the influence of a series of weather indicators, the effects of the blockade policy on reducing air pollution were systematically evaluated by using linear regression, event study and RD design.

Empirical analysis shows that the restriction measures adopted by 103 county-level units in Hubei have significantly reduced air pollution emissions. The *AQI* decreased by 15.316%, and the concentrations of four air pollutants (PM_{10}, NO_2, $PM_{2.5}$ and SO_2) decreased by 19.607%, 12.395%, 11.448% and 1.278% respectively. For further study, we analyzed the events study by incorporating a series of "event occurrence times" into regression equation. The results showed that *AQI,* $PM_{2.5}$, PM_{10} and NO_2 all showed a rebound trend about 30 days after the implementation of the blockade policy, which indicated that the temporary lockdown could not bring about continuous improvement of air quality. We also made RD estimation, and found that the concentrations of *AQI,* $PM_{2.5}$, PM_{10} and NO_2 decreased by 35.402%, 29.207%, 14.809% and 7.751% respectively. This is consistent with the change trend of the above results, but the change range is obviously larger than the previous one. We conducted placebo test, sensitivity test of sample selection and different bandwidth estimation to ensure the robustness of the results all of which confirmed the above results. In addition, we further discussed the causes of different pollutants' varying degrees and the inapplicability of using the blockade policy to improve air quality.

5.2 Policy Suggestions

According to the above analysis, the lockdown policy adopted by 103 county-level units in Hubei province has significantly reduced air pollution emissions, but the improvement in air quality is not sustainable. Based on the research results, this paper puts forward the policy suggestions from the following two aspects:

5.2.1 Promote green travel and reduce traffic emission sources

The emission reduction effect is very significant in the case of traffic shutdown during the epidemic, but the high-intensity traffic restriction will cause great economic cost, and the traffic flow restriction policy is not sustainable. Even in the face of COVID-19, a major public health event, travel patterns will not change substantially in the short term. However, as one of the main sources of air pollution, it is necessary to strengthen the effective prevention and control of exhaust pollution. Therefore, this paper proposes to improve air quality by strengthening automobile exhaust emission reduction technology in the following aspects.

First of all, strengthen relevant policy constraints. In view of the environmental pollution caused by automobile exhaust, a simple driving restriction policy cannot bring about sustainable environmental improvement. It is necessary to promulgate relevant policies to restrict the entry into the market of vehicles that do not meet the emission standards of exhaust pollution, and to scrap the vehicles that exceed the standards in an orderly manner, so as to reduce the emission of toxic gases from exhaust gas. Capacity building of vehicle exhaust testing, meanwhile, should keep pace with the market demand, the construction way can draw lessons from foreign advanced I/M management mode, the government set up the regulation of the professional team in the field of motor vehicle exhaust testing, vehicles for routine testing of the city, to detect unqualified cases should be given a fine processing.

Secondly, improve fuel quality and cleanliness. With the proposal of China's dual carbon target, the development of new energy vehicles will be an inevitable trend. The research and development of new energy is imminent. At present, the most mainstream new energy technology is electric drive, such as pure electricity and hybrid electricity. In terms of electric energy acquisition, there are lithium batteries, fuel cells, solar cells and so on. New energy vehicles have the characteristics of strong power, low pollution, energy saving and emission reduction. Remove bring new types of new energy solutions, the current mainstream models for diesel locomotives, the market's relatively large, so to solve a lot of fuel engine exhaust emissions is one of the most important way, through the fuel quality improvement to reduce exhaust emissions, can effective implementation in the actual operation level.

Finally, the promotion of public transport vehicles. Despite the high economic cost of traffic restrictions, the air quality improvement brought by traffic restrictions during the lockdown period is obvious to all. Therefore, in the context of the explosive growth of motor vehicles, this paper suggests to improve the relevant policies of vehicle purchase restriction, prevent excessive growth of cars, take appropriate measures to limit the number of vehicles, regularly limit the number of vehicles, improve public transport travel supporting measures, and guide the new trend of green and energy-saving travel. Under certain conditions, the construction of a new way of urban railway travel, on the premise of meeting the emergence of convenience, fast travel will greatly increase people's choice of public transport as the main way of travel.

5.2.2 Promote end-of-pipe governance and improve emission reduction efficiency

The effect of reducing emissions by adjusting industrial structure and limiting production scale is limited. In the context of dual carbon targets, some polluting industries may be reduced in size. However, some of these industries, as essential sectors of national economy, will not only affect the development of local economy, but also may have negative radiating effects through the national division of labor network. Therefore, one-size-fits-all limits on production scale cannot bring good pollution reduction effects.

In order to achieve the goal of “carbon peak” and “carbon neutral”, it is necessary to steadily promote the adjustment of industrial structure, especially the internal adjustment of the secondary industry. The key to the green development of the secondary industry and internal energy and chemical industry lies in the transformation and upgrading of the production process. Reducing the dependence on labor force through technological upgrading is the main direction of carbon reduction in light industry. Strengthening the prevention and control of industry, especially light industry, energy and chemical industry and other manufacturing polluters, can significantly improve air quality. In the manufacturing industry, there are also high-tech industries such as medicine and polymer materials, whose heavy pollution means that their development mode is still extensive, and it is urgent to realize the dual transformation and upgrading of structure and technology. To realize efficient development in the adjustment of industrial structure is an important direction for these industries in the future. This paper suggests that in the short term, we should give priority to promoting the end treatment of polluting industries mentioned above, and stabilize the cost through corresponding incentive and subsidy mechanism. In the long term, the development of emission reduction technology of polluting industries should be included in local assessment targets to improve efficiency.

Declarations

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CRediT author statement

Shuke Fu and ***Jiachao Peng***: Conceptualization, Methodology, Software, Data curation, Writing- Original draft preparation. ***Zhuo Ma***: Writing- Original draft, Visualization, Investigation. ***Jie Xiong***: Supervision. ***Zhuo Ma***, ***Jiabei Liu***, and ***Jiachao Peng***: Software, Validation, Reviewing and Editing,

References

Akshansha, C., and Ramesh, S. 2020. Decline in PM 2.5 concentrations over major cities around the world associated with COVID-19. *Environmental research*: 187. https://doi.org/10.1016/j.envres.2020.109634

Almond, D., Du, X. and Zhang, S. 2020. Ambiguous pollution response to COVID-19 in China. *In National Bureau of Economic Research*.

Bao, R., and Zhang, A. 2020. Does lockdown reduce air pollution? Evidence from 44 cities in northern China. *Science of the total environment*: 731. https://doi.org/10.1016/j.scitotenv.2020.139052

Chen, X., Zhang, L., Huang, J., Song, F., Zhang, L., Qian, Z., Trevathan, E., Mao, H., Han, B., Vaughn, M., Chen, K., Liu, Y., Chen, J., Zhao, B., Jiang, G., Gu, Q., Bai, Z., Dong, G. and Tang, N. 2016. Long-term exposure to urban air pollution and lung cancer mortality: A 12-year cohort study in Northern China. *Science of the Total Environment*: 855-861. https://doi.org/10.1016/j.scitotenv.2016.07.064

Dang, H. H., and Trinh, T. 2021. Does the COVID-19 lockdown improve global air quality? New cross-national evidence on its unintended consequences. *Journal of Environmental Economics and Management*, 105: 102401. https://doi.org/10.1016/j.jeem.2020.102401

Dantas, G., Siciliano, B., Fran a, B. B., Da Silva, C. M. and Arbilla, G. 2020. The impact of COVID-19 partial lockdown on the air quality of the city of Rio de Janeiro, Brazil. *Science of the Total Environment*. https://doi.org/10.1016/j.scitotenv.2020.139085

Deschìnes, O., and Shapiro, M. G. A. J. 2017. Defensive Investments and the Demand for Air Quality: Evidence from the NOx Budget Program. *American Economic Review*, (10): 2958-2989. https://doi.org/10.1257/aer.20131002

Fu, S., Ma, Z. and Peng, J. 2021. Political blue sky in fog and haze governance: evidence from the local major international events in China. *Environmental Science and Pollution Research*, (1): 775-788. https://doi.org/10.1007/s11356-020-10483-y

Greenstone, M., and Schwarz, P. 2018. China is winning its war on air pollution, at least in Beijing. *International environment reporter*, (2): 139-140.

Han, R., Wang, S., Shen, W., Wang, J., Wu, K., Ren, Z. and Feng, M. 2016. Spatial and temporal variation of haze in China from 1961 to 2012. *Journal of Environmental Sciences*: 134-146. https://doi.org/10.1016/j.jes.2015.12.033

Hanna, R. A. B. C. and Oliva, P. B. E. 2015. The effect of pollution on labor supply: Evidence from a natural experiment in Mexico City (Article). *Journal of Public Economics*: 68-79.

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

He, G., Pan, Y. and Tanaka, T. 2020. The short-term impacts of COVID-19 lockdown on urban air pollution in China. *Nature Sustainability*, 3(12): 1005-1011. https://doi.org/10.1038/s41893-020-0581-y

Kuang, X., Yuku, W., Guang, W., Bin, F. and Yuanyuan, Z. 2018. Spatiotemporal Characteristics of Air Pollutants (PM10, PM2.5, SO2, NO2, O3, and CO) in the Inland Basin City of Chengdu, Southwest China. *Atmosphere*, 9(2). https://doi.org/10.3390/atmos9020074

Li, P. A., Lu, Y. B. and Wang, J. C. 2020. The effects of fuel standards on air pollution: Evidence from China (Article). *Journal of Development Economics*. https://doi.org/10.1016/j.jdeveco.2020.102488

Li, X. L. X., Qiao, Y. Q. Y., Zhuc, J. Z. J., Shi, L. S. L. and Wang, Y. W. Y. 2017. The "APEC blue" endeavor: Causal effects of air pollution regulation on air quality in China. *Journal of cleaner production*: 1381-1388. https://doi.org/10.1016/j.jclepro.2017.08.164

Lin, H., Liu, T., Fang, F., Xiao, J., Zeng, W., Li, X., Guo, L., Tian, L., Schootman, M., Stamatakis, K. A., Qian, Z. and Ma, W. 2017. Mortality benefits of vigorous air quality improvement interventions during the periods of APEC Blue and Parade Blue in Beijing, China. *Environmental Pollution*, (Part A): 222-227. https://doi.org/10.1016/j.envpol.2016.09.041

Lleras-Muney, A. 2010. The needs of the army: Using compulsory relocation in the military to estimate the effect of air pollutants on children's health. *Journal of Human Resources*, (3): 549-590. https://doi.org/10.1353/jhr.2010.0016

Mahato, S., Pal, S. and Ghosh, K. G. 2020. Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. *Science of the Total Environment*. https://doi.org/10.1016/j.scitotenv.2020.139086

Jiang, Q., Sun, Y. L., Wang, Z and Yin, Y. 2015. Aerosol composition and sources during the Chinese Spring Festival: fireworks, secondary aerosol, and holiday effects. *Atmospheric Chemistry and Physics*, 15(11). https://doi.org/10.5194/acp-15-6023-2015

Shi, X., and Brasseur, G. P. 2020. The Response in Air Quality to the Reduction of Chinese Economic Activities During the COVID-19 Outbreak. *Geophysical research letters*: e2020GL088070. https://doi.org/10.1029/2020GL088070

Qiang, Z., Yixuan, Z., Dan, T., Min, S., Shuxiao, W., Yuanhang, Z., Xiangde, X., Jinnan, W., Hong, H., Wenqing, L., Yihui, D., Yu, L., Junhua, L., Zifa, W., Xiaoye, Z., Yuesi, W., Jing, C., Yang, L., Qinren, S., Liu, Y., Guannan, G., Chaopeng, H., Meng, L., Fei, L., Bo, Z., Junji, C., Aijun, D., Jian, G. and Qin. 2019. Drivers of improved $PM_{2.5}$ air quality in China from 2013 to 2017. *Proceedings of the National Academy of Sciences*, 116(49). https://doi.org/10.1073/pnas.1907956116

Sahraei, M. A., Ku kapan, E. and odur, M. Y. 2021. Public transit usage and air quality index during the COVID-19 lockdown. *Journal of environmental management*, 286. https://doi.org/10.1016/j.jenvman.2021.112166

Shao, S., Li, X. and Cao, J. 2019. Urbanization promotion and haze pollution governance in China. *Economic Research Journal*, 54(02): 148-165.

Viard, V. B. A., and Fu, S. B. 2015. The effect of Beijing's driving restrictions on pollution and economic activity (Article). *Journal of Public Economics*: 98-115. https://doi.org/10.1016/j.jpubeco.2015.02.003

Wang, P., Chen, K., Zhu, S., Wang, P. and Zhang, H. 2020. Severe air pollution events not avoided by reduced anthropogenic activities during COVID-19 outbreak. *Resources, Conservation and Recycling*: 104814. https://doi.org/10.1016/j.resconrec.2020.104814

Xu, W. Q., Sun, Y. L., Chen, C., Du, W., Han, T. T., Wang, Q. Q., Fu, P. Q., Wang, Z. F., Zhao, X. J., Xue, Y., Wang, Y., Li, X., Tian, H., Nie, L., Wu, X., Zhou, J. and Zhou, Z. 2018. Multi-dimension apportionment of clean air parade blue phenomenon in Beijing. *Journal of Environmental Sciences*, (3): 29-42. https://doi.org/10.1016/j.jes.2017.03.035

Zhou, L. B., Ji, D. S., Wang, P. C. and Worsnop, D. R. 2015. Aerosol composition, oxidation properties, and sources in Beijing: results from the 2014 Asia-Pacific Economic Cooperation summit study. *Atmospheric Chemistry and Physics*, (23): 13681-13698. https://doi.org/10.5194/acp-15-13681-2015

Zhu, Y., Xie, J., Huang, F. and Cao, L. 2020. Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China. *Science of the Total Environment*. https://doi.org/10.1016/j.scitotenv.2020.138704

Figures

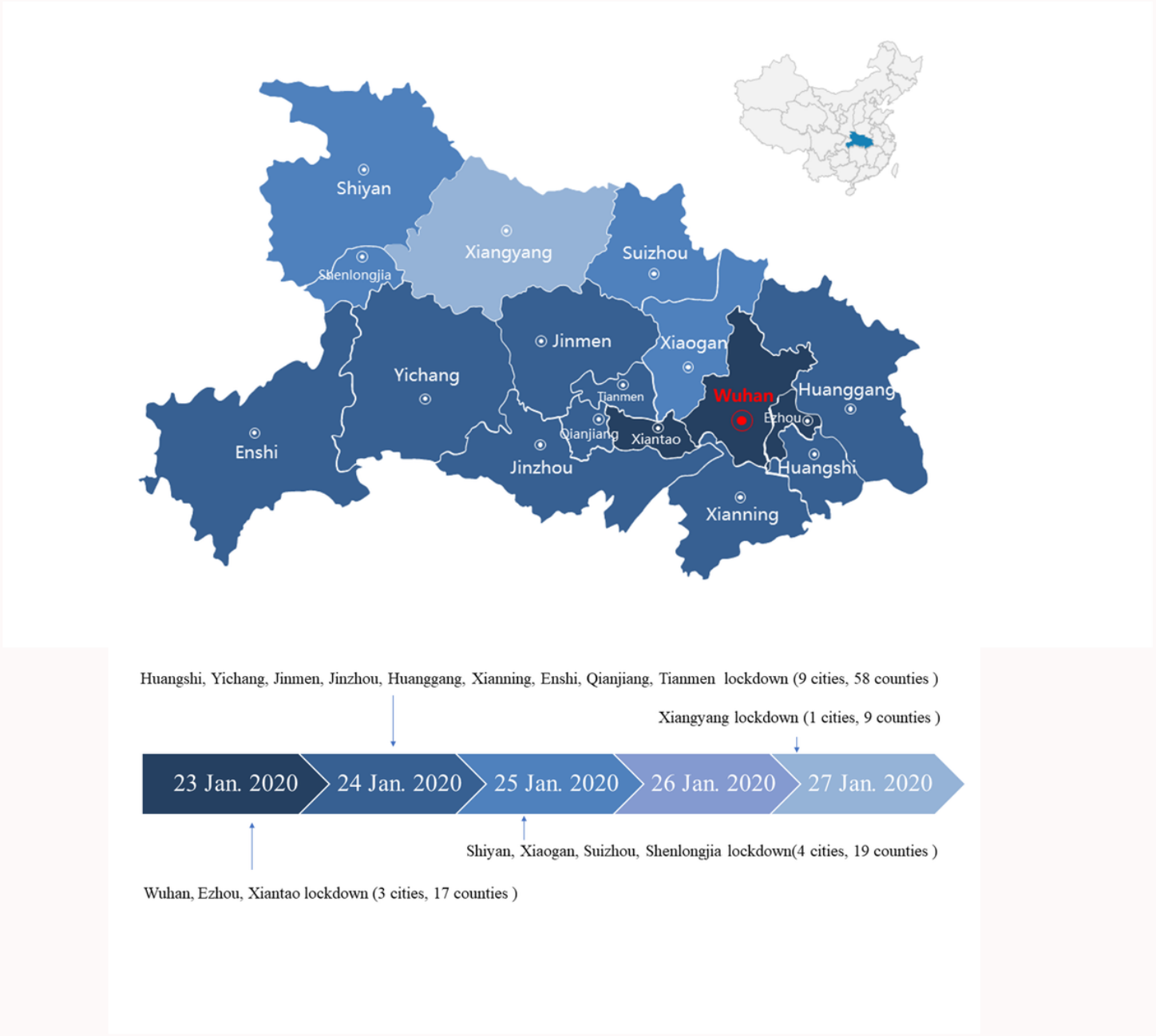

Figure 1

Dates of lockdown timeline of cities in Hubei Province Note: The unsealing time in Wuhan is April 8th, while in other areas it is March 25th.

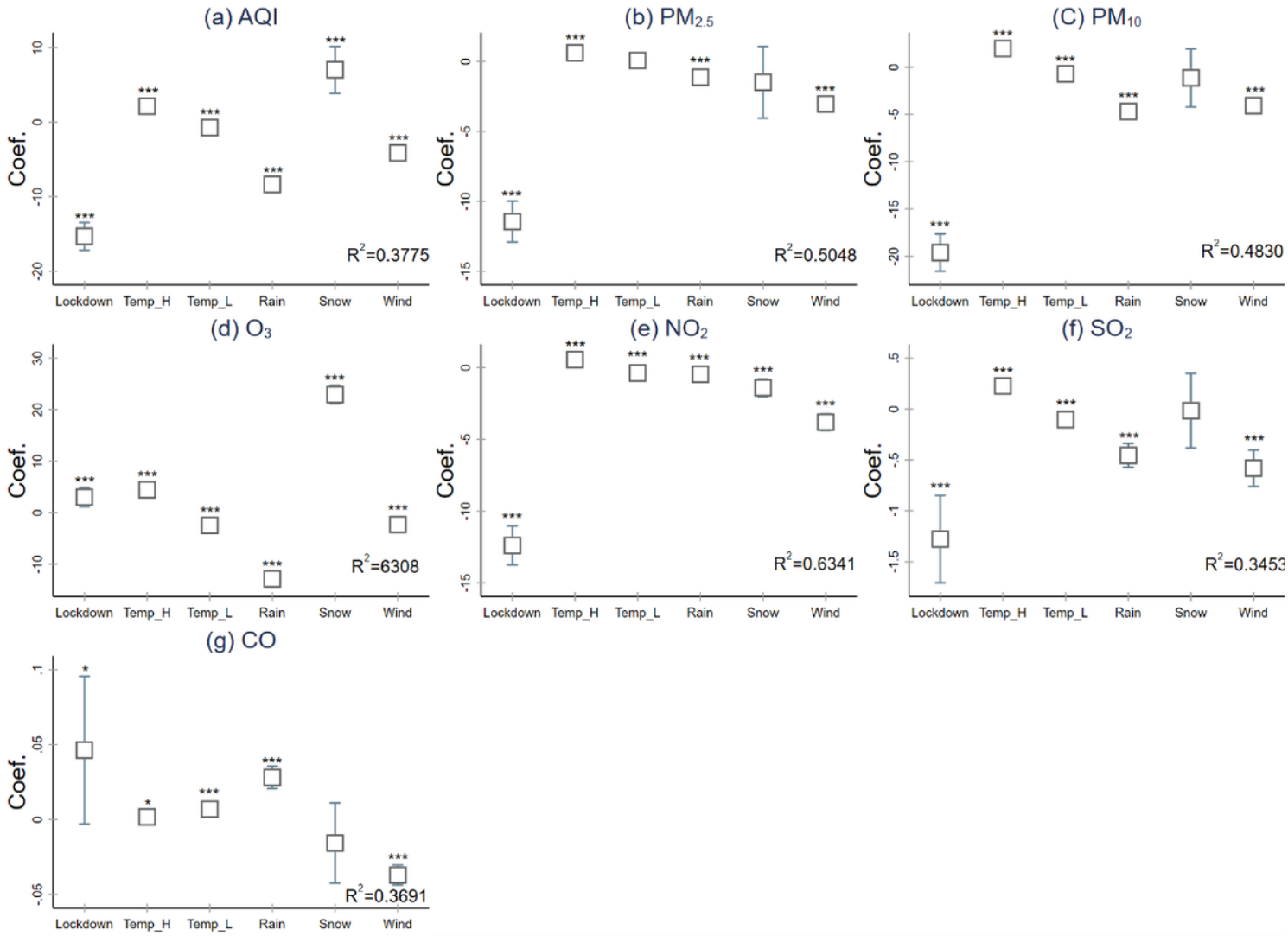

Figure 2

Full Sample Regression Results Note*, **, and *** respectively indicate significance levels of 10%, 5%, and 1%, All regressions control weather factors, regional and time effects. Coef. is the estimated coefficient value, the vertical line is 95% CI of the estimated coefficient (Coef.)

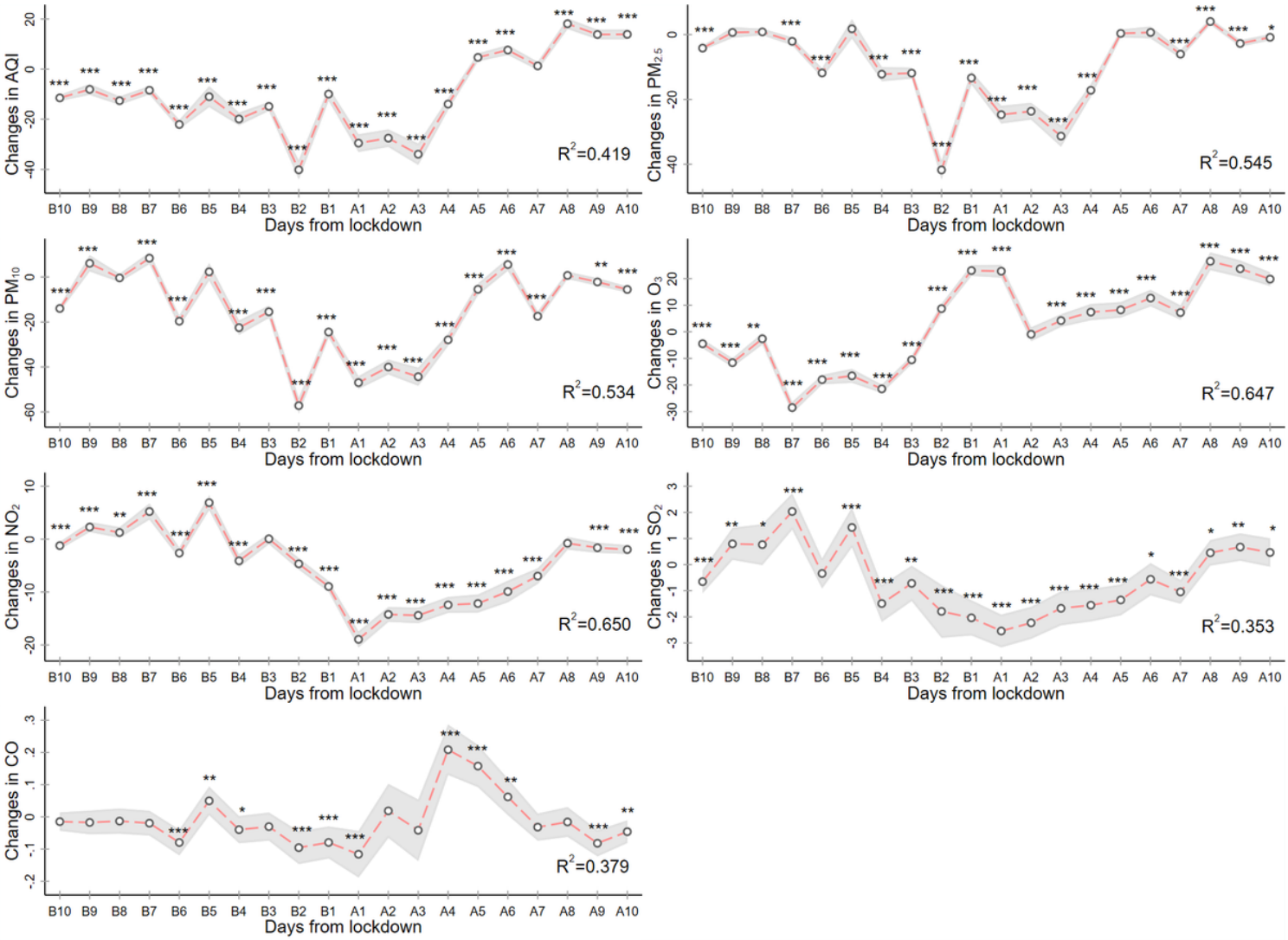

Figure 3

Time Event Analysis Note*, **, and *** respectively indicate significance levels of 10%, 5%, and 1%, All regressions control weather factors, regional and time effects.

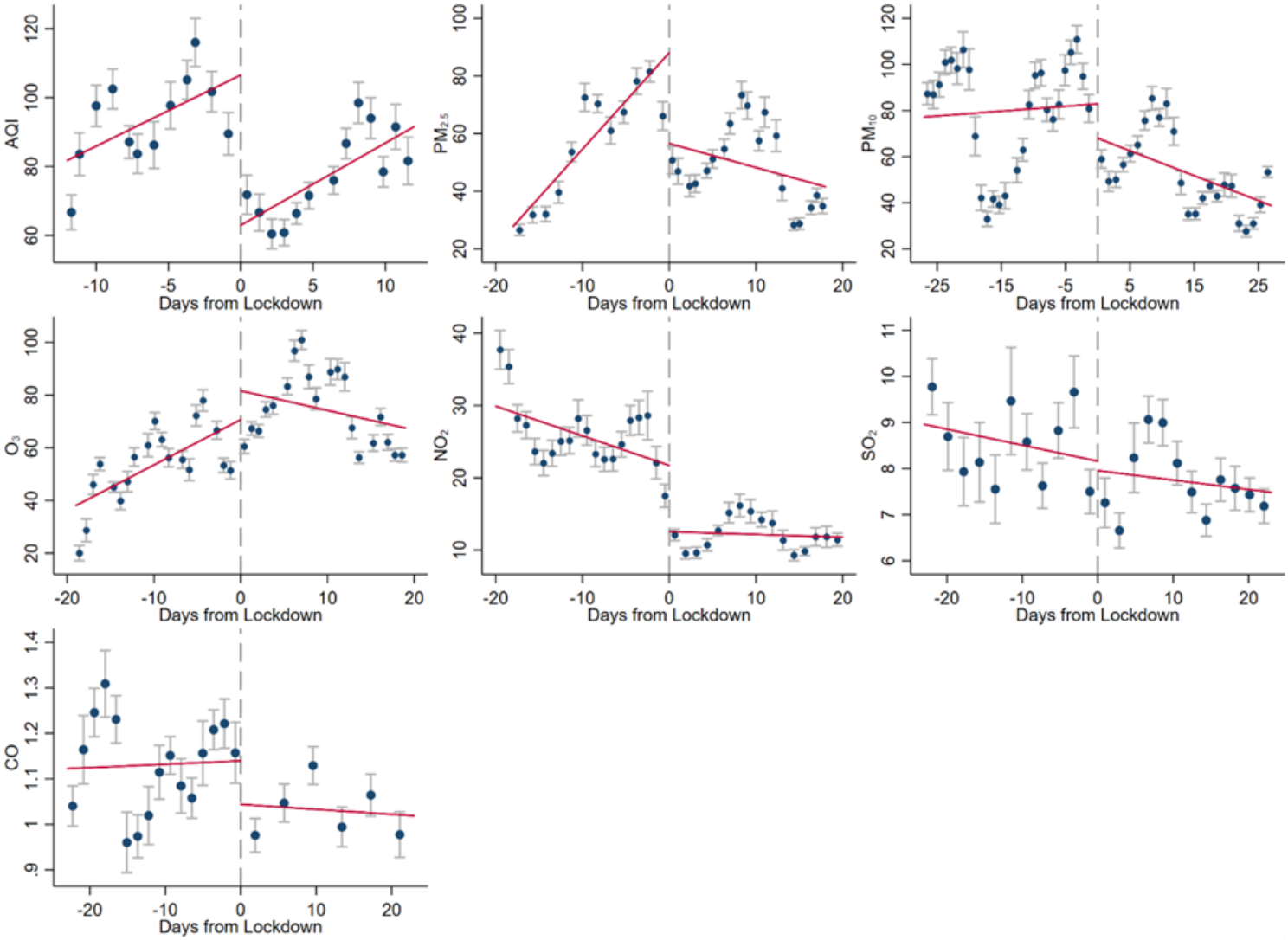

Figure 4

Fitting curve before and after discontinuity Note: When the horizontal axis is less than 0, it means that the blockade policy has not yet occurred. When it is greater than 0, it means that the blockade policy has started to be implemented.