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Air Quality and Winter Heating: Some Evidence from China

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ABSTRACT

This paper analyzes the effects of central winter heating prevailing in North China on air pollution level. Qin-Mountains and Huai-River borderline that distinguishes the heating and non-heating areas is considered to be a good quasi-natural experiment. Regression discontinuity design as well as relevant robustness checks and placebo tests are combined to verify the effects. Distinctions of the effects regarding different groups of areas located in different latitudes are also taken into consideration. Finally, we find that central winter heating contributes to the growth of all major air pollutants of 17.62% on average between non- and heating seasons considering all important cities in heating areas in north China excluding the effects brought by other natural conditions like weather. As latitude increases, central heating contributes more to air pollution level. In the coldest areas, the contribution to the increase of winter air pollutants can reach 54% in terms of particulate pollution in some year. One exciting thing is that there is a downward trend for the effects of winter heating on air pollution level in recent years, reflecting a good performance of national environmental policy on the improvement of air quality.

Keywords: Air Pollution, Central Winter Heating, North China, Qin-Mountains and Huai-River, PM2.5

JEL Classifications: Q4, Q5, Q3, R1

1. INTRODUCTION

Till the end of 2016, the total heating areas in north China are 20.6 billion m^2, among which 14.1 billion m^2 are for urban area. . (Huang et al., 2019) As is reported by the document "planning for clean heating in winter in northern areas for 2017-2021" issued by National Development and Reform Commission and other 10 ministries of China, the main energy coal used for heating accounts for 83% of total heating areas. Coal used for heating exhausts 0.4 billion tons of standard coal each year. In urban areas in the north, most of the households use the heating from the central heating systems which are around 7 billion m^2 (Su et al., 2018). In the meantime, China is becoming largest energy consumers and largest CO_2 emitter in the world. Air pollution problem has become one of the most striking issues for the public in China. This is also linked to the central winter heating systems in China as large amount of coal has been burnt for heating every year, generating great amount of air pollution. Chinese government is consistently working on improving the air quality level and protecting environment. For example, "Planning for clean heating in winter in northern areas for 2017-2021" has pointed out that the country should gradually update its energy type from coal to cleaner energy including natural gas, electricity and so on. To clarify the effects of central heating on air pollution in China is of great importance and necessity.

Central heating, also called district heating, is a system run by a central cogeneration plant through a system of insulated pipes stretching into heating users who could be either business or civilian. The energy of central heating may differ from place to place including fossil fuels, biomass or even nuclear power. The central heating system has been existing for almost 150 years. The first central heating system appeared in Annapolis in the U.S.A. in 1853. (Iken, 2010). The word "central" stands for "centralized" instead of "scattered" or "decentralized". The latter word stands for a decentralized heating system run by residents or companies themselves. For central heating, the cogeneration runs the whole system and residents and companies could buy this heating service directly from those plants. Central heating is a term used very frequently in China and it's directly translated from the Chinese word "jizhonggongre". "Jizhong" means "central" or "centralized". "Gongre" means "heating". Here in this paper, we use the word central heating to stand for the term district heating used mostly in countries of Europe and North America.

Not all areas of the country have been equipped with central heating systems due to their different locations and climatic conditions. At the beginning of 1950s, Chinese government set a borderline between the heating area and non-heating area, i.e., Huai-River and Qin-mountains borderline. (Guo et al, 2015) The borderline distinguished the heating area and non-heating area precisely and was deemed as a stable national policy in China. Areas north of the borderline receive central winter heating services from the municipally operated power plants while areas south of the borderline have no access to these heating services as there are no central heating cogeneration plants in these areas. The heating borderline generates a good natural experiment of distinguishing areas with central heating and without heating; thus, it can be used as a good tool to detect the influences of central heating on air pollution in China.

In this paper, we firstly collect the existing literature related to this and then we move on to some basic statistical analysis. After that, main estimation and robustness checks are conducted. At last, we explore the effects across districts in China. In general, effects of central heating on air pollution are verified and distinctions of these effects among different areas are also discussed. After specifying these effects and distinctions, useful policy enlightenment and suggestions will be made for future decision makings.

2. LITERATURE REVIEW

There are some existing articles of analyzing the effects of central winter heating on air pollutants. We first look at the papers discussing winter heating effects in other countries outside China. The literature focuses mostly on some case studies with respect to a certain area in some countries. Some of the papers only mention the potential effects of winter heating but do not calculate specifically. Most of the cases are in countries with relatively more severe air pollution problems.

Cichowicz et al. (2017) figured out that the distinctions between the summer season and winter season in terms of the air pollutants like PM10, sulfur dioxide, nitrogen dioxide, carbon monoxide and ozone were large. They did a case study of Wielkopolska, Poland. Papers discussing this issue in Poland are not rare to find, e.g., Dordevic et al. (2011) analyzed the effects of pollutant emission from district heating systems on the correlation between air quality and health risk.

Wang et al. (2017) took Ulaanbaatar, Mongolia as an example and analyzed the levels of PM2.5 in 2010 heating season and found out a significant increase when the heating season came. Guttikunda (2008) also pointed out that heating was one of the main factors influencing the air quality of Ulaanbaatar.

Angius et al. (1995) mentioned that vehicular traffic and emissions from building heating systems were two main sources of pollutants in the Milan, Italy and decomposed these two effects for several air pollutants like NOx and CO.

Ghafhazi et al. (2011) analyzed particulate matter emissions from wood biomass in district heating in Vancouver, Canada. They also compared the degrees of effects of different wood fuels and found that low quality wood fuel, such as forest residues, bark, wood waste, or co-firing of willow, in moving grate boilers produces particulate emissions remarkably higher than that of wood pellets or dry saw dust and wood material.

The following papers focus on the research status of China.

One of the representatives is from Almond et al. (2009). The technique used in this paper was a cross-sectional regression discontinuity-style estimation closely related to regression discontinuity design model (RD design). The data they used were annual daily average concentrations of TSP (Total Suspended particulates), NOx and SO2 during the period of 1981-1993. This was during the period when China started open-up policy but the whole economy was still highly centralized. The result told us that heating policy led to dramatically higher TSP levels in the north.

Liang et al. (2015) took winter heating in Beijing as a quasi-experiment. The technique they used was basically a non-parametric regression model. It drew the conclusion that the heating in general contributes 50% of increase of PM2.5 in Beijing.

Xiao et al. (2015) applied more engineering-based method to detect whether winter heating had an essential impact on air quality in north China. Their results showed a significant increase in air pollution level in heating season. The average AOD during the heating season (0.32) was more than five times higher as during the non-heating seasons (0.06). In general, winter heating contributed a lot to particle pollution in north China.

There are several papers published in Chinese journals discussing this problem.

Chen et al. (2017) used daily data of 39 stations in north China from 2013 to 2014 to analyze the effects of winter heating on air pollution. They controlled the meteorological data as control variables and found that the increase of air pollutants because of winter heating was roughly 20% from a panel data estimation. A regression discontinuity design of 3-day and 7-day windows showed that the effects were not significant.

Li et al. (2017) analyzed the winter heating effects using the dataset from 2013 to 2015 and figured out that the air pollutants increased substantially. Although the sample size of stations included were much bigger than Chen's paper, they used the weekly data from 2013 to 2015. They found out that the PM2.5 increases by 26.79% and SO2 increases by 74.10%. Luo et al. (2018)'s research was focused on analyzing the effects of central heating policy on AQI (air quality index). Their samples were larger and include periods from the 1st of January of 2013 to 31st of December of 2015, which is longer than Chen's paper. This paper analyzes a very important policy enacted by central government in 2013 called "air pollution 10 items" including 10 important policies for air pollution abatement. Air pollution 10 items' main contents include reduction of pollutants, restrictions of production capacity of high pollution industries, adjustment of the energy structure and so on.

All the above papers discussing this issue about China are considering the data earlier than 2015 and covering a short period for one or two years. They do not discuss the heterogeneities district by district as well as dynamics of these effects in recent years. Here in this paper, we consider the data from 2015 to 2019 and cover the 78 major cities in south and north China. Samples of north China are used for our main estimation. Samples of south China are used for comparison and checks. We conduct several different checks to verify these effects and work out possible conclusions for Chinese air pollution abatement. We also compare the effects of different districts and different years.

3. DATA

As meteorological conditions for heating-cities vary, different cities have different winter heating periods with different starting and ending days. Here in this paper, we consider air pollutants and meteorological data for 41 stations/cities with central winter heating. The northernmost city surveyed is Qiqihar, with the latitude 47.33°N roughly on the same latitude as Zurich, Switzerland. The southernmost city under investigation is Xuzhou with the latitude 34.27°N roughly on the same latitude as Tunisia, a North African country on the fringe of Sahara Desert. The vast territory of the country offers us a large sample of our test.

As we have mentioned above, central heating systems are distributed in cities in north China. Therefore, we will only pick up stations in urban areas. Actually, most Chinese air quality monitoring stations are distributed in city centers, revealing the air pollution situation in urban areas.

The chosen cities and their starting and ending days of heating are listed in the Appendix I along with their longitudes and latitudes and winter average temperatures. We categorize these cities referring to their provincial locations. Province is an administration division higher than cities. Beijing, Tianjin and Shanghai are three provincial cities. They are also included as provinces in Appendix I. These dates are quoted from the local laws or regulations of central winter heating in different cities in China. In recent years, more and more heating plants start their services ahead of the legal starting day and sometimes they will delay the ending day in order to offer better services. During the time when companies offer services ahead of the legal starting day, the water temperature is kept very low. When the formal starting day comes, they will adjust water temperature immediately to the needed level. Although the actual starting day of heating is a bit earlier than the legal one, it won't really make any sense to actual influence to the air quality. Li et al. (2017) dropped the data for the first week as the water temperature is still low and unstable. Here in this research, legal starting day is used as the threshold.

Another interesting point is that, although some cities have legal heating-starting days in their city regulations, they will not usually conform to those starting days in practice. For example, for the city Yan'an, according to the "regulations of central heating of city Yan'an", the starting day should be on November, 15th. In practice, the starting day is on November, 1st. November, 1st will be used as the threshold in the estimation.

We classify these cities according to their winter average temperatures. The winter average temperatures are calculated using the mean value of daily average temperature from December, to February. For example, the average winter temperature of 2016 are the mean value of daily temperatures of December of 2016, January of 2017 and February of 2017. Cities of Northeast China usually have the longest heating periods as these cities have long and bitterly cold winters. The persistence and degree of coldness is the No.1 among all these cities (See Group I in Tables 1 and 2). Cities of northwest China have considerably long winters as cities of northeast China but their temperatures are much milder, so they will still enjoy long heating periods (See Group II). For the cities with average winter temperature above -5 degrees and below 0 degree, their winters are much milder and acceptable (See Group III) and most of these cities are located in warm temperate zone. There are still some cities located just on or slightly north of the heating borderline with winter temperatures above 0 degree. The winters of these cities are even much milder. These cities are included in Group IV. As temperatures are different for each year, the classification is slightly different (Tables 1 and 2).

As central heating lasts a long period, it's not too sensitive to the data frequency that is going to be analyzed. Li et al. (2017) applied the weekly data to do the estimation. We use the air pollutants data well recorded by the National Urban Air Quality Real-time Publishing Platform run by the Ministry of Ecology and Environment of the People's republic of China. The recorded data are hourly data. This database includes the ground level pollutants' concentration of around 2000 stations across whole China. These hourly data are collapsed into daily data by taking average of hourly data every day. In order to eliminate possible inaccuracies, we calculate the mean of several nearby air stations in one city as the air pollutants level of one city. We match the air quality monitoring stations with our meteorological stations. Air quality monitoring stations that are far from the corresponding

Table 1: Grouping of heating cities in terms of average winter temperatures of 2016

Groups	Cities
Group I: <−10°C	Harbin, Mudanjiang, Qiqihar, Karamay,
Group II:-10°C~−5°C	Baotou, Hohhot, Changchun, Chengde, Datong, Benxi, Shenyang, Urumqi
Group III:-5°C~0°C	Zhangjiakou, Qinhuangdao, Tangshan, Langfang, Baoding, Taiyuan, Yinchuan, Yingkou, Anshan, Dandong, Yan'an, Korla, Xining
Group IV: 0°C~5°C	Qingdao, Jinan, Weifang, Yantai, Rizhao, Taian, Zhangqiu, Beijing, Tianjin, Kaifeng, Anyang, Zhengzhou, Sanmenxia, Xingtai, Linfen, Xuzhou

*Average winter temperature is calculated according to the dataset from the NMC.

Table 2: Grouping of heating cities in terms of average winter temperatures of 2017

Groups	Cities
Group I: <10°C	Qiqihar, Harbin, Mudanjiang, Karamay, Changchun , Urumqi
Group II:-10°C~−5°C	Baotou, Hohhot, Chengde, Zhangjiakou, Datong, Yingkou, Benxi, Dandong, Shenyang, Korla, Xining
Group III:-5°C~0°C	Yantai, Beijing, Tianjin, Qinhuangdao, Tangshan, Langfang, Baoding, Taiyuan, Yinchuan, Anshan, Yan'an
Group IV: 0°C~5°C	Qingdao, Jinan, Weifang, Rizhao, Taian, Zhangqiu, Kaifeng, Anyang, Zhengzhou, Sanmenxia, Xingtai, Linfen, Xuzhou

*Average winter temperature is calculated according to the dataset from the NMC.

meteorological stations are eliminated. These pollutants are measured with ground equipment and consist of PM2.5, PM10, NO_2, SO_2, O_3, CO and an overall calculation of AQI (Air Quality Index).

As the time of central heating varies from city to city, we try to unify the dates by denoting these dates with numbers. We use number 0 to denote the starting day of heating. The next will be 1 and so on. The days before the starting day will be denoted by −1, −2 and so on. In order to balance our data, we will firstly estimate the 120-day window data meaning that days before the starting day and after that are 120 days excluding the starting day. That will be in total 241 days. To identify the causal relations, we will consider to change our window to verify the robustness of our estimation. Let's take Jinan as an example. The starting day of heating in Jinan in 2017 is 15th of November formally, so 15th of November is our 0-day. If we follow the 120-day estimation, the length of our data for 2017 is from 18.07.2017 to 15.03.2018. Other cities are applicable to this example. The 120-day estimation data for 2018 will be from 18.07.2018 to 15.03.2019.

Here in our further estimation below, we will consider the air pollutants and meteorological data in the year 2015, 2016, 2017 and 2018.

As we will do further tests for causal relations, we also collect data for the non-heating cities for checks. There are 37 cities in non-heating areas taken into consideration. Figures 1 and 2 illustrate all these stations in the north and south graphically. One thing needed to mention is that the two figures are the partial cuts of the whole map and they are just schematic plots.

Daily meteorological data are collected from the National Meteorological Information Center run by the National Meteorological Center of China. These data are daily data recording average wind speed, maximum wind speed, wind direction at maximum wind speed, maximum humidity, minimum humidity, average temperature, maximum temperature, minimum temperature, daily sunshine hours and precipitation. We will take them as our control variables in our estimation part.

In summary, we will use both the meteorological data and air quality data of 41 winter-heating cities and 37 non-winter heating cities of the years 2015, 2016, 2017 and 2018.

4. PRELIMINARY STATISTICAL ANALYSIS

4.1. Heating Ratio and Heating Grade

We calculate the average pollutants level 120 days before and after the heating starting days. We use the data from 2015 to 2019. This calculation could give us the initial contrast of the air pollutants level in winter heating periods and non-winter heating periods. In order to make results more concise, we only present the provincial level data. We calculate the ratio between the air pollutants level between heating periods and non-heating periods. For simplicity, we define this ratio heating ratio as:

$$Heating\ ratio_{it} = \frac{Air\ pollutants\ level\ in\ heaitng\ periods}{Air\ pollutants\ level\ in\ non\text{-}winter\ heating\ periods}$$

Table 3 can help us illustrate this indicator.

Table 4 is a matrix containing all heating grades of various provinces in north China in 2018 with all cities combined. All the air pollutants except ozone have heating grades higher than 1, showing a significant rise in air pollutants level when heating starts. The provinces in higher latitudes tend to have higher heating grades coinciding with our intuition. As for the type of pollutants, PM2.5 and SO_2 have higher heating grades than other types of pollutants, showing the burning of coal for heating will contribute much to the increase these two pollutants.

We find out that cities with heating grade 4 are mostly located in the far north. For provinces that are located at relatively lower latitudes, these ratios are smaller. We try to illustrate this point by Figure 3. These graphs show us the relation between the city latitudes and heating ratios using the city-level data across all these 5 years. It shows that the heating ratio and latitudes have a positive

Table 3: Heating ratio and heating grade

Range of heating ratio	Description	Heating grade
Lower than 1	Not obvious	1
Between 1 and 2	Obvious	2
Between 2 and 3	Very obvious	3
Higher than 3	Extreme obvious	4

Table 4: Heating grade matrix of provinces and pollutants

Province	PM2.5	PM10	AQI	SO2	NO2	CO	O3
Beijing	2	2	2	3	2	2	1
Tianjin	2	2	2	2	2	2	1
Shandong	2	2	2	2	2	2	1
Hebei	2	2	2	3	2	2	1
Shanxi	3	2	2	4	2	2	2
Jiangsu	3	2	2	2	2	2	1
Heilongjiang	4	3	3	4	2	2	1
Liaoning	2	2	2	3	2	2	2
Jilin	3	2	2	4	2	2	1
Xinjiang	3	2	2	2	2	2	1
Shaanxi	2	2	2	4	2	2	1
Ningxia	2	2	2	4	2	2	1
Inner Mongolia	3	2	2	3	2	3	1
Qinghai	2	2	2	2	2	2	1
Henan	3	2	2	2	2	2	1

Figure 1: Heating cities in North China

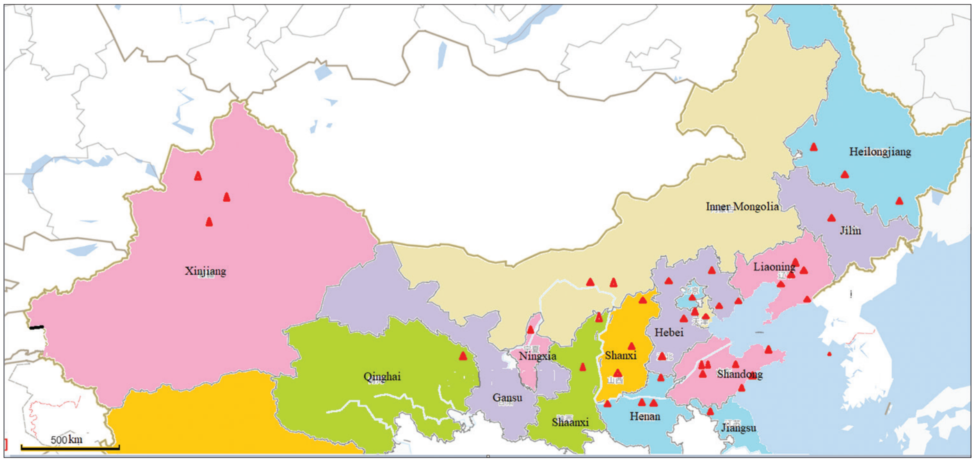


Figure 2: Non-heating cities in South China

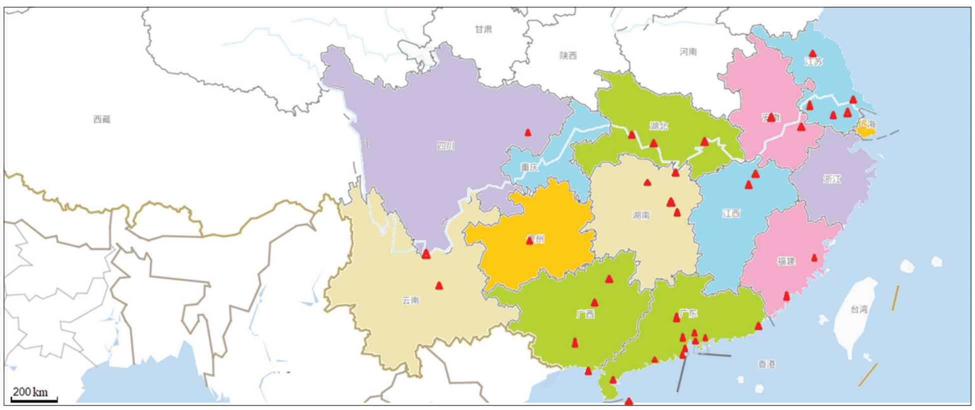
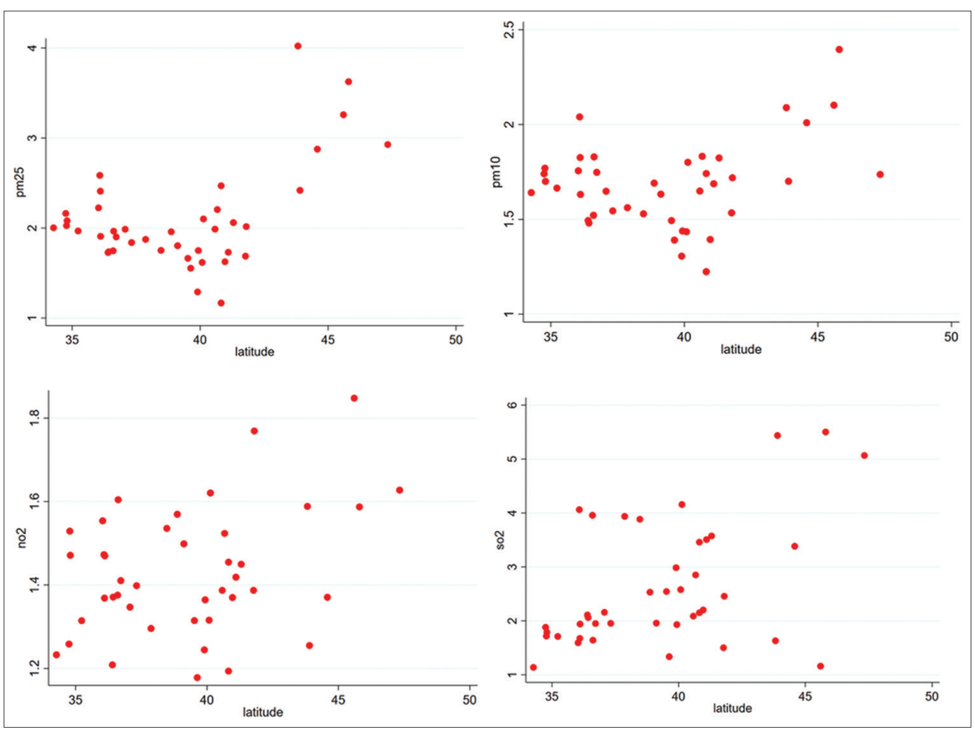


Figure 3: Scatter diagrams between heating ratios and latitudes (2015-2019)



relation for PM2.5, PM10 and SO_2. Through reading Figure 3, we know that cities with highest heating ratios are mostly located in the far north. As for the cities in lower latitudes, they are more scattered and do not follow certain rules.

Although these data have significant difference, we still cannot say that winter heating does cause more severe air pollution because the meteorological conditions are not taken into account. But these data could give us the initial pattern of the possible winter heating effects on air pollutants level.

4.2. Dynamics of Heating Ratio

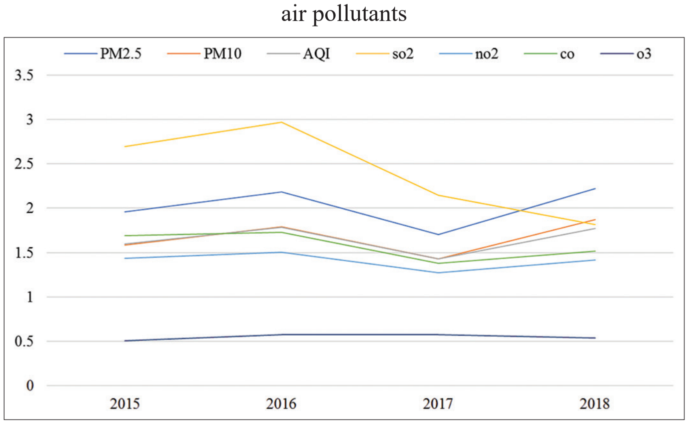
In recent years, China has put forward many policies and regulations of improving the air quality level and update winter heating systems to bring down the air pollutants' emissions. One of the representatives is residential coal-switch policy. Households were encouraged to replace their coal-heating systems with systems powered by natural gas and electricity. This policy started from 2012 and was accelerated after 2016. (Liu et al., 2021).

Now we will discuss the dynamics of heating ratios. All sample data from 2015 to 2019 are used to calculate the overall heating ratios for 41 cities in the north. We take heating ratio as an indicator for degrees of the effects on air pollution and figure 4 illustrates the dynamics of heating ratios from 2015 to 2018.

Figure 4 illustrates this question well. Generally speaking, SO2 and PM2.5 are pollutants with highest heating ratios. Winter of 2016 is considered as the worst year of central heating on air quality level in China. From the year 2017, Chinese government started to implement the coal-to-gas campaign very quickly. In 2017, Hebei province completed the project of 2.1 million households to replace coal with gas as their major heating energy. As the demand of gas suddenly increased in that winter, many provinces in north China experienced the shortage of natural gas, leading to a higher price of gas. At last, some places had to switch gas back to coal in order to bring down the heating costs. On December 14th, 2017, the National Bureau of Statistics released market price changes for important products in the circulation sector and stated that the price of the natural gas increased by 23.6% from December 1st to 10th, 2017.

In 2018, coal-switch policy was still implemented but asked to stay in a controllable pace to avoid rapid growth of related energy prices. For the data of 2018, we can witness an obvious rise in heating ratios. But for SO_2, heating ratio was in a lower level than 2017. In 2018, the government started to promote the campaign of using more low sulfur coal. That's the reason why heating ratio of SO_2 still decreased in that year.

Figure 4: Time series for average heating ratios in terms of different air pollutants



In general, the environmental policy for winter heating has achieved good results. The big gaps between heating season and non-heating season have been partially filled. These results have also been verified by the estimation results below.

4.3. Graphical Analysis

In order to make sure that these discontinuities really exist, we conduct some graphical analyses before we go further into our estimation. As there are numerous cities in the dataset, we take some cities as our examples to show the existence of the discontinuity. Harbin is one of the coldest provincial capital cities in North China and is taken as an example. We take the data of 2015, (meaning the data between 2015 and 2016) and choose 5 as the bin size. Then we take average of the air pollutants within each bin and plot the mid value and the average pollutants level. The time length of this analysis is 100 days before the starting day and 100 days after the starting day, thus in total 201 days. Figure 5 is the plot of choosing bin size 5. Figure 6 is the plot of the real data. It is easy for us to see that the discontinuity does exist.

5. BENCHMARK ESTIMATION

Our main estimation equation is very straightforward. The methodology is a discontinuity-based panel estimation model. The main estimation method refers to Chen and Whalley (2012). We will use random-effects model to estimate the overall effects of central heating across all these stations. Several different checks of our main estimation results will be conducted:

1. 70-day and 30-day estimation for northern heating cities.
2. A randomly-chosen date as our starting date of central heating.
3. Southern stations as control group.
4. Regression between air pollutants' level and daily minimum temperature.
5. Estimation of different districts.

5.1. Panel Data Estimation

In this part, a panel data setting is employed to analyze the general performance of winter-heating effects on air quality level. We include the stations with central winter heating systems distributed in different parts of the province with different latitudes and longitudes. All meteorological variables are also included in the estimation formula as control variables. Besides, day of month and day of week are also important control variables included. Some papers control more factors, like Luo et al. (2018) control holiday factors. Here in this estimation, holiday factors are not taken into account.

The methodology is presented as follows:

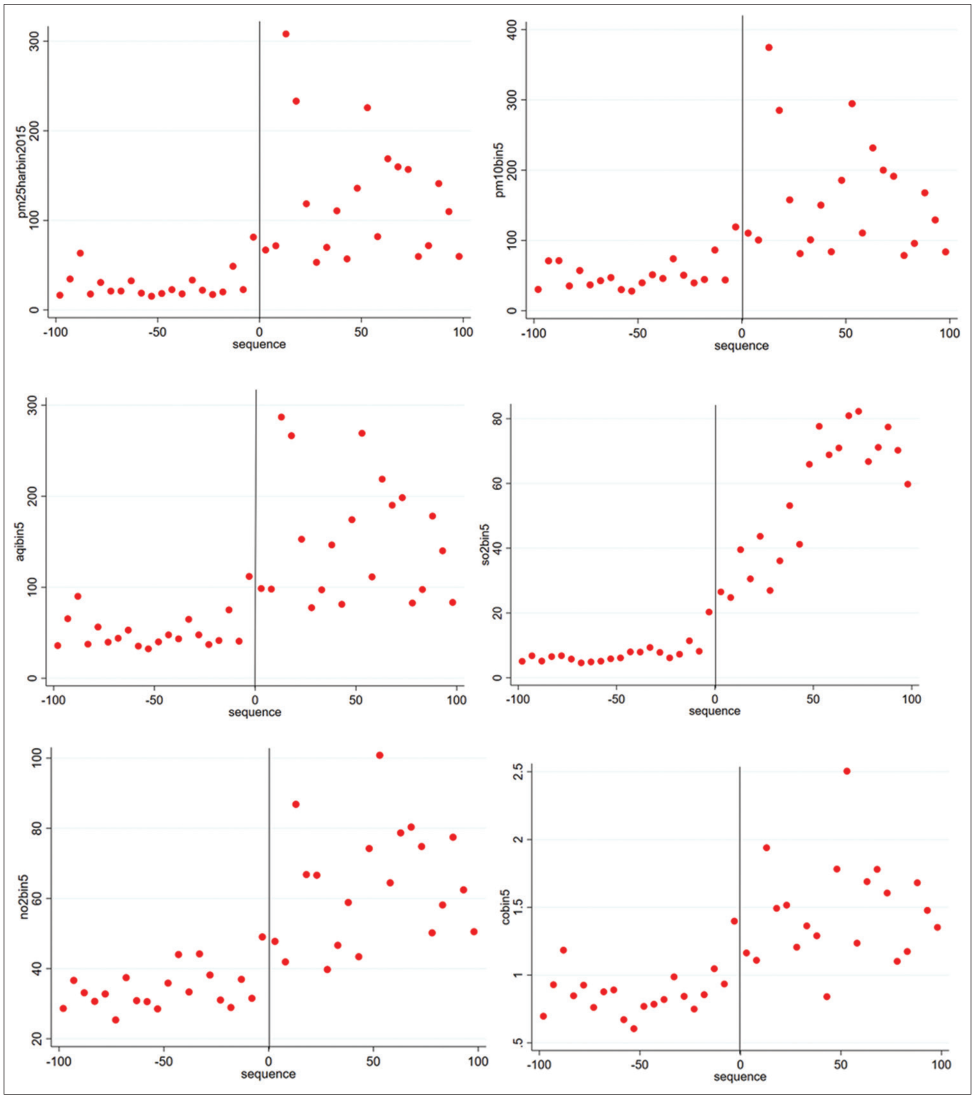
$$lnAQI_{it} = \alpha + \beta_1 Heating_{it} + \gamma X_{it} + f(t) + u_{it} \quad (1)$$

The interpretation of the variables are as follows:

α_i-city-specific intercept

Heating-if this is a heating-day, then it equals 1, otherwise it equals 0.

Figure 5: Plot of average pollutants' level and days using bin size 5 data, PM2.5, PM10, AQI, SO2, NO2, CO respectively



X_{it}-includes all control variables, like meteorological variables: average daily wind speed(m/s), maximum daily wind speed(m/s), wind direction at the maximum wind speed (from 1 to 16), maximum relative humidity, minimum relative humidity, average temperature (°C), maximum daily temperature, minimum daily temperature, daily precipitation (mm), daily sunshine hours (h), day of week, day of month. Considering that the control variables and pollutants level might have non-linear relations, we include the squared terms of all meteorological variables to capture these characteristics.

f(t)-here we use a third-order polynomial of time to smooth the time series.

$\ln AQI_{it}$-log value of ground level air pollutants' concentration of PM2.5, PM10, AQI, SO_2, NO_2, CO and O_3.

Table 5 records all outcomes of heating variables. Heating is the most important variable in this estimation. If this variable is positive and statistically significant, it shows the central heating has some effects on air pollution. The higher this coefficient is, the stronger these effects are. Except ozone, coefficients of heating for all the main pollutants are significant and positive, showing a strong relationship between winter heating and air pollution. As we use log term of the pollutants concentration, we can interpret the coefficients as the growth rate of the air pollutants before and after the start of central heating. We categorize the estimation results into four years. Year 2015 means that we use the data from middle of 2015 (120 days before the start of heating) to the beginning of 2016 and so on.

The panel estimation shows that the central heating does have impact on air pollution. In the year 2015, the average growth of air pollutants level for $PM_{2.5}$, PM_{10}, AQI, SO_2, NO_2 and CO are 16.68%, 8.72%, 11.33%, 44.96%, 9.08% and 14.95%. The average growth rate is 17.62%. In the year 2016, the average growth rate is 18.85%. The growth rate of 2017 and 2018 are 12.36% and 10.81%. The effects have a downward trend from 2015 to 2018 denoting possible effects of environmental protection and pollution abatement policy. PM2.5, SO2 and CO are considered as three most significant pollutants. This result is a little bit different from the ones in Table 4 and Figure 6. This may be due to the

Figure 6: Plot of average pollutants' level and days using real data, PM2.5, PM10, AQI, SO2, NO2, CO respectively

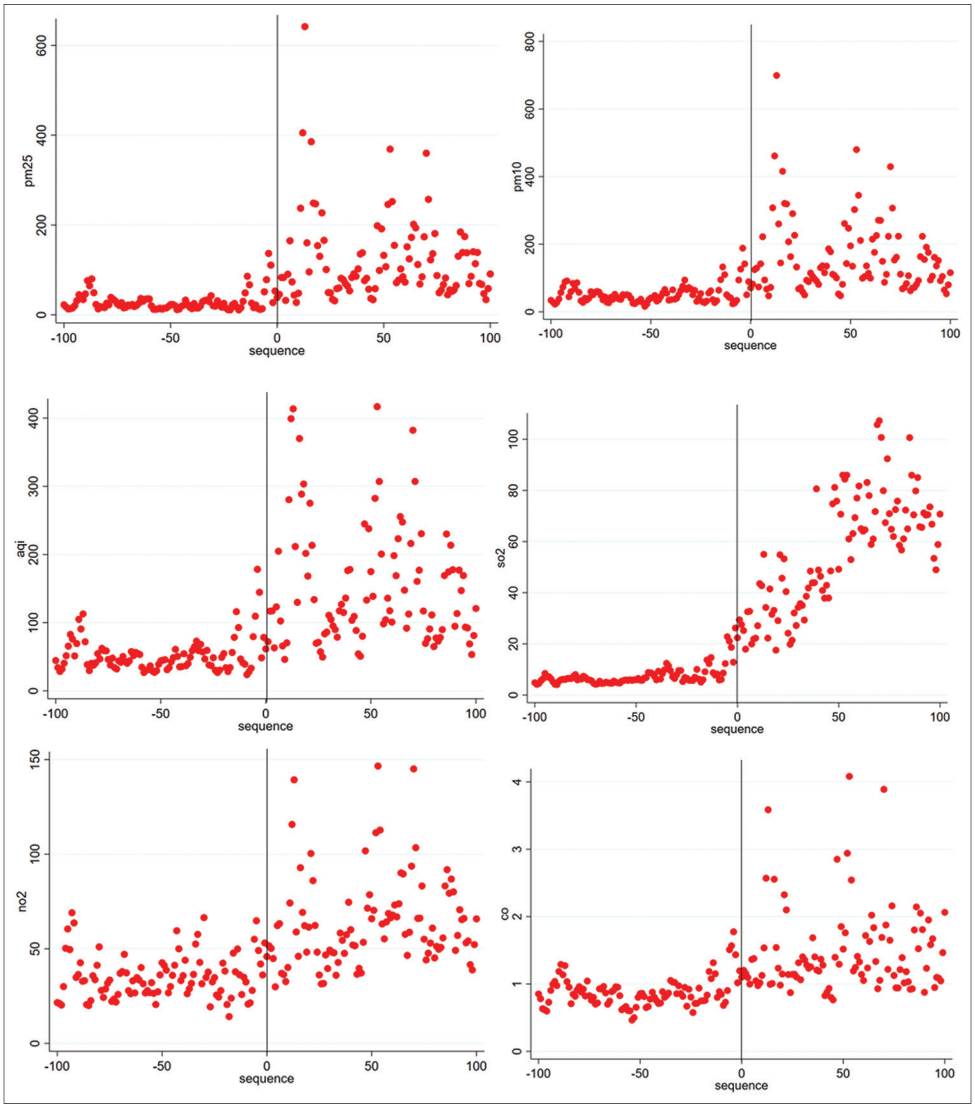


Table 5. Main estimation results-heating variable

Year	2015	2016	2017	2018
ln(PM2.5)	.1667682 ***	.1874954 ***	0.146451 ***	.0814049***
	(0.1667682)	(0.0277874)	(0.0268458)	(0.0259384)
ln(PM10)	.087151 ***	.1659112 ***	0.064659 ***	0.152648 ***
	(0.0276284)	(0.024481)	(0.0227535)	(0.0224731)
ln(AQI)	.1132887 ***	.1722787 ***	.0861463 ***	0.122962 ***
	(0.0242602)	(0.021823)	(0.0199243)	(0.0194907)
ln(SO_2)	.4495528 ***	.3518401 ***	0.266326 ***	0.099754 ***
	(0.027895)	(0.0255567)	(0.0225326)	(0.0212529)
ln(NO_2)	0.090772 ***	.081558 ***	.0704906***	0.064584 ***
	(0.0190431)	(0.0164114)	(0.0166159)	(0.0170803)
ln(CO)	.1495492 ***	.1720082 ***	0.107332***	.1268716 ***
	(0.0203425)	(0.019698)	(0.0178241)	(0.0173937)
ln(O_3)	-0.055211 **	-.0829268 ***	-0.031988 ***	-.1542912 ***
	(0.0258571)	(0.0291579)	(0.0197583)	(0.020316)
Obs	8613	9578	9579	9415

Statistical significance: * p<0.1 **p<0.05 ***p<0.01

introduction of meteorological variables. As sensitivity of air pollutants concentration on meteorological variables differ from one type of air pollutants to another, this could bring different results when meteorological variables are introduced. Ozone has a rather different behavior compared with other types of pollutants. Central heating can reduce the sunlight intensity and can reduce the concentration of ozone.

The dynamics of these coefficients basically conform to the analysis of heating ratios in Figure 6. 2016 is considered peaks

Table 6: Pollutants and meteorological variable (2017)

Year 2017	Wind speed	Maximum humidity	Minimum humidity	Sunshine hours	precipitation
ln(pm25)	-.0040256***	.0112705***	.0169516***	-.0032498***	-.0000297 **
	(0.0268458)	(0.0008177)	(0.0016089)	(0.0001871)	(0.000147)
ln(pm10)	-.0024016***	.0038132***	.0132433***	-.0028182***	-.0000217*
	(0.0005904)	(0.0006924)	(0.0013629)	(0.0001583)	(0.0000125)
ln(aqi)	-.0022103***	.0064769***	.0107464***	-.0023921***	-.0000153
	(0.0005169)	(0.0006062)	(0.0011933)	(0.0001385)	(0.0000109)
ln(SO_2)	-.00444***	-.003414***	.0136416***	-.00248***	-.0000128
	(0.0005858)	(0.0006868)	(0.0013509)	(0.0001572)	(0.0000124)
ln(NO_2)	-.0075413***	.0025403***	.0080988***	-.0021585***	5.98e-06
	(0.0004316)	(0.0005061)	(0.0009957)	(0.0014998)	(9.12e-06)
ln(CO)	-.003974 ***	.0064701***	.005518 ***	-.0021017***	-.0000129
	(0.0004631)	(0.000543)	(0.0010683)	(0.0001242)	(9.78e-06)
ln(O_3)	.0033877***	-.0041892***	.0084477***	.0020897***	-6.13e-06
	(0.0197583)	(0.0006003)	(0.0011824)	(0.000137)	(0.0000108)
Obs	9579	9579	9579	9579	9579

Statistical significance: * p<0.1 **p<0.05 ***p<0.01

Table 7: Pollutants and meteorological variable (2018)

Year 2018	Wind speed	Maximum humidity	Minimum humidity	Sunshine hours	precipitation
ln(PM25)	-.0048546***	.0115558***	.0192123***	0026477***	-.0008022***
	(.0007596)	(.0008438)	(.0016509)	(.0001688)	(.0000726)
ln(PM10)	-.0036499***	.0037682***	.014256***	0023219***	-.0008732***
	(.0006582)	(.0007311)	(.0014304)	(.0001463)	(.0000629)
ln(AQI)	-.0031723***	.006223***	.0134135***	0019056***	-.0007035***
	(.0005707)	(.0006339)	(.0012404)	(.0001268)	(.0000546)
ln(SO_2)	-.0044712***	-.007964***	.0190294***	0016754***	-.0000782
	(.0006231)	(.0006921)	(.0013536)	(.0001385)	(.0000595)
ln(NO_2)	-.0095497***	.0005002	.0106211***	-.0015365***	-.000122**
	(.0005008)	(.0005562)	(.0010878)	(.0001113)	(.0000478)
ln(CO)	-.004311***	.0064598***	.008706***	-.0014621***	-.0000879*
	(.0005099)	(.0005664)	(.0011077)	(.0001133)	(.0000487)
ln(O_3)	.0023781***	-.0024022***	.0071929***	.0011456***	-.0000328
	(.0005948)	(.0006608)	(.0012929)	(.0001322)	(.0000569)
Obs	9415	9415	9415	9415	9415

Statistical significance: * p<0.1 **p<0.05 ***p<0.01

for all pollutants. 2017 is the turning point for many pollutants to drop. The effects of year 2018 rebounds a little bit.

5.2. Pollutants and Meteorological Variable

We also present the coefficients of the meteorological variables and see the signal of these coefficients (Tables 6 and 7). The coefficients of daily average wind speed are negative, showing strong wind could reduce the concentration of air pollutants level. Humidity and pollutants have a positive relationship, showing pollutants concentration are higher when air humidity is higher. Precipitation and pollution have a negative relation, meaning rainfall could reduce air pollution. Sunshine hours and pollution have a negative relation. The coefficients of these meteorological variables could give us some intuition of how these variables influence air pollutants level before and after winter heating periods. As for daily minimum temperature, we will discuss it in 6.4.

In order to judge whether the winter heating does have causal relationship with air pollution in China, several checks are performed. The checks are as follows:

1. To shorten the window from 120 days to 70 days and 30 days to see whether the results still hold.

Table 8: 70-day window estimation

Year	2015	2016	2017	2018
ln(PM25)	1362371***	0900192***	2192966***	0346457
	0407709	0340861	0332876	0283574
ln(PM10)	1158908***	0617931**	1608685***	0.09029***
	0356298	0298535	0272793	0257656
ln(AQI)	0973959***	0576139 **	1511437***	0502926**
	0318649	0269864	0242496	(0.0219035)
ln(SO_2)	3203356***	2752436***	228628 ***	0295164
	0342975	0311677	026105	0235203
ln(NO_2)	056501**	0080786	0910328***	0181265
	0237783	0191153	0187602	0164391
ln(co)	0.084589***	007343	0898649***	0275931
	0256816	0245965	0220315	019206
ln(o_3)	003464	0134841	0283638	0836336***
	0303538	030159	0250188	(0.0234883)
Obs	5242	5538	5560	5387

Statistical significance: * p<0.1 **p<0.05 ***p<0.01

2. To assume another date other than the real starting day as our starting date of central heating and we see whether the results are still positive and significant.
3. To take the non-heating cities presented in Figure 6 as our control group to estimate the equation (1). We take the 15th of November as the heating starting date. We want to see whether

those results are still positive and significant.

4. We also consider a regression between the air pollutants level and daily minimum temperature. We want to see whether they have a negative relation. The lower the temperature is, the more fossil fuels are burnt for heating and lead to more air pollution.

These checks can help us further make sure the estimation results are robust and causal relationship between central winter heating and degrees of air pollution in China exists.

5.3. 70-day (30-day) Window Check

We shorten our estimation window from 120-day to 70-day to see whether the results are still significant. The methodology remains exactly the same as equation (1). 70-day window means 70 days before the starting date and 70 days after the starting date.

From the results 70-day window check, we find out that most of the coefficients are still positive and significant, showing a strong correlation between the winter heating and air pollution level. Compared with the 120-day estimation results, most of the coefficients are smaller. Some of the small coefficients in 120-day estimation are not significant in our 70-day estimation. In general, PM2.5 and SO_2 are still on the list of most sensitive pollutants to heating. But the dynamics of the coefficients are different from the results of 120-day window estimation. As the samples we get are different, this result is not beyond our expectation. We could think of some explanations for this. Central heating systems always need to a process to run smoothly. For the first couple of weeks, the system might be not completely open so that the number of pollutants emitted are limited. Actually, the heating plants have this motivation of postponing the time when the system is completely open because the air temperature for the first or two weeks often don't drop that low. Heating users are not sensitive to the actual water temperature of their heating radiators as the room temperature is still very high at the beginning of the heating periods. If we take 30-day window data, the coefficients might not be that significant (Table 8).

Table 9: Another starting day

100-day window	August 15th	2016	2017
ln(PM2.5)		0.089012 ***	0.078201 ***
		(0.0282223)	(0.0274319)
ln(PM10)		0.051224 **	0.084632 ***
		(0.0235385)	(0.0222405)
ln(AQI)		0.0253113	0.076689 ***
		(0.0194928)	(0.0183619)
ln(SO_2)		0.205359 ***	0.108826 ***
		(0.0253872)	(0.0234827)
ln(NO_2)		0.090227 ***	0.028814 **
		(0.0167546)	(0.0164598)
ln(CO)		0.089622***	0.0122792
		(0.0191114)	(0.0171536)
ln(O_3)		0.129901 ***	0.089709 ***
		(0.0229918)	(0.0204558)
Obs		8241	8241

Statistical significance: * p<0.1 **p<0.05 ***p<0.01

Table 10: Group 1 and Group 2 of non-heating cities*

	City name (average winter temperature)
Group 1: mild winters	Changde(7.9), Guiyang(7.4), Hefei(5.4), Hauian(4.3), Jingzhou(7.4), Kunming(10.5), Kunshan(7.5), Lushan(4.3), Maanshan(6.5), Nanchang(9.5), Nanchong(8.8), Nanjing(6.4), Nantong(6.2), Wuxi(6.8), Wuhan(6.8), Yichang(7.2), Yueyang(8.7), Changsha(8.7), Zhuzhou(9.0)
Group 2: warm winters	Beihai(20.3), Dongguan(17.2), Fuzhou(13.8), Guangzhou(15.5), Guilin(12.1), Haikou(20.0), Huiyang(16.6), Liuzhou(14.4), Qingyuan(16.0), Xiamen(15.3), Shantou(17.3), Shenzhen(17.9), Yangjiang(17.7), Zhanjiang(18.2), Zhongshan(17.1), Zhuhai(17.7), Panzhihua(15.0), Nanning(13.8)

*Average winter temperature is calculated according to the dataset from the NMC.

5.4. Another Starting Day

An imaginary winter heating starting day is chosen as our cut-point instead of the real ones. It can be seen whether the results still hold if the start day of heating is changed. A 100-day window is used for this estimation. August, 15th is chosen as the "imaginary" heating starting day. We don't choose a day in September because some cities in higher latitudes will start their heating very early (the earliest is on October, 1st). There will be a large percentage of days included in this estimation that are heating days, which might probably lead to inconclusive results. A day that is earlier in July is not chosen as some cities in the far north have very long heating periods. We choose 100 instead of 120 as the time length because there can be many days of heating included in the 120-day estimation. The methodology is exactly the same as equation (1). The estimation results are presented in table 10. For simplicity, we only include estimating results of 2016 and 2017. The results are reasonable. The coefficients conform to our expectation except SO2. It seems that the SO2 still have an upward trend even it's not a true heating day, but the increase is smaller compared to our main estimation results in table 6. PM2.5 and PM10 have even negative coefficients, showing an obvious drop of air pollutants level.

5.5. Southern Cities as Our Samples

We collect the air quality data for cities without winter heating and use a 70-day window to do this estimation for simplicity (Tables 10 and 11). We use the November, 15th as our imaginary winter heating start day.

As is discussed before, these southern cities could be further divided into two groups. One is the group without central heating systems but has the heating demand, meaning that families will use their own heating facilities to heat themselves in order to spend their shorter but still colder winters. These cities are mostly located nearer to the heating borderline. (See Group 1 in Table 11). The other group of cities are those without any necessary heating systems, although there are some years of extreme winter temperatures, their winters are still very warm. Ordinary air conditioning systems would work. The frequency of using air conditioning systems in these cities is smaller than that in summer times. The cities included here are listed on Table 11 Group 2 with criteria of their average winter temperatures of 2016 and 2017 covering December, January and February, that is, the average winter temperatures are the average of temperatures of December of 2016, January of 2017, February of 2017, December of 2017, January of 2018 and February of 2018

We compare our estimation results here with our main estimation results. All the coefficients are insignificant. As the samples we use include many stations near to the borderline (Group 1), which could receive some pollutants from the heating areas. These cities can also produce their own heating pollutants by decentralized heating systems. We conduct two estimations using the Group 2 data and all data of both group 1 and group 2. Results are presented in Tables 11 and 12.

We compare all these estimation results. We've found that all coefficients for 70-day window of Group 2 are either insignificant or significant but negative. It's a very strong conclusion that some pollutants drop dramatically among these warm winter cities when winter comes. Because they do not have central heating systems, these cities do not only witness a rise in air pollutants level but a drop in air pollution level. This is a rather reasonable result showing the influence of central heating systems on air pollution in winter heating cities in north China.

Table 11: Cities of Group 2

	2016	2017
ln(pm25)	0232542	6291514***
	0.021343	0595099
ln(pm10)	0149368	5069349***
	0.112391	0478854
ln(aqi)	0082784	4805121***
	0046106	0442847
$\ln(SO_2)$	0048219	2242318**
	0000949	0729257
$\ln(NO_2)$	0140015	1624022***
	0030782	0605069
ln(co)	06695 **	0720111**
	005277	0679478
$\ln(o_3)$	0504302	4418947***
	0139261	0557276
Obs	2740	2740

Statistical significance: * p<0.1 **p<0.05 ***p<0.01

Table 12: Cities of Group 1 and Group 2 combined

	2016	2017
ln(pm25)	0401916	4768123***
	0313152	0344061
ln(pm10)	0516047*	3923477***
	0282398	0292222
ln(aqi)	0235158	3644688***
	0248328	0255298
$\ln(SO_2)$	031259	1209167***
	02551	0237115
$\ln(NO_2)$	060675***	1835142***
	0204383	0213553
ln(co)	0802284***	092349 ***
	0163542	0164671
$\ln(o_3)$	0147565	2992211 ***
	0267301	0299207
OBS	5640	5640

Statistical significance: * p<0.1 **p<0.05 ***p<0.01

5.6. Minimum Daily Temperature and Air Pollutants Level

In this part, we are considering temperature as a variable of connecting air pollutants level and winter heating. The basic logic is like this. When temperature is in lower level, the central heating facilities like heating plants will burn more fossil fuels with coal being the most important fuel.

The emissions of air pollutants will increase crucially, letting the air pollutants deteriorate. Daily minimum temperature is considered as one of the most important reference. The heating plant will adjust its water temperature according to the air temperatures every day. The coldest period of a day is at midnight when temperature drops to the minimum. In order to keep the indoor temperature stable at a comfortable level, the heating plant will add more fuels and burn out more coal, which will generate more pollutants. One method of checking whether winter heating has substantial effects on air quality level is to consider the daily minimum temperature and air pollutants level. If the effects are significant, we will get the following results: the colder the weather, the higher the air pollutants' level will be after considering other control variables. And we can say that winter heating does have a great impact on air quality level in these cities. We try to build up a simple econometric model to examine this. We include the data of all heating areas listed in the table. We use a simple OLS model just to see the relation between these variables.

The basic methodology is

$$\ln(AQI_{it}) = \alpha + \beta \min temp_{it} + \gamma X_{it} + u_{it} \qquad (2)$$

mintemp is the minimum daily temperature. X_{it} is the control variable including average daily wind speed, maximum daily wind speed, wind direction at maximum daily wind speed(m/s), maximum daily relative humidity, minimum daily humidity, sunshine hours and precipitation. Days of week and month are also included in the control variables. Quadratic terms of these meteorological variables are also included. We omit the indicator variable heating and stress the minimum daily temperature as our

Table 13: Minimum daily temperature and air pollutants level

	ln(pm25)	Ln(pm10)	ln(AQI)	$\ln(SO_2)$	$\ln(NO_2)$	ln(CO)	$\ln(O_3)$	Obs
2015	0018889***	0012397 ***	001838 ***	0026096***	0010802***	0008798***	0013425***	8611
	0001449	0001247		0001585	0000987	0001007	0001089	
2016	001728***	0012967***	0013894***	0022903***	0008526***	0010885***	0014895***	9578
	0001485	0001271	0001132	0001667	0000973	0001095	0001759	
2017	0012***	0008743***	000958***	002392***	0006875***	0008481***	0015922***	9579
	0001335	0001058	0000946	0001261	0000825	0000892	0000799	
2018	0011143***	0008053***	000806***	0007318 ***	0001103	0005735***	0011956***	9415
	0001509	0001287	0001118	0001349	0001014	0001349	0001005	
Overall	0013968***	0013968***	0014291***	0025908***	0008821***	0010087***	0014418***	3718
	0000605	0000605	0000532	0000774	0000464	0000503	0000584	

Statistical significance: * p<0.1 **p<0.05 ***p<0.01

Table 14. Year 2016: By average winter temperature

Group	ln(pm25)	ln(pm10)	ln(AQI)	ln(SO2)	Ln(NO2)	Ln(CO)	Ln(O3)	OBS
I	.4600003 ***	.2625374 ***	.2998621***	.436316 ***	.3227574***	.2780826***	.0369017	1`440
	.0745488	.0653833	.0571576	.0697265	.0701496	.050378	.0551536	
II	.1465075 ***	.213535***	.1808092 ***	.3168856 ***	.0227864	.1125625**	-.0814876	2400
	.0496248	.0443232	.0373542	.0524035	.0453319	.0425835	.1361505	
III	.1842249***	.2291958 ***	.2120198 ***	.5949237	.1881849 ***	.2451483***	-.117536**	2399
	.0665395	.0560389	.0509971	.0855088	.0372659	.0479371	.0560516	
IV	.2401624 ***	.182277 ***	.2003202 ***	.3204206 ***	.2023239***	.2598358***	-.2314623***	2859
	0.000	.0474174	.0423785	.0588094	.0375744	.0425513	.0434371	

Statistical significance: * p<0.1 **p<0.05 ***p<0.01

Table 15:Year 2017 By average winter temperature

Group	ln(pm25)	ln(pm10)	ln(AQI)	$\ln(SO_2)$	$Ln(NO_2)$	Ln(CO)	$Ln(O_3)$	OBS
I	.5416884***	.3354049***	.313466***	.6499211***	.1764009***	.1101177**	.059841	1440
	(0.068763)	(.0557604)	(.0508761)	(.0676721)	(.0537195)	(.0449643)	(.0464957)	
II	.1744047***	.1241293***	.1068305***	.3549782***	.0510317	.1075357***	-.0678201	2160
	(.0634941)	(.0448741)	(.037052)	(.0494578)	(.0391491)	(.0411429)	(.0372179)	
III	.1560668***	.1311119**	.1408444***	.26909***	.0892169**	.1526883***	.0690939	2400
	(.0605333)	(.0516781)	(.0436218)	(.0823031)	(.0369414)	(0.0463137)	(0.0474669)	
IV	.1232101**	.0724796*	.2009224***	.1622219***	.0511519	.0641058	-.0787474**	3099
	(.0523462)	(.0420903)	(.0409851)	(.0469505)	(.0341852)	(.0404652)	(.0367423)	

Statistical significance: * p<0.1 **p<0.05 ***p<0.01

main variable. Control variables remain unchanged. The estimation results are presented in Table 13. We firstly use all the data from 2015 to 2019 to estimate equation (2) and then do the estimation period by period. The data are exactly the same with what we use in our main estimation.

Nearly all the estimation results are negative and statistically significant at the 1% level. We can interpret the coefficient of PM2.5 for 2015 like this: in the winter of 2015, every time when daily minimum temperature drops by 1°C, the concentration level of PM2.5 will increase by 1.9%. It shows a rather obvious potential effects of the daily minimum temperature level on air pollution.

These results could verify the air pollution effects of central winter heating.

6. CHECKS

Here in this part, we are considering an interesting question of whether districts have different characteristics in terms of their heating effects on air pollutants. As we have mentioned, winter average temperatures could possibly reveal the effects of central heating, the cities in higher latitudes would probably have higher winter heating effects because they have burnt more fossil fuels to keep warm in winters. This hypothesis will be verified in the first part. We carry on the same estimation methodology of equation (1) for four districts according to Tables 1 and 2. These four groups of districts are classified based on the average winter temperatures discussed in chapter 3.

We carry on our estimation of equation (1) using the classification in Tables 1 and 2. We want to compare whether heating effects are different when we use the average winter temperatures as our classification criteria.

Generally speaking, the results are easy to interpret. As the winter temperatures for four districts are increasingly higher, the degrees of the effects will be smaller. Higher temperatures indicate weaker degrees of heating and fewer emissions. Overall, group I has always the largest effects for both years. Group IV has relatively the lowest effects for both years.

Counter examples do occur. The degrees of these effects do not always drop. The cities in group I have largest degrees. For cities in group II, III and IV, there are some counter examples. We can partially owe these counter examples to the cities we choose in group II and group III. These two groups include some cities that are located in sparsely populated areas in Northwest China. These cities are populous but scattered. There aren’t so many other big cities surrounding them. We suppose that this character of their locations could give these big cities much advantageous conditions for the diffusion of air pollutants. Cities in group IV are all situated in populous areas in China and their emissions could be influenced by each other. The overall diffusive conditions are worse. Therefore, we can often witness these counter examples when we compare the results for group II and III with group IV.

One possible explanation for these counter examples are the environmental policy effects that are not taken into consideration. There are countless policies put forward by central government, provincial government and municipal government. Although the policy from central government is the same all across the country, the degrees of enforcement are not always the same. As for the provincial and municipal policies, these are different all across different provinces and different cities. Although we have taken meteorological variables as our main control variables, it’s difficult to include these policies into our analysis. One policy has different degrees enforcement and thus have different effects on air pollution abatement. The degree of enforcement is hard to measure. Of course, this can be a very good research idea for the coming papers.

Though these defects exist obviously, the results can still give us a general pattern of the existence of these effects. The higher latitudes the cities have, the higher pollutants level they have (Tables 14 and 15).

7. CONCLUSION

Through main estimation and various robustness and placebo checks, we can draw conclusion that central heating does have a strong impact on the winter air quality in north China. In our main estimation, we find that central winter heating contributes to the growth of all major air pollutants of 17.62% on average between non- and heating seasons considering all important cities in heating areas in north China excluding the effects brought by other natural conditions like weather. For 2016, the number is 18.85%. The growth rate of 2017 and 2018 are 12.36% and 10.81%. The effects have a downward trend from 2015 to 2018 denoting possible effects of environmental protection and pollution abatement policy. We conduct several checks, all of which lead to the same conclusion. The largest effects are mostly on the particulate pollution (PM2.5), SO2 and CO. These three pollutants are considered to be more related to coal burning, which is the main energy for heating in China right now.

In the placebo checks of cities without winter heating in the south, we find that the imaginary heating start day does not generate any differences in air pollutants, showing a good contrast result for the north that areas without winter heating do not have significant distinctions between winter and summer. In the analysis of cities in different temperature zones, cities in higher latitudes tend to have higher air polluting effects as more coal is burnt for heating. For instance, in 2016, the increase of air pollutants level due to winter heating in the coldest areas amounts to 54.2% in terms of PM2.5. Moreover, daily air pollutants' concentration and daily minimum temperatures have negative relationship found in another check. As for the dynamics of these effects, if we compare the results of 2015 to 2019, we have found that the effects are fluctuating a bit but the overall trend is downward, which shows good achievements made by the country's new environmental policies.

All the above evidence shows clearly that winter central heating plays an essential part in pushing up air pollutants level in heating areas. According to the conclusion, we can work out some suggestions by districts for the local governments. Firstly, in order to get a good air quality level in winter, people should still focus on the reduction of the effects of winter heating by reducing the overall burning of fossil fuels, updating the heating technology, changing the heating energy from coal to gas and introducing more renewable and clean heating energy. Secondly, colder places in China should be more aware of the importance of reducing air pollutants through updating heating technologies and energies. Local governments should pay more attention to areas with colder weather conditions. Last but not the least, as meteorological variables have shown good correlation with air pollutants level, the country should construct more reliable forecasting systems for air pollutants' level. Forecasting and warning systems taking care of winter heating conditions are necessarily to be introduced for residents to self-adjust their behaviors during air polluting days. Actually, this is what China is doing right now and it has already achieved good results.

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APPENDIX

Appendix I: Information of Heating Cities

Province name	City	Location*	Start**	End	Average winter temperature***(2016)	Average winter temperature (2017)
Sh0andong	Qingdao	36.03N 120.18E	11.15	04.05	2.8	1.3
	Jinan	36.40N 117.00E	11.15	03.15	3.1	1.3
	Weifang	36.43N 119.06E	11.15	03.15	1.5	0.5
	Yantai	37.32N 121.24E	11.16	03.30	0.9	-1.1
	Rizhao	35.23N 119.32E	11.25	03.25	2.7	1.4
	Taian	36.11N 117.08E	11.15	03.15	2.0	0.2
	Zhangqiu	36.72N 117.53E	11.15	03.15	1.8	0.5
Inner	Baotou	40.58N 110.00E	10.15	04.15	-7.2	-8.8
Mongolia	Hohhot	40.82N 111.65E	10.15	04.15	-6.9	-9.3
Heilongjiang	Harbin	45.80N 126.53E	10.20	04.20	-13.7	-17.7
	Mudanjiang	44.58N 129.60E	10.15	04.15	-12.0	-15.2
	Qiqihar	47.33N 123.95E	10.15	04.15	-14.3	-17.7
Jilin	Changchun	43.90N 125.32E	10.25	04.10	-9.7	-13.4
Beijing	Beijing	39.90N 116.40E	11.15	03.15	0.2	-1.5
Tianjin	Tianjin	39.12N 117.20E	11.15	03.15	0.5	-1.8
Henan	Kaifeng	34.80N 114.30E	11.15	03.15	4.3	2.9
	Anyang	36.10N 114.38E	11.15	03.15	3.1	1.5
	Zhengzhou	34.75N 113.62E	11.15	03.15	4.6	3.2
	Sanmenxia	34.78N 111.20E	11.15	03.15	3.4	1.3
00Hebei	Chengde	40.97N 117.93E	11.01	03.25	-5.2	-7.4
	Zhangjiakou	40.82N 114.88E	11.01	03.31	-5.0	-7.5
	Qinhuangdao	39.93N 119.60E	11.05	04.05	-1.1	-4.9
	Tangshan	39.63N 118.20E	11.15	03.15	-2.2	-4.0
	Xingtai	37.07N 114.48E	11.15	03.15	1.6	0.7
	Langfang	39.52N 116.70E	11.15	03.15	-1.4	-3.6
	Baoding	38.87N 115.47E	10.15	04.15	-0.9	-2.2
Shanxi	Taiyuan	37.87N 112.55E	11.01	03.31	-1.1	-3.3
	Datong	40.08N 113.30E	10.25	04.10	-7.2	-7.3
	Linfen	36.08N 111.52E	11.15	03.15	2.9	0.7
Ningxia	Yinchuan	38.47N 106.28E	11.01	03.31	-2.2	-4.9
Liaoning	Yingkou	40.67N 122.23E	11.01	04.01	-3.9	-6.7
	Anshan	41.10N 122.98E	11.01	03.31	-3.2	-3.6
	Benxi	41.30N 123.77E	11.01	03.31	-6.7	-9.4
	Dandong	40.13N 124.38E	11.01	03.31	-3.9	-6.9
	Shenyang	41.80N 123.43E	11.01	03.31	-7.0	-9.9
Shaanxi	Yan'an	36.60N 109.48E	11.01	03.31	-1.7	-4.6
Jiangsu	Xuzhou	34.27N 117.18E	11.21	03.10	4.2	2.5
Xinjiang	Korla	41.77N 86.15E	11.01	03.31	-3.5	-5.8
	Karamay	45.60N 84.87E	10.15	04.15	-11.1	-13.2
	Urumqi	43.82N 87.62E	10.10	04.10	-6.8	-10.0
Qinghai	Xining	36.62N 101.78E	10.15	04.15	-4.7	-6.7

*The data for locations are available from the website: https://jingwei.supfree.net/

** The starting and ending date are from the city regulations and local news.

***Winter average temperatures are calculated according to the dataset of national meteorological center.