Estimating the Impact of Central Winter Heating on Air Quality in China

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Abstract

We use a difference in difference model to examine the impact of central winter heating on air pollution in China. The estimation includes how does the winter heating affect (i) air quality, and (ii) hazard level of pollutants. Our data are daily Air Quality Index (AQI) records in mid-November when the heat is turned on and mid-March when heat is turned off in over 150 cities. Both Ordinary Least Square (OLS) and Ordered Logit model show that winter heating contributes significantly to air pollution, especially in the period when central heating is switched on. The central heating causes 51.3% higher AQI, and the air is 13% more likely to be hazardous to the sensitive group (hazard level=3). Northern cities are more polluted than southern ones. It is also found that air quality in cities with higher GDP per capita is better; population, number of cars and electricity used by industry also contribute to air pollution.

Key Words: Air pollution, winter heating, Huai-River policy, urban development.

JEL classification: Q53; Q58; R1

Fueled by the large scale of urbanization and industrialization, China has experienced a near 10% average annual growth in the last three decades (Zheng et al. 2014). From 1990 to 2013, the population had increased by 322 million, urban population rate had increased by 26%, and energy consumption per capita had increased by 165%. Accompanying the economy growth, however, is a sacrifice of the environment. Like many other developing countries, China is now faced with serious air pollution. One notorious pollutant is particulate matter. In 2014, the population-weighted average exposure to $PM_{2.5}$ was 52 $\mu g/m^3$ while it was 10.75 $\mu g/m^3$ in the US, 14.82 $\mu g/m^3$ in the euro zone and 31.54 $\mu g/m^3$ in the world (World Bank 2014).

This paper focuses on the relationship between coal consumption and air pollution. The background behind this topic is that in North China, haze has become the most frequent weather in winter. According to the Air Quality Report 2014 (CNEMC 2015), Jing-Jin-Ji area experienced 156 days of poor air quality, and the PM_{10} index was 70$\mu g/m^3$ which is much higher than air quality standard (50$\mu g/m^3$ in 24 hours). In Beijing, air quality in near half a year in 2014 was reported as "unhealthy" (Air Quality Index>150). In some other cities, it was even worse. Haze lasted for more than two-thirds of the year in Xi'an (278 days) as well as Shijiazhuang (323 days). Compared with summer, air pollution is more serious in winter, especially for northern cities; one reason is that the cold weather in winter impedes dissipation of air pollutants, another reason is supposed to be that the central winter heating aggravates air pollution in northern cities.

In many literatures it is found that there is an increasing relationship between greenhouse gas emissions and per capita income (Auffhammer and Carson 2008; Zheng et al. 2011), and this also indicates an increase in the energy consumption and the emission of air pollutants (Ramanathan and Feng 2009). Direct energy consumption can be divided into three sectors, transportation, industrial and residential use. In industrial sector, concentration of industrial activities drive the fast economic growth following with deteriorated environmental quality (Zheng et al. 2014; Cao et al. 2011) ; in transportation sector, car stock and travels promote a concentration of pollution in urban areas (Han and Hayashi 2008; Viard and Fu 2015). It is also found that households use of biomass for cooking also generates indoor pollutant emissions (Malla 2013). China's development relies heavily on energy consumption, coal accounts for up to 70% of the total energy sources, and this is much higher than coal use in developed countries (20%-30%). Coal combustion is considered as one of the most important sources of air pollution (He, Huo and Zhang 2002; Tian et al. 2012) and it contributes as much as 51% to the average $PM_{2.5}$ in the whole country (Hu and Jiang 2013) as well as 16.7% to the PM_{10} concentration (Zheng et al. 2014).

Air pollution has a variety of negative impacts, they are documented in the form of economic cost (Quah and Boon 2003; Wang and Mauzerall 2006), infant mortality (Luechinger 2014; Arceo-Gomez, Hanna and Oliva 2012; Cesur, Tekin and Ulker 2015), health and happiness impact (Mukhopadhyay and Forssell 2005; Matus et al. 2012; Li, Folmer and Xue 2014), etc. Policies have been made in the economic viewpoint such as setting a higher levy rate (Li, Wu and Zhang 2015), moving the dominant energy supply to natural gas, nuclear and renewable energy (van Vliet et al. 2012) etc.

This paper is trying to answer such a question: does the coal-based central winter heating affect local air quality? And different with the impact analysis of air pollution in above literatures, we also use the hazard level[1] to describe the health impact of air quality change caused by winter heating. Every year in China, the winter central heating in North China is turned on around Nov. 15th and keeps running until Mar. 15th in the next year, which forms a large scale increase in the residential coal consumption. Based on this we come up with the hypothesis that the winter heating aggravates the air pollution in urban area. The central winter heating policy has long been considered as a scaled, economical way to warm the air, but few studies focuses on its impact on air quality. Our research will fill this gap.

The rest of this article is organized as follows. The next section provides a brief description of the central heating policy and relative research. The third section introduces the empirical model. The fourth section presents data source and description statistics. The last two sections give results and conclusion. Figures and tables are listed at the end.

The central heating policy

[1] The hazard level standard is defined by EPA (2009) and detailed introduction is proved in section 4.

The central winter heating system was established during 1950-1980, and the heat is provided by state-owned enterprises (Chen et al. 2013), urban areas are supplied with central heating every year, but the heating is not throughout the country. On the issue of central heating, China is divided into two parts by the Qin Mountain-Huai River line, along which the average temperature in winter is 0° Celsius. This division is named "Huai-River Policy". According to the policy, every year from Nov. 15^{th} to Mar. 15^{th} in the next year, hot steam is piped to the households in northern cities and the residents only need to pay a relatively low fee based on the size of their houses (3$/m^2/month). Cities located in southern of Huai River are not provided with central heating.

Figure 1.

Figure 1. shows the geographical division by Huai Policy.

The central heating system is coal-based and technically inefficient. Most heat is provided by coal-fired, heat-only boilers or combined heat generators which are less efficient in energy conversion compared to electric, gas, and oil heating systems (Wang, Lin and Lee 1995). When the heating is switched on, there is a sharp increase in coal combustion and a large amount of Total Suspended Particulates (TSP) as well as nitrogen oxides and sulfur dioxides are released into the air, forming the main components of air pollutants. Researchers in chemical science and environmental economics have consistently agreed that coal combustion can release hazardous air pollutants, especially when the process is insufficient. The incomplete combustion of coal in the boilers causes a release of at least three measured types of air pollutants (Bi et al. 2007). It is widely believed that burning coal generates substantial TSP (Total Suspended Particulars) emissions, SO_2, NO_2, and cause huge air pollution (Muller, Mendelsohn and Nordhaus 2011).

The impact of winter heating has long been overlooked; there is less research focusing on the environmental change caused by the coal-based winter heating system. In recent years, some economists have tried to look into this issue. By analyzing Beijing's haze weather, Ni (2013) figured out that winter heating is one important reason for air pollution. Almond et al. (2009) looked into 1981-1993 China's air pollution data and found that northern cities have relative higher TSP concentration, but the result does not hold for SO_2 and NO_2; the models do not include variables of the city characteristics, which indicates that there may be endogeneity. Chen et al. (2013) studied the mortality data of 1991-2000 in China and found that due to "Huai-river Policy," people in the north bear longer sustained exposure to air pollution and their life expectancies are about 5.5 years lower owing to an increased incidence of cardiorespiratory mortality. At the same time, there is a justifying voice for winter heating policy. Xiao et al. (2015) argue that the central heating system contributes less air pollution compare to other heating activities because central heating is more efficient than family level self-heating; emission control technologies are applied in the central heating system such that there is fewer air pollutants emission than fugitive emissions from individual heating devices.

The purpose of this paper is to use empirical data to test whether China's central winter heating has significant negative effect on the local air quality. We take the Huai-river Policy as a natural experiment and the treatment of central winter heating is only to the cities in the north, dummies are used denoting city's location and heating status. One encouraging development is that since 2011, China Environment Agency established the system to measure $PM_{2.5}$, PM_{10}, O_3, NO_2, NO_2, and CO and monitor centers were established to provide the hourly report of air quality index in most cities, data are more available and more accurate.

Empirical Model

Base on the specialty of our research problem, two dummy variables will be employed in the analysis.

The dependent variable, air quality, is measured by Air Quality Index (AQI) which is an integrated index composed by O_3, SO_2, NO_2, CO, $PM_{2.5}$, and PM_{10}; the higher AQI indicates worse air condition. We also adopt hazard level to estimate the potential health impact of winter heating. The hazard level is ordered, corresponding to AQI and the levels are "good" "moderate" "unhealthy for sensitive people" "unhealthy" and "very unhealthy." By defining the dependent variable in this way, we could get a rough estimation on the health concern caused by central heating. The detailed definition of hazard level is given in the next section.

Our models are

(1) $AQI_{it} = \alpha + \beta X_{it} + \delta Heat_t + \theta North_i + \rho Heat_t * North_i + \gamma_i + \epsilon_t$

(2) $Hazard\ Level_{it} = \alpha + \beta X_{it} + \delta Heat_t + \theta North_i + \rho Heat_t * North_i$

$+\gamma_i + \epsilon_t$

AQI is the Air Quality Index for city i at time t, Hazard Level is the corresponding categories which are defined in Table 1. X are control variables for city i, including GDP per capita, population, number of taxis and buses, green land area etc.. $North$ is a dummy variable indicating whether city i is to the north of Huai River or to the south.

$Heat$ is a dummy variable indicating whether heating is provided, then we have

(3) $Heat_t = \begin{cases} 0 & t = Nov.10 - Nov.14 \\ 1 & t = Nov.15 - Nov.19 \\ 1 & t = Mar.10 - Mar.14 \\ 0 & t = Mar.15 - Mar.19 \end{cases}$

The OLS model can be used as the baseline for the following estimation. We expect that δ, θ and ρ reflect a positive relationship between central winter heating and air pollution indexes.

Regarding using this method, the following assumptions must be specialized.

a. At the cutoff point, there is no other treatment to the cities except for switching on winter heating.

There are three main air pollution sources in China, vehicular emissions, biomass burning and coal combustion (Chan and Yao 2008; Duan and Tan 2013). Here we assume that transportation activities and power plants' production activities do not change in a short time (in this paper, this period is ten days).

b. Cities cannot precisely manipulate the 'assignment variable'.

That is, all the cities in the north of the Qin Mountain-Huai River will be provided with central heating; the only experiment at the cutoff point is central heating being switched on or off. Cities cannot manipulate the time of central heating.

Data Sources and Descriptive Statistics

Data on environmental air pollution in China is relatively scarce compared to developed countries, and data quality is questionable (Zheng and Kahn 2013; Ghanem and Zhang 2014). In this paper, the Air Quality Index and hazardous level daily records are from Ministry of Environmental Protection of the People's Republic of China. In the records, there are 158 cities in the period of beginning of heating in 2014 (5 days before Nov. 15th and 5 days after), and 357 cities in the period at the end of heating in 2015 (5 days before Mar. 15th and 5 days after).

Haze is mainly a term used in weather forecasting, air pollution is measured by the density of $PM_{2.5}$, PM_{10}, SO_2, NO_x, CO, O_3. The standards on air quality levels are slightly different across countries, and in this paper the air quality measurement is Air Quality Index (AQI)[2]. and Levels of Health Concern. Based on the Clean Air Act, EPA calculates AQI with five major air pollutants: particulate matter, carbon monoxide,

[2] We do not talk about how to calculate AQI here in detail but for more information please refer to (USEPA, 2006, 2009). A quick access can also be found at: http://www.iqa.mddefp.gouv.qc.ca/contenu/calcul_en.htm

nitrogen dioxide, sulfur dioxide and ground-level ozone. Relative standard is shown in the following table:

Table 1

Hazard levels are designed according to AQI; higher AQI corresponds to higher hazard level which means the air is more polluted and more harmful to people's health. At "good level", air quality is considered satisfactory, and the pollution has little or no risk. At "moderate" level, air quality is considered acceptable but the pollution may cause health concern for a certain group of people. At "unhealthy for sensitive groups" level, people with lung disease, older adults and children are exposed to greater health risk. At "unhealthy" level, the pollution could do harm to everyone exposed to the air. At "very unhealthy" level, everyone may experience more serious health effects. At "hazardous" level, it would trigger a health warning of emergency conditions. The entire population is more likely to be affected.

City characteristics, including GDP, population, number of buses and taxis, etc. are from the China City Year Book. GDP per capita is exchanged into dollars in the year 2014, variable population only counts the people living in urban area. Given the limited available data, the number of taxis and buses are presented instead of the total number of automobiles. Greenland is the green covered, completed area (1000 hectare). Electricity consumption for industrial use (10^4 GWh), the latitude of the city (north) are also included in the estimation.

Table 2

In the first period, when heating is switched on, the AQI ranges from 13 to 404 with the mean 99.43, standard deviation 47.69 and number of available observations in this period is 1560; in days around the ending of heating, the AQI ranges from 21 to 339, with the mean 92.16, standard deviation 42.74 and number of available observations in this period is 2710. The difference in observation number is due to the newly established monitors in relatively smaller cities. The latitudes of the cities are between N 18.25 and N 50.25. We use data only for 2014-2015 winter because prior 2014 there are no such detailed records available for most cities in China.

Results

We adopt two dependent variables, AQI, which is a continuous variable, and hazard level which is a discrete variable. There are also two periods' data, one observed period is when central winter heating is switched on in the winter, and the other one is the period when heating is switched off in the next spring. With this information, we had both OLS and Ordered Logit for two periods.

Figure 2.

Figure 2. shows that the AQI data distribution is skewed, but the AQI after taking logarithm is more normally distributed, so we will use log_AQI in our OLS models.

Table 3

Table 3 shows the Ordinary Least Square estimation results, column 1 is the result from data in period Nov.10th to Nov. 19th in 2014 (Nov. 15th is the cutoff day when cities in the north of Huai River switch heating on). Column 2 shows estimation using data in the period of Mar.11th to Mar. 20th in 2015 (Mar. 15th is the day when central heating is switched off). We are interested in the coefficients of two dummy variables: north and heat.

In general, the AQI in northern cities is 23.8% higher than those in southern cities, which means cities above Huai River line have heavier air pollution. On a national scale, the AQI increased by 51.3% after the heating is switched on. At the mean, the AQI jumps from 99 to 150 and this indicates a higher level of hazard. Column 2 shows that when the central heating is switched off, the AQI in the southern cities increase by 14.9%, this means the air quality gets worse. This is not quite in our expectation that we assume when heating stops, the air quality should turn better. It might be explained that, although central heating ends and coal burning stops, the existed particulate matter, nitrogen dioxide, sulfur dioxide, etc. are still floating in the air; it is also possible that when the central heating is shut down, residents choose alternative heating resource, i.e. coal stoves and biomass burning, these offset the decrease of pollutants emission from central heating plants. In winter, the wind blows mostly towards the south direction, cities in southern China are prone to be affected by the air pollution in the north part of China.

For other variables, we can read from column 1, an increase in $100 in GDP per capita would introduce 10.8% decrease in the Air Quality Index, which aligns to former findings(Costantini and Monni 2008; Stern and Common 2001). More population, buses and more electricity used for industry generate more air pollution. Per 1000 hectare increase in grassland indicates a decrease of 3.3% in AQI. Cities in higher latitude are more polluted than those in a lower latitude.

Table 4

Table 4 shows the Ordered Logit regression estimation with the discrete variable-hazard level. Column 1 and column 2 reports results for the switching-on period and switching-off period in respect. Corresponding to Air Quality Index, the health hazard is divided into 6 level, good, moderate, unhealthy for sensitive groups, unhealthy, very unhealthy and hazardous, they are given value 1-6. Similar to the OLS model, the Ordered Logit estimation results show that air pollution in the north part of China is relative more hazardous. At hazard level 2, the marginal effect of variable date is 0.558, which means in a city where air pollution hazard level is "moderate," the central heating makes the air 55.8% more likely to become "unhealthy for sensitive groups." And the marginal effect of date dummy at hazard level 3 is 0.273, which means in a city where air pollution hazard level is "unhealthy for sensitive groups," the central heating makes the air 27.3% more likely to become "unhealthy."

Another interesting finding is that in the situation of China, Air Quality Index curve is downward sloping with GDP per capita, as is shown in Figure 3. The left figure is generated using 158 cities' November AQI data and the right one uses records in March, a panel data of 367 cities. Cities with higher GDP per capita enjoy relatively better air quality.

Figure 3.

To check the assumption that before heating the air pollution in northern cities and southern cities are similar, we did a sensitivity check. In this section, we divide the winter period before heating is switched on into two periods, day1-2 and day3-5, which denotes a new dummy variable of date. The regression result using all data before heating is given by column 1 in Table 4. Later we divide five dates in winter after heating is switched on into two periods, day6-8 and day9-10 and generate a new dummy variable, the result is given by column 2.

Table 5

This table shows that in the five days before heating is switched on, the air quality gets even slightly better in later 3 days compared with former 2 days. In the second column, we see that air quality in 4^{th} and 5^{th} days while heating is on is slightly worse than the first 3 days. Compared with the marginal effect we get in Table 3 (0.513), we could conclude that central heating does aggravate air pollution in Northern China.

Conclusion

We study the impact of central winter heating on air quality in China and start a new viewpoint in China's air pollution dynamics. The Huai-River policy is considered as a natural experiment and a difference in difference model is designed in terms of the time difference (heating switches on and off) and geographic difference of cities (north and south). We find that cities located in northern China are more polluted than cities in the south; the central heating causes 51.3% higher AQI in northern cities and in the south air quality also get slightly worse (14.9%) when they come to the heating period. Before heating is switched on, the mean of AQI is slightly below 100, and it indicate that on average the air is moderate to health, heating causes the air to be 13% more likely to be “hazardous to sensitive groups” (hazard level=3). It is also found that cities with higher GDP per capita have less air pollution; population, number of cars and electricity used by industry also contribute to air pollution.

Central heating has a long history with the citizens living to the north of Huai-River, it is cleaner than self-heating provided by coal or wood (which is common in the rural area), and it is much cheaper than air conditioner based heating. For households in the city, warmth generated by the central heating is the same as air conditioning, but they can spend less, such that residents have no incentive to reject central heating. However, cheaper central heating is not necessary cheaper if we add the external social cost of air pollution. Central heating and burning coal, or air conditioning with electricity, which one is more socially cheaper? There might be no exact answer. However, we suggest that cleaner energy should be explored to generate heat for household in northern China, such as solar and cleaner electricity.

As many environment scholars suggest, temperature, mildness, wind direction will all influence the air quality, though we have made the assumption that within observed periods these factors are static, it could be more precise in estimation if we can add them into the model. This is a limitation of this paper; we look for further research on this topic with more precise data and sophisticated methodology.

Reference:

Almond, D., Y. Chen, M. Greenstone, and L. Hongbin. 2009. "Winter Heating or Clean Air? Unintended Impacts of China's Huai River Policy." *American Economic Review* 99 (2): 184–90.

Arceo-Gomez, E., R. Hanna, and P. Oliva. 2012. "Does the Effect of Pollution on Infant Mortality Differ between Developing and Developed Countries? Evidence from Mexico City." *NBER Working Paper* 126(1):1–5.

Auffhammer, M., and R.T. Carson. 2008. "Forecasting the path of China's CO2 emissions using province-level information." *Journal of Environmental Economics and Management* 55(3):229–247.

Bi, X., Y. Feng, J. Wu, Y. Wang, and T. Zhu. 2007. "Source apportionment of PM10 in six cities of northern China." *Atmospheric Environment* 41(5):903–912.

Cao, G.L., X.Y. Zhang, S.L. Gong, X.Q. An, and Y.Q. Wang. 2011. "Emission inventories of primary particles and pollutant gases for China." *Chinese Science Bulletin* 56(8):781–788.

Cesur, R., E. Tekin, and A. Ulker. 2015. "Air pollution and infant mortality: evidence from the expansion of natural gas infrastructure." *The Economic Journal.*

Chan, C.K., and X. Yao. 2008. "Air pollution in mega cities in China." *Atmospheric Environment* 42(1):1–42.

Chen, Y., A. Ebenstein, M. Greenstone, and H. Li. 2013. "Evidence on the Impact of Sustained Exposure to Air Pollution on Life Expectancy from China 's Huai River Policy." *Massachusetts Institute of Technology Department of Economics Working Paper Series* 13(15):1–53.

Costantini, V., and S. Monni. 2007. "Environment , human development and economic growth." *Ecological Economics* 64, no. 4 (2008): 867-880.

Duan, J., and J. Tan. 2013. "Atmospheric heavy metals and Arsenic in China: Situation, sources and control policies." *Atmospheric Environment* 74:93–101.

Ghanem, D., and J. Zhang. 2014. "'Effortless Perfection:' Do Chinese cities manipulate air pollution data?" *Journal of Environmental Economics and Management* 68(2):203–225.

Han, J., and Y. Hayashi. 2008. "Assessment of private car stock and its environmental impacts in China from 2000 to 2020." *Transportation Research Part D:*

Transport and Environment 13(7):471–478.

He, K., H. Huo, and Q. Zhang. 2002. "Urban air pollution in China: Current Status, Characteristics, and Progress." *Annual Review of Energy and the Environment* 27(1):397–431.

Hu, D., and J. Jiang. 2013. "A Study of Smog Issues and PM 2 . 5 Pollutant Control Strategies in China." *Journal of Environmental Protection* 4(July):746–752.

Li, X., X. Wu, and F. Zhang. 2015. "A method for analyzing pollution control policies: Application to SO2 emissions in China." *Energy Economics* 49:451–459.

Li, Z., H. Folmer, and J. Xue. 2014. "To what extent does air pollution affect happiness? The case of the Jinchuan mining area, China." *Ecological Economics* 99:88–99.

Luechinger, S. 2014. "Air pollution and infant mortality: A natural experiment from power plant desulfurization." *Journal of Health Economics* 37(1):219–231.

Malla, S. 2013. "Household energy consumption patterns and its environmental implications: Assessment of energy access and poverty in Nepal." *Energy Policy* 61:990–1002.

Matus, K., K.M. Nam, N.E. Selin, L.N. Lamsal, J.M. Reilly, and S. Paltsev. 2012. "Health damages from air pollution in China." *Global Environmental Change* 22(1):55–66.

Mukhopadhyay, K., and O. Forssell. 2005. "An empirical investigation of air pollution from fossil fuel combustion and its impact on health in India during 1973-1974 to 1996-1997." *Ecological Economics* 55(2):235–250.

Muller, B.N.Z., R. Mendelsohn, and W. Nordhaus. 2011. "American Economic Association Environmental Accounting for Pollution in the United States Economy." *The American Economic Review* 101(5):1649–1675.

Quah, E., and T.L. Boon. 2003. "The economic cost of particulate air pollution on health in Singapore." *Journal of Asian Economics* 14(1):73–90.

Ramanathan, V., and Y. Feng. 2009. "Air pollution, greenhouse gases and climate change: Global and regional perspectives." *Atmospheric Environment* 43(1):37–50.

Stern, D.I., and M.S. Common. 2001. "Is There an Environmental Kuznets Curve for Sulfur?" *Journal of Environmental Economics and Management* 41:162–178.

Tian, H., J. Gao, L. Lu, D. Zhao, K. Cheng, and P. Qiu. 2012. “Temporal trends and spatial variation characteristics of hazardous air pollutant emission inventory from municipal solid waste incineration in China.” *Environmental science & technology* 46(18):10364–71.

Viard, V.B., and S. Fu. 2015. “The effect of Beijing’s driving restrictions on pollution and economic activity.” *Journal of Public Economics* 125:98–115.

van Vliet, O., V. Krey, D. McCollum, S. Pachauri, Y. Nagai, S. Rao, and K. Riahi. 2012. “Synergies in the Asian energy system: Climate change, energy security, energy access and air pollution.” *Energy Economics* 34(SUPPL. 3):S470–S480.

Wang, T.J., R.J. Lin, and L.J. Lee. 1995. “Tool Heat Transfer Analysis in Resin Transfer Molding.” *International Polymer Processing* 10(4):364–373.

Wang, X., and D.L. Mauzerall. 2006. “Evaluating impacts of air pollution in China on public health: Implications for future air pollution and energy policies.” *Atmospheric Environment* 40(9):1706–1721.

Xiao, Q., Z. Ma, S. Li, and Y. Liu. 2015. “The Impact of Winter Heating on Air sPollution in China.” *PLoS ONE* 10(1):e0117311.

Zheng, S., and M.E. Kahn. 2013. “Understanding China’s Urban Pollution Dynamics.” *Journal of Economic Literature* 51(3):731–772.

Zheng, S., C. Sun, Y. Qi, and M.E. Kahn. 2014. “the Evolving Geography of China’S Industrial Production: Implications for Pollution Dynamics and Urban Quality of Life.” *Journal of Economic Surveys* 28(4):709–724.

Zheng, S., R. Wang, E.L. Glaeser, and M.E. Kahn. 2011. “The greenness of China: Household carbon dioxide emissions and urban development.” *Journal of Economic Geography* 11(5):761–792.

Figures and Tables:

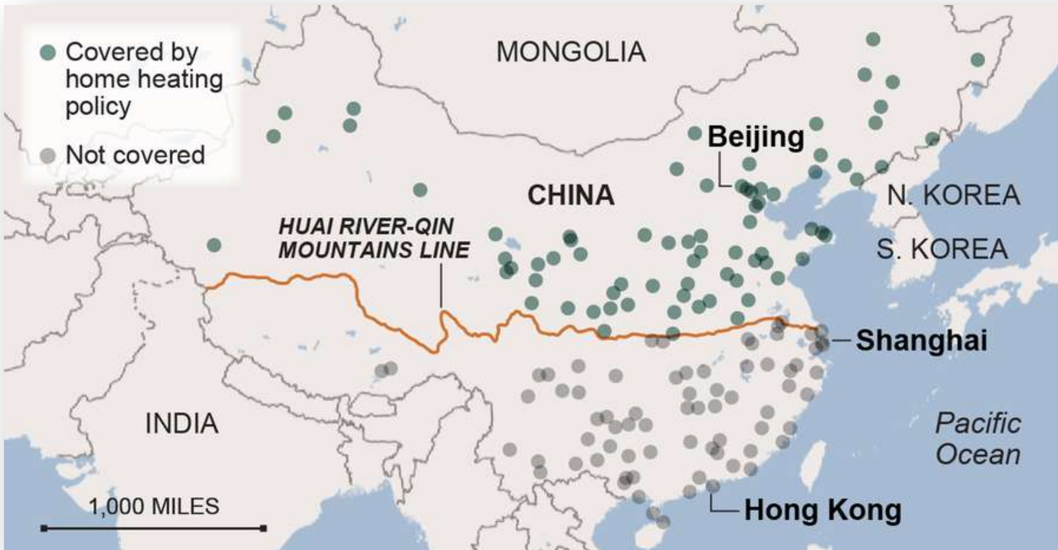

Figure 1. Map of Qin Mountain-Huai River Policy

Note: the orange line named "Huai river-Qin Mountain Line" divides China into two parts; cities located in the north (ex. Beijing) are covered by central heating and southern cities (ex. Shanghai) are not covered

Resource: map box, open street map, 11/2014.

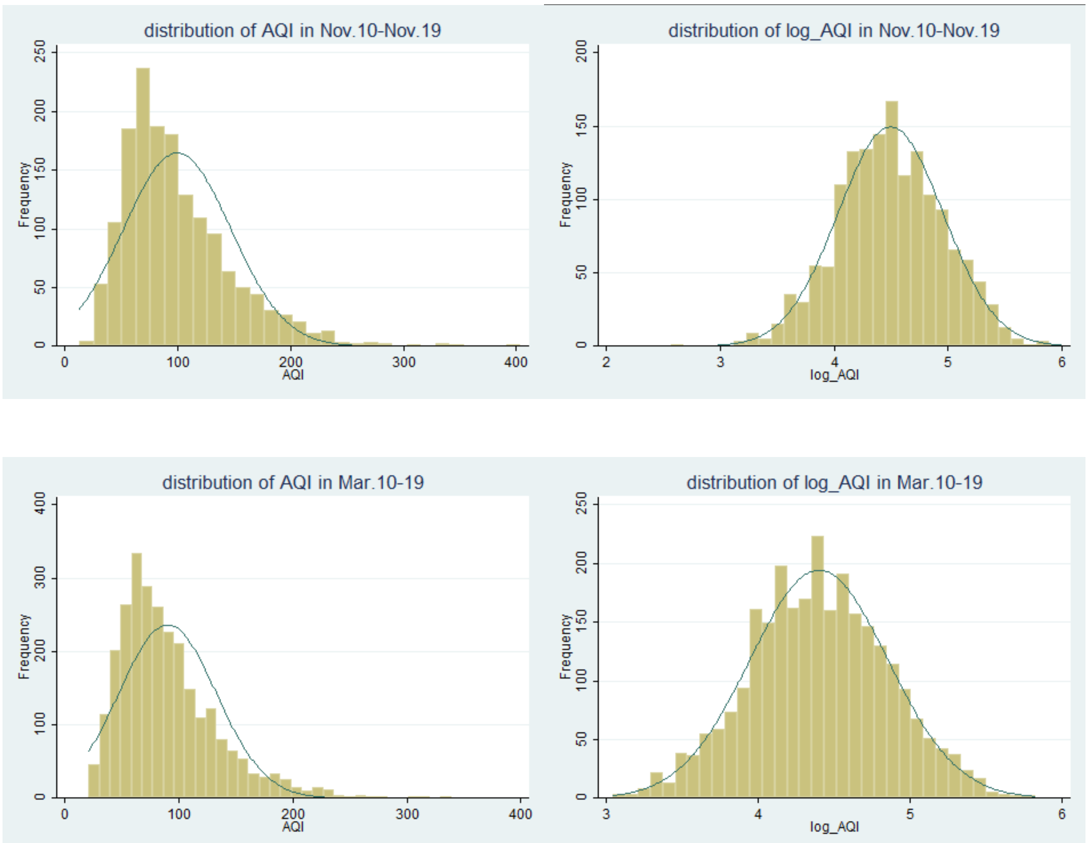

Figure 2. Density plot of Air Quality Index (AQI) and logged AQI in two periods

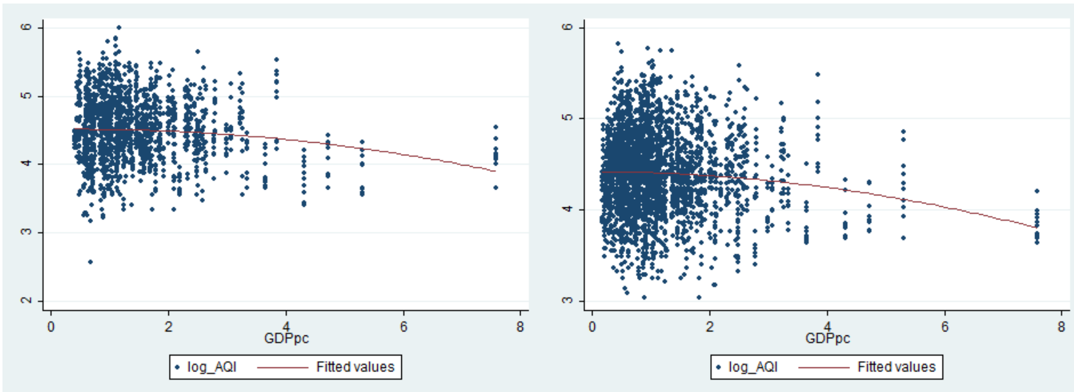

Figure 3. Scatter of GDP per capita and Air Quality Index in Logarithm

Table 1. Air Quality Index and Corresponding Hazardous Level

Air Quality Index (AQI Values)	Levels of Health Concern	Values in Regression
0-50	Good	1
51-100	Moderate	2
101-150	Unhealthy for Sensitive Groups	3
151-200	Unhealthy	4
201-300	Very Unhealthy	5
301-500	Hazardous	6

Table 2. Summary Statistics for Key Variables

Variable	Obs	Mean	Std. Dev.	Min	Max
Air Quality Index[a]	1560	99	48	13	404
Air Quality Index[b]	2708	90.164	42.744	21	339
Pollution level[a]	1560	2.466	0.953	1	6
Pollution level[b]	2708	2.294	0.875	1	6
GDP (million)	2710	20551	40721	443	346691
Population (ten million)	2710	1.455	1.842	0.15	17.87
Industrial enterprises (thousand)	2710	0.559	1.082	0.010	9.642
buses(thousand)	2700	1.48	3.072	0.046	30.590
taxies(thousand)	2710	3.29	6.262	0.125	67.046
green land(thousand hectares)	2710	0.702	1.469	0.003	13.144
Industrial electricity use (10^4 gwh)	2610	0.651	0.962	0.001	7.995
Latitude (North)	2710	33	6.557	18.250	50.250

Notes: For City characteristics, we use only data in 2014, the AQI are collected in two periods. Due to the development of monitor system, the number of observation increases in the second period.

[a] Data are from the period when heating is turned on, i.e. Nov.10-Nov.19 in 2014, and Nov.15 is the cutoff pint when the heat was turned on;

[b] Data are from the period when heating is turned off, i.e. Mar.10-Mar.19 in 2015, and Nov.15 is the cutoff pint when the heat was turned off;

Table 3. OLS Results: Winter Heating Impact on Air Quality (Logged AQI)

	(1) Heat switch-on period (Nov. 10-Nov. 19)	(2) Heat switch-off period (Mar. 10-Mar. 19)
GDP per capita	-0.108***	-0.118***
	(0.160)	(0.138)
Population	0.763***	0.095
	(0.123)	(0.107)
Industry enterprises	0.086***	0.000
	(0.018)	(0.017)
Buses	0.017***	0.019***
	(0.006)	(0.006)
Taxi	-0.024***	-0.007**
	(0.003)	(0.003)
Greenland	-0.033***	-0.019*
	(0.010)	(0.010)
Electricity used by industry	0.024	0.086***
	(0.021)	(0.019)
Latitude	0.012***	0.004**
	(0.003)	(0.002)
South × Heat=1	0.149***	-0.149***
	(0.028)	(0.021)
North × Heat=0	0.238***	0.178***
	(0.043)	(0.030)
North × Heat=1	0.513***	0.248***
	(0.043)	(0.030)
Constant	3.980***	4.254***
	(0.077)	(0.056)
Observations	1460	2588

Note: Standard errors in parentheses = "* $p<0.1$ ** $p<0.05$ *** $p<0.01$"

Table 4. Ordered Logit Results: Winter Heating Impact on Health (Hazard Level)

	(1) Heat switch-on period (Nov. 10-Nov. 19)	(2) Heat switch-off period (Mar. 10-Mar. 19)
GDP per capita	-0.543***	-0.557***
	(0.841)	(0.687)
Population	2.868***	0.348
	(0.582)	(0.541)
Industry enterprises	0.340***	-0.063
	(0.089)	(0.083)
Buses	0.091***	0.078***
	(0.030)	(0.029)
Taxi	-0.105***	-0.027*
	(0.015)	(0.014)
Greenland	-0.147***	-0.055
	(0.050)	(0.049)
Electricity used by industry	0.169*	0.370***
	(0.099)	(0.091)
Latitude	0.058***	0.025***
	(0.014)	(0.009)
South × Heat=1	0.504***	-0.662***
	(0.141)	(0.107)
North × Heat=0	0.919***	0.665***
	(0.215)	(0.140)
North × Heat=1	2.192***	0.928***
	(0.215)	(0.142)
Observations	1460	2588

Note: Standard errors in parentheses= "* p<0.1 ** p<0.05 *** p<0.01"

Table 5. Sensitivity Check at Period When Heat is Switched on

	(1) Nov. 10-Nov. 14	(2) Nov. 15-Nov. 19
	Heat=0	Heat=1
	log_AQI	log_AQI
GDP per capita	-0.109***	-0.107***
	(0.241)	(0.205)
Population	0.961***	0.565***
	(0.185)	(0.158)
Industry enterprises	0.124***	0.047**
	(0.027)	(0.023)
Buses	0.014	0.019**
	(0.009)	(0.008)
Taxi	-0.033***	-0.016***
	(0.005)	(0.004)
Greenland	-0.032**	-0.034**
	(0.015)	(0.013)
Electricity used by industry	0.008	0.040
	(0.031)	(0.026)
Latitude	0.022***	0.001
	(0.004)	(0.003)
North=1	0.191***	0.412***
	(0.056)	(0.048)
Time Dummy	-0.055*	0.046*
	(0.032)	(0.027)
Constant	3.686***	4.417***
	(0.115)	(0.098)
Observations	730	730

Note: Standard errors in parentheses ="* p<0.1 ** p<0.05 *** p<0.01"