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# Winter Heating or Clean Air? Unintended Impacts of China's Huai River Policy

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Air quality in China is notoriously poor. Ambient concentrations of Total Suspended Particulates (TSP) 1981–1993 were more than double China's National Annual Mean Ambient Air Quality Standard of 200 mg/m$^3$ (Xiaohui Bi et al. 2007) and five times the level that prevailed in the United States before passage of the Clean Air Act in 1970. Further, it is frequently claimed that air quality is especially poor in northern Chinese cites. For example, following a career in the southern city of Shanghai, Prime Minister Zhu Rongji quipped: "If I work in your Beijing [in northern China], I would shorten my life at least five years."[1]

This paper assesses the role of a procrustean Chinese policy in generating stark differences in air quality within China. During the 1950–1980 central planning period, the Chinese government established free winter heating of homes and offices as a basic right via the provision of free coal fuel for boilers. The combustion of coal in boilers is associated with the release of air pollutants, especially TSP. Due to budgetary limitations, however, this right was extended only to areas located in northern China. The line formed by the Huai River and Qinling Mountains denotes the border between northern and southern China.

Matching air pollution and weather data for 76 Chinese cities, we find the heating policy led to dramatically higher TSP levels in the north. This result holds both in a cross-sectional regression discontinuity-style estimation approach and in a panel data setting that compares the marginal effect of winter temperature on TSP in northern and southern China, after controlling for all permanent city-level determinants of TSP concentrations and transitory ones common to all Chinese cities. In contrast, we fail to find evidence that the heating policy leads to increases in sulfur dioxide ($SO_2$) and nitrogen oxide ($NO_x$) concentrations.

## I. Brief Background on China's Heating System and Huai River Policy

China's heating system was established during the three decades of the planned regime, 1950–1980. In this period, heating was considered a basic right and the government provided free heating for homes and offices, either directly or through state-owned enterprises. Commercial heating did not arrive in China until the mid-1990s, i.e., after the analysis period. The legacy of this system remains today as many homes and offices continue to receive free heat.

Due to budgetary limitations, the Chinese government limited the heating entitlement to areas located in northern China. The border between northern and southern China is defined by the Huai River and Qinling Mountains. The average January temperature is roughly 0° Celsius along this line.

Northern Chinese cities received free unlimited heating between November 15 and March 15. In contrast, heating was (and largely remains) nonexistent in the south because the government

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[1] "Special Report: A Great Wall of Waste—China's Environment." *The Economist*, August 21, 2004, 55–57.

did not supply a heating infrastructure, nor was there a private sector to supply it until recently. Indeed, it is widely recognized that winters are cold and uncomfortable in cities that are just south of the Huai River, like Nanjing, Shanghai, and Chengdu.

The Chinese heating system is coal-based and technically inefficient. Most heat was and is provided by coal-fired heat-only boilers or combined heat and power generators, which are inefficient in energy usage compared to electric, gas, and oil heating systems in industrial countries (T. J. Wang et al. 2000; Yi Jiang 2007). For a residential building, heat typically comes from a boiler in the building or a separate heating facility; in either case, boilers burn coal to heat water which is sent through iron pipes to each household. In this case, heated water frequently travels long distances before reaching a household, during which there is substantial energy loss.

The incomplete combustion of coal in these boilers leads to the release of at least three measured types of air pollution. There is little doubt that this causes substantial TSP emissions. All coal combustion also produces $SO_2$ and $NO_x$. The amounts produced of these pollutants vary with the kind of coal used, which in turn varies geographically (although we were unable to obtain data on this). Estimates from the mid-1990s suggest that all (i.e., industrial and non-industrial) coal combustion is responsible for 87 percent and 76 percent of $SO_2$ and $NO_x$ emissions, respectively (National Research Council 2004).

This paper's central task is to provide the first systematic documentation of the impacts of China's Huai River Policy on TSP, $SO_2$, and $NO_x$ concentrations.[2] This is done in two ways. First, we test whether concentrations are higher in northern cities, relative to southern ones, after adjustment for a polynomial in latitude. This test is similar to a regression discontinuity approach that has become increasingly popular in recent years (Thomas D. Cook and Donald T. Campbell 1979; Greenstone and Justin Gallagher 2008; Li and Lingsheng Meng 2008). Second, we test whether concentrations are higher in northern cities, relative to their long-run average, after adjustment for realized temperature. This approach takes advantage of the substantial interannual variation in temperature to compare the impact of changes in temperature on ambient pollution concentrations in northern and southern China.

## II. Data Sources and Descriptive Statistics

This paper utilizes two primary datasets. The first is a city-by-year data file that reports annual daily average concentrations of TSP, $SO_2$, and $NO_x$ during the period 1981–1993. The data file is unbalanced and a total of 76 cities have a recorded concentration for at least one pollutant in one year. The data were downloaded from a World Bank Web site and are part of its "Economics of Pollution Control Research" project. The World Bank compiled the 1981–1990 data from the China Environmental Quality Report, produced by the China National Environmental Monitoring Station, dated July 1991; the 1991–1993 data come from the China Environment Yearbooks from China's State Environmental Protection Administration.

The second data file is the average daily temperature reported for each year-month-city triplet. It was collected from the China Meteorological Administration and covers the years 1981–1993, so our analysis will be limited to these years. We calculate a city's winter temperature in a given year as the simple average of the December through February mean temperatures. In 58 cities we can match pollution and weather data for at least one year.

Figure 1 displays the location of each city in our analysis. The Huai River/Qinling Mountains line is the dark line in the figure that divides China into its north and south parts. Although the dividing line ranges between 33.03° and 34.25° latitude, there are not enough cities within this interval to obtain empirically meaningful estimates of the impact of being located north of the line while nonparametrically controlling for latitude.

[2] There is some evidence that this heating policy leads to substantial increases in pollution concentrations during the winter months. Shuxian Fan et al. (2004) show that in Yinchuan, TSP concentrations are significantly higher in the winter than during the rest of the year. In the capital city of Xinjiang, Wulumuqi, 90 percent of the pollutants in the winter are emitted from the heating system (China Xinjiang 2006). Jinhuan Qiu and Liquan Yang (2000) find that visibility in five northern cities in winter was much lower than during the rest of the year between 1980 and 1994.


FIGURE 1. NORTHERN AND SOUTHERN CITIES IN CHINA DIVIDED BY HOME HEATING POLICY

*Source:* Harvard Map Collection, Lamont Library (ESRI ArcGIS 9.3 projection of 58 cities with TSP data)

Table 1 reports summary statistics for some key variables. Most striking are the levels of air pollution concentrations. For comparison, the average US TSP concentration among monitored cities ranged between 100 $mg/m^3$ (1964) and 42 $mg/m^3$ (1993) during the years 1964–1998. Further, the standard deviation of the annual city-specific means ranged between 13 (1992 and 1993) and 61 $mg/m^3$ (1970).[3]

China's mean TSP concentrations over the 1980–1995 period were 538 $mg/m^3$, more than five times US levels *prior* to the Clean Air Act! Further, the standard deviation of the annual city-level means was 330 $mg/m^3$. The mean $SO_2$ concentration in the China data is 109 $mg/m^3$, which is substantially greater than the 1990 US average of 23 $mg/m^3$. The $NO_x$ concentrations are more similar: 40.5 $mg/m^3$ in the US versus 56.5 $mg/m^3$ in China, which may reflect the relatively low levels of motor vehicle usage in China during this period.

It is evident that China provides a unique opportunity to study the impacts of air pollution concentrations on willingness to pay for clean air and human health at pollution levels far exceeding those ever recorded in the US or any other country. The availability of these data is a key ingredient in any such study, but equally important is the identification of

[3] The US TSP calculations are derived from monitor-level TSP data that the authors obtained by filing a Freedom of Information Act request with the EPA (see Kenneth Chay and Greenstone, 2003a, b, and 2005 for further data details).

TABLE 1—SUMMARY STATISTICS FOR KEY VARIABLES

| Variable | Observations | Mean | Standard deviation | Min | Max |
|---|---|---|---|---|---|
| Total suspended particulates (mg/m$^3$) | 399 | 538 | 330 | 80 | 2,770 |
| Sulfur dioxide (mg/m$^3$) | 449 | 109 | 82.2 | 2 | 520 |
| Nitrogen oxides (mg/m$^3$) | 401 | 56.5 | 24.6 | 7 | 164 |
| Winter temperature (°F) | 455 | 32.6 | 14.0 | −1.6 | 66.6 |
| Year | 455 | 1987 | 3.90 | 1981 | 1993 |
| Latitude (° North) | 455 | 35.0 | 6.35 | 20.1 | 47.3 |
| 1 (North of Huai River) | 455 | 0.613 | 0.488 | 0 | 1 |

*Notes:* The entries are calculated across all nonmissing city observations during the 1980–1993 period. The data file is unbalanced and a total of 76 cities have a recorded concentration for at least one pollutant in one year. Fifty-eight cities have at least one year of nonmissing total suspended particulates data. The same 58 cities have at least one year of nonmissing sulfur dioxide data. A total of 41 cities have nonmissing nitrogen oxides data.

plausibly exogenous variation in air pollution. The remainder of the paper explores whether China's Huai River policy provides variation in air pollution at these extraordinary concentrations.

## III. Econometric Strategy

This section describes the two econometric models used to examine the impact of the Huai River policy on air pollution concentrations. Model 1 is:

$$(1)\quad TSP_{ct} = \alpha + \beta\, 1(North)_c + \pi f(Latitude)_c + \mu_t + \varepsilon_{ct},$$

where $c$ references a city and $t$ indexes a year. The dependent variable is the average daily TSP concentration in a city by year. (We also estimate models for $SO_2$ and $NO_x$ concentrations.) The outcome is adjusted for a polynomial of degrees latitude, which flexibly adjusts for the association between this variable and air pollution concentrations (e.g. due to temperature, topography, hours of daylight, etc.). Additionally, the model includes year fixed effects, $\mu_t$, to capture the influence of the business cycle in the unbalanced panel.

The parameter of interest is $\beta$, the coefficient on the indicator variable $1(North)_c$: whether the city lies above or below the Huai River line. It assesses whether pollution concentrations are higher in northern cities, after flexibly adjusting for their latitude and the year fixed effects. To the extent that unobserved determinants of air pollution concentrations in northern cities (permanent or transitory) change discretely at the Huai River line, estimates of the heating policy's impact obtained from Model 1 will be biased.

Therefore, we also estimate the following equation, which we refer to as Model 2:

$$(2)\quad TSP_{ct} = \alpha + \rho\ Winter\ Temperature_{ct} + \lambda\,[Winter\ Temperature_{ct} \times 1(North)_c] + \delta_c + \mu_t + \varepsilon_{ct}.$$

This equation adjusts for the realized winter temperature and city fixed effects, $\delta_c$, as well as unrestricted year effects. Importantly, the city fixed effects remove permanent differences in air pollution concentrations across cities, and thereby address a limitation of Model 1.

The parameter of interest is $\lambda$. It captures the marginal effect of winter temperature on TSP in the north, as distinct from the relationship between temperature and TSP in the south (after adjustment for the city and year fixed effects). Due to the Huai River/Qinling Mountains–based heating policy, northern households can respond to cold temperatures by altering their consumption of heat derived from coal-based sources. Southern households typically do not have this opportunity. Consequently, $\lambda$ provides a second test for this policy's negative externalities, measured by air quality.

## IV. Results

Figure 2 previews the Model 1 TSP results visually. It plots the bivariate relationship

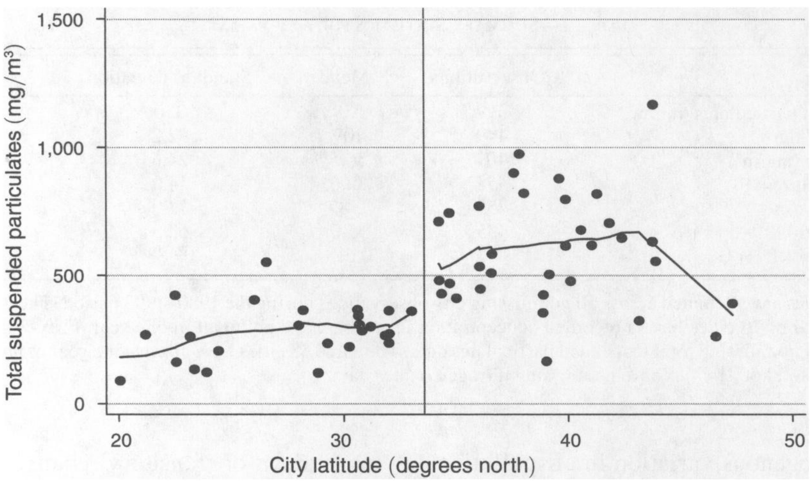


FIGURE 2. MEAN TOTAL SUSPENDED PARTICULATE CONCENTRATION FROM 1980-1993 BY CITY LATITUDE

*Note:* The vertical line is drawn at 33.6°, which is in the middle of the latitude range covered by the Huai River/Qinling Mountains line.

between a city's average TSP concentration calculated for all available years from 1981 to 1993 and latitude. The fitted values come from nonparametric regressions using William S. Cleveland's (1979) tricube weighting function and a bandwidth of 0.5, estimated separately for cities on either side of the Huai River/Qinling Mountains line. Thus, they represent a moving average of the TSP concentration across latitude. The data points represent each city's mean TSP concentration.

The figure presents dramatic evidence that northern cities have higher TSP concentrations. An especially convincing feature of the graph is the evidence of a discontinuous increase in TSP concentrations at latitudes just above the Huai River line. This jump is meaningful, because it seems improbable that other determinants of air pollution change as discretely to the north of the line as the heating policy.

We begin by focusing on the Model 1 TSP results, which are in the first three columns of the top panel of Table 2. The column 1 specification controls for latitude. Column 2 adds the square of latitude as a covariate and column 3 adds a cubic term to the column 2 specification. The striking finding from columns 1 and 2 is that annual average TSP concentrations are roughly 300 mg/m$^3$ higher in northern cities. To put this in perspective, this statistically significant difference is more than three times the concentration of TSP that prevailed in the United States before the passage of the Clean Air Act in 1970.[4] In the richer, but possibly overparameterized column 3 specification, the difference declines to about 200 mg/m$^3$ but would still be judged to be statistically different from zero at conventional levels.

The Model 1 $SO_2$ and $NO_x$ results generally indicate higher concentrations in northern cities. However, they are poorly determined and none of them would be judged to be statistically significant at conventional levels.

We also conducted a falsification exercise based on the location of the Yangtze River. In particular, we designated all cities to the north of this river as northern cities and classified the others as southern cities. Since there is not a heating policy based on the Yangtze River, the null hypothesis is that pollution concentrations are equal to the north and south of the river. Indeed, fitting a version of Model 1 that utilizes theses Yangtze-based designations fails to find evidence of higher TSP concentrations to the north of the Yangtze River. Similarly, we cannot reject the null that $SO_2$ and $NO_x$ concentrations are equal in the north and south of the Yangtze (results available upon request).

[4] In results available upon request, adjustment for longitude does not substantially affect the estimates of $\beta$.

TABLE 2—ESTIMATED IMPACTS OF HUAI RIVER/QINLING MOUNTAINS POLICY ON AIR POLLUTION CONCENTRATIONS

| | Total suspended particulates | | | Sulfur dioxide | | | Nitrogen oxides | | |
|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| *Model 1* | | | | | | | | | |
| 1(North) | 318*** | 312*** | 204*** | 37.1 | 33.3 | 29.4 | 10.1 | 8.55 | −4.40 |
| | [96.2] | [80.4] | [96.5] | [33.0] | [32.3] | [48.3] | [10.4] | [10.1] | [12.0] |
| Observations | 399 | 399 | 399 | 449 | 449 | 449 | 401 | 401 | 401 |
| $R^2$ | 0.44 | 0.44 | 0.47 | 0.00 | 0.01 | 0.01 | 0.08 | 0.08 | 0.08 |
| Latitude | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| Latitude squared | No | Yes | Yes | No | Yes | Yes | No | Yes | Yes |
| Latitude cubed | No | No | Yes | No | No | Yes | No | No | Yes |
| Year fixed effects | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes |
| *Model 2* | | | | | | | | | |
| Winter temperature | −2.78 | 6.53 | | −0.50 | −0.64 | | −1.28* | −0.91* | |
| | [5.78] | [4.69] | | [0.91] | [0.63] | | [0.71] | [0.45] | |
| 1(North) × winter temperature | | −24.05** | | | 0.35 | | | −0.97 | |
| | | [10.10] | | | [1.77] | | | [0.87] | |
| Observations | 399 | 399 | | 449 | 449 | | 401 | 401 | |
| $R^2$ | 0.63 | 0.64 | | 0.86 | 0.86 | | 0.58 | 0.58 | |
| City fixed effect | Yes | Yes | | Yes | Yes | | Yes | Yes | |
| Year fixed effect | Yes | Yes | | Yes | Yes | | Yes | Yes | |

*Notes:* The table reports estimation results from fitting versions of equations (1) and (2). In addition to some regression statistics, the table reports key parameter estimates and estimated standard errors below, in brackets. The standard errors are clustered at the city level. See the text for further details.

***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

The lower panel presents the results from two versions of Model 2. We first focus on the TSP results. The column 1 specification simply includes the main effect for winter temperature. The point estimate indicates that across the entire sample there is little evidence of a relationship between winter temperature deviations and annual TSP concentrations.

The column 2 specification adds the interaction between winter temperature and an indicator for the city being north of the heating line. The estimate indicates that a 1°F decrease in the *winter* temperature is associated with a 24 mg/m$^3$ increase in the *annual* mean daily TSP concentration in northern cities, relative to southern ones. This effect is also enormous relative to current US TSP levels, especially because the temperature variable is calculated during three months but the TSP concentration is calculated over 12 months. Indeed, the estimate implies that a 1°F decrease in the winter temperature is associated with an increase in winter TSP concentrations of roughly 100 mg/m$^3$ (again in the north, relative to the effect in the south).

Model 2 again fails to find evidence that the heating policy affects $SO_2$ and $NO_x$ concentrations. This finding that the heating policy does not have a detectable impact on $SO_2$ and $NO_x$ concentrations is unexpected in light of the TSP results. In the absence of city-level inventories of emissions sources, it is unclear whether this finding casts doubt on the validity of the TSP findings. Thus, at this point, we simply note the absence of an association between the policy and concentrations of these pollutants.

## V. Discussion and Future Directions

Using a unique data file on air pollution concentration in 76 Chinese cities, this paper has documented a systematic relationship between the TSP concentrations and the Huai River/

Qinling Mountains heating policy. We conclude that Chinese heating policy led to higher pollution concentrations in northern China. This result holds in a cross-sectional regression discontinuity-style estimation approach and in a panel data setting that compares the impact of changes in temperature on ambient TSP concentrations in northern and southern cities. In contrast, there is little evidence that the heating policy leads to increases in $SO_2$ and $NO_x$ concentrations.

More broadly, this paper has uncovered a source of variation in air pollution that can be used to study the impacts of air quality on human health and individuals' valuations of clean air at pollution concentrations far above those ever recorded in the US or any other country. Extrapolation from US-based studies suggests that the costs of these levels of TSP are substantial in terms of human health and welfare more generally (Chay and Greenstone 2003a, b, and 2005; Chay, Carlos Dobkin, and Greenstone 2003). However, the relatively low levels of air pollution and high incomes in the US mean that extrapolation is unlikely to be valid. An important direction for future research is to assess these costs in China.

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