

# Winter Heating or Clean Air?

## Unintended Impacts of China's Huai River Policy

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### Abstract

This paper examines the impact of prenatal exposure to total suspended particulates (TSP) on birth weight. We exploit variation in coal use patterns in China induced by government regulations that provided free home heating north of the Huai River. We demonstrate that cities north of the Huai River have persistently higher TSP levels, and the difference is most severe during cold winters. By exploiting within-city variation in weather over time, we find that average birth weight is 14 grams lower for each additional  $100 \mu\text{g}/\text{m}^3$  of prenatal TSP exposure. We also find that the impact is largest among births already at risk of being low birth weight, such as births to lower educated mothers and births in the bottom quartile of the birth weight distribution.

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# 1 Introduction

Air quality in China is notoriously poor. Ambient concentrations of Total Suspended Particulates (TSP) from 1981-1993 were more than double China's National Annual Mean Ambient Air Quality Standard of  $200 \mu\text{g}/\text{m}^3$  (Bi et al. 2007) and five times the level that prevailed in the US before the passage of the Clean Air Act in 1970. Furthermore, air quality is especially poor in northern China, which is home to several of the world's most polluted cities (World Bank 2007). Following a career in the southern China city of Shanghai, Prime Minister Zhu Rongji reportedly quipped in 1999: "If I work in your Beijing [located in northern China], I would shorten my life at least five years" (The Economist 2004).

This paper assesses the role of a seemingly arbitrary Chinese policy in producing dramatic differences in air quality within China, and resulting differences in health outcomes. During the 1950-1980 period of central planning, the Chinese government established free winter heating of homes and offices via the provision of free coal for fuel boilers as a basic right. The combustion of coal in boilers is associated with the release of air pollutants, and in particular, the discharge of fine particulate matter that can be extremely harmful to human health. These particles, which are small enough to penetrate deeper into the lungs than other pollutants, are primarily associated with the combustion of fossil fuels, such as coal. Due to budgetary limitations, however, this right to home heating was only extended to areas located in northern China, which is defined by the line formed by the Huai River and Qinling mountain range (see Figure 1). As we will demonstrate, the particulate levels in cities north of the line are significantly higher than in cities south of the line, a difference which persisted for several decades – and continues to be relevant today.

China provides a useful context in which to examine the relationship between air quality and human health outcomes for several reasons. First, China's air is extremely polluted and there is dramatic regional variation in this pollution. Regional variation in TSP levels in China is partly due to the aforementioned home heating policy, and partly due to meteorological factors that make northern China more vulnerable to high TSP levels, holding emissions constant (World Bank 2007). Second, for the period in question, mobility was extremely restricted in China, and

so for our sample most individuals will be observed where they lived, and it will be a location pre-determined by household registration – overcoming a limitation present in many studies of the effects of air quality on health outcomes, where selective migration may lead to biased estimates. Third, China’s problems with air pollution in the 1970s encouraged policymakers to establish monitoring stations throughout the country, and as a result we are able to construct a rich data set of air quality readings from cities in China from 1981-1991. During this period, we also have access to monthly temperature readings, and so are able to exploit within-city variation in air quality driven by weather (and the policy) to assess the impact of the policy on both ambient air quality and infant health outcomes. Therefore, data availability makes China a suitable context for analyzing the role of air pollution on infant health outcomes, and the role of the policy in explaining regional variation in infant health outcomes in China.

As demonstrated by Almond et al. (2009), we find that the winter heating policy led to dramatically higher TSP levels in northern China.<sup>1</sup> We demonstrate this in a cross-sectional regression discontinuity-style estimation approach, where we exploit the home heating policy and the difference in coal use just north of the line formed by the Huai River and Qinling Mountains. We also demonstrate that this result holds in a panel data setting, where we compare 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. As a result of the large first-stage impact of the home heating policy on TSP levels, we examine the role of the policy on infant health outcomes. Our focus is on infant outcomes since the exposure window for an infant is observable and narrow, thereby allowing for better measurement of pollution exposure and allowing us to take full advantage of inter-annual variation in pollution due to the home heating policy. We analyze a matched sample of births and recorded air quality using a survey of children conducted by UNICEF in 1992. The UNICEF survey provides detailed information on the characteristics particular to parents that could affect birth weight (e.g. income)

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<sup>1</sup>Almond et al. (2009) examine data for all cities with air quality monitoring stations in China between 1981-1993 and demonstrate the impact of the policy on TSP levels, but fail to find an impact of the policy on sulphur dioxide or nitrous oxide levels. In this paper, we examine the health consequences of the TSP variation associated with the policy, and focus on a sample of cities between 1981-1991 where birth outcomes and pollution readings are available.

and also provides information on the over 26,000 births that occurred in cities covered by China's National Air Quality Monitoring system. We are able to exploit the impact of the policy on within-city variation in TSP levels over time to identify a causal link between ambient air quality and birth weight.

Our examination reveals a large impact of China's high TSP levels on average birth weight. As a baseline estimate, we find using OLS that an additional  $100 \mu\text{g}/\text{m}^3$  of TSP in a child's year of birth reduces birth weight by 8-9 grams. Using 2SLS exploiting the Huai River instrument and the severity of winter during a woman's pregnancy, we estimate that an additional  $100 \mu\text{g}/\text{m}^3$  is associated with a reduction in average birth weight of 14 grams. We also find that the impact is largest among births already at risk of being low birth weight, with the largest impacts found for lower educated mothers and among births in the bottom quartile of the birth weight distribution. Based on our estimates that the Huai River policy induced nearly a  $500 \mu\text{g}/\text{m}^3$  increase in ambient TSP levels for births occurring in cities just north of the boundary, this would suggest a 70 gram decrease in average birth weight. As a baseline, heavy smoking during pregnancy is thought to reduce birth weight by roughly 300 grams (Evans and Ringel 1997; Wilcox 1993). In combination, these estimates imply that China's coal use and the associated particulate matter is imposing a cost on human health from ambient inhalation that is nearly a quarter as large as if a pregnant woman had smoked heavily instead. Our results are robust to several specification checks and falsification exercises, including 2SLS results using a regression-discontinuity approach and falsification exercises with alternative policy borders, such as the Yangtze river.

The paper is organized as follows. In the next section, we present background on China's air quality and the link between the home heating policy and increased air pollution north of the Huai River. The third section presents the data and descriptive statistics on which our analysis is based. The fourth section demonstrates our econometric strategy. The fifth section reports our results. We conclude in section 6.

## **2 China's Heating System and the Huai River Policy**

China's heating system was established during the three decades of the planned regime (1950-1980). During this period, heating was provided to residents at no cost by the government via state-owned enterprises (SOEs). The state continued to provide free heating systems for residential and office buildings until 1998, and commercialized heating did not appear until the mid-1990s. Due to budgetary concerns, however, the Chinese government was forced to limit the free home heating policy to northern areas. Northern China is designated by a border formed by the Huai River and Qinling Mountains. Cities north of this border receive unlimited free heating between November 15 and March 15. In contrast, heating has been largely non-existent in southern China due to the lack of government-supplied heating facilities. A private sector for heating has appeared only recently. Indeed, it is widely recognized that winters are cold and uncomfortable in cities that are just south of the Huai River, such as Nanjing, Shanghai, and Chengdu.

The Chinese heating system is coal-based and technically inefficient. It uses either coal-fired heat-only boilers or combined heat and power generators, both of which are inefficient compared to the electric, gas and oil heating systems used in many industrial countries (Wang et al. 2000; Jiang 2007). Heat for a residential building typically comes from a coal-burning boiler located either in the same building or in a heating factory. Heated water is sent to each household through iron pipes, often traveling long distances and losing significant energy along the way, requiring the burning of more coal. Adding to the inefficiency of the system is the lack of proper pricing mechanisms. Although many urban residents in northern China have started to pay for heating, they do so through a single lump sum payment, and no meter system exists to measure the amount of heat used by a household. With an inefficient heating system, harsh winters in northern areas, and continued robust economic growth, it is no surprise that China consumes 39% of the world's coal (British Petroleum 2009). This coal use has had severe consequences for ambient air quality.

Coal consumption is associated with the emission of soot, the particulate matter that enters the environment when coal is burned. The incomplete combustion of coal in these boilers leads to

the release of air pollutants. There is little doubt that this causes substantial particle emissions, and large differences during the sample period are observed between northern and southern China. The disparity in the level of total suspended particulates (TSP) is particularly large during the winter months. Fan et al. (2004), Bi et al. (2007), and He et al. (2001) show that in cities across northern China, TSP concentrations are significantly higher in the winter than the rest of the year. In the capital city of Xinjiang, Wulumuqi province, 90% of pollutants in winter months are emitted by the heating system (Tianshan 2006). Qiu and Yang (2000) find that, for 1980-1994, visibility in five northern cities was much lower in winter than throughout the rest of the year.

We examine the impact of China's Huai River policy on air pollution concentrations using two econometric strategies. First, we test whether concentrations are higher in northern cities relative to southern ones, after adjustment for a polynomial in latitude. This test has some similarities with a regression discontinuity-style approach that has become increasingly popular in recent years (Cook and Campbell 1979; Greenstone and Gallagher 2008; Almond et al. 2008). Second, we test whether concentrations are higher in northern cities, relative to their long run average, after adjustment for the realized temperature in year. This approach takes advantage of the substantial inter-annual variation in temperature to compare ambient concentrations in northern and southern cities in years where the ambient temperatures are similar. We then proceed to exploit this plausibly exogenous variation in air quality to estimate the impact of air pollution on birth weight.

### **3 Data Sources and Descriptive Statistics**

This paper utilizes three primary data sets. Air quality data is compiled from China's national monitoring system, which reports the recorded annual daily average concentration of TSP for the cities in our sample for 1981-1991. The second data source necessary for the analysis is monthly average temperature data, which is available for each city in which we have air quality monitor data. These data are collected by the China Meteorological Administration and allow us to calculate for each city the average winter temperature, which we define as the average temperature for

November-February. Our third data set is a large sample of births that overlap with our air quality readings. We focus on the UNICEF fertility survey of 1992, which is among the largest surveys of child welfare ever conducted in China, and provides detailed information on both births and features of the mother and household. The air quality and weather data are matched to the survey, and each reported birth is assigned the TSP and winter temperature experienced during the woman's pregnancy, given as  $TSP_{jt} = ATSP_{jt-1}(1 - W_{jt}) + ATSP_{jt}W_{jt}$ . This is necessary because TSP is only available annually, and we are interested in the pre-natal exposure to air pollution.

Table 1 reports summary statistics for the matched sample of births and TSP measures, which consists of births between 1981 and 1991 where air quality monitoring readings are available. The most striking result is the average level of TSP's observed for the period. We report that the average birth in our sample is assigned a TSP  $\mu\text{g}/\text{m}^3$  of 715. While TSP readings were high in northern China, the readings were quite high during this period even in the south, which averaged 325 TSP  $\mu\text{g}/\text{m}^3$ . For comparison, prior to the Clean Air Act in the United States, the average TSP recorded was 100  $\mu\text{g}/\text{m}^3$  (1964) among monitored cities and US standards<sup>2</sup> require cities to have concentrations below 75  $\mu\text{g}/\text{m}^3$  (US Environmental Protection Agency<sup>3</sup>). As another point of reference, many observers worried about Beijing's air quality for the Olympic Games on the basis of the city's poor environmental record in recent years. Between 1981 and 2003, however, Beijing's TSP levels had declined from 1,100 to 252  $\mu\text{g}/\text{m}^3$  – meaning that for the sample of births we observe, particulate matter was roughly 4 times higher than *today's* levels. The atrocious environmental record for China during this window provides an interesting context in which to examine the health consequences of air pollution using some of the highest recorded pollution readings in history (World Bank 2007).

Our focus is on how birth outcomes respond to air quality. For each birth in the sample, we observe the mother's age, education, and household income, the sex of the birth, and importantly, the temperature during the winter months overlapping with the pregnancy. The table reflects that

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<sup>2</sup>The US standard was changed in 1987 to regulate particulate matter that was smaller than 10 microns ( $\text{PM}_{10}$ ), and again in 1997 to regulate particulate matter that is smaller than 2.5 microns ( $\text{PM}_{2.5}$ ). The 75  $\mu\text{g}/\text{m}^3$  is the most recent available US TSP standard.

<sup>3</sup>[http://www.epa.gov/ttn/catc/cica/airq\\_e.html#3](http://www.epa.gov/ttn/catc/cica/airq_e.html#3)

the average southern birth was exposed to monthly temperatures averaging 47<sup>0</sup>F, whereas northern births were exposed to more extreme conditions, with the average birth being exposed to a monthly temperature of 28<sup>0</sup>F, below freezing and a temperature that would induce extensive coal use. Since we are interested in exploiting the Huai River Policy's effect on coal use, we consider samples that are increasingly close to the border, which lies at roughly 33<sup>0</sup> latitude. While the overall sample contains 24,088 births, in the sample restricted to births very close to the border (between 30<sup>0</sup> and 35<sup>0</sup>), we have only 6,466 births – but for those births, the policy presumably has the most relevance and our identification strategy is most compelling. In the next section, we examine how recorded TSP readings change near the Huai river, and how the responsiveness of TSP to winter temperature is different on either side of the river at these extraordinary TSP concentrations.

## 4 Impact of the Huai River Policy and Winter Temperature on TSP Levels

One method for examining the impact of the home heating policy on TSP is to exploit the discontinuity in the cost of coal for home heating at the river and the impact on TSP levels by estimating

$$TSP_{ijt} = \alpha_0 + \alpha_1 N_j + f(L_j) + X_{ijt}\Gamma + \gamma_t + \epsilon_{ijt} \quad (1)$$

where  $TSP_{ijt}$  is the total suspended particulates in city  $j$  in year  $t$  experienced by fetus  $i$ .  $N_j$  is a "North" dummy indicating whether city  $j$  is north of the Huai river,  $f(L_j)$  is a polynomial function of the latitude of city  $j$ ,  $X_{ijt}$  is a vector of the observable characteristics of the birth that might influence birth weight other than air quality (e.g. parental income),  $\gamma_t$  is a set of year fixed effects, and  $\epsilon_{ijt}$  is a disturbance term. Under the assumption that a city's TSP reading would be a smooth function of latitude if not for the home heating policy, the North dummy identifies the causal effect of being north of the river on TSP levels. In this circumstance, the impact of the policy would be identified by  $N_j$ , and  $N_j$  would represent an instrument for air quality that could be used to

estimate the impact of air quality on other outcomes, such as birth weight. In fact, air quality does rise discontinuously near the Huai river, and persistent differences are observed between cities north and south of the border, and in particular, in places near the river.

Figure 2 previews these results visually. It plots the bivariate relation between the average TSP concentration observed in a particular city and its latitude. The plots are done separately for cities to the North and South of the Huai River/Qinling Mountains line and come from the estimation of nonparametric regressions that use Cleveland’s (1979) tricube weighting function and a bandwidth of 0.5. 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 upon crossing this line as does the heating policy.

As shown in panel 1 of Table 2, in the overall sample the North dummy is estimated to be associated with 534  $\mu\text{g}/\text{m}^3$  increase in TSP. In restricted samples closer to the Huai river, the result is somewhat larger: when the sample is restricted to births between 28<sup>o</sup> and 40<sup>o</sup> latitude, the impact of being above the Huai is a 715  $\mu\text{g}/\text{m}^3$  increase in TSP. This is compelling evidence that the rule affected TSP concentrations, but for inference regarding infant outcomes, we focus on a strategy in which we account for time-invariant factors that might be particular to a city. It also may be that observables change near the border, making the quasi-regression discontinuity strategy inappropriate for inference regarding infant outcomes and air quality.

Our main identification strategy exploits both the discontinuity at the river and within-city (across-year) variation in the severity of a winter. Specifically, we estimate the following equation:

$$TSP_{ijt} = \delta_0 + \delta_1 T_{jt} + \delta_2 N_j T_{jt} + X_{ijt} \Gamma + \mu_j + \gamma_t + \epsilon_{ijt} \quad (2)$$

where  $T_{jt}$  refers to the average temperature during winter months in city  $j$  in year  $t$ ,  $\mu_j$  is a set of city fixed effects, and  $N_j T_{jt}$  is a variable that takes on the value zero for all southern cities, and takes on the value of  $T_{jt}$  for northern cities. Under the assumption that in the absence of the

home heating policy, TSP levels would not be differentially responsive to temperature north and south of the Huai river, we can identify the causal impact of temperature variation on air pollution by this interaction term. This strategy can also be thought of as a "differences in differences" approach, since we anticipate that air pollution will be worse in cold winters both above and below the Huai river, but the impact will be larger above the Huai river. Since the models include city fixed effects, we are essentially comparing the differential influence of the within-city change in weather on pollution across the river. We expect that a colder (relative to a city's own average) winter will pollute a northern city more than a southern city because of the policy and the low price of coal-driven indoor heating. In Figure 3, we present a visual preview of our identification strategy, and plot the bivariate relation between TSP and winter temperature, separately for births occurring north and south of the Huai river. The plot reflects that the gradient between winter temperature and TSP levels is noticeably steeper in northern China than southern China. This plot is very similar in spirit to our main identification strategy in which we exploit within-city variation in temperature.

As reported in panel 2 of Table 2, the impact of winter temperature on TSP readings in northern cities is large. Each additional degree of winter temperature in northern China lowers the observed TSP by  $73 \mu\text{g}/\text{m}^3$ , and this estimate is significant at the 1% level. In the samples of births closer to the Huai river, we observe a similar effect; for births between  $28^\circ$  and  $40^\circ$  latitude, each additional degree of winter temperature lowers the TSP by  $98 \mu\text{g}/\text{m}^3$ . For births very close to the river (between  $30^\circ$  and  $35^\circ$  latitude), we estimate that each degree lowers TSP by  $49 \mu\text{g}/\text{m}^3$ , but the estimate is only statistically significant at the 10% level due to the small sample size. Note that this result is found even after including city, year, and month fixed effects. Provided that cold winters do not differentially affect other factors that would affect birth weight between north and south, this provides a valid instrument for the TSP in utero experienced by the fetus. While it is straightforward to demonstrate that the instrument is essentially randomly assigned in the sense that parents who have children in cold winters are similar to parents who have children in other

winters<sup>4</sup>, we are also interested in evaluating whether the relationship between winter temperature and birth weight we observe is in fact driven by air pollution, or potentially by other factors that would violate the exclusion restriction. We will further examine challenges to our identification assumption in the next section.

## 5 Empirical Results on TSP and Birth Weight

### 5.1 OLS

In Table 3, we present the results of OLS models of the impact of air quality on infant outcomes. These models are of the form:

$$BW_{ijt} = \beta_0 + \beta_1 TSP_{ijt} + X_{ijt}\Gamma + \mu_j + \gamma_t + \epsilon_{ijt} \quad (3)$$

where infant  $i$ 's birth weight is modeled as a function of pre-natal exposure to particulates  $TSP_{ijt}$ , the covariates of the family  $X_{ijt}$ , and fixed effects to account for variation in birth weight particular to city  $j$  and year  $t$ . In column 1, we present a baseline calculation where we regress birth weight on TSP, and fail to account for time-invariant features of the city or measures of family resources (e.g. household income). Not surprisingly, these results are very noisy and are wrong-signed - the coefficient indicates that air pollution raises birth weight, but it is not statistically significant. We present in columns 2-4 richer models in which we add control variables that can allow us to more narrowly focus on the relationship of air quality and birth weight. The results in column 2, which include city fixed effects, indicate that an additional 100  $\mu\text{g}/\text{m}^3$  of measured TSP is associated with an 8.58 gram reduction in birth weight, which is statistically significant at the 1% level. In column 3, we include additional controls for the month of an infant's birth, and find that the result is largely unchanged – an additional 100  $\mu\text{g}/\text{m}^3$  of measured TSP is associated with an 8.52 gram reduction in birth weight. In column 4, we present results which include a rich set of controls,

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<sup>4</sup>In results available upon request, we find that our instrument (winter temperature in the north) is not correlated with observable features of our infant sample, such as mother's education, or household income.

including the sex of the infant, the mother’s age, household income, mother’s education, and find the results are only changed slightly: an additional  $100 \mu\text{g}/\text{m}^3$  of measured TSP is associated with an 8.52 gram reduction in birth weight, which is statistically significant at the 1% level. In column 4, we augment the set of controls to include the winter temperature assigned to the birth, and find a very similar result - that an additional  $100 \mu\text{g}/\text{m}^3$  of measured TSP is associated with an 7.96 gram reduction in birth weight. These results are actually quite similar to other estimates for China, such as Wang et al. (1997) who found a 6.9 gram reduction in birth weight in a sample of mothers in several neighborhoods in Beijing. These results, however, are subject to the normal caveats with OLS models. It may be that TSP variation within a city across time is associated with other confounding factors that may either improve or worsen infant health outcomes. We proceed with our IV models which attempt to address the potential endogeneity of TSP exploiting the Huai River Policy and plausibly exogenous variation due to within-city variation in temperature over time.

## 5.2 Reduced Form

This paper’s main identification strategy relies on inter-annual variation in temperature to identify the relationship between TSP and birth weight. In Table 4, we present the results of the reduced form relationship between the instrument for air quality and birth weight. These models are of the form:

$$BW_{ijt} = \phi_0 + \phi_1 T_{jt} + \phi_2 N_j T_{jt} + X_{ijt} \Gamma + \mu_j + \gamma_t + \epsilon_{ijt} \quad (4)$$

where we are interested in the coefficient on the interaction between the winter temperature and the dummy for North of the Huai. A graphical (and simplified) version of this regression is presented in Figure 4, where we regress birth weight directly on temperature and control for year and city fixed effects, as well as demographic controls. The figure reflects that extremely cold winters are associated with lower birth weights. We proceed in Table 4 with more rigorous analysis, which exploits the North-South comparison. As shown in column 1, in the overall sample, births north of the Huai river in cold winters have lower birth weights. Specifically, an additional  $1^\circ$  increase in

temperature is associated with a 10.5 gram increase in recorded birth weight, which is statistically significant at the 10% level. These models include a rich set of controls for the features of the parents as well as city and year fixed effects. Note that the other coefficients reflect that birth weight is correlated with other measures of wellbeing and resources. Birth weights are higher for older mothers, higher income families, and for mothers with more education. In columns 2-5, we report the results of the same regressions in samples increasingly close to the Huai river border. Among births between 28° and 40° latitude, the impact of an additional degree is to increase the birth weight by 18.99 grams, which is statistically significant at the 1% level. The results in the sample very close to the river, where we include only births between 30° and 35°, indicate that a 1° increase in temperature north of the Huai is associated with a 19.6 gram increase in birth weight, but this is not statistically significant due to the smaller sample size and larger standard error of the estimate.

### 5.3 2SLS

In Table 5, we present the 2SLS estimates of the impact of TSP on birth weight using the interaction of winter temperature and a North dummy as an instrument for TSP levels.

$$BW_{ijt} = \beta_0 + \beta_1 \widehat{TSP}_{ijt} + X_{ijt}\Gamma + \mu_j + \gamma_t + \epsilon_{ijt} \quad (5)$$

where  $\widehat{TSP}_{ijt}$  is the fitted value for TSP following from our first stage reported in panel 2 of Table 2. In column 1 we report the 2SLS results for the overall sample, and we estimate that a 100  $\mu\text{g}/\text{m}^3$  increase in TSP is associated with a 14.3 gram decline in birth weight, statistically significant at the 5%. Relative to the OLS estimate of 7.96 grams, and this indicates that 2SLS produces coefficients that are nearly twice as large. In samples closer to the river, the point estimates are even larger. As shown in column 2, among births between 28° and 40° latitude, an additional 100  $\mu\text{g}/\text{m}^3$  of TSP reduces birth weight by 20.5 grams. For births within the narrow range of 30° and 35°, the coefficient indicates that a 100  $\mu\text{g}/\text{m}^3$  increase reduces birth weight by 39.9 grams, but this

is measured imprecisely and is not statistically significant. These results are compelling evidence that the Huai river policy is adversely affecting birth outcomes. Our results are identified off variation in air quality due to the steeper TSP-temperature gradient observed in northern China, and indicate that infants born following severe winters have lower birth weight. We explore in the next section the robustness of our main result to alternative specifications, and subject our empirical strategy to a set of falsification exercises.

#### **5.4 Robustness Checks and Falsification Exercises**

In Table 6, we present a set of robustness checks and falsification exercises with respect to the use of temperature and the Huai river policy as an instrument for TSP levels. In row 1, we report the result for a baseline first stage and 2SLS estimate from Table 2 and 4, which reflect that an additional degree of temperature in the North reduces TSP by  $73 \mu\text{g}/\text{m}^3$ , and that an additional 100 units of TSP lower birth weight by 14.3 grams. A potential challenge to our identification strategy is that our result is missing the potential impact of it being very cold indoors in the South since the policy affected not only ambient air quality but also people's access to sufficient indoor heating, implying a violation of the exclusion restriction. As an attempt to rule out this effect, we include controls (row b) for whether the average monthly temperature in the winter was below  $40^\circ\text{F}$ , and the interaction of this dummy for extreme weather with the North dummy. We continue to include in this specification all the regressors from our baseline, including a main effect for winter temperature. If temperature only affects infant health in extreme conditions, but TSP rises linearly with the use of coal, this specification should allow us to control for the direct impact of very cold weather in either the North or South on birth weight that is separate from the impact of TSPs, which are also affected by extreme temperature. The results are very similar to our baseline results but with slightly larger point estimates for 2SLS (14.3 versus 16.6). As a second robustness check, we include instead a full set of controls for the temperature in non-winter months (March-October) and this variable interacted with the North dummy. The result is very similar to the base case result (14.3 versus 15.0), and provides further support for the claim our identification is being

driven by responsiveness to cold winters, rather than the variation in temperature for the other months.

In panel 3, we present the results from a set of falsification exercises to further explore the Huai river instrument's validity and our empirical results. In a first specification, we examine whether other demarcations in China have relevance for air quality. We examine whether a first stage and statistically significant 2SLS result exists for a set of alternative demarcations. Using a 25<sup>0</sup> border, a 40<sup>0</sup> border, or a Yangtze border, we find that none of these are able to produce a statistically significant first stage and 2SLS result.<sup>5</sup> This is compelling evidence that the air pollution induced by the coal policy associated with the Huai River-Qingling Mountains border is in fact responsible for the results in our main sample. In our last robustness check, we assess whether air quality affects post-natal birth weight. Note that in our regressions, our measure of TSP is a weighted average of air quality for each birth. As a falsification exercise, we examine whether post-natal air quality has a statistically significant relationship with birth weight. This is actually a high-powered falsification exercise, because these measures are correlated, since our TSP measures are annual and many births will have highly correlated natal- and post-natal TSP readings. However, the result shows that TSP in the post-natal window is much more weakly correlated with the birth weight, indicating that TSP levels are affecting birth weights.

In Table 7, we report the 2SLS estimates for the impact of air quality using the quasi-regression discontinuity strategy. The results reflect that areas just north of the Huai river have higher infant mortality. In the overall sample, we estimate that an additional 100  $\mu\text{g}/\text{m}^3$  of TSP are associated with a reduction of 7.4 grams in average birth weight. In the sample near the Huai river, however, we estimate that an additional 100  $\mu\text{g}/\text{m}^3$  of TSP reduce birth weight by 17.8 grams. In these specifications we do not include city fixed effects, however, and the models do not fit as tightly, yielding larger standard errors. While the Huai river discontinuity strategy may be slightly weakened by permanent factors specific to a city that affect infant outcomes, it is compelling that the 2SLS estimate produced using the border are roughly similar to our main results.

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<sup>5</sup>The Yangtze falsification is composed of all observations south of the Yangtze, and north of the Yangtze but south of the Huai.

## 5.5 Heterogeneity

In Table 8, we examine the heterogeneity in the impact of air pollution on birth weight. In panel 1, we stratify the sample of births by the mother's education level. Among mothers in the bottom third of the distribution (primary education or less), we estimate using 2SLS that an additional  $100 \mu\text{g}/\text{m}^3$  of TSP lowers birth weight by 36 grams, more than twice as large as our overall effect. In contrast, among mothers with an intermediate level of education (junior high) or in the highest category (high school and beyond) we find that an additional  $100 \mu\text{g}/\text{m}^3$  of TSP lowers birth weight by 11 grams, and these results are not statistically significant. In panel 2, we present an alternative strategy in which we stratify our sample into low, medium, and high birth weight births. Among births with low birth weight (less than 3,000 grams) we find that an additional  $100 \mu\text{g}/\text{m}^3$  of TSP lowers birth weight by 18 grams, statistically significant at the 1% level. In contrast, for births in the intermediate category (3,000-3,500 grams) or in the highest category ( $>3,500$  grams) we estimate smaller coefficients (-.02) and (-.10) and these estimates are not statistically significant. This indicates that births that are at risk of being low birth weight are most affected by air pollution. In panel 3, we present a final examination of the heterogeneity of the effect by considering how TSP affects the chance a birth has either very low birth weight ( $<2,750$  grams), low birth weight ( $<3,000$  grams), or below median birth weight ( $<3,250$  grams). The outcome variable in these regressions is a binary for whether the birth weight was lower than the specified level, and the results reflect that exposure to air pollution has the greatest impact at the tail of the distribution. We estimate that an additional  $100 \mu\text{g}/\text{m}^3$  of TSP increases the probability of the birth having a very low birth weight by 8%, significant at the 5% level. In contrast, the impact of TSP is negligible at affecting the chance of a birth being in the bottom quarter or below the median birth weight.

These results have important implications for the expected health consequences of our estimate of the average impact of TSP on birth weight. Since air quality appears to affect those of lower means (education) and those births which are already at risk of being low birth weight, the health consequences of the pollution are likely to be large since these parents are less able to cope with a more vulnerable infant. The fact that the impact is largest in inducing birth weights in the

bottom 10% of the distribution suggests that infants exposed to China's air pollution might have significantly lower endowments of health at birth. In light of evidence of non-linear impacts of birth weight on health outcomes, where large benefits are observed from avoiding births with very low birth weight (Behrman and Rosenzweig 2004), this amplifies the relevance of our estimate of the effect on average birth weight. Future research should examine how these adverse outcomes affect infant health later in life using our instrument and the plausibly exogenous variation in birth weight it induces, in light of the academic debate over the relevance of birth weight in causing adult health problems (Almond, Chay, and Lee 2005; Black 2007). Our identification strategy also provides variation in birth weight that could be used to examine how parents respond to a negative health "shock". It is an open research question whether parents compensate or reinforce the endowment associated with a birth outcome, and our analysis presents novel variation in birth weight (endowment) that could, in combination with measures of parental investment, shed light on this question that has drawn attention from recent research (e.g. Rosenzweig and Zhang 2009).

## **6 Conclusions**

This paper examines the impact of neonatal exposure to total suspended particulates (TSPs) on birth weight using the extraordinary levels of ambient particulate matter observed in Chinese cities during the 1980s. Using a unique data file on air pollution concentration in cities across China, this paper has demonstrated that the Huai River-Qinling Mountains heating policy leads to dramatically higher TSP levels in northern China. This result holds in a cross-sectional regression discontinuity-style estimation approach and in a panel data setting that compares pollution concentrations in northern and southern cities in years when they have similar winter temperatures. In a matched sample of births and TSP readings, we have demonstrated that these high levels of particulate matter are leading to lower birth weights in China, and that children who had the misfortune of being in utero during a harsh winter are suffering the consequences of China's extensive coal use. In combination with the large body of evidence demonstrating that lower birth weight may lead

to serious health problems later in life, this suggests that the health consequences of China's air pollution are being felt by the most vulnerable population. The health consequences of China's high TSP levels on infant outcomes and the potential enduring impact may help explain why life expectancy in China has not risen more quickly, in spite of the country's rapid economic progress.

This paper has documented severe consequences to the air pollution in China due to the extensive use of coal for energy. Coal remains China's primary energy source, and it remains a national challenge to switch to cleaner forms of energy in light of the large economic costs of doing so. In this paper, we demonstrate the health consequences associated with the choice of coal, and hope to provide further support for those who are encouraging China to invest in cleaner energy. We have shown birth weights are highly responsive to particulate matter at the high levels observed in China, and the results further bolster the case for stronger environmental regulation in China as the country grapples with its environmental problems. While China's State Environmental Protection Agency (SEPA) has gained clout in recent years, and air quality in China improved markedly during the 1990s, there are still challenges in China's political arena in dealing seriously with the environmental consequences of the country's economic growth – and China remains home to many of the world's dirtiest cities. Our results represent further evidence supporting the call to enforce tougher environmental standards in China, and establish regulations that will encourage individuals and firms to adopt alternative sources of energy.

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**Table 1**

Sample Means among Births in Air Quality and Natality Sample (1981-1991)

Statistic	North	South	Differences
	(1)	(2)	(3)
Total Suspended Particulates ( $\mu\text{g}/\text{m}^3$ )	714.6	324.7	389.87***
Birth weight (grams)	3,286	3,192	93.25***
Sex (Male=1)	0.52	0.52	0.01
Mother's Age	33.29	33.36	-0.07
Log of Household Income	7.07	7.21	-0.14***
Mother's Years of Education	8.98	8.83	0.16***
Latitude	39.59	29.56	10.03***
Year of Birth	1985.63	1985.66	-0.04
Month of Birth	6.21	6.00	0.21***
Winter Temperature ( $^{\circ}\text{F}$ )	27.57	47.16	-19.59
Sample Sizes			Total
Births between 23 $^{\circ}$ - 47 $^{\circ}$ (ALL)	17,592	6,496	24,088
Births between 27 $^{\circ}$ - 42 $^{\circ}$	13,722	5,387	19,109
Births between 28 $^{\circ}$ - 40 $^{\circ}$	12,070	5,387	17,457
Births between 29 $^{\circ}$ - 37 $^{\circ}$	2,576	4,934	7,510
Births between 30 $^{\circ}$ - 35 $^{\circ}$	1,540	4,926	6,466

*Source* : China Environmental Yearbooks (1982-1992), China Meteorological Administration (1981-1991), United Nations International Children's Fund (UNICEF) Fertility Survey (1992)

*Note* : The sample is all births in cities where air quality data is available from China's Air Quality Monitoring Sites, and infant outcome data is available from the UNICEF fertility survey. China is divided into North and South by a line formed by the Huai River and Qingling mountain range (approximately 33 $^{\circ}$  latitude). Winter temperature is the average monthly temperature recorded for November, December, January, and February. The TSP level for each birth is calculated as the weighted average of the annual TSP reading for year of the child's birth and the preceding birth, with the weights determined by birth month.

**Table 2****Estimated Effect of Home Heating Policy on Total Suspended Particulates (TSP)**

	(1)	(2)	(3)	(4)	(5)
Geographic Sample	All	27° - 42°	28° - 40°	29° - 37°	30° - 35°
Panel 1: Quasi Regression Discontinuity using North-South Border					
1(North)	533.5*** (112.20)	597.6*** (134.00)	714.9*** (238.20)	424.60 (300.70)	324.20 (409.90)
Cubic Latitude	Y	Y	Y	Y	Y
Demographic Controls	Y	Y	Y	Y	0
Year FE	Y	Y	Y	Y	Y
Month FE	Y	Y	Y	Y	Y
City FE	N	N	N	N	N
R Squared	0.52	0.59	0.60	0.67	0.68
N	22,164	17,231	15,579	6,937	5,893
Panel 2: City Fixed Effects Strategy exploiting North-South Border and Severity of Winter					
1(North) *Winter	-73.43*** (22.60)	-93.73*** (22.68)	-98.03*** (24.59)	-53.98** (22.52)	-49.04* (23.54)
Temperature (°F)					
Demographic Controls	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y
Month FE	Y	Y	Y	Y	Y
City FE	Y	Y	Y	Y	Y
R Squared	0.76	0.79	0.80	0.81	0.81
N	22,164	17,231	15,579	6,937	5,893

\* significant at 10% \*\* significant at 5%. \*\*\* significant at 1%.

*Source* : China Environmental Yearbooks (1982-1992), China Meteorological Administration (1981-1991), United Nations International Children's Fund (UNICEF) Fertility Survey (1992)

*Note* : The dependent variable in each regression is the Total Suspended Particulates assigned to the birth, as described in Table 1. The variable "1(North)" is a dummy for whether the birth occurred in a city covered by the home heating policy, which is all cities north of the line formed by the Huai River and Qingling mountain range (approximately 33° latitude). The final four specifications restrict the sample to births occurring between the listed latitude range. Winter temperature is the average monthly temperature recorded for November, December, January, and February. All models in panel 2 include a control for the winter temperature in the city and year. The demographic controls are listed in Table 1.

**Table 3**

OLS Models of the Effect of Total Suspended Particulates (TSP) on Birth Weight (grams)

	(1)	(2)	(3)	(4)
TSP ( $\mu\text{g}/\text{m}^3$ )	0.012 (0.03)	-0.0858*** (0.02)	-0.0852*** (0.02)	-0.0796*** (0.02)
Demographic Controls	N	N	N	Y
Year FE	Y	Y	Y	Y
Month FE	N	N	Y	Y
City FE	N	Y	Y	Y
R Squared	0.004	0.027	0.028	0.048
N	24,088	24,088	24,088	22,208

\* significant at 10% \*\* significant at 5%. \*\*\* significant at 1%.

*Source* : China Environmental Yearbooks (1982-1992), China Meteorological Administration (1981-1991), United Nations International Children's Fund (UNICEF) Fertility Survey (1992).

*Note* : The dependent variable in each regression is the birth weight recorded for the birth. The sample is all births in cities where air quality data is available, and infant outcome data is available from the UNICEF fertility survey. Temperature is the average temperature in the winter months overlapping with the mother's pregnancy. The TSP level for each birth is calculated as the weighted average of the annual TSP reading for year of the child's birth and the preceding birth, with the weights determined by birth month. The demographic controls are mother's age, education, household income, and the sex of the child. Standard errors are robust and clustered at the city level.

**Table 4**

Reduced Form Models of the Effect of Winter Temperature (°F) Interacted with North of the Huai on Birth Weight (grams)

	(1)	(2)	(3)	(4)	(5)
Geographic Sample	All	27°- 42°	28°- 40°	29°- 37°	30°- 35°
1(North) *Winter Temperature (°F)	10.51* (6.24)	18.99*** (6.67)	20.08** (7.54)	25.64** (10.11)	19.56 (14.38)
Demographic Controls	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y
Month FE	Y	Y	Y	Y	Y
City FE	Y	Y	Y	Y	Y
R Squared	0.047	0.046	0.046	0.052	0.041
N	22,208	17,231	15,579	6,937	5,893

\* significant at 10% \*\* significant at 5%. \*\*\* significant at 1%.

*Source* : China Meteorological Administration (1981-1991), United Nations International Children's Fund (UNICEF) Fertility Survey (1992)

*Note*: The dependent variable in each regression is the birth weight recorded for the birth. The sample is all births in cities where air quality data is available, and infant outcome data is available from the UNICEF fertility survey (1992). The demographic controls are mother's age, education, household income, and the sex of the child. A main effect for temperature is also included. Standard errors are robust and clustered at the city level.

**Table 5**

2SLS Models of the Effect of Total Suspended Particulates (TSP) on Birth Weight (grams) using Winter Temperature ( $^{\circ}$ F) Interacted with North as an Instrument for TSP

	(1)	(2)	(3)	(4)	(5)
Geographic Sample	All	27 $^{\circ}$ - 42 $^{\circ}$	28 $^{\circ}$ - 40 $^{\circ}$	29 $^{\circ}$ - 37 $^{\circ}$	30 $^{\circ}$ - 35 $^{\circ}$
TSP ( $\mu$ g/m $^3$ )	-0.143**	-0.203***	-0.205***	-0.475	-0.399
	(0.07)	(0.07)	(0.07)	(0.33)	(0.45)
Demographic Controls	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y
Month FE	Y	Y	Y	Y	Y
City FE	Y	Y	Y	Y	Y
R Squared	0.047	0.045	0.045	0.036	0.031
N	22,208	17,231	15,579	6,937	5,893

\* significant at 10% \*\* significant at 5%. \*\*\* significant at 1%.

*Source* : China Environmental Yearbooks (1982-1992), China Meteorological Administration (1981-1991), United Nations International Children's Fund (UNICEF) Fertility Survey (1992)

*Note*: The dependent variable in each regression is the birth weight recorded for the birth. The sample is all births in cities where air quality data is available, and infant outcome data is available from the UNICEF fertility survey (1992). The results of the first stage are reported in Panel 2 of Table 3. The demographic controls are mother's age, education, household income, and the sex of the child. A main effect for temperature is also included. Standard errors are robust and clustered at the city level.

**Table 6**

Robustness Checks and Falsification Exercises: 2SLS Models of the Effect of Total Suspended Particulates (TSP) on Birth Weight (grams)

	First Stage: TSP=f(North x Temp)	2SLS: Birthweight=f(Fitted TSP)
	(1)	(2)
Panel 1: Actual Sample		
(a) Huai River Instrument (base case)	-73.43*** (22.60)	-0.143** (0.07)
Panel 2: Robustness Checks using Additional Weather Controls		
(b) Add Extreme Weather Controls	-73.87*** (22.95)	-0.166** (0.07)
(c) Add Summer Temperature Controls	-74.11*** (18.10)	-0.150** (0.07)
Panel 3: Falsification Tests		
(d) 25° Latitude	-27.35 (17.81)	0.158 (0.23)
(e) 40° Latitude	-19.66 (21.53)	0.18 (0.41)
(f) Yangtze River	15.45 (12.6)	-2.132 (1.58)
(g) Post-Natal TSP	-98.46** (41.45)	-0.095 (0.06)

\* significant at 10% \*\* significant at 5%. \*\*\* significant at 1%.

*Source* : China Environmental Yearbooks (1982-1992), China Meteorological Administration (1981-1991), United Nations International Children's Fund (UNICEF) Fertility Survey (1992)

*Note* : Each cell in the table represents the coefficient from a separate regression. In the first column, the dependent variable in each regression is TSP and the regression coefficient is reported for the interaction term of the winter temperature and the policy. In the second column, the regressor shown is the 2SLS coefficient estimate for TSP, using the instrument from column 1. In the first panel, the regression for the full actual sample is reported. In the second row, dummies are added for the winter being colder than 40°, and this dummy interacted with being north of the Huai river. In the third row, a term is added for the average temperature in the city in summer (March-October) months interacted with a north dummy. In the third panel, falsification exercises are presented. The first and second rows present results where the policy is presumed to have been instituted along the border defined by 25° and 40° latitude respectively. The third specification presumes the policy was instituted along the Yangtze river. The last specification uses post-natal TSP as the RHS variable instead of pre-natal TSP.

**Table 7**

2LS Models of the Effect of Total Suspended Particulates (TSP) on Birth Weight (grams) using North of the Huai as an Instrument for TSP

	(1)	(2)	(3)	(4)	(5)
Geographic Sample	All	27°- 42°	28°- 40°	29°- 37°	30°- 35°
TSP ( $\mu\text{g}/\text{m}^3$ )	-0.074 (0.10)	-0.116 (0.08)	-0.060 (0.09)	-0.892 (0.58)	-0.178 (0.48)
Cubic in Latitude	Y	Y	Y	Y	Y
Demographic Controls	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y
Month FE	Y	Y	Y	Y	Y
City FE	N	N	N	N	N
R Squared	0.029	0.031	0.033	N/A	0.03
N	22,164	17,231	15,579	6,937	5,893

\* significant at 10% \*\* significant at 5%. \*\*\* significant at 1%.

*Source* : China Environmental Yearbooks (1982-1992), United Nations International Children's Fund (UNICEF) Fertility Survey (1992)

*Note* : The dependent variable in each regression is the Total Suspended Particulates assigned to the birth, as described in Table 1. The variable "1(North)" is a dummy for whether the birth occurred in a city covered by the home heating policy, which is all cities north of the line formed by the Huai River and Qingling mountain range (approximately 33° latitude). The final four specifications restrict the sample to births occurring between the listed latitude range. The demographic controls are listed in Table 1.

**Table 8****Heterogeneity in the Impact of Total Suspended Particulates on Birth Weight**

	(1)	(2)	(3)
<b>Panel 1: Impact of TSP on Mean Birth Weight for Subsets of Mothers by Education</b>			
	Low Education	Middle Education	Upper Education
TSP ( $\mu\text{g}/\text{m}^3$ )	-0.355** (0.14)	-0.107 (0.10)	-0.108 (0.15)
N	2,878	9,618	9,799
<b>Panel 2: Impact of TSP on Mean Birth Weight for Subsets of the Birth Weight Distribution</b>			
	Births less than 3,000g	Births between 3,000g and 3,500g	Births 3,500g and above
TSP ( $\mu\text{g}/\text{m}^3$ )	-0.182*** (0.07)	-0.0173 (0.02)	-0.099 (0.07)
N	7,247	7,267	7,781
<b>Panel 3: Impact of TSP on Probability of having Birth Weight below a Percentile</b>			
	In Bottom 10%	In Bottom 25%	Below Median
TSP ( $\mu\text{g}/\text{m}^3$ )	0.0799** (0.03)	-0.013 (0.08)	0.062 (0.09)
N	22,295	22,295	22,295

\* significant at 10% \*\* significant at 5%. \*\*\* significant at 1%.

*Source* : China Environmental Yearbooks (1982-1992), China Meteorological Administration (1981-1991), United Nations International Children's Fund (UNICEF) Fertility Survey (1992)

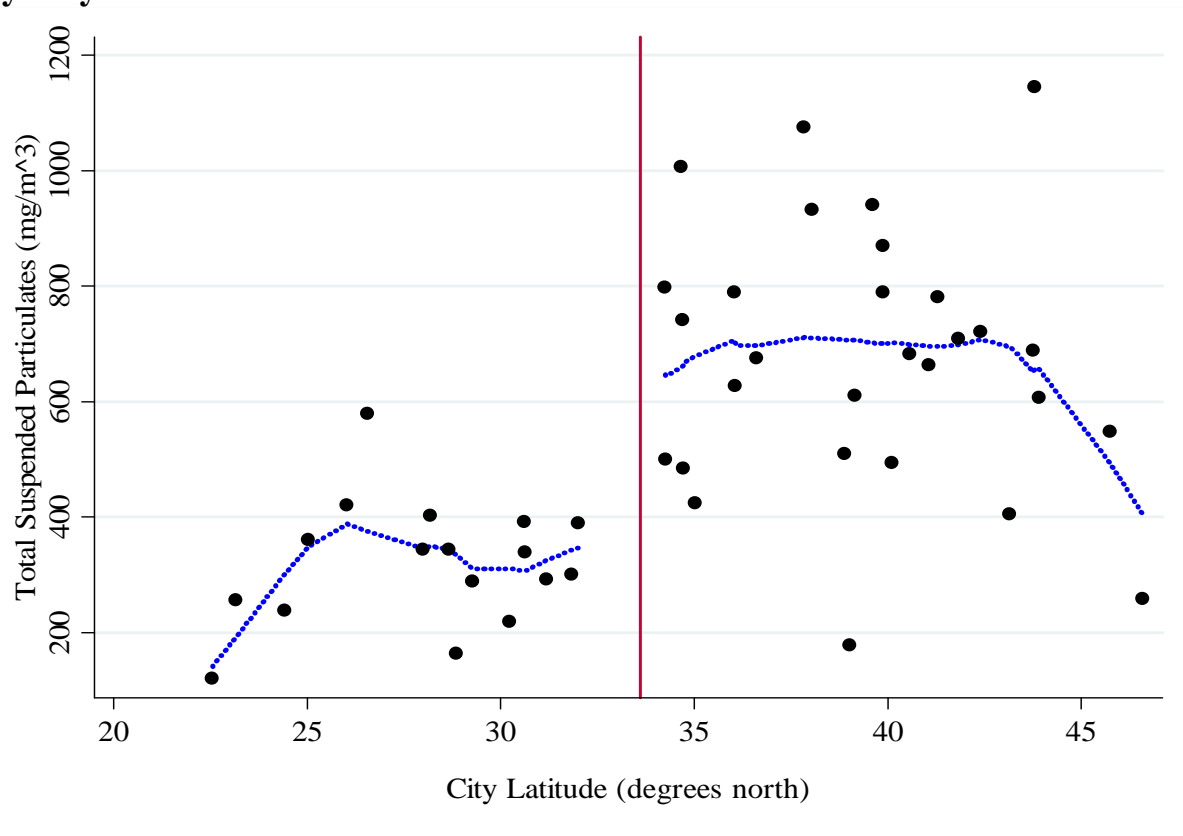
*Note* : Each cell in the table represents the coefficient from a separate regression. All regressions are 2SLS models using 1(North) \* Winter Temperature as the instrument. In panel A, we estimate the impact of TSP on mean birth weight for different subsamples of mothers stratified by education. In panel B, we estimate the impact of TSP on mean birth weight for different subsamples of the birth weight distribution. In panel C, we examine the impact of TSP on the probability of having a birth weight below 2,700 grams (10th percentile), 3,000 grams (25th percentile), and 3,250 grams (median). The dependent variable in these regressions is a dummy for having a birth weight lower than the listed percentile. The coefficient in panel C is reported per 1,000 units of TSP. Low education in panel A refers to mothers with primary or less, middle education is mothers with more than primary but less than high school degree, and high education is high school graduates and beyond.

**Figure 1: North and South China Denoted by Huai River/Qinling Mountains 0° Celsius Line**



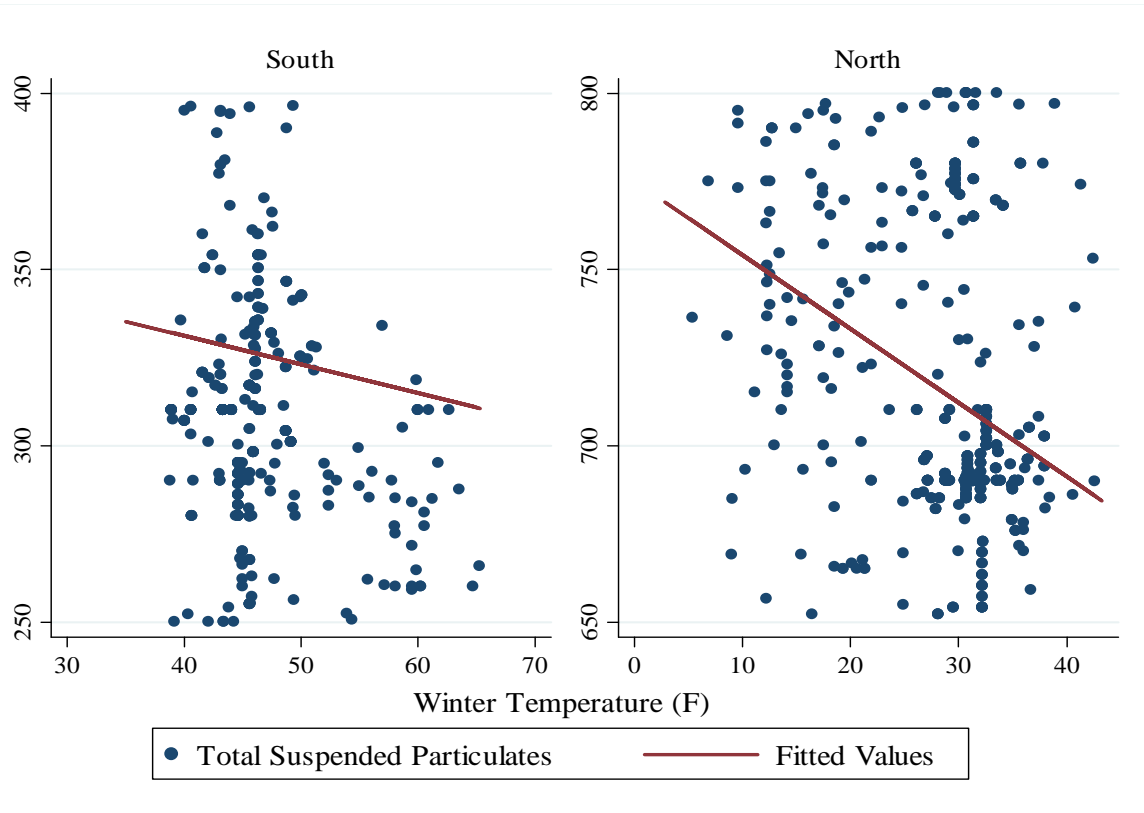
*Note* : The cities shown are the locations of the air quality monitoring stations in China. Cities north of the solid line were covered by the home heating policy.

**Figure 2: Mean Total Suspended Particulate Concentration from 1981-1991 by City Latitude**



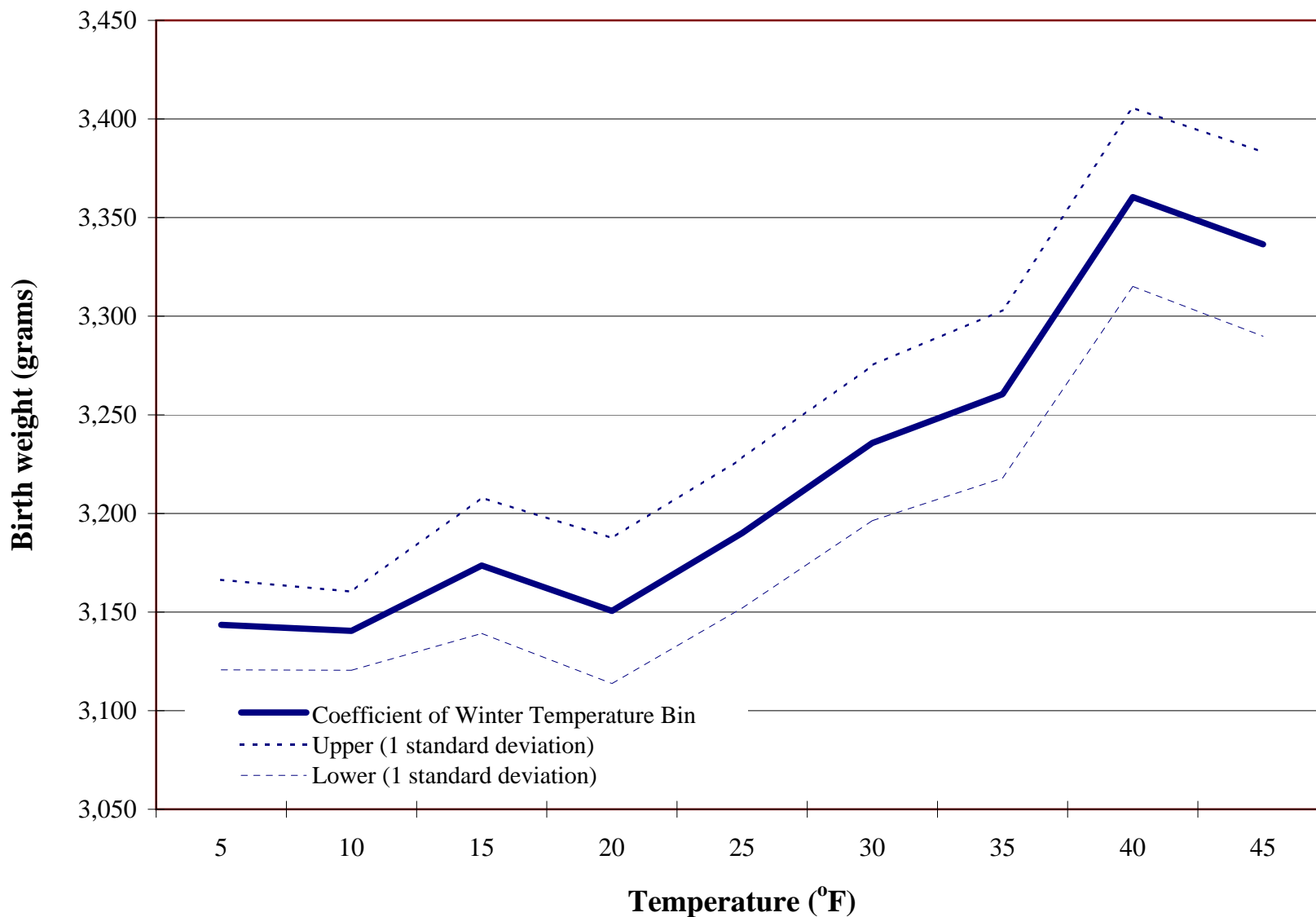
*Note* : The vertical line is drawn at 33.6°, which is in the middle of the latitude range covered by the Huai River/ Qinling Mountains line. Each observation is the average TSP reading in a particular city in our matched sample of air quality and infant outcomes. Infant outcome data are taken from the UNICEF fertility survey (1992) and TSP readings are taken from China's Environmental Yearbooks (1982-1992).

**Figure 3: Relationship between Winter Temperature and Total Suspended Particulates**



*Note* : The results above are scatterplots and fitted values from models where the TSP for a particular birth is predicted by a linear regression using the average winter temperature (in Fahrenheit) for the birth as the dependent variable. Each observation is the TSP reading and winter temperature for a birth in our sample, and we plot 5% of the births. The regression is estimated over all births in which we observe weather and a TSP reading, separately for northern and southern China. Infant outcome data are taken from the UNICEF fertility survey (1992), TSP readings are taken from China's Environmental Yearbooks (1982-1992), and weather data is taken from China's Meteorological Administration data (1981-1991).

**Figure 4: Birth Weight by Winter Temperature During Pregnancy**  
China UNICEF Fertility Survey (1981-1991)



*Note* : The figure above plots the predicted birth weight associated with each temperature bin. The prediction is based on a regression of birth weight on dummies for the temperature bin, year and city fixed effects, and demographic control variables (sex of birth, mother's education, household income). Temperature refers to the average monthly temperature overlapping with the winter during the year of the child's birth.