Evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River policy

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This paper's findings suggest that an arbitrary Chinese policy that greatly increases total suspended particulates (TSPs) air pollution is causing the 500 million residents of Northern China to lose more than 2.5 billion life years of life expectancy. The quasi-experimental empirical approach is based on China's Huai River policy, which provided free winter heating via the provision of coal for boilers in cities north of the Huai River but denied heat to the south. Using a regression discontinuity de(ri4h5,672Tmxmce)-34927verex(Chin4cy)-352.4m[(3)-240.687 Huai

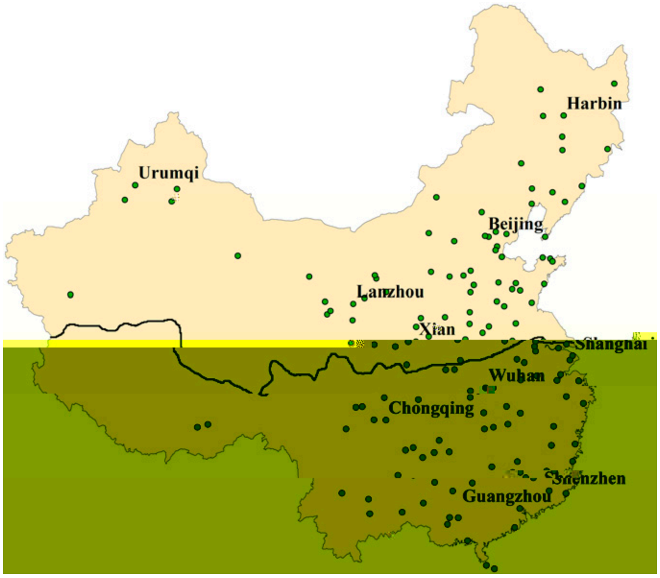


Fig. 1. The cities shown are the locations of the Disease Surveillance Points. Cities north of the solid line were covered by the home heating policy.

TSPs for 90 cities fro 1981 to 2000. These data were co piled through a co bination of hand entry fro Chinese-language publications and access to electronic files (11). We obtained the data by co bining the results of a World Bank project with infor ation fro hard copies of *China Environment Yearbook* to generate a single co prehensive file of air pollution across Chinese cities for our period.

Although there is recent evidence that air pollution readings in Chinese cities are anipulated by policy akers, with a tendency for officials to underreport pollution, we believe that anipulation was not a serious issue during the period we study (12). First, for the period of our study, govern ent officials' evaluations were pri arily based on econo ic growth rather than environ ental indices (13). Second, the readings were also generally not widely available, which reduced the incentive to publish inaccurate infor ation. Indeed, it has been reported extensively that Chinese officials onitored air pollution concentrations beginning in the late 1970s but this infor ation was not publicly released until 1998 (14). Also, our analysis relies on testing for differences in air pollution readings near the Huai River, so unless the data were anipulated differently north and south of the river, is easure ent would not bias the results in an obvious fashion. Moreover, even in the presence of anipulation of pollution concentrations, the esti ates of the health i pacts of living north of the Huai River will not be affected.

The ortality data are derived fro China's Disease Surveillance Points (DSPs) syste (15). The DSP is a set of 145 sites chosen to be nationally representative (bench arked against the 1990 China census) so that it captures China's variation in wealth, urbanicity, and geographic dispersion. The DSP records all deaths and population counts at the sites and yields a nationally representative annual sa ple of deaths (16). The analysis will rely on the data taken fro roughly 500,000 deaths recorded at sites between 1991 and 2000, and population counts by age and sex that are used to convert the recorded deaths into city-level ortality rates for ages 1, 5, and 10 y and 5-y incre ents through age 80. Additionally, these ortality rates are used to calculate an overall ortality rate based on China's age distribution in 2000 and life expectancy at birth, both easured annually for the 125 locations. In *SI Appendix*, we discuss why the results are unlikely to be driven by is easure ent in a location's ortality rate fro either igration or the transfer of sick rural residents to urban hospitals.

I portantly, the cause of death is also recorded after ultiple validation checks. We classify causes of death as either cardiorespiratory or noncardiorespiratory. The cardiorespiratory causes of death that are those that have been linked to a bient air quality and include heart disease (17), stroke (18–20), lung cancer (21), and respiratory illnesses (22, 23). Causes of death presu ably unrelated to air quality include other cancers, accidental or violent deaths, and various sto ach ail ents. Together, these two categories cover all causes of death.

We collected a range of deter inants of ortality and life expectancy, besides TSPs, that are used as control variables in the subsequent statistical analysis. We obtained daily average te perature data for each location in the air pollution sa ple fro the World Meteorological Organization that was used to calculate annual heating and cooling degree days (24). We also co piled a series of variables fro China's 2000 census that are potentially related to health outco es: average education of county residents, anufacturing's share of e ploy ent, the percentage of residents with urban registration, and the percentage of residents with access to tap water. The data file also includes an inco e variable taken fro the DSP, which placed each site into one of four inco e categories.

To esti ate the i pact of long-run exposure to pollution, the location-level panel data are collapsed to a 125-observations, location-level, cross-sectional dataset, because the Huai River regression discontinuity design is funda entally a cross-sectional design. This data file is obtained by averaging the annual location-specific easures of ortality rates, life expectancies, pollution concentrations, weather variables, and other covariates across the available years. Additionally, we used a geographic infor ation syste to identify the degrees latitude that each city centroid is north of the Huai River line and erged this infor ation into the final dataset. *SI Appendix* provides ore details on the procedure used to collapse the data file and the data sources.

Econometric Model

We use two approaches to esti ate the relationship between TSPs and hu an health. The first approach is a "conventional" strategy that uses ordinary least squares to fit the following equation to the cross-sectional data file:

$$Y_j = \beta_0 + \beta_1 TSP_j + X_j \Gamma + \varepsilon_j, \qquad [1]$$

where TSP_j is the total suspended particulates concentration in city j, X_j is a vector of the observable characteristics of the city that ight influence health outco es other than air quality, and ε_j is a disturbance ter . The dependent variable is Y_j, which is either a easure of ortality rates in city j or its residents' life expectancy, which is a si ple function of age-specific ortality rates.

The coefficient β_1 easures the effect of TSP exposure on ortality, after controlling for the available covariates. Consistent esti ation of β_1 requires that unobserved deter inants of ortality do not covary with TSP_j after adjust ent for X_j. Thus, the conventional approach rests on the assu ption that linear adjust ent for the li ited set of variables available in the census re oves all sources of confounding. With data fro the United States, Chay et al. (9) have docu ented the sensitivity of the esti ated TSP–adult ortality relationship to s all changes in specification and sa ple, which is consistent with the possibility that o itted variables bias plagues the conventional approach.

The second approach leverages the regression discontinuity (RD) design i plicit in the Huai River policy to easure its i pact on TSP concentrations and life expectancy. The RD design was developed ore than five decades ago and has been used successfully to test the causal nature of relationships in a wide range of fields including psychology, education, statistics, biostatistics, and econo ics (25, 26).

Table 1. Summary statistics

Variable	South (1)	North (2)	Difference in means (3)	Adjusted difference in means (4)	*P* value (5)
Panel 1: Air pollution exposure at China's Disease Surveillance Points					
TSPs, $\mu g/m^3$	354.7	551.6	196.8***	199.5***	<0.001/0.002
SO_2, $\mu g/m^3$	91.2	94.5	3.4	−3.1	0.812/0.903
NO_x, $\mu g/m^3$	37.9	50.2	12.3***	−4.3	<0.001/0.468
Panel 2: Climate at the Disease Surveillance Points					
Heating degree days	2,876	6,220	3,344***	482	<0.001/0.262
Cooling degree days	2,050	1,141	−910***	−183	<0.001/0.371
Panel 3: Demographic features of China's Disease Surveillance Points					
Years of education	7.23	7.57	0.34	−0.65	0.187/0.171
Share in manufacturing	0.14	0.11	−0.03	−0.15***	0.202/0.002
Share minority	0.11	0.05	−0.05	0.04	0.132/0.443
Share urban	0.42	0.42	0.00	−0.20*	0.999/0.088
Share tap water	0.50	0.51	0.02	−0.32**	0.821/0.035
Rural, poor	0.21	0.23	0.01	−0.33*	0.879/0.09
Rural, average income	0.34	0.33	0.00	0.24	0.979/0.308
Rural, high income	0.21	0.19	−0.02	0.27	0.772/0.141
Urban site	0.24	0.25	0.01	−0.19	0.859/0.241
Predicted life expectancy	74.0	75.5	1.54***	−0.24	<0.001/0.811
Actual life expectancy	74.0	75.5	1.55	−5.04**	0.158/0.044

The sample (n = 125) is restricted to DSP locations within 150 km of an air quality monitoring station. TSP ($\mu g/m^3$) in the years 1981–2000 before the DSP period is used to calculate city-specific averages. Degree days are the deviation of each day's average temperature from 65°F, averaged over the years 1981–2000 before the DSP period. The results in column (4) are adjusted for a cubic in degrees of latitude north of the Huai River boundary. Predicted life expectancy is calculated by OLS using all of the demographic and meteorological covariates shown. All results are weighted by the population at the DSP location. One DSP location is excluded due to invalid mortality data. *Significant at 10%, **significant at 5%, ***significant at 1%. Sources: China Disease Surveillance Points (1991–2000), *China Environment Yearbook* (1981–2000), and World Meteorological Association (1980–2000).

This paper's RD design exploits the discrete increase in the availability of free indoor heating as one crosses the Huai River line (with no availability to the south and, in principle, co plete availability north of the line). Specifically, we separately test whether the Huai River policy caused a discontinuous change in TSPs at the river and a discontinuous change in life expectancy. The respective necessary assu ptions are that any unobserved deter inants of TSPs or ortality change s oothly as they cross the river. If the relevant assu ption is valid, adjust ent for a sufficiently flexible polyno ial in distance fro the river will re ove all potential sources of bias and allow for causal inference.

In practice, we esti ate the following equations to test for the i pacts of the Huai River policy:

$$TSP_j = \alpha_0 + \alpha_1 N_j + \alpha_2 f(L_j) + X_j \kappa + \nu_j \quad \textbf{[2a]}$$

$$Y_j = \delta_0 + \delta_1 N_j + \delta_2 f(L_j) + X_j \phi + u_j, \quad \textbf{[2b]}$$

where j references a city or location in China. TSP_j is the average annual a bient concentration of TSPs in city j over the period 1980–2000 and Y_j is a easure of city j's ortality or life expectancy at birth. N_j is an indicator variable equal to 1 for locations that are north of the Huai River line, $f(L_j)$ is a polyno ial in the degrees north of the Huai River, and X_j is a vector of the de ographic and city characteristics, other than air quality, that are associated with ortality rates (*SI Appendix* gives details).

This design can also be used to develop esti ates of the i pact of TSP concentrations on life expectancy. Specifically, if the Huai River policy only influences ortality through its i pact on TSPs, then it is valid to treat Eq. **2a** as the first stage in a two-stage least-squares (2SLS) syste of equations. An i portant appeal of the 2SLS approach is that it produces esti ates of the i pact of units of TSPs on life expectancy, so the results are applicable in other settings. The second-stage equation is

$$Y_j = \beta_0 + \beta_1 T\hat{S}P_j + \beta_2 f(L_j) + X_j \Gamma + \varepsilon_j, \quad \textbf{[2c]}$$

where $T\hat{S}P_j$ represents the fitted values fro esti ating (Eq. **1**) and the other variables are as described above. The 2SLS approach offers the prospect of solving the confounding or o itted

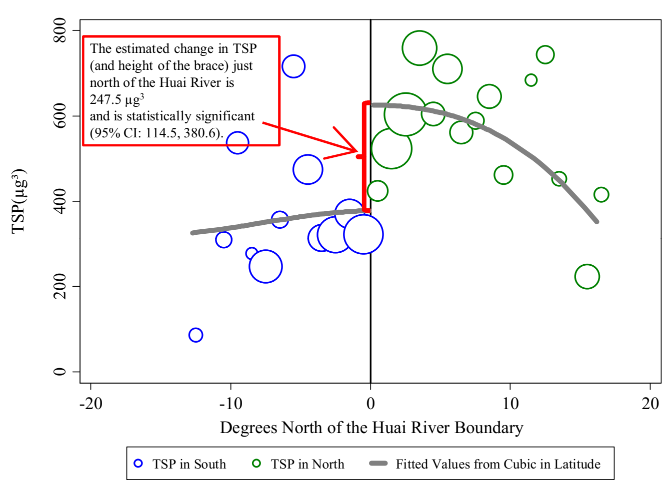
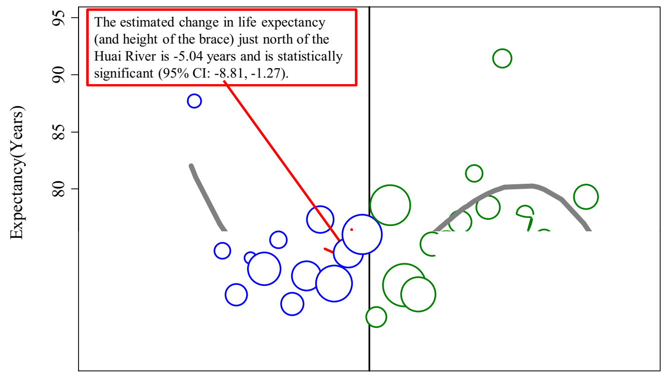


Fig. 2. Each observation (circle) is generated by averaging TSPs across the Disease Surveillance Point locations within a 1° latitude range, weighted by the population at each location. The size of the circle is in proportion to the total population at DSP locations within the 1° latitude range. The plotted line reports the fitted values from a regression of TSPs on a cubic polynomial in latitude using the sample of DSP locations, weighted by the population at each location.



variables proble associated with the esti ation of the air pollution–health effects relationship and is a solution to the attenuation bias associated with the is easure ent of TSP.

Results

Summary Statistics. Table 1 reports the su ary statistics for several of the key deter inants of ortality rates and provides evidence on the validity of the RD design. Colu ns (1) and (2) report the eans in cities south and north of the Huai River line. Colu n (3) reports the ean difference between the North and the South. Colu n (4) also reports the difference, but this ti e it is adjusted for a cubic polyno ial in degrees north of the Huai River so that it is a test for a discontinuous change at the Huai River line. A direct test of the RD design's identifying assu ption that unobservables change s oothly at the boundary is, of course, i possible, but it would nevertheless be reassuring if observable deter inants change s oothly at the boundary. (This is analogous to the test in rando ized control trials that observable deter inants of the outco e are independent of treat ent status.) Colu n (5) reports the P values associated with the tests that the differences in colu ns (3) and (4) are equal to zero.

Two key points e erge fro this table. First, there are large differences in TSP exposure a ong Southern and Northern Chinese residents, but not for other for s of air pollution (e.g., sulfur dioxide and nitrous oxides) owing to the greater distances that they travel. Second, there are substantial differences in the deter inants of ortality rates (e.g., te perature and predicted life expectancy) between the South and North, but adjust ent for the cubic polyno ial in latitude greatly reduces these differences and causes the to beco e statistically insignificant. This finding supports the validity of the RD design and the 2SLS approach to inferring the causal relationship between TSPs and life expectancy.

Graphical Analysis. The paper's pri ary findings are presented graphically in Figs. 2–4. Fig. 2 plots cities' TSP concentration against their degrees north of the Huai River boundary. The line is the fitted value fro the esti ation of the first-stage Eq. **1**, without adjust ent for X_j. The circles represent the average TSP concentration across locations within 1° latitude distance bins fro the Huai River; each circle's size is proportional to the nu ber of DSP locations within the relevant 1° bin. The discontinuous change in a bient TSP concentrations to the north of the border indicates that the Huai River policy increased TSP concentrations in the North by about 200 μg/ ^{3}. In contrast, *SI Appendix*, Figs. S1 and S2 graphically confir that sulfur dioxide and nitrous oxide concentrations are approxi ately equal on the two sides of the Huai River.

Fig. 3 repeats the graphical exercise in Fig. 2, except here it plots life expectancy against degrees north of the Huai River boundary. The striking finding is that there is a discrete decline in life expectancy at the border of roughly 5 y, which irrors the increase in TSPs. Together, Figs. 2 and 3 reveal a sharp increase in TSPs and a sharp decline in life expectancy at precisely the location where the Huai River policy went into effect. The results in Fig. 3 are also evident in *SI Appendix*, Fig. S3 in the sa ple of DSP sites within 5° latitude of the Huai River.

Fig. 4 graphically assesses the validity of this paper's approach by testing whether predicted life expectancy, calculated as the fitted value fro an ordinary least-squares (OLS) regression of life expectancy on all covariates except TSPs (just as in Table 1), differs at the Huai River's border. Specifically, this equation includes all of the covariates listed in panels 2 and 3 of Table 1, and these variables collectively explain a substantial portion of the variation in life expectancy ($R^2 = 0.265$). It is evident that predicted life expectancy is essentially equal just to the north and south of the border (Table 1 reports a P value of 0.81 fro a test of equal life expectancy). Also note that *SI Appendix*, Table S2 de onstrates that dietary and s oking patterns are si ilar in the North and South, suggesting that these deter inants of life expectancy are unlikely to explain the sharp decline in life expectancy north of the border.

Regression Results. Table 2 reports the results fro the application of the conventional OLS approach. The esti ation of Eq. **1** with four different dependent variables is reported: the overall ortality rate, the cardiorespiratory ortality rate, the noncardiorespiratory-related ortality rate, and life expectancy. The set of controls are reported at the botto of the table. The first three rows indicate that a 100 μg/ ^{3} increase in TSPs is associated with a statistically significant 3% increase in the ortality rate that is entirely due to an increase in cardiorespiratory causes of death. The colu n (2) specification in the final row indicates that a 100 μg/ ^{3} increase in TSPs is associated with a loss in life expectancy of about 0.52 y (95% CI: 0.07, 0.97).

Table 3 presents the RD results fro the esti ation of Eqs. **2a** and **2b** in panel 1 and the 2SLS results fro Eq. **2c** in panel 2. In colu n (1), the specification includes a cubic in distance fro the Huai River (easured in degrees of latitude). Colu n (2) adds the available covariates to the specification. Colu n (3) uses an alternative RD approach, which li its the sa ple to locations within

Table 2. Impact of TSPs (100 μg/m^3) on health outcomes using conventional strategy (ordinary least squares)

Dependent variable	(1)	(2)
ln(All cause mortality rate)	0.03* (0.01)	0.03** (0.01)
ln(Cardiorespiratory mortality rate)	0.04** (0.02)	0.04** (0.02)
ln(Noncardiorespiratory mortality rate)	0.01 (0.02)	0.01 (0.02)
Life expectancy, y	−0.54** (0.26)	−0.52** (0.23)
Climate controls	No	Yes
Census and DSP controls	No	Yes

n = 125. Each cell in the table represents the coefficient from a separate regression, and heteroskedastic-consistent SEs are reported in parentheses. The cardiorespiratory illnesses are heart disease, stroke, lung cancer and other respiratory illnesses. The noncardiorespiratory-related illnesses are violence, cancers other than lung, and all other causes. Models in column (2) include demographic controls and climate controls reported in Table 1. Regressions are weighted by the population at the DSP location. *Significant at 10%, **significant at 5%, ***significant at 1%. Sources: China Disease Surveillance Points (1991–2000), *China Environment Yearbook* (1981–2000), and World Meteorological Association (1980–2000).

5° latitude of the Huai River and reduces the sa ple size fro 125 to 69. With this s aller sa ple, latitude is odeled with a first-order polyno ial. The specification details are noted at the botto of the table.

The first row of Table 3, panel 1 confir s that the i pact of the Huai River policy on TSPs is robust to adjust ent for the covariates and the alternate RD approach (*SI Appendix*, Fig. S3). The re aining rows suggest that this policy increases ortality rate by 22–30% and that this is al ost entirely due to higher rates of ortality a ong cardiorespiratory causes. The esti ates in the final row indicate that there is a discontinuous decrease in life expectancy of ~5 y to the north of the boundary.

Panel 2 in Table 3 reports on the 2SLS esti ates. Colu n (2) esti ates suggest that a 100 μg/ ^{3} increase in TSPs is associated with an increase in the overall ortality rate of 14% or 0.14 ln points (95% CI: 0.005, 0.275) and a decline in life expectancy of 3.0 y (95% CI: 0.39, 5.61). Again, the results see to be driven entirely by higher ortality rates fro cardiorespiratory causes of death.

The heterogeneity in the results across the population is explored in *SI Appendix*. *SI Appendix*, Table S3 reveals that the ortality and life expectancy findings hold for en and wo en. *SI Appendix*, Table S4 and Fig. S4 de onstrate that the i pacts on cardiorespiratory ortality rates are generally evident over the entire course of the life cycle, not just for the young and old.

The basic results are also robust to a wide variety of specification checks. *SI Appendix*, Tables S5 and S6 docu ent that the results are qualitatively unchanged by using alternative ethods to assign TSP concentrations to DSP locations. *SI Appendix*, Table S7 shows that the panel 1 results are qualitatively unchanged by expanding the sa ple to the full set of 144 DSP locations (with valid ortality data) fro the 125 locations with TSP data. Further, the results are unchanged by adjust ent for distance fro the coast (*SI Appendix*, Table S8).

We additionally explored the robustness of the results to alternative approaches to i ple enting the RD design. *SI Appendix*, Table S9 reports a set of goodness-of-fit tests that lead us to e phasize odeling distance fro the Huai River with a cubic polyno ial in latitude. *SI Appendix*, Table S10 docu ents that a first- or second-order polyno ial in latitude best fits the data in the sa ple that is restricted to locations within 5° latitude of the river, and that the results are qualitatively si ilar using either approach. *SI Appendix*, Table S11 reports on specifications that allow the polyno ial to differ to the north and south of the river. The goodness-of-fit statistics support separate quadratics north and south of the Huai River, and this specification suggests a so ewhat s aller increase in TSPs at the border but a larger decline in life expectancy.

A natural concern related to the research design is that the govern ent used the Huai River as the de arcation line for changes in other govern ent policies related to public health, and this would confound the esti ates of TSPs on health. This possibility is itigated by the fact that the Huai River is not a border used for ad inistrative purposes. The Huai River follows the January 0° average te perature line (Celsius), and this was in fact the basis of its choice as a ethod to divide the country for free heating. Further, local policies generally hew to ad inistrative boundaries associated with cities and provinces; indeed, the Huai River cuts through several provinces. Nevertheless, we co piled so e additional variables on city-level policies that are plausibly related to health fro the *China City Statistical Yearbook*. We exa ine whether there is any discontinuity in these variables at the

Table 3. Using the Huai River policy to estimate the impact of TSPs (100 μg/m^3) on health outcomes

Dependent variable	(1)	(2)	(3)
Panel 1: Impact of "North" on the listed variable, ordinary least squares			
TSPs, 100 μg/m^3	2.48*** (0.65)	1.84*** (0.63)	2.17*** (0.66)
ln(All cause mortality rate)	0.22* (0.13)	0.26* (0.13)	0.30* (0.15)
ln(Cardiorespiratory mortality rate)	0.37** (0.16)	0.38** (0.16)	0.50*** (0.19)
ln(Noncardiorespiratory mortality rate)	0.00 (0.13)	0.08 (0.13)	0.00 (0.13)
Life expectancy, y	−5.04** (2.47)	−5.52** (2.39)	−5.30* (2.85)
Panel 2: Impact of TSPs on the listed variable, two-stage least squares			
ln(All cause mortality rate)	0.09* (0.05)	0.14** (0.07)	0.14* (0.08)
ln(Cardiorespiratory mortality rate)	0.15** (0.06)	0.21** (0.09)	0.23** (0.10)
ln(Noncardiorespiratory mortality rate)	0.00 (0.05)	0.04 (0.07)	0.00 (0.06)
Life expectancy, y	−2.04** (0.92)	−3.00** (1.33)	−2.44 (1.50)
Climate controls	No	Yes	Yes
Census and DSP controls	No	Yes	Yes
Polynomial in latitude	Cubic	Cubic	Linear
Only DSP locations within 5° latitude	No	No	Yes

The sample in columns (1) and (2) includes all DSP locations (*n* = 125) and in column (3) is restricted to DSP locations within 5° latitude of the Huai River boundary (*n* = 69). Each cell in the table represents the coefficient from a separate regression, and heteroskedastic-consistent SEs are reported in parentheses. Models in column (1) include a cubic in latitude. Models in column (2) additionally include demographic and climate controls reported in Table 1. Models in column (3) are estimated with a linear control for latitude. Regressions are weighted by the population at the DSP location. *Signi ficant at 1%. Sources: China Disease Surveillance Points (1991–2000), *China Environment Yearbook* (1981–2000), and World Meteorological Association (1980–2000).

Huai River in *SI Appendix*, Table S12. The results de onstrate that the null hypothesis that these variables are equal on both sides of the Huai River generally cannot be rejected. We also reesti ate our Table 3 specification with the addition of these variables in *SI Appendix*, Table S13. We find that the addition of these variables to the Table 3 specifications leaves our results largely unchanged, and even suggests odestly larger losses of life expectancy than those reported in Table 3.

Interpretation. The 2SLS esti ates suggest that a 100 μg/ ^{3} increase in TSPs leads to a decline in life expectancy of 3.0 y (95% CI: 0.4, 5.6). This esti ate is ore than five ti es larger than one obtained fro the application of a conventional least-squares approach to the sa e data. The difference suggests that the OLS esti ates understate the true effect owing to so e co bination of o itted variables bias (e.g., unobserved factors that i prove health and are positively correlated with TSPs, such as inco e and hospital quality) and easure ent error. Further, it is about half the agnitude of the esti ated i pact of an equal unit of particulate atter s aller than 2.5 μ ($PM_{2.5}$) fro the pioneering study of Pope et al. (27). There are at least three i portant differences between the studies that co plicate direct co parisons: (*i*) $PM_{2.5}$ is believed to be ore lethal than the larger particles that also qualify as TSPs; (*ii*) the setting for the $PM_{2.5}$ results is the United States between 1980 and 2000, when particulate concentrations were just a fraction of current concentrations in China; and (*iii*) this study's results are based on a RD design, which can produce causal esti ates in nonexperi ental settings.

A related issue is whether the Huai River heating policy caused behavioral responses that a plify or itigate the esti ated ortality i pacts of TSPs. For exa ple, the heating policy very likely leads people in the North to spend ore ti e indoors, where te peratures are presu ably higher; this would be protective of hu an health. Alternatively, the greater ti e indoors ay cause people to reduce their exercise and increase their exposure to indoor air pollution that would be har ful to health. Further, the free provision of coal is an in-kind transfer that increases households' disposable inco e, and this ay cause northern households to alter their consu ption patterns in ways that are protective (e.g., edical care) or har ful (e.g., tobacco or alcohol) for health. In the case where these behavioral responses affect ortality, the 2SLS esti ates of the i pact of TSPs on ortality would be invalid, although the esti ated ortality effects of the Huai River heating policy (e.g., panel 1 of Table 3) would still be valid. Ulti ately, the esti ated i pacts of TSPs on ortality should be interpreted with these caveats in ind because the necessary data to test for these behavioral responses are unavailable.

Conclusions

The analysis suggests that the Huai River policy, which had the laudable goal of providing indoor heat, had disastrous consequences for health, presu ably due to the failure to require the installation of sufficient pollution abate ent equip ent. Specifically, it led to TSP concentrations that were 184 μg/ ^{3} higher (95% CI: 60, 308) or 55% higher in the North and reductions in life expectancies of 5.52 y (95% CI: 0.8, 10.2) in the North due to elevated rates of cardiorespiratory ortality.

The population in Northern China between 1990 and 2000 exceeded 500 illion. Consequently, our results i ply that the Huai River policy led to a staggering loss of over 2.5 billion life years. Further ore, data fro 2003 to 2008 indicate that PM_{10} (particulate atter s aller than 10 μ) concentrations are 22.9 μg/ ^{3} higher (95% CI: 13.5, 23.3) or 26% higher north of the Huai River, suggesting that residents of the North continue to have shortened lifespans. The TSP concentrations that prevailed during the study period greatly exceed the current concentrations in developed countries but are not atypical for any cities in developing countries today, such as India and China. These results ay help explain why China's explosive econo ic growth has led to relatively ane ic growth in life expectancy. More broadly, this paper's results ay be useful in for ing policy as developing countries search for the opti al balance between econo ic growth and environ ental quality (28).

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