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# The Long-Term Impact of Energy Poverty and Its Mitigation on Educational Attainment: Evidence From China

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# The Long-Term Impact of Energy Poverty and Its Mitigation on Educational Attainment: Evidence From China *

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## Abstract

Existing studies demonstrate the short-run connection between environmental conditions and academic performance. However, the long-term effects of exposure to adverse living conditions on academic achievement remain underexplored. This study investigates the long-term impact of energy poverty, and policy interventions aimed at alleviating it, on the academic performance of Chinese schoolchildren starting from infancy. It specifically utilizes the Huai River Policy, which provides free winter heating exclusively to northern regions in China but not to adjacent southern regions. My findings suggest a significant positive influence of winter heating on schoolchildren's academic performance, with a more pronounced effect for children born during winter months. The insights gained from this research could inform policy debates to enhance educational outcomes and human well-being.

Keywords: energy poverty, academic performance, climate

JEL Codes: I24, I25, Q51, Q54, Q58

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## 1. Introduction

In recent years, there has been evidence of a more frequent occurrence of extreme temperature shocks globally (Francis et al., 1998). One example of such shocks is the occurrence of colder and snowier winters in various parts of the planet (Cohen et al., 2021), affecting over a billion people who have no access to modern heating sources or cannot afford them (IEA, 2018). Such lack of access to heating sources is often referred to as *energy poverty* [1], and a body of research connects it to health, education, and household income (Thomson et al., 2017; Banerjee et al., 2021; Okushima, 2016). Moreover, several papers demonstrate the negative impact of short-run extreme temperature exposure on educational attainment and the long-run impact of early life adverse climate exposure on outcomes during adulthood (Goodman et al., 2018; Cook & Heyes, 2020; Isen et al., 2017; Maccini & Yang, 2009).

This paper is the first to identify the long-term impact of energy poverty and its link to academic performance at the school level. Moreover, this study investigates the lasting impact of energy poverty mitigation by focusing on China's Huai River Policy. This policy was introduced at 1950s and grants free winter heating for provinces that are located to the north of the river, but not for southern provinces. China is a developing country, which faces both hot and cold climates, and a significant part of its population has experienced and/or is experiencing energy poverty (Lin & Wang, 2020).

The primary empirical objective of this paper entails the examination of the causal relationship between environmental conditions experienced during early-life stages and subsequent outcomes in later life. Specifically, the aim is to investigate whether individuals who are born into households benefiting from the provision of free winter heating exhibit higher levels of academic achievement in comparison to their counterparts from southern provinces in China. I hypothesize that early adverse environmental conditions have a lasting negative impact on the health of newborns (Campbell et al., 2014). Thus, the affected infants could perform worse in school compared to unaffected ones. To test this hypothesis, I construct a linear model in which the outcome variable is the standardized math test scores of the schoolchildren born in cities of northern and southern provinces.

[1] Reddy et al. (2000) define energy poverty as "the absence of sufficient choice in accessing adequate, affordable, reliable, high-quality, safe and environmentally benign energy services to support economic and human development".

The input variables include a set of meteorological measurements for each infant taken before and after the birth month, the season of birth dummies, and individual-level variables obtained from survey data from Rozelle (2016).

In this cross-sectional study, I examine the differences in educational attainment between children born in cities on the north and south sides of the Huai river. I distinguish the infants based on their birth months and create two groups named *Winter* and *Summer*. The Winter group consists of schoolchildren born in the winter months when average outdoor temperature levels are below 5°C [2]. The Summer group comprises infants born during months when the average outdoor temperature was 15°C or higher. Following this, I assign dummy variables to represent these groups. I also account for outdoor temperatures and other climate variables for up to 3 months before and after the birth of a child. I focus on math test exams as the literature demonstrates that mathematical learning during an early age is important for later success in life (Clements & Sarama, 2011). Moreover, several studies have demonstrated the importance of early mathematics education compared to other subjects for better achievement later in school (Duncan et al., 2007; Claessens et al., 2009). Lastly, cognitive skills play an important role in early math development (Decker & Roberts, 2015). Thus, the negative impact on infants' health from adverse environmental conditions could damage their math learning process and consequently have a lasting negative impact on future well-being.

For the group of northern and southern cities with a similar climate and distance from the policy line, the results indicate a statistically significant positive impact of free winter heating on standardized math test scores. Specifically, the impact is distinct for schoolchildren born during the winter months in northern cities, whereas the math scores of infants born during summer in both northern and southern cities are similar. Thus, my study demonstrates that reducing energy poverty has long-term effects on school performance, particularly for children born during harsh weather conditions. Next, I examine the long-term outdoor climate impact on academic performance. The results indicate a small but positive and significant impact of rising temperature levels, during the before-birth (pregnancy) period, on the academic achievement of schoolchildren born during the winter months. However, I do not find an impact for the summer season. Moreover, my results demonstrate that boys perform significantly worse than girls, and that a migrant

[2]According to historical climate data from Statistic Intelligence, in China an outdoor temperature level below 5°C is considered winter season.

father in the household negatively affects the academic performance of an infant. These results are consistent with existing literature (Thorell et al., 2013; Liu et al., 2018).

Subsequently, I run a placebo test to examine the impact of the heating policy among only northern and southern cities. I hypothesize that if the difference between the academic performance of schoolchildren born during winter in northern and southern cities comes from the heating policy, then there should not be such a difference among only northern (or southern) cities. That is to say, infants born during winter in northern (or southern) cities should perform similarly. The results of the placebo test show no statistically significant difference in the educational attainment of infants born during both the summer and winter seasons in both northern and southern cities.

Lastly, I account for factors that can potentially represent alternative drivers to the proposed treatment. These include addressing the possibility of migration from the birth city to another location (e.g., from north to south) and considering the short-term temperature impact during the test day. Additionally, I compare the air pollution levels for cities close to the policy line during the years when math exams were conducted. Finally, I examine the birth rates within my sample based on year seasons, and also compare birth rates between northern and southern cities.

I contribute to several areas of the literature. Firstly, my study focuses on the long-term impact of energy poverty and its mitigation through specific heating policies on academic performance at the school level. A growing literature demonstrates the impact of energy poverty on various dimensions of human life. Banerjee et al. (2021) analyze the relationship between energy poverty, health, and education. The authors utilize country-level data from 1990 to 2017 on a yearly basis. The results of their study demonstrate a negative impact on health and schooling years resulting from energy poverty. Another aspect of human life affected by energy poverty is household finances. Okushima (2016) examines energy poverty in Japan from 2004 to 2013. The author establishes the negative impact of energy poverty on household income levels, especially for households consisting of a single parent (usually the mother) and child. While the above papers point out the negative impact of energy poverty on health, schooling years, and income level, they are either conducted at the country level or demonstrate the short-run impact. In contrast to those papers, my study utilizes a more granular dataset consisting of approximately 19,000 students from 15 cities in northern and southern China. This dataset provides an opportunity to generate more comprehensive results. Furthermore, my research specifically focuses on individuals who were born during periods of energy poverty and examines the impact on their later-life wellbeing.

Secondly, my study examines the long-term outdoor climate impact on educational attainment at the school level, particularly the lasting temperature effect on future academic performance. A number of studies document the long-term effects of extreme temperature exposure on other aspects of human life. In particular, Isen et al. (2017) find that the season of birth and the temperature exposure associated with that season has a lasting effect on the life wellbeing of individuals. The authors demonstrate that, during the first year of infant life, an additional day with a temperature above 32°C will lower the infant's annual earning by around $30 at age 29-31. Maccini & Yang (2009) also analyze the lasting consequences of environmental conditions. However, instead of temperature exposure, they examine rainfall levels in early life and establish that higher rainfall in early life increases health and socioeconomic levels for women, but these results do not hold for men. Although these studies demonstrate that early environmental conditions have long-term effects during adulthood, there is a lack of evidence regarding the long-term impact of outdoor temperature on academic performance at the school level, especially for infants born in cold climates. Therefore, my study contributes to this area by focusing on infants born during both warm and cold weather, while also investigating the lasting impact of climate conditions during the pregnancy period.

The above studies demonstrate that environmental conditions, such as temperature and rainfall level, have a lasting impact on future outcomes. The literature demonstrates that child health and early childhood development are key for human capital. Moreover, early-age interventions are an effective strategy to reduce social costs and increase economic growth (Heckman, 2011, 2012; Doyle et al., 2009; Attanasio et al., 2022). Thus, investigating population groups born during extreme environmental conditions is beneficial for improving future human well-being. Hence, this research contributes to the literature on early-life environmental conditions and later-life wellbeing by analyzing the case of China.

The rest of this paper is organized as follows: Section 2 provides brief historical background on the Huai River Policy, Section 3 describes the data used for the analysis. Section 4 describes the estimation model. Section 5 provides the empirical results. Section 6 concludes.

## 2. Huai River Heating Policy

The Huai River heating system was established in China between 1950 and 1980, in the era of centralized economic planning. During this time, heating was considered a fundamental right, and the government provided free heating to households and offices through state-owned enterprises or direct provision. However, the provision of free heating was limited to the northern regions of China, which were demarcated from the southern regions by the Huai River (Figure 1) , where the average January temperature ranges approximately from 0°C to 5°C. As a consequence, cities situated north of the river implemented a centralized heating infrastructure powered by coal, ensuring unlimited free heating during the winter season. Conversely, in the southern regions, heating was largely absent as the government did not establish heating infrastructure, and the private sector has only recently begun supplying it. Consequently, it is widely acknowledged that cities just south of the Huai River experience cold and uncomfortable winters (Ebenstein et al., 2017; Almond et al., 2009).

Figure 1: Free Winter Heating in the Northern Provinces Above the Line


*Notes:* The figure shows the map of China. The black line represents the heating policy line. The green dots represent the cities located in the northern (above the line) and southern (below the line) regions. For the analysis discussed later in the Data and Estimation sections, I have data available only for a subset of these cities. Source: Ebenstein et al. (2017)

## 3. Data and Summary Statistics

In order to empirically examine the impact of the Huai River Policy on the educational attainment of Chinese schoolchildren, I have obtained the Chinese schoolchildren's academic performance data from Rozelle (2016). The dataset consists of 18,888 observations of students in grades 4 to 6 and includes information on their academic performance, birth year (1998 - 2009) and month, city of birth, gender, and parents' migration status. The measure of academic performance in this dataset is the standardized math test scores collected by Rozelle (2016) during years 2014 and 2015. The dataset encompasses students from 15 Chinese cities situated in both the northern and southern regions. However, for the main analysis, I use a subset of these cities. The main criterion for choosing the cities is their proximity to the policy line. This ensures that they have matching weather conditions, which is important for the analysis. The selected cities (Appendix: Figure A.1), which are approximately 100 km away from both sides of the policy line, guarantee similar climates (Appendix: Figure A.2). Furthermore, these groups of cities (north vs south) also have similar population change levels [3].

I obtained the meteorological data for China from Custom Weather [4]. This dataset covers the period from 1980 to 2020 and comprises average daily and monthly observations of various climate variables at the city level, including outdoor temperature, wind speed, and sea level pressure.

Table 1 presents the summary statistics for the main variables. The summary statistics include the main individual-level variables and outdoor temperature measurements from all cities available in the dataset, and from the subset of cities located closest on both sides of the river, with similar weather conditions and comparable distances (around 100km) from both sides of the policy line.

[3] Balance tables - Table 2

[4] https://customweather.com/

Table 1: Summary Statistics

All Cities

| | Mean | SD | Min | Max | N |
|---|---|---|---|---|---|
| Male | 0.52 | 0.49 | 0.00 | 1.00 | 10934 |
| Birth Year | 2003 | 1.13 | 1998 | 2009 | 10934 |
| Grade | 4.66 | 0.52 | 4.00 | 6.00 | 10934 |
| Migrant Father | 0.29 | 0.45 | 0.00 | 1.00 | 10934 |
| Temperature - Winter | -1.01 | 4.59 | -10.13 | 5.3 | 10934 |
| Temperature - Summer | 24.69 | 3.73 | 14.99 | 34.74 | 10934 |

Cities with similar climate and distance (around 100 km) from the policy line

| | Mean | SD | Min | Max | N |
|---|---|---|---|---|---|
| Male | 0.50 | 0.50 | 0.00 | 1.00 | 1192 |
| Birth Year | 2003 | 0.93 | 1999 | 2009 | 1192 |
| Grade | 5.01 | 0.69 | 4.00 | 6.00 | 1192 |
| Migrant Father | 0.39 | 0.49 | 0.00 | 1.00 | 1192 |
| Temperature - Winter | 4.22 | 0.90 | 2.38 | 5.3 | 1192 |
| Temperature - Summer | 21.96 | 3.42 | 14.99 | 29.8 | 1192 |

*Notes:* The table presents summary statistics: first for all the northern and southern cities in the data set. The second part of the table includes only northern and southern cities that are located by an equal distance from both sides of the policy line, and have similar weather conditions. In all specifications, I include only infants whose mothers are not migrants to ensure that a child is born, raised and studies in one city.

# 4. Estimation

### 4.1 Model

I examine whether the Huai River heating policy has a positive impact on educational attainment. To test this hypothesis, I estimate a linear model in which the dependent variable is the standardized math test results, while explanatory variables are the dummy for those born in cities of northern regions with free heating, dummies for those born during summer and winter periods, and a set of climate variables. For each child, I collect meteorological observations in the range of 3 months before and after the birth date. Additionally, I control for children's grades, gender, and their parent's migration status. For the analysis, I run the following model:

$$Y_{icsmt} = \beta_1 * Heat_i + \beta_2 * Summer_{icsmt} + \beta_3 * Winter_{icsmt} +$$
$$+ \beta_4 * Heat_i * Summer_{icsmt} + \beta_5 * Heat_i * Winter_{icsmt} +$$
$$+ \Sigma_{j=6}^{k} * \beta_j * M_{icsmt} + \Sigma_{k+1}^{p} * \beta_{k+1} * C_i + \epsilon_s$$

Where $Y_{icsmt}$ is the standardized math test score of child ***i***, born in year ***t***, on month ***m***, who was born and studied in city ***s***, in grade ***c*** (4 to 6). $Heat_i$ is a dummy variable that equals 1 for individuals born in cities located in northern regions with access to free winter heating. $Summer_{icsmt}$ and $Winter_{icsmt}$ are dummy variables representing the seasons of birth. $\Sigma_{j=6}^{k} * \beta_j * M_{icsmt}$ represents a set of meteorological variables, including average monthly measurements of outdoor temperature, wind speed, and atmospheric pressure. Climate measurements for each infant are collected within a 6-month range, covering 3 months before and after birth. $\Sigma_{j=k+1}^{p} * \beta_{k+1} * C_i$ consists of control variables, such as the infant's gender, school grade at the time of testing, and the father's migration status. Finally, $\epsilon_s$ denotes the error term, and the standard errors are clustered at the city level. In the model, $\beta_4$ and $\beta_5$ capture the impact of being born in northern cities during the summer and winter periods, respectively. The coefficient of interest is $\beta_5$, which shows the interaction between the free heating dummy and the dummy that identifies the season of birth. The coefficient captures the impact of free heating on academic performance for infants born during winter. It is presumed that $\beta_4$ will be small and insignificant as it focuses on infants born during the summer period when heating is not necessary.

I start the examination by focusing on the cities that are located close to both sides of the river (policy line). This means that those cities have the same climate, but part of them are located on the northern side (i.e. have free heating) and the others are in the southern part.

### 4.2 Identification Assumption

The identification assumption of this study is the following: by controlling the infants' birthplace (north vs south), birthdate, gender, migration status, and climate measurements at birth there should not be any unobservable variables that could be systematically correlated with both heating policy exposure in early life and later academic performance. The balance tables (Table 2) are conducted for the selected cities within a 100km distance from the policy line. The sample in northern and southern cities is somewhat different. I will, thus, control for individual differences in the empirical estimates. The differences in outdoor temperature measurements for individuals in northern and southern cities (i.e., in winter, summer, and yearly temperature) are relatively small. However, the temperature differences at the city level are almost similar and only vary by less than 0.4°C in winter months. I am not aware of any literature suggesting that these small differences could significantly impact my outcomes. Moreover, multiple hypothesis tests were conducted with different specifications to adjust the significance level [5].

Table 2: Balance Tables for Northern vs Southern Cities with Similar Climate and Distance from Policy Line

| | Mean-S | Mean-N | Mean Diff | N | SE | p-value |
|---|---|---|---|---|---|---|
| Male | 0.409 | 0.539 | -0.131 | 1192 | 0.032 | 0.000 |
| Birth Year | 2003.625 | 2003.915 | -0.290 | 1192 | 0.059 | 0.000 |
| Migrant Father | 0.341 | 0.402 | -0.061 | 1192 | 0.031 | 0.050 |
| Population Change (Annual) | 2.871 | 3.972 | -1.101 | 27 | 0.468 | 0.020 |

Average monthly outdoor temperature levels

| | Mean-S | Mean-N | Mean Difference | N | SE | p-value |
|---|---|---|---|---|---|---|
| Whole Year | 14.567 | 16.214 | -1.646 | 1192 | 0.460 | 0.000 |
| Winter | 0.411 | 0.715 | -0.303 | 1192 | 0.091 | 0.000 |
| Summer | 8.577 | 10.068 | -1.490 | 1192 | 0.732 | 0.000 |

*Notes:* The table includes balance table results. The data for the population is taken from: http://www.macrotrends.net/, and covers the period of infants' birth year range.

## 5. Main Results

### 5.1 Heating Impact

Table 3 shows the results for the main specification for cities with around 100km distance from both sides of policy line. Each column includes different measurements of climate variables including 1, 2 and 3 months after (column 1 to 3) and before (columns 4 to 6)

[5]The tests results can be found in Appendix: Table A.4

birth. The interaction between the heating and winter dummy is positive and significant. This interaction demonstrates a positive impact on infants born during the winter season in a city in the northern province. This result could be evidence that free winter household heating has a positive lasting impact on academic performance. In other words, the reduction of energy poverty in households improves the future academic performance of infants. Furthermore, the interaction between heating and summer dummy is very small and insignificant. This coefficient indicates that children born during the summer period (when there is no heating necessary) in both northern and southern cities perform similarly.

The rest of the results demonstrate that boys in the sample perform significantly worse compared to girls. One possible explanation for these results could be that the exposure to adverse environmental conditions has a different impact scale for boys and girls (Hanna & Oliva, 2016). Moreover, the literature indicates that in China, boys usually have lower executive functioning compared to girls (Thorell et al., 2013). Next, having a migrant father has a negative impact on math test scores. This is because parental migration negatively affects the child's psychosocial well-being and often leads to insufficient assistance and care for the children (Zhao et al., 2018; Liu et al., 2018). However, this impact is not statistically significant in most cases.

Table 3: Household Heating and Outdoor Climate Impact

Dependent variable: Standardized math exam scores

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Heat x Winter | 0.155* | 0.145* | 0.115* | 0.198* | 0.186* | 0.155** |
| | (0.047) | (0.038) | (0.020) | (0.018) | (0.022) | (0.009) |
| Heat x Summer | -0.0374 | -0.0373 | -0.0191 | -0.176 | -0.182 | -0.188 |
| | (0.599) | (0.448) | (0.404) | (0.183) | (0.158) | (0.130) |
| Heat | 0.610** | 0.616** | 0.659** | 0.806** | 0.892** | 0.942** |
| | (0.007) | (0.004) | (0.009) | (0.004) | (0.005) | (0.002) |
| Summer | 0.0217 | 0.0432 | 0.105 | -0.0119 | -0.00557 | 0.0294 |
| | (0.867) | (0.619) | (0.307) | (0.638) | (0.913) | (0.137) |
| Winter | -0.0157 | 0.0123 | -0.0596 | -0.0238 | -0.00241 | 0.0201 |
| | (0.848) | (0.904) | (0.497) | (0.313) | (0.949) | (0.109) |
| heightControls | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 1192 | 1192 | 1192 | 1192 | 1192 | 1192 |

*Notes:* The table tests the impact of the heating policy in northern (winter heating) and southern cities with similar climate and distance from policy line. Each column includes a different set of meteorological variables. Specifically, columns 1 to 3 include average monthly meteorological measurements after 1, 2, and 3 months of infants' birth. Meanwhile, columns 4 to 6 include measurements for 1, 2, and 3 months before the infants' birth. The full table can be found in the Appendix (Table A.5). Standard errors are clustered at the city level, and the wild bootstrap approach has been utilized.
p values in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

### 5.2 Further Results

Next, I check the outdoor climate impact for infants born during the summer and winter seasons. The results (Appendix: Table A.6) show that for schoolchildren born during winter, the rising temperature levels before birth (pregnancy period) have a small but positive and significant impact on their future educational attainment, while for those born during the summer season, the impact of rising temperature levels is close to zero and not statistically significant. These results may highlight the importance of suitable environmental conditions during the pregnancy period for the benefit of an unborn child. Subsequently, I run the same model again, but this time I include simultaneously meteorological variables both before and after birth with the following range: 1, 2, and 3 months before and after the infant's birth. That is to say, for each case (1, 2, and 3 months) I have 2, 4, and 6 months of climate measurements for each child. The results (Appendix: Table A.7) show that during the pregnancy period, the rising outdoor temperature has a positive and significant (but only in one specification) impact on math test scores. Given that the outdoor temperature range is around 2°C to 28°C for the analyzed cities, the results are consistent with studies that examine the impact of extreme temperature exposure on human wellbeing (Isen et al., 2017; Carleton et al., 2020).

### 5.3 Placebo Test and Additional Robustnes Checks

In order to indirectly assess the validity of the identification assumption, I run a placebo test to ensure that the observed impact comes from winter heating. In this test, I shift the heating policy line to the north and focus only on the northern cities with free heating during the winter period. Specifically, I take the cities in the northern provinces and divide them into 2 groups according to their distance from the heating policy line: group 1 includes the treated cities with free heating, and group 2 consists of the untreated (false) cities that in reality have free winter heating, but I treat them as if they do not. In other words, I move the policy line up (to the north) and treat northern cities that are now under the new policy line as cities with no heating. I have done the same for southern cities, by shifting the policy line down to the south (Appendix: Figure A.3). The goal of this placebo test is to check whether there is a large and significant impact among children born during winter and summer in only northern and southern cities. The results demonstrate no such impact (Appendix: Table A.8 and Table A.9).

One of the potential concerns in my analysis could be that given the heating policy, the parents could plan the pregnancy period to avoid adverse environmental conditions. However, in the data, the share of births per season is similar (Appendix: Figure A.4). Additionally, for academic attainment, I am using the standardized math test scores, and the literature demonstrates (Goodman et al., 2018; Cook & Heyes, 2020) that short-run exposure to extreme temperatures during the test/exam period could impact academic performance. However, in my sample, the tests were taken during April and May, when the temperature level varied through a comfortable range of 18 - 20 °C (Appendix: Figure A.5). Furthermore, it is possible that an infant was born in a given location, but at some point changed the city of residence (i.e. migrate from a southern to a northern city). This could potentially affect the results, and thus I control for the child's parents' migration status to avoid this issue. Finally, in China, coal serves as the primary source for heating (Almond et al., 2009). Consequently, this leads to air pollution, which can hinder academic performance and negatively impact infant health in the short term due to upper respiratory irritation (Kampa & Castanas, 2008). Therefore, during the years (2014 and 2015) when the math exam was conducted in my dataset, I compare various air pollution measures in the analyzed cities to ensure their similarity. (Appendix: Table A.10).

## 6. Conclusion

Infants' development during the premature stage is crucial for human capital, and an adverse environment during early childhood could hinder future well-being. This research demonstrates that exposure to energy poverty during infancy damages later academic performance in school. Moreover, policies aimed at reducing energy poverty could help alleviate this impact. In particular, my findings indicate the long-term positive effects of providing free household heating on the educational attainment of Chinese schoolchildren. Although the current datasets require improvements to facilitate a more comprehensive analysis, the results from this study can be valuable for governments and local administrations in formulating targeted policies to enhance the well-being of future generations.

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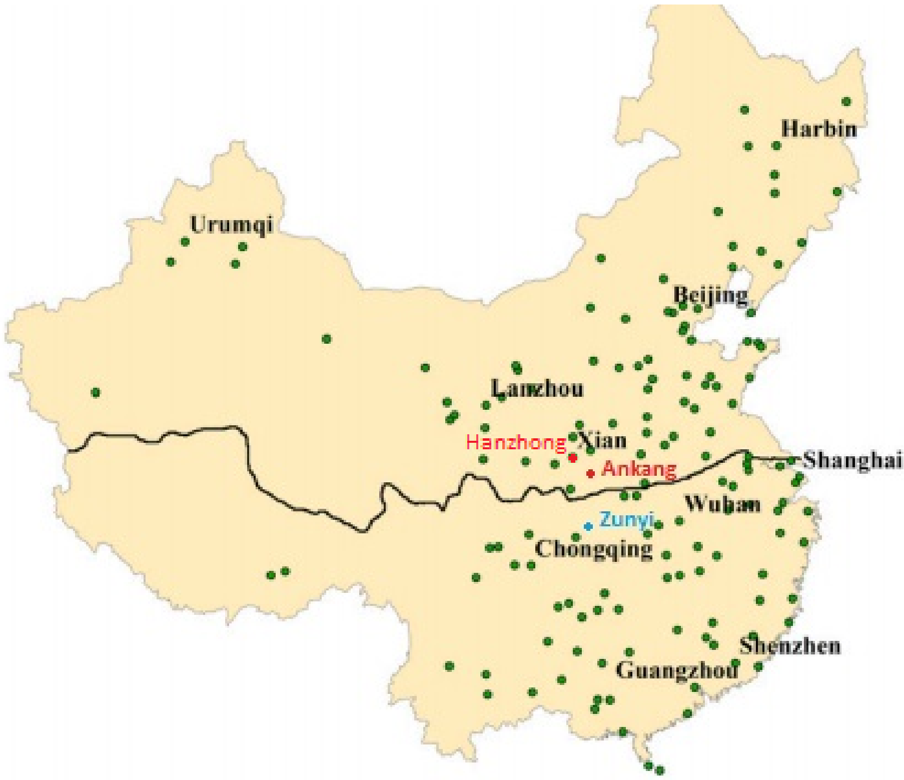
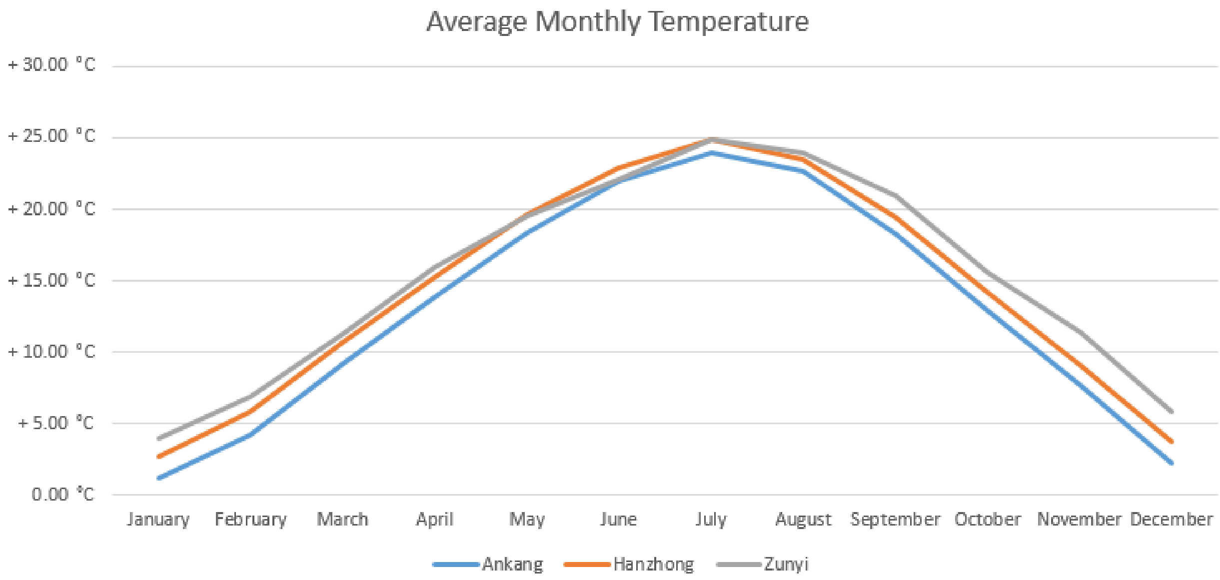
## Appendix

Figure A.1: Cities near the Huai River



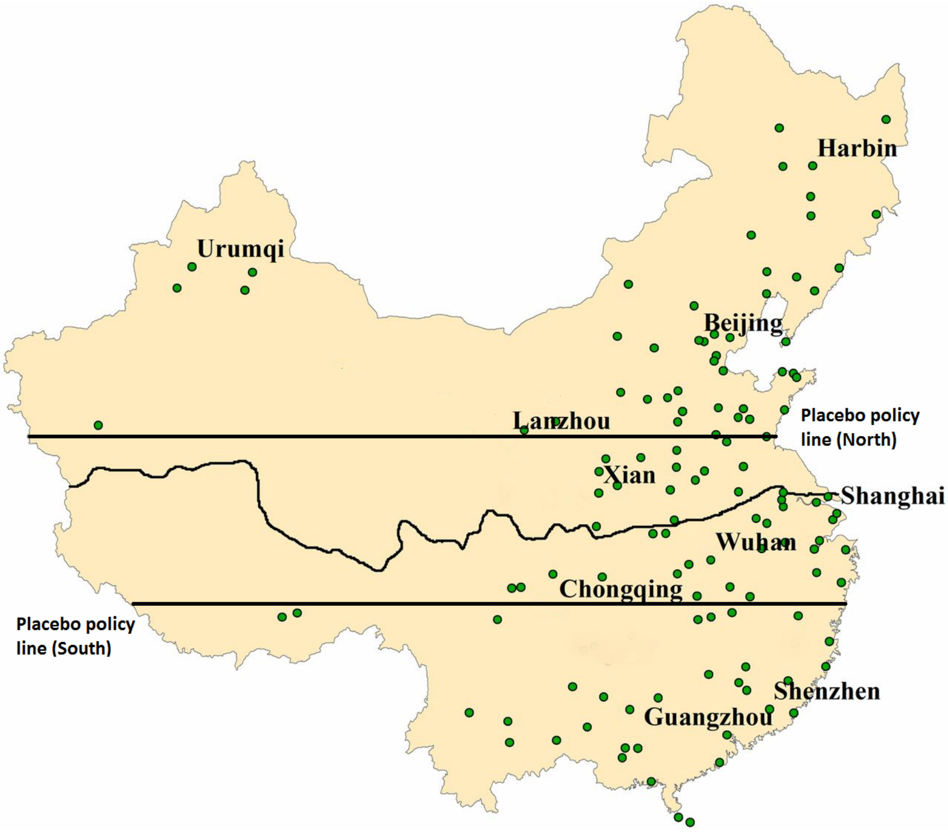

*Notes:* The figure depicts a map of China, illustrating a subset of cities situated around 100km north and south of the policy line, characterized by similar climate conditions. Source: Own modification of Ebenstein et al. (2017)

Figure A.2: Average Monthly Temperatures (1998 - 2009)



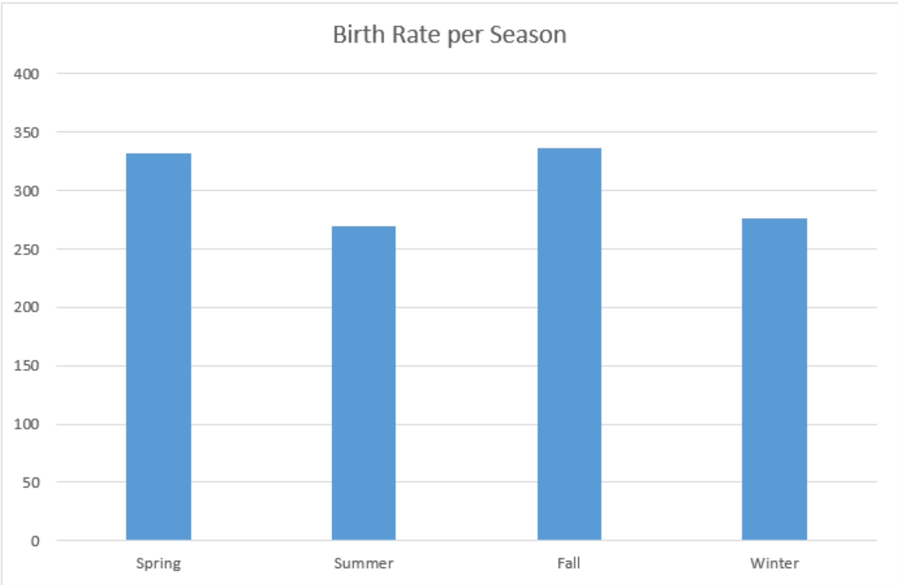

*Notes:* The figure displays average monthly temperature levels for a subset of cities near the policy line, covering the range of infant birth years. Source: https://stat.world/en

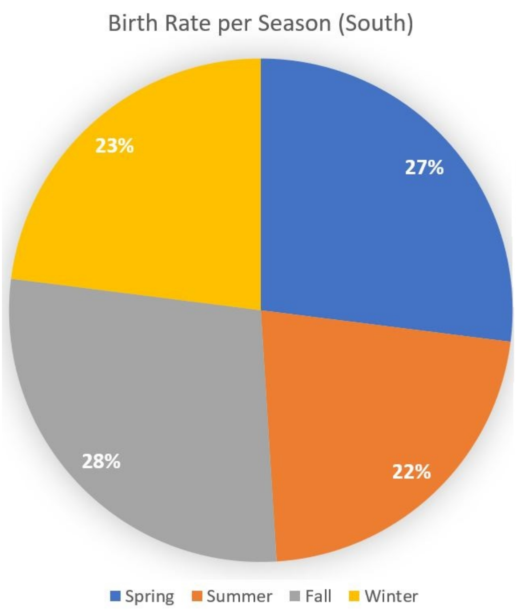
Figure A.3: Placebo test (North and South)

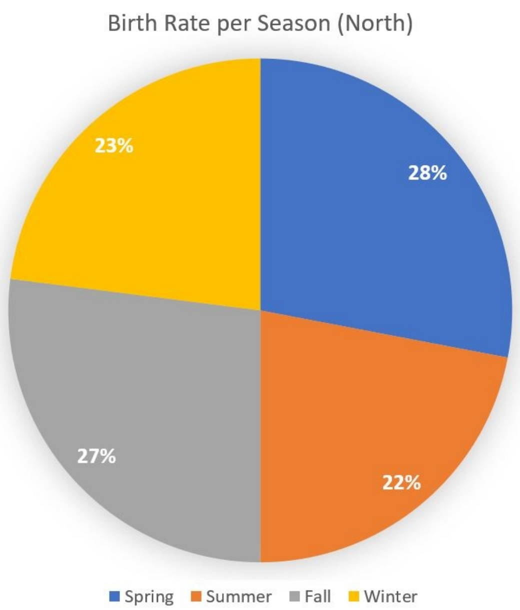



*Notes:* The figure demonstrates the new placebo policy lines for only northern and southern cities. Source: Own modification of Ebenstein et al. (2017)

Figure A.4: Birth Rate per Season: Whole Sample and South vs North

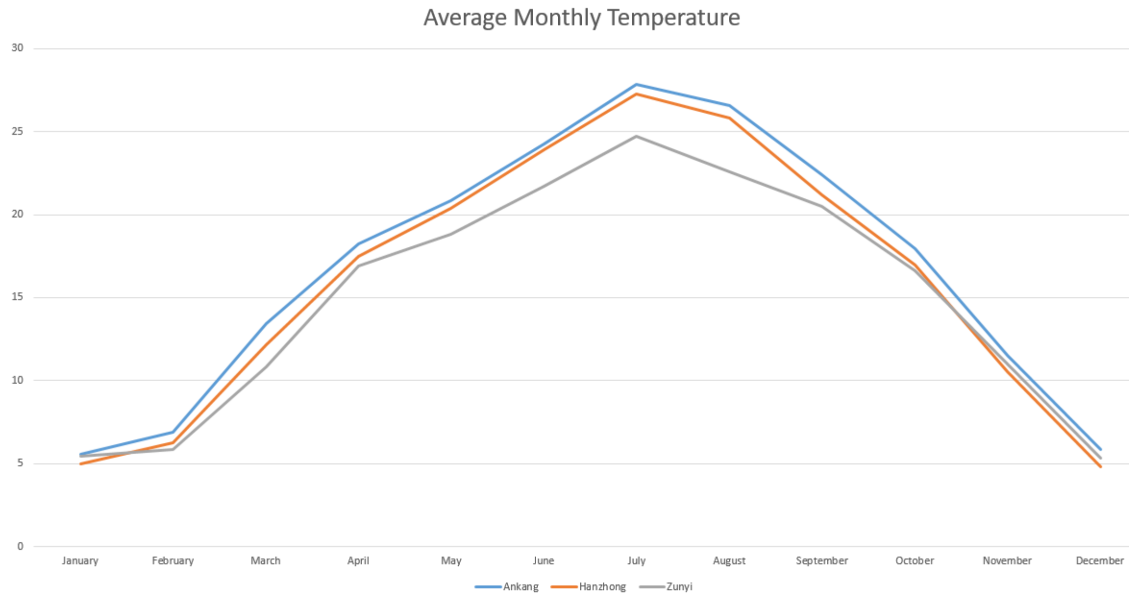



*Notes:* The figures display the birth rates per season for the entire sample, as well as the comparison between cities in the northern and southern regions. Source: Own calculations

Figure A.5: Average Monthly Temperatures (2014 - 2015)




*Notes:* The figure displays average monthly temperature levels for a subset of cities near the policy line, covering the years when math exams were taken. Source: https://stat.world/en

Table A.4: Multiple Hypothesis Testing for Cities with Similar Climate and Distance from Policy Line

| | Model p-value | Holm-Bonferroni | Benjamini-Hochberg |
|---|---|---|---|
| Heat x Winter | 0.005 | 0.005 | 0.009 |
| Heat x Summer | 0.343 | 0.010 | 0.031 |
| Male | 0.000 | 0.004 | 0.004 |
| Father Migrant | 0.108 | 0.006 | 0.018 |

*Notes:* I perform multiple hypothesis testing for all coefficients in the model with different testing concepts. The table presents the results only for the main coefficients of interest.

Table A.5: Household Heating and Outdoor Climate Impact

| Dependent variable: Standardized math exam scores | | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Heat | 0.610** | 0.616** | 0.659** | 0.806** | 0.892** | 0.942** |
| | (0.007) | (0.004) | (0.009) | (0.004) | (0.005) | (0.002) |
| Father Migrant | -0.107 | -0.106 | -0.106* | -0.0986 | -0.0960 | -0.0976 |
| | (0.074) | (0.057) | (0.048) | (0.071) | (0.052) | (0.053) |
| Grade | 0.157 | 0.146 | 0.139 | 0.133 | 0.124 | 0.121 |
| | (0.126) | (0.158) | (0.216) | (0.108) | (0.121) | (0.153) |
| Summer | 0.0217 | 0.0432 | 0.105 | -0.0119 | -0.00557 | 0.0294 |
| | (0.867) | (0.619) | (0.307) | (0.638) | (0.913) | (0.137) |
| Winter | -0.0157 | 0.0123 | -0.0596 | -0.0238 | -0.00241 | 0.0201 |
| | (0.848) | (0.904) | (0.497) | (0.313) | (0.949) | (0.109) |
| Heat x Summer | -0.0374 | -0.0373 | -0.0191 | -0.176 | -0.182 | -0.188 |
| | (0.599) | (0.448) | (0.404) | (0.183) | (0.158) | (0.130) |
| Heat x Winter | 0.155* | 0.145* | 0.115* | 0.198* | 0.186* | 0.155** |
| | (0.047) | (0.038) | (0.020) | (0.018) | (0.022) | (0.009) |
| Male | -0.104** | -0.104** | -0.104** | -0.0967** | -0.103*** | -0.105** |
| | (0.002) | (0.002) | (0.001) | (0.005) | (0.001) | (0.001) |
| Heat x Male | 0.0301 | 0.0338 | 0.0355 | 0.0255 | 0.0353 | 0.0413 |
| | (0.587) | (0.475) | (0.418) | (0.610) | (0.390) | (0.280) |
| Temp1 | 0.0256 | | | | | |
| | (0.213) | | | | | |
| Wind1 | 0.131 | | | | | |
| | (0.474) | | | | | |
| Pressure1 | 0.0193 | | | | | |
| | (0.230) | | | | | |
| Temp2 | | 0.0375 | | | | |
| | | (0.343) | | | | |
| Wind2 | | 0.202 | | | | |
| | | (0.517) | | | | |
| Pressure2 | | 0.0333 | | | | |
| | | (0.379) | | | | |

| | Math \| \| \| \| | Math \| \| \| \| | Math | Math | Math | Math |
|---|---|---|---|---|---|---|
| Temp3 | | | 0.0304 | | | |
| | | | (0.479) | | | |
| Wind3 | | | 0.257 | | | |
| | | | (0.516) | | | |
| Pressure3 | | | 0.0359 | | | |
| | | | (0.448) | | | |
| TempB1 | | | | 0.0131* | | |
| | | | | (0.018) | | |
| WindB1 | | | | 0.278 | | |
| | | | | (0.143) | | |
| PressureB1 | | | | 0.00191 | | |
| | | | | (0.404) | | |
| TempB2 | | | | | 0.000527 | |
| | | | | | (0.930) | |
| WindB2 | | | | | 0.348 | |
| | | | | | (0.119) | |
| PressureB2 | | | | | -0.00748 | |
| | | | | | (0.544) | |
| TempB3 | | | | | | -0.00922 |
| | | | | | | (0.269) |
| WindB3 | | | | | | 0.386 |
| | | | | | | (0.074) |
| PressureB3 | | | | | | -0.0127 |
| | | | | | | (0.108) |
| Observations | 1192 | 1192 | 1192 | 1192 | 1192 | 1192 |

*Notes:* The table tests the impact of the heating policy in northern (free winter heating) and southern cities with similar climate and distance from the policy line. Each column includes a different set of meteorological variables. Specifically, columns 1 to 3 include average monthly meteorological measurements after 1, 2, and 3 months of infants' births. Meanwhile, columns 4 to 6 include measurements for 1, 2, and 3 months before the infants' births. Standard errors are clustered at the city level, and the wild bootstrap approach has been utilized.
p values in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A.6: The Outdoor Temperature Impact

Dependent variable: Standardized math exam scores

| | (1) | (2) | (3) | (4) |
|---|---|---|---|---|
| Winter x Temp2 | -0.0590 | | | |
| | (0.693) | | | |
| Summer x Temp2 | 0.0486 | | | |
| | (0.338) | | | |
| Winter x Temp3 | | -0.00171 | | |
| | | (0.990) | | |
| Summer x Temp3 | | 0.0415 | | |
| | | (0.318) | | |
| Winter x TempB2 | | | 0.0534* | |
| | | | (0.050) | |
| Summer x TempB2 | | | 0.0100 | |
| | | | (0.493) | |
| Winter x TempB3 | | | | 0.0633** |
| | | | | (0.002) |
| Summer x TempB3 | | | | 0.00734 |
| | | | | (0.551) |
| Controls | Yes | Yes | Yes | Yes |
| Observations | 1192 | 1192 | 1192 | 1192 |

*Notes:* The table examines the impact of outdoor temperature on academic attainment. Each column represents the intersection of the season of birth dummy variable with temperature measurements for that season. The temperature measurements are taken 2 and 3 months before birth (TempB2 and TempB3) as well as 2 and 3 months after birth (Temp2 and Temp3). Standard errors are clustered at the city level, and the wild bootstrap approach has been utilized.

p values in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A.7: Household Heating and Outdoor Climate Impact

Dependent variable: Standardized math exam scores

| | (1) | (2) | (3) |
|---|---|---|---|
| Heat x Winter | 0.148** | 0.145** | 0.139** |
| | (0.009) | (0.007) | (0.005) |
| Heat x Summer | -0.0409 | -0.0578 | -0.0631 |
| | (0.459) | (0.359) | (0.343) |
| Heat | 0.595* | 0.589* | 0.583* |
| | (0.022) | (0.023) | (0.023) |
| Summer | 0.0768 | 0.00666 | -0.00798 |
| | (0.436) | (0.942) | (0.936) |
| Winter | -0.104 | -0.0567 | -0.0479 |
| | (0.181) | (0.388) | (0.466) |
| Temp1 | -0.00712 | | |
| | (0.483) | | |
| TempB1 | 0.0112** | | |
| | (0.005) | | |
| Temp2 | | 0.00493 | |
| | | (0.568) | |
| TempB2 | | 0.00689 | |
| | | (0.135) | |
| Temp3 | | | 0.00849 |
| | | | (0.435) |
| TempB3 | | | 0.00874 |
| | | | (0.240) |
| Controls | Yes | Yes | Yes |
| Observations | 1192 | 1192 | 1192 |

*Notes:* The table tests the impact of the heating policy in northern (free winter heating) and southern cities with similar climate. Each column simultaneously includes outdoor temperature measurements both before and after the birth. Standard errors are clustered at the city level, and the wild bootstrap approach has been utilized.

p values in parentheses

* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A.8: Household Heating and Outdoor Climate Impact (Placebo - North)

Dependent variable: Standardized math exam scores

| | (1) | (2) | (3) | (4) | (5) | (6) |
|---|---|---|---|---|---|---|
| Heat x Winter | -0.110 | -0.114 | -0.115 | -0.108 | -0.111 | -0.114 |
| | (0.160) | (0.128) | (0.116) | (0.152) | (0.137) | (0.126) |
| Heat x Summer | -0.151 | -0.136 | -0.130 | -0.156 | -0.151 | -0.151 |
| | (0.155) | (0.170) | (0.154) | (0.077) | (0.070) | (0.072) |
| Heat | 0.163 | 0.167 | 0.169 | 0.162 | 0.160 | 0.157 |
| | (0.531) | (0.516) | (0.507) | (0.536) | (0.541) | (0.549) |
| Summer | 0.132 | 0.0866 | 0.0662 | 0.153 | 0.146 | 0.139 |
| | (0.623) | (0.697) | (0.703) | (0.252) | (0.146) | (0.084) |
| Winter | 0.0824 | 0.101 | 0.0940 | 0.0548 | 0.0537 | 0.0514 |
| | (0.596) | (0.287) | (0.113) | (0.614) | (0.491) | (0.421) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 8058 | 8058 | 8058 | 8058 | 8058 | 8058 |

*Notes:* The table includes the results from a placebo test conducted among only northern cities, with the policy line shifted to the north. Each column includes a different set of meteorological variables. Standard errors are clustered at the city level, and the wild bootstrap approach has been utilized.

p values in parentheses

$^{*}$ $p < 0.05$, $^{**}$ $p < 0.01$, $^{***}$ $p < 0.001$

Table A.9: Household Heating and Outdoor Climate Impact (Placebo - South)

| Dependent variable: Standardized math exam scores | | | | | | |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Heat x Winter | -0.0306 | 0.0194 | 0.0197 | -0.0184 | -0.00243 | 0.00709 |
| | (0.274) | (0.649) | (0.782) | (0.378) | (0.931) | (0.804) |
| Heat x Summer | 0.0989 | 0.0739 | 0.0590 | 0.0865 | 0.0213 | -0.00833 |
| | (0.184) | (0.069) | (0.117) | (0.096) | (0.825) | (0.894) |
| Heat | 0.0469 | -0.0644 | 0.00476 | 0.121 | -0.0948 | -0.175 |
| | (0.491) | (0.350) | (0.940) | (0.147) | (0.448) | (0.513) |
| Summer | 0.103 | 0.143 | 0.149 | 0.0812 | 0.0773 | 0.0170 |
| | (0.628) | (0.520) | (0.512) | (0.386) | (0.371) | (0.838) |
| Winter | -0.116 | -0.172 | -0.180 | -0.126 | -0.116 | -0.0516 |
| | (0.168) | (0.087) | (0.115) | (0.081) | (0.099) | (0.313) |
| Controls | Yes | Yes | Yes | Yes | Yes | Yes |
| Observations | 2886 | 2886 | 2886 | 2886 | 2886 | 2886 |

*Notes:* The table includes the results from a placebo test conducted among only southern cities, with the policy line shifted to the south. Each column includes a different set of meteorological variables. Standard errors are clustered at the city level, and the wild bootstrap approach has been utilized.
p values in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table A.10: Balance Table for Cities with Similar Climate and Distance from Policy Line

| Average daily air pollution levels | | | | | | |
|---|---|---|---|---|---|---|
| | Mean-South | Mean-North | Mean Diff | N | SE | p-value |
| pm25 | 137.111 | 119.160 | 17.950 | 1083 | 2.853 | 0.000 |
| pm10 | 76.349 | 60.685 | 15.664 | 1080 | 1.963 | 0.000 |
| no2 | 18.694 | 12.941 | 5.753 | 1082 | 0.407 | 0.000 |
| so2 | 16.902 | 12.941 | 7.472 | 1081 | 0.534 | 0.000 |
| co | 9.280 | 13.301 | -4.021 | 1079 | 0.331 | 0.000 |

*Notes:* The air pollution data was obtained from: https://aqicn.org/. The available historical air pollution data covers the period from 2014 to 2015. The surveys measuring academic performance were undertaken in 2014 and 2015.

# Abstrakt

Stávající studie potvrzují krátkodobou souvislost mezi životním prostředím a akademickým výkonem. Dlouhodobé účinky vystavení nepříznivým životním podmínkám na studijní výsledky však zůstávají neprozkoumané. Tato studie zkoumá dlouhodobý dopad energetické chudoby a politických intervencí, zaměřených na její zmírnění, na akademický výkon čínských školáků počínaje z dětství. Konkrétně využívá politiku Huai River Policy, která poskytuje bezplatné zimní vytápění výhradně severním regionům v Číně, ale ne sousedním jižním regionům. Moje zjištění naznačují významný pozitivní vliv zimního vytápění na školní výkony školáků, s výraznějším vlivem u dětí narozených v zimních měsících. Poznatky získané z tohoto výzkumu by mohly být základem pro politické debaty s cílem zlepšit výsledky vzdělávání a lidské blaho.

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