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Central Heating Policy and Population Migration in China: An Empirical Study

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ABSTRACT

The Huai River policy divides the country into the areas with and without central heating. This paper first determines the location of the south-north central heating borderline in China based on the Huai River policy, and then studies the differences in population migration between the north and the south. It proposes three factors that influence people's decision to migrate through district heating: heating costs, indoor living conditions, and outdoor air quality. Through the empirical analysis of the county-level data adjacent to the heating borderline in China, the following three basic conclusions are drawn: first, based on the estimation of the total sample, the total effect of central heating on population in-migration is negative; Second, central heating positively impacts in-migration in wealthier counties, while the impact is negative in less-developed counties. Third, the heating boundary policy affects population migration via air pollution. However, air pollution is not the decisive factor.

Keywords: Central Heating, The Heating Boundary, Population Migration, Air Pollution, The Huai River Policy
JEL Classifications: Q4, Q5, J1, J6

1. INTRODUCTION

Central heating is the expression of district heating in the Chinese context. The word "central" means "centralized" instead of "scattered". Central heating in China is closely connected to the nation's policy as heating-induced energy exhaustion could generate high costs and air pollution. As a result, the country has set winter heating boundaries since the establishment of district heating in the 1950s. The boundary formed a fixed dividing line to distinguish heated areas from unheated areas. The areas with cold winters could have state-planned central heating systems, while areas with warmer winters did not. The boundary was set based on winter temperature levels, which hasn't changed since the 1950s (Nuorkivi, 2016). The borderline is the zero-degree isotherm of January, coinciding with two critical geographical matters in China: the Huaihe River and Qinling Mountains. The policy of classifying the areas with and without heating is called the Huai River policy. The heating district north of the boundary has installed central heating in its apartments to provide comfortable living conditions. In the south, without central heating systems, people may endure humidity and coldness. They may purchase personal heating facilities like air conditioners, natural furnaces, or electric heaters. Even in the north, central heating systems are mainly concentrated in urban areas, including the central urban areas of the prefecture-level cities and counties. The residents living slightly south of this borderline have suffered the most. Families living near the borderline may be sensitive to this policy and may respond differently.

This study focuses on the policy impact on population migration. The Huai River policy produces differences in air pollution, living comfort, and heating costs between the borderline. People near the heating border will weigh these three aspects and choose to live in areas with or without heating. Then, population migration impacts the economic vitality of the nearby regions, which may generate more regional differences.

Across the country, discussions about the introduction of central heating systems in the south have been trendy in recent years as some southerners want to have central heating as well. Guo et al. (2015) pointed out that this issue had already become a national debate. At the national level, the government must balance the effects of energy exhaustion and air pollution. From the residents' point of view, they are more interested in central heating services for affordable comfort without spending excessive money. At the same time, a moderate rise in air pollution might be acceptable. Residents may also balk at introducing these systems if the heating systems produce massive air pollutants.

Existing literature has proven that winter heating can produce more air pollution. Papers linking the relationship between winter heating and air pollution are not hard to find (Almond et al., 2009; Liang et al., 2015; Xiao et al., 2015; Li and Cao, 2017). They all discovered that winter heating had an essential impact on the increased air pollutants in China. There are also papers discussing the impact imposed by air pollution on population migration in China. Chen et al. (2013) studied the effect of air pollution on life expectancy in China and found that this impact did exist and was very significant. Gao and Sampattavanija (2022) explored the marginal effects of winter heating on air pollution in China. They found that central winter heating could bring up major air pollutants by 17.62% on average until 2019. There are also large groups of papers trying to determine the impact of air pollution on people's health, life expectancy, productivity, and even prices in the housing market (Chay et al., 2005; Tanaka, 2015; Hanna et al., 2015).

Papers discussing the effects of heating policy on household expenditures and living comfort are rare. Fielding (2011) found that people like to stay in areas with district heating. Gale and Heath (2000) thought that places with higher heating costs would not be attractive for in-migration. People might be attracted by better living conditions and choose to move to those cities with winter heating systems. Meanwhile, they might be worried about the costs. This paper will explore the policy-induced distinctions in migration north and south of the heating borderline. We use a county-level dataset.

Gao and Sampattavanija (2023) developed a theoretical model and validated a U-shaped relationship for population migration in areas south of the heating borderline using the prefecture-level datasets. They did not consider the migration situation north of the borderline. This study is different from that one. In this study, we want to know the population migration status between the heating borderline and use the data of counties just adjacent to the heating borderline.

The following sections will be arranged like this. Section 2 will further explain the heating policy in China. Section 3 explains how population migration is measured in this paper. Section 4 is the theoretical analysis and hypothesis. Section 5 is our benchmark estimation and robustness checks. Section 6 is the conclusion and policy implications.

2. "HEATING BOUNDARY" POLICY

The "Heating boundary" policy is a central-planned policy that sets the borderline between the heating and non-heating areas. This borderline considers the winter climate. Regions with colder winters are included on the northern side of this borderline. As regions in the more "southern" parts have higher humidity levels and receive more rainfall, they could have less sunshine, and the felt air temperature is not much higher than in the north.

The "heating boundary" policy is also called the Huai River policy as the boundary roughly coincides with one of the most crucial geographical boundaries in China, the Qin-Mountain and Huai River boundary of China, which is also the 0° isotherm of January and 800 mm-isohyet.

A criterion for deciding the construction of heating systems is important. To precisely measure the heating status of a place, we define the heating density as

$$populationHeating\ dentisy = Central\ heating\ area\ / \ permanent\ population \quad (1)$$

The prefecture-level cities near the central heating borderline could be divided into Group I, Group II, and Group III. Cities with heating density larger than 1 are included in Group I. Cities with heating density higher than 0, but <1 are included in Group III. Cities with heating density equal to 0 are included in Group II. Appendix A reports information about the operation of central heating systems near the heating boundary in China.

3. POPULATION MIGRATION

China has a vast territory and imbalanced degrees of development. As economic development varies from city to city, it is normal for people to migrate from one place to another across the country because they change their studies, employment, marital status, or other issues. Central heating borderline may generate differences in indoor living conditions and outdoor air pollution levels and influence migration. The mechanical population growth can represent population migration. Population growth is composed of the natural growth and the mechanical growth. Natural growth means the natural deaths and births. Mechanical growth means the growth engendered by migration.

The mechanical growth rate (M_t) can be calculated using the general growth rate (G_t) minus the natural growth rate (N_t).

$$M_t = G_t - N_t \quad (2)$$

In our further analysis, we will use M_t as the proxy variable for migration. In the actual estimation, G_t will be taken as the dependent variable and N_t is the control variable. In addition, we also introduce the actual increment in population, Δ_t.

The followings are the introduction of the G_t and Δ_t.

The gross growth rate G_t of the permanent population (PP) is defined as

$$G_t = PP_t / PP_{t-1} \quad (3)$$

The increment between the permanent population of period t and the permanent population of the period (t-1) is defined as

$$\Delta_t = PP_t - PP_{t-1} \quad (4)$$

G_t and Δ_t are the dependent variables (they are equivalent) and N_t (Natural) is the independent variable in our further estimations.

4. HEATING AND POPULATION MIGRATION

The mechanism by which heating affects migration is as follows.

Heating can make winter room temperature more comfortable, raising people's living comfort and attracting in-migration. We call this effect the "encouraging effect."

Areas with central heating services have naturally colder winter temperatures as they are located north, which will generate higher heating costs without considering the policy effect. In addition, central heating services are usually charged in the total amount. Although the unit price might be lower than scattered heating, the total amount is larger. Migrant workers engaged in informal work are sensitive to the cost. They may want to use the personal heating facilities to save the total cost. In this sense, heating policy might inhibit the inflow of residents. This effect is defined as the "cost-related depressing effects." We infer that people of different income levels will have different attitudes toward central heating services.

Another aspect is that when people enjoy higher room temperatures, they endure more air pollutants, as heating, through burning coal and other fossil fuels, has been proven to worsen the air quality. This aspect can depress population in-migration. We call this effect the "pollution-related depressing effects." The total effects are the sum of both encouraging and depressing effects (cost-related and pollution-related).

Whether central heating systems could be an advantage or disadvantage for households depends on the rank of heating costs, indoor living comfort, and outdoor air quality. For example, we could guess migrant workers might be more interested in having better living conditions than having good air quality. After all, air quality benefit is a long-term issue.

If we add these three effects, we could conclude that the encouraging effects are more significant than the pollution-related depressing effects. The depressing effects caused by higher heating costs might be the most crucial part. The sum of these three might cause a negative impact of central heating on population migration. This hypothesis needs to be further verified.

5. EMPIRICAL ANALYSIS

5.1. Methodology

The methodology for the benchmark estimation is

$$G_{it} = \alpha + \beta heating_i + \gamma longitude_i + \delta GDP_{it} + f\left(latitude_i\right) + \mu N_{it} + \theta Province_i + \lambda City_i + \varepsilon_{it} \quad (5)$$

$$\Delta_{it} = \alpha + \beta heating_i + \gamma longitude_i + \delta GDP_{it} + f\left(latitude_i\right) + \mu N_{it} + \theta Province_i + \lambda City_i + \varepsilon_{it} \quad (6)$$

The methodology is inspired by Almond et al. (2009), Chen and Whalley (2012). Two dependent variables G_{it} and $\varnothing_{it}$ have been explained in section 4.

Heating is the key independent variable in the model. It is a dummy variable with values of either 0 or 1. According to Appendix A, regions included in Group I have a value of 1, and regions in Group II and III have a value of 0.

GDP is the counties' gross domestic product that controls the economic performance of the cities and changes according to time.

Longitude: variable indicates the longitude of cities and does not change over time.

f(latitude): a polynomial of latitude to smooth the relationship between latitude and G_t. Latitude controls the natural conditions, including climate, temperature, and location.

N_{it} is the natural growth rate of the permanent population and is used as a control variable to exclude the natural growth from the total growth.

Province and City control county affiliation.

The technique here is the regression discontinuity design (RD design). The most important factor affecting the heating demand is temperature, and there is a direct correlation between temperature and latitude. If the Huai River policy does not exist, the influence of latitude on heating demand should be continuous. Due to the Huai River policy, the influence of latitude on heating demand and even migration is artificially cut off. Therefore, RD design is used to analyze the effect of the Huai River policy on migration. Using a polynomial with latitude as an independent variable can help fit in the relationship between latitude and migration.

5.2. Data

China's administrative division systems include the nation-level, provinces (provincial-level municipalities), prefecture-level cities, counties, towns, and villages. Prefecture-level cities belong to provinces. Counties are affiliated to prefecture-level cities and managed by prefecture-level governments. Counties are the minimum administrative units with accurate statistics in China.

In order to make the estimation more convincing, we use county-level data as our samples. In the benchmark estimation, counties right along the borderline are included (Figure 1). Appendix B reports the counties included in our sample.

The dataset is a panel spanning from 2007 to 2019. It is unbalanced because some data of the dependent variables are missing. The data on the variable Heating are derived from the official statistical reports and local news from government-related websites. The longitude and latitude of the counties are retrieved from the websites https://jingwei.supfree.net/.

G, Δ, GDP, and Natural growth rates of permanent population (N) originate from the statistical yearbooks of the related prefecture-leveled cities. The descriptive statistics are listed in Table 1.

5.3. Benchmark Estimation

A random effects model and a pooled OLS work out the coefficients of equations (1) and (2).

The estimation results are reported in Table 2. We use a second-order polynomial in the estimation in case of a collinearity problem.

The key independent variable Heating has negative and significant coefficients in all these regression results. The negative values show that the population outflow has been amplified in central heating areas, suggesting that the depressing effects are larger than the encouraging effects in general. This result reveals that non-heating areas have higher mechanical population growth.

Table 1: Descriptive statistics

Variables	Obs	Mean	SD	Min	Max
G	972	0.9987	0.0244	0.8156	1.2492
Δ	972	−0.0764	2.0789	−19.1449	21.0949
Latitude	972	33.7803	0.7207	32.1168	35.1754
Longitude	972	112.7609	3.7303	104.8840	118.8320
GDP	972	173.9910	147.1641	2.6730	959.7000
N	972	5.4644	2.7275	0.4000	38.7800
Heating	972	0.5442	0.4983	0	1

The coefficients of Longitude are negative, contradicting our intuition, although they are not statistically significant for the estimation of the variable G. The variable Longitude controls the east-west location. GDP affects migration positively. The variable N has positive coefficients. Controlling the effects of natural growth, we can estimate the mechanical population growth generated by the movement of the population.

5.4. Robustness Checks

Our robustness checks have the following specifications. In robustness check I, the variable Longitude is deleted with other variables unchanged. In check II, only the variable GDP is deleted. In robustness check III, we use the first-order polynomial of latitude instead of a second-order latitude polynomial. In check IV, we delete the variables Province and City and run the estimation. The estimation results are in Table 3.

The estimation results remain good properties of robustness. All robustness checks show a negative linkage between the dependent variable and Heating. We can infer that the heating costs and air pollution (depressing effect) generated by central heating systems might be the main factors resulting in this situation. The estimation results of Δ are similar to G and omitted here.

5.5. Air Quality and Population Migration

We conduct the following estimation to verify the relationship between the central heating borderline and population migration.

$$G_{it} = \alpha + \beta Air_{it} + \gamma longitude_i + \delta GDP_{it} + \theta Province_i + \lambda City_i + f(latitude_i) + \mu N_{it} + \varepsilon_{it} \quad (7)$$

Table 2: Benchmark estimation-G_t

	RE (G)	OLS (G)	RE (Δ)	OLS(Δ)
Heating (SE)	−0.0060*** (0.0020)	−0.0060*** (0.0020)	−0.4276** (0.1741)	−0.4310*** (0.1650)
Latitude	−0.1410 (0.1101)	−0.1411 (0.1098)	−9.6563** (9.7939)	−9.8045 (9.2991)
$Latitude^2$	0.0021 (0.0016)	0.0021 (0.0016)	0.1443** (0.1459)	0.1465 (0.1308)
Longitude	−0.0004 (0.0003)	−0.0004 (0.0003)	−0.0274* (0.0254)	−0.0281 (0.0242)
GDP	0.00002*** (7.04e-06)	0.00002*** (7.03e-06)	0.00210*** (0.0006114)	0.00211*** (0.0005957)
n	1.2766* (0.6663)	1.2751* (0.6655)	124.2152** (57.5476)	121.4651*** (56.3850)
Province	0.0048* (0.0026)	0.0048* (0.0026)	0.4310* (0.2346)	0.4382** (0.2227)
City	−0.0004* (0.0002)	−0.0004* (0.0002)	−0.0318* (0.0189)	−0.0324* (0.0180)
Obs	972	972	972	972

(Numbers in parentheses are the standard errors of the coefficients. *P<0.1 **P<0.05 ***P<0.01. The same below)

Figure 1: Counties included in the benchmark estimation

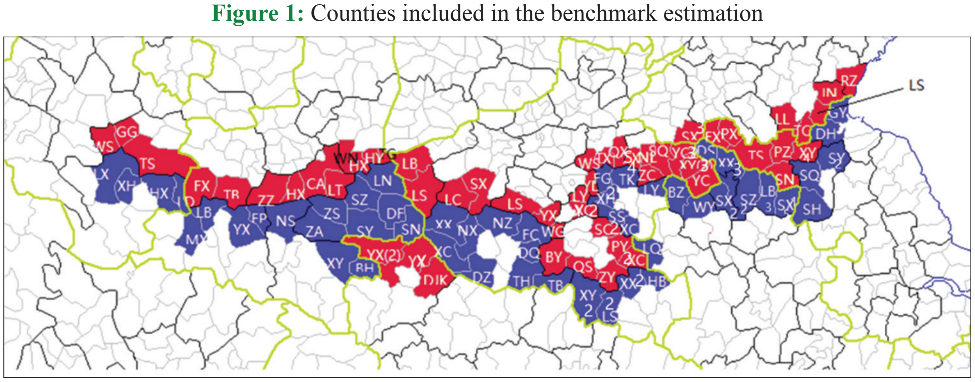


Table 3: Robustness checks-growth

Robustness Check:	I	II	III	IV
Heating	−0.0058*** (RE)	−0.0065***	−0.0055**	−0.0055**
Latitude	−0.1137	−0.1194	0.0009	−0.2528**
Latitude²	0.0017	0.0018	----------	0.0038**
Longitude	----------	0.0002	−0.0003	−0.0005*
GDP	0.00002***	---------	0.00002***	0.00002***
n	1.1250*	0.07308	1.3485**	1.5849**
Province	0.0045*	0.0059**	0.0058**	------------
City	−0.0003	−0.0005**	−0.0004**	------------
OBS	972	972	972	972

$$\Delta_{it} = \alpha + \beta Air_{it} + \gamma longitude_i + \delta GDP_{it} + \theta Province_i + \lambda City_i + f\left(latitude_i\right) + \mu N_{it} + \varepsilon_{it} \quad (8)$$

The indicator variable heating is deleted, and the air quality variable is introduced. The variable Air denotes the concentration of PM2.5 in these counties year on year. All the data remain unchanged except for introducing the new variable Air. Air data is obtained from the Dalhousie University dataset, which records the concentration of PM2.5 in 2850 counties across China. Air denotes the air pollution levels of these counties in China.

The estimation results show a negative correlation between air pollution and population in-migration (Table 4). In other words, the air pollution generated by central heating systems engenders distinctions in the mechanical population growth on both sides of the heating borderline.

Table 4: Air-G and Δ estimation results

Growth	G	Δ
Air	−0.0002** (0.0001)	−0.0106 (0.0072)
Latitude	−0.0998 (0.1088)	−6.3588 (9.8787)
Latitude²	0.0015 (0.0016)	0.0944 (0.1471)
Longitude	0.0003 (0.0004)	0.0124 (0.0343)
GDP	0.00002** (7.51e−06)	0.00186*** (0.0007)
N	1.7229*** (0.6674)	182.7372*** (152.7945)
Province	0.0024 (0.0025)	0.2392 (0.2300)
City	−0.0002 (0.0002)	−0.0161 (0.0185)
Obs	959	959

Table 5: Estimation with the variable Air-G and Δ

RE	G	Δ
Heating	−0.0060*** (0.0020)	−0.4286** (0.1751)
Air	−0.0002** (0.0001)	−0.0106 (0.0072)
Latitude	−0.1619 (0.1102)	−10.8549 (9.8463)
Latitude²	0.0024 (0.0016)	0.1626 (0.1468)
Longitude	0.0002 (0.0004)	0.0054 (0.0338)
GDP	0.00002** (7.49e−06)	0.0018*** (7.49e−06)
N	1.4320** (0.6713)	132.8263** (58.1406)
Province	0.0051*(0.0027)	0.4351**(0.2385)
City	−0.0004*(0.0002)	−0.0322* (0.0192)
Obs	959	959

5.6. Air as a Control Variable

The above analysis shows that the heating boundary could impact population migration through air pollution. In this section, we will include the variable Air as the control variable. The following regression is performed:

$$G_{it} = \alpha + \beta Heating_i + Air_{it} + \gamma longitude_i + \delta GDP_{it} + \theta Province_i + \lambda City_i + +f\left(latitude_i\right) + \mu N_{it} + \varepsilon_{it} \quad (9)$$

$$\Delta_{it} = \alpha + \beta Heating_i + Air_{it} + \gamma longitude_i + \delta GDP_{it} + \theta Province_i + \lambda City_i + +f\left(latitude_i\right) + \mu N_{it} + \varepsilon_{it} \quad (10)$$

These regressions can decompose the effects of central heating into air pollution effect and other effects (Table 5). We could compare the estimation results with our benchmark estimation to know the effects of different aspects. The variable Heating's coefficient is still negative but slightly larger than in the benchmark estimation. Air hampers migration but in a mild way. All these further illustrate that air pollution does not play a decisive role among these three effects. Heating costs and living comfort could be the most important ones.

5.7. Heterogeneity by Economic Development

In section 5.6, we verified air pollution's impact on population migration. The negative effect between central heating and population migration still exists after the control of air pollution effect. This shows that the heating-costs-related depressing effect may account for a dominant proportion. Therefore, counties with different levels of economic development may have different situations. In this section, we classify the dataset into different GDP per capita groups and compare the results across regions of different economic development. The estimation methodology is the same as what we used in section 5.6.

We classify the dataset into two groups, one with a higher GDP per capita and the other with less GDP per capita, using a critical value c. As economic development is dynamic, we do not take one place as an indivisible part. Some counties' GDP increases in recent years and can be included in the higher group. We want to compare the coefficients of the two groups to verify whether the depressing effects generated by higher heating costs are more significant in the poorer group and less significant in the wealthier group. People's attitudes might differ among those living in one area but with different wage levels.

The GDP per capita is calculated using the variable GDP and permanent population. We first set criterion c at 50,000 RMB. Counties with higher than 50,000 GDP per capita are classified as high-income groups. We perform these regressions in different groups and compare the results with the previous ones. Table 6 reports the estimation results.

To further verify the result, we run the estimation with the change of the classification criteria from 20,000 to 60,000, respectively. We run the regressions under the conditions that the GDP per capita is larger than this criterion c and <c (Table 7). Then we plot the relationship between the critical values and the values of the coefficients Heating (Figure 2).

In the high-income group, the coefficient of Heating is positive, showing a positive relationship between central heating and population migration. In this situation, the encouraging effect plays a decisive part. The extra data have an inverse result that central heating negatively impacts migration in the low-income group. By changing criteria c, we find that the positive impact increases when the classification criteria are raised according to Table 8. Moreover, the significant level is also raised when c increases. When c increases, the regressions with the remaining data (GDP per capita < c) have weaker and weaker depressing effects. Figure 2 illustrates the finding more intuitively. The negative effect turns positive when the classifying criterion is larger than some point c.

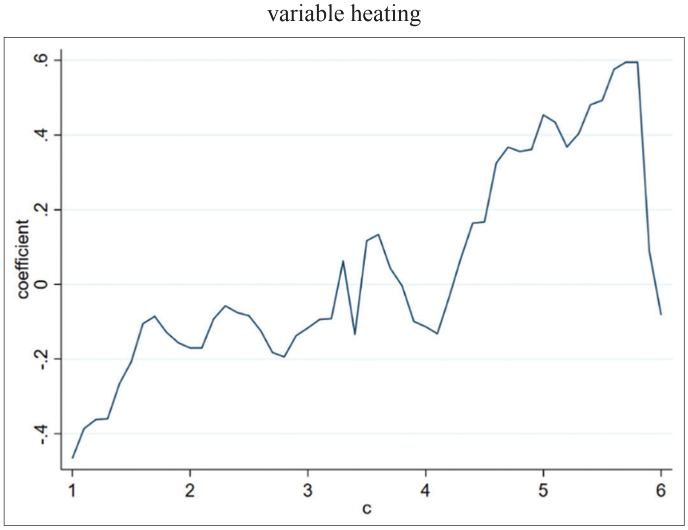
Table 6: Estimation in different groups-G

G	Group 1 (GDP per capita>50,000)	Group 2 (GDP per capita<50,000)
Heating	−0.0061*** (0.0021)	0.0077*** (0.0030)
Air	−0.0002** (0.0001)	0.00001 (0.0001)
Obs	64	908

Table 7: Regression results with changing criteria c-Δ

Group 1	Coefficient	Group 2	Coefficient
GDP per capita>20,000	−0.1701	GDP per capita≤20,000	−0.8801**
>25,000	−0.0840	≤25,000	−0.6004**
>30,000	−0.1166	≤30,000	−0.4953**
>40,000	−0.1131	≤40,000	−0.4464**
>42,000	−0.0342	≤42,000	−0.4412**
>44,000	0.1639	≤44,000	−0.4429**
>46,000	0.3244**	≤46,000	−0.4348**
>48,000	0.3558***	≤48,000	−0.4338**
>50,000	0.4534***	≤50,000	−0.4286**
>52,000	0.3679**	≤52,000	−0.4254**
>54,000	0.4808**	≤54,000	−0.4230**
>55,000	0.4926**	≤55,000	−0.4267**
>60,000	−0.0821	≤60,000	−0.4240**

Figure 2: Plot between criterion c and coefficient of the variable heating



In light of the above results, we can conclude that people living in more developed counties care more about the room living conditions than heating costs; thus, the total effect is positive in high-income counties while negative in low-income counties.

6. CONCLUSION AND POLICY IMPLICATIONS

This paper first determines the location of the central heating boundary line through an Internet survey. Then it selects county-level data to analyze the differences in mechanical population growth on both sides of the central heating boundary. The study finds that the heating borderline has accounted for differences in population migration. The study results can be summarized in the following three points:

First, from the analysis of the whole sample, the mechanical growth of the population in areas with heating is weaker than that in areas without heating. District heating does not attract further population inflows. Differences in migration stem from differences in indoor living comfort, heating costs, and air pollution. The inhibitory effect of central heating is greater than the promoting effect, and the total effect is negative.

Second, the effect of central heating on migration is positive in wealthier counties. In contrast, the effect in less affluent counties is negative. This shows that residents in poor areas are more sensitive to heating costs, while residents in richer areas are more concerned about the living comfort brought by heating.

Third, the effect of district heating on migration is partly through its impact on air quality, but this effect is minimal. Indoor living comfort and heating costs have a greater impact on migration.

In recent years, there have been voices among the Chinese people to push the heating borderline southward, that is, to revise the current Huai River policy. From a macro perspective, the policy revision should consider the following three aspects: construction and operation costs, potential pollution, and improved living standards, which are consistent with the three aspects mentioned above at the micro level. This study can provide some policy implications for promoting central heating in non-heating areas in China.

First, our analysis shows that the Huai River policy can affect the population mobility patterns and potentially affect economic development. The population is an important indicator affecting future resource allocation and policy orientation. Policymakers must consider the impact of resource reallocation when revising the policy.

Second, air quality is not decisive in determining migration decisions. Heterogeneity analysis finds that heating systems are more attractive to people in richer counties. This conclusion deserves further argument. Policymakers should focus more on district heating costs than air pollution when promoting district heating programs to households. Households in areas with different development levels may have different attitudes toward central heating. Different promotion strategies should be adopted. Central heating is not entirely a benefit for residents. It can also become a burden for residents, especially when the public shares some building costs. Policymakers should seek broad public input when they advance district heating projects in the south.

REFERENCES

Almond, D., Chen, Y., Greenstone, M., Li, H. (2009), Winter heating or clean air? Unintended impacts of China's Huai river policy. American Economic Review, 99(2), 184-190.

Chay, K.Y., Greenstone, M. (2005), Does air quality matter? Evidence from the housing market. Journal of Political Economy, 113(2), 376-424.

Chen, Y., Ebenstein, A., Greenstone, M., Li, H. (2013), Evidence on the impact of sustained exposure to air pollution on life expectancy from China's Huai River policy. Proceedings of the National Academy of Sciences, 110(32), 12936-12941.

Chen, Y., Whalley, A. (2012), Green infrastructure: The effects of urban rail transit on air quality. American Economic Journal: Economic Policy, 4(1), 58-97.

Fielding, A.J. (2011), The impacts of environmental change on UK internal migration. Global Environmental Change, 21, S121-S130.

Gale, L.R., Heath, W.C. (2000), Elderly internal migration in the United States revisited. Public Finance Review, 28(2), 153-170.

Gao, Y., Sampattavanija, S. (2022), Air quality and winter heating: Some evidence from China. International Journal of Energy Economics and Policy, 12(4), 455-469.

Gao, Y., Sampattavanija, S. (2023), China's Huai river policy and population migration: A U-shaped relationship. International Journal of Energy, Environment, and Economics, 29(4), 471-492.

Guo, J., Huang, Y., Wei, C. (2015), North-South debate on district heating: Evidence from a household survey. Energy Policy, 86, 295-302.

Hanna, R., Oliva, P. (2015), The effect of pollution on labor supply: Evidence from a natural experiment in Mexico City. Journal of Public Economics, 122, 68-79.

Li, J., Cao, J. (2017), Empirical analysis of the effect of central heating on air pollution in China. China Journal of Economics, 4(4), 138-150.

Liang, X., Zou, T., Guo, B., Li, S., Zhang, H., Zhang, S., Chen, S.X. (2015), Assessing Beijing's PM2.5 pollution: Severity, weather impact, APEC and winter heating. Proceedings of the Royal Society A: Mathematical, Physical and Engineering Sciences, 471(2182), 20150257.

Nuorkivi, A. (2016), District heating and cooling policies worldwide. In: Advanced District Heating and Cooling (DHC) Systems. United Kingdom: Woodhead Publishing. p17-41.

Tanaka, S. (2015), Environmental regulations on air pollution in China and their impact on infant mortality. Journal of Health Economics, 42, 90-103.

Xiao, Q., Ma, Z., Li, S., Liu, Y. (2015), The impact of winter heating on air pollution in China. PLoS One, 10(1), e0117311.

Appendixes

Appendix A: Central heating status in cities near the heating borderline

Province	City (Group)	Heating area (1000 m²)*	Heating density (m²/person)
Shandong	Rizhao (I)	24400 (2019)	8.22
	Linyi (I)	69551 (2019)	6.31
	Zaozhuang (I)	33560 (2019)	8.71
Jiangsu	Xuzhou (I)	12010 (2010)	1.33
	Lianyungang, Suqian, Huaian (II)	-----------	0
Henan	Shangqiu (I)	12000 (2020)	1.54
	Luohe (III)	1500 (2020)	0.63
	Pingdingshan (I)	18000 (2018)	3.61
	Nanyang (II)	4900 (2016)	0.50
	Xinyang (II)	4000 (2019)	0.65
	Zhumadian (I)	9600 (2020)	1.37
	Zhoukou (II)	---------	≈0
	Xuchang (I)	15000	3.01
	Luoyang (I)	76370 (2021)	11.03
	Sanmenxia (I)	13000 (2021)	6.39
	Kaifeng (I)	36000 (2021)	7.46
Hubei	Xiangyang (II)	1500 (2021)	0.29
	Shiyan (I)	11050 (2019)	5.36
	Xiaogan, Suizhou (II)	----------	0
Anhui	Suzhou (II)	85 (2019)	≈0
	Huaibei, Bozhou, Fuyang, Huainan, Bengbu, Chuzhou (II)	----------	≈0
Shaanxi	Shangluo (II)	850 (2021)	≈0.42
	Baoji (I)	38851 (2021)	11.70
	Xianyang (I)	29100 (2021)	7.35
	Tongchuan (I)	10200 (2021)	14.61
	Weinan (I)	11000 (2021)	2.35
	Hanzhong (II), Ankang (II)	------------	≈0
Shanxi	Yuncheng (I)	24720 (2019)	5.22
Gansu	Longnan (II)	--------	0
	Tianshui (I)	24403 (2021)	8.25
Sichuan	Mianyang (II), Bazhong (II), Guangyuan (II)	-------	0

*These data are obtained from the official websites and news reports of the local governments

Appendix B: Counties alongside the heating borderline in Figure 1

County abbreviation and its full name

WS (Wushan), TG (Tongguan), GG (Gangu), LX (Lixian), TS (Tianshui), XH (Xihe), HX (Huixian), FX (Fengxian), NX (Neixiang), LD (Liangdang), LB (Liuba) MX (Mianxian), LB2 (Lingbao), LS (Lushi) SN (Shangnan), DJK (Danjiangkou), XC (Xichuan), XX (Xixia), LC (Luanchuan), SX (Songxian), LS (Lushan), NZ (Nanzhao), TB (Taibai), YX (Yangxian), ZZ (Zhouzhi), FP (Foping), DZ (Dengzhou), HY (Huayin), DF (Danfeng), FC (Fangcheng), LN (Luonan) TH (Tanghe), CA (Changan), YX (Yexian) ZA (Zhenan), WG (Wugang), ZS (Zhashui) BY (Biyang), XY (Xunyang), TB (Tongbai), LT (Lantian), XY2 (Xinyang), LS2 (Luoshan), WN (Weinan), SZ (Shangzhou), ZY (Zhengyang), SY (Shanyang), XX2 (Xixian), YX2 (Yunxi), XC2 (Xincai), BH (Baihe), PY (Pingyu), HX (Huaxian), WY (Woyang), LY (Linying), XH2 (Xihua), FG (Fugou), SX2 (Suixi), TK (Taikang), HB (Huaibin), LQ (Linquan), SS (Shangshui), XC3 (Xiangcheng), SC2 (Shangcai), YC (Yongcheng), YC2 (Yancheng), YC3 (Yucheng), YL (Yanling), XX3 (Xiaoxian), WS (Weishi), XY3 (Xiayi), TX (Tongxu), QX (Qixian), SX3 (Shanxian), SX4 (Suixian), FX (Fengxian), NL (Ningling), PX (Peixian), SQ (Shangqiu), PZ (Pizhou), ZC (Zhecheng), LS3 (Linshu), DS (Dangshan), DH (Donghai), TC (Tongcheng), SX5 (Sixian), JN (Junan), LL (Lanling), SY2 (Shuyang), , SH (Sihong), SZ2 (Suzhou), SN (Suining), XY4 (Xinyi), LB3 (Lingbi)