Environment for Development

Discussion Paper Series

May 2020 ■ EfD DP 20-15

Energy Poverty and Household Heating Energy Transition in Rural China

Xiao-Bing Zhang, Lunyu Xie, Xinyi Zhang, and Xian Hu

Central America
Research Program in Economics and Environment for Development in Central America Tropical Agricultural Research and Higher Education Center (CATIE)

Chile
Research Nucleus on Environmental and Natural Resource Economics (NENRE)
Universidad de Concepción

China
Environmental Economics Program in China (EEPC)
Peking University

Colombia
The Research Group on Environmental, Natural Resource and Applied Economics Studies (REES-CEDE), Universidad de los Andes, Colombia

Ethiopia
Environment and Climate Research Center (ECRC), Policy Studies Institute, Addis Ababa, Ethiopia

Ghana
The Environment and Natural Resource Research Unit, Institute of Statistical, Social and Economic Research, University of Ghana, Accra

India
Centre for Research on the Economics of Climate, Food, Energy, and Environment, (CECFEE), at Indian Statistical Institute, New Delhi, India

Kenya
School of Economics
University of Nairobi

Nigeria
Resource and Environmental Policy Research Centre, University of Nigeria, Nsukka

South Africa
Environmental Economics Policy Research Unit (EPRU)
University of Cape Town

Sweden
Environmental Economics Unit
University of Gothenburg

Tanzania
Environment for Development Tanzania
University of Dar es Salaam

Uganda
EfD-Mak, School of Economics and Department of Agribusiness and Natural Resource Economics, Makerere University, Kampala

USA (Washington, DC)
Resources for the Future (RFF)

Vietnam
University of Economics
Ho Chi Minh City, Vietnam

Contents

Energy Poverty and Household Energy Transition in Rural China

Xiao-Bing Zhang, Lunyu Xie, Xinyi Zhang, and Xian Hu*

Abstract

To alleviate environmental problems and accelerate households' energy transition to cleaner fuel, the Chinese government has enforced a household heating energy transition program in the Jing-Jin-Ji Region. Through subsidies and mandates, the program substitutes household heating coal with electricity, natural gas, or cleaner coal. The program has effectively decreased the emission of air pollutants; however, it also has led to a sharp increase in household heating costs. Through a large-scale household survey in Beijing and Hebei, we find that *coal to electricity* and *coal to gas* significantly increased energy poverty (high ratios of energy expenditure to income), while *clean coal replacement* reduced energy poverty. The extent of energy poverty in Beijing remained stable, but it increased in Hebei by fifteen percentage points, which is a 70 percent increase. We also find that households with lower income, lower education, smaller household size and larger housing area are more likely to have high ratios of energy expenditure to income, and therefore are more likely to experience energy poverty. Furthermore, households with lower income are negatively affected by the program to a larger degree in terms of the increase in the ratio of energy expenditure to income and the likelihood of being pushed into energy poverty. These findings call the attention of policy makers to low-income households when designing and implementing policies.

Keywords: coal to electricity; coal to gas; clean coal replacement; energy poverty; heating energy transition

JEL Codes: Q48, D63

* Xiao-Bing Zhang (corresponding author: xiaobing.zhang@ruc.edu.cn), School of Applied Economics, Renmin University of China. Lunyu Xie and Xinyi Zhang, School of Applied Economics, Renmin University of China, Beijing, PRC. Xian Hu, School of Economics and Management, Tsinghua University, Beijing.
.

1. Introduction

To reduce air pollution and carbon emissions and to promote households' energy transition, the Chinese government has adopted many measures to reduce the use of coal. One of the most recent and massive programs is the household heating energy transition program. This is intended to convert household heating fuel from coal to natural gas (*coal to gas*), electricity (*coal to electricity*), or cleaner coal (*clean coal replacement*), through mandates and subsidies. Over the past several years, the central government has spent 35.12 billion yuan and 43 cities in Northern China[1] have been covered by this program.[2] Despite the heavy subsidy, this program draws many complaints, such as the soaring heating cost burden on the participating households. Energy poverty unexpectedly became a side effect of this energy transition program.

Energy poverty is defined in terms of two components: availability and affordability of modern energy which meets a household's basic needs (Foster et al., 2000). If modern energy sources are not available and affordable, households are forced to use fuels that cause dangerous indoor and outdoor air pollution, as well as greenhouse gas emissions (Guertler, 2012; Jenkins, 2010; Sovacool, 2012). This paper investigates the effects of China's household heating energy transition program on energy poverty, depicts the cohorts that are more likely to experience energy poverty, and identifies those who are negatively affected to a larger degree by the program. Based on the findings, policy implications are proposed to alleviate the energy poverty problem caused by the program.

Energy availability is measured by accessibility of modern energy such as electricity, solar power, etc. Availability is often a problem in rural areas of developing countries (Jian-ping, 2013; Li et al., 2011; Pachauri and Spreng, 2004). Affordability is usually measured by indicators such as the ratio of household energy expenditure to household income. Households with an energy affordability problem are susceptible to changes in income, energy price, and energy efficiency. Given that China has expanded electricity coverage to 100% of households in the country as of 2017,[3] energy availability is not the key problem in the area studied in this paper. We therefore focus on the affordability of energy.

[1] Some households in Northern China are connected to district-wide heating, known as "central heating." The households in this study were not connected to central heating and have to heat their homes individually.
[2] China Coal Consumption Cap Plan and Policy Research Project: China Coal Comprehensive Management Report 2019 https://max.book118.com/html/2019/0831/8067022053002045.shtm
[3] World Bank's Electricity Access Report: http://documents.worldbank.org/curated/en/364571494517675149/pdf/114841-REVISED-JUNE12-FINAL-SEAR-web-REV-optimized.pdf

Energy poverty in terms of affordability is widely discussed in developed countries such as the UK, the US, Ireland, and other EU countries, mostly focusing on winter heating energy expenditures. Previous literature has measured the breadth of energy poverty (e.g., Hills, 2011; Hills, 2012; Li et al., 2014), and investigated characteristics of energy-poor households (ONPE 2016).[4] For example, Chaton and Lacroix (2018) found that households with high income and education are less likely to experience energy poverty. Mould and Baker (2017) found that households with elder members or children are vulnerable to energy poverty.

Few studies investigate the impact of an energy transition program on energy poverty. One possible reason is that energy transition programs generally aim to address both energy availability and affordability, so energy poverty is expected to be alleviated. The subsidy element of the household heating energy transition program in China was expected to address affordability of the substituting energy. However, given the mandatory nature of the policy – and despite the subsidy – energy poverty seemed to increase. This paper measures this unexpected effect.

The household heating energy transition program was piloted in Beijing in 2014, expanded to "2+4" cities in the Jing-Jin-Ji air pollution prevention core area in 2015, and extended to "2+26" cities along the Jing-Jin-Ji pollution transmission channel.[5] The program is mandatory and is implemented from the top down. The central government first selects the cities and sets the annual target number of covered households in each province; the provincial government then decomposes the number of targeted households into lower levels of government, and finally to villages; then, a specific transition plan is jointly made for the selected village by the National Development and Reform Commission (NDRC) and the local government, based on the village's characteristics, such as distance to downtown, infrastructure condition, financial capacity, villagers' income level and preferences, etc. All households in the selected villages are required to participate, and participation is strictly supervised.

Two of the types of substitute energy (i.e., electricity and gas) are more expensive than the substituted energy (i.e., coal). Because of the high costs of the transition, the various levels of government have ensured participation through a combination of high subsidies and mandatory orders. The transition involves either electricity grid upgrade (for the *coal to electricity* program) or gas pipeline extension

---

[4] ONPE, 2016. Les chiffres-clés de la précarité énergétiques. Edition n°2- Mars 2016. ONPE: French National Observatory of Energy Poverty.

[5] The Jing-Jin-Ji region is the area of Beijing city (Jing), Tianjin city （Jin), and Hebei province (Ji). The "2+4" cities are Beijing, Tianjin, and four cities in Hebei province. The "2+26" cites are Beijing, Tianjin, and 26 cities in Hebei, Henan, Shanxi, and Shandong provinces, which are on the pollution transmission channel to Beijing.

and construction of LPG distribution stations (for the *coal to gas* program), as well as the replacement of heating devices. The governments cover the cost of infrastructure construction, and provide subsidies for fuel cost and for equipment replacement at the household level.

Previous literature has shown that the social benefit of this transition program exceeds the cost (e.g., Zhang et al., 2019; Xie et al., 2020). However, how the costs are distributed, in terms of poverty and equity, has not been paid enough attention so far. Rural households, who tend to be poor, experienced sharp increases in heating expenditure after enrolling in the program, even with the subsidy. Energy poverty is likely to be intensified among these households.

Through a large-scale household survey in Beijing and Hebei, we find that *coal to electricity* and *coal to gas* significantly increased the degree of energy poverty, while *clean coal replacement* reduced energy poverty. The breadth of energy poverty in Beijing remained stable, while it increased in Hebei by fifteen percentage points, which is a 70 percent increase. We also find that households with lower income, lower education, smaller household size, and larger housing areas are more likely to be in energy poverty. Based on these findings, we explore the reasons and propose policy suggestions.

The remainder of this paper is organized as follows: section 2 describes the method for measuring energy poverty; section 3 introduces the survey and the data; section 4 presents the energy poverty conditions before and after the program, investigates the heterogeneous results between Beijing and Hebei, and explores the reasons; section 5 identifies the characteristics of the households that are more likely to be in energy poverty and those that are affected to a larger degree by the program; section 6 concludes and proposes policy implications.

2. Measurement of Energy Poverty

Earlier literature provides many measures of energy poverty; in these the main point of disagreement has been how to set the energy poverty line. The first measurement of energy poverty was proposed by Boardman (1991). It defined a household to be in energy poverty if the household needs to spend more than 10% of its total income to meet the necessary energy consumption. The threshold of 10% is based on survey data in Britain in 1988, when the poorest 30% of the population spent 10% of their income on average on energy. In that survey, the sample median ratio of energy expenditure to income was 5%, and twice the median was thought to be disproportionate (Isherwood and Hancock, 1979) and therefore appropriate to define energy poverty. The threshold of 10% was then widely used (Mohan et al., 2018), until Boardman (2010) himself pointed out that, as economic and social conditions had changed, using twice the median as the threshold would be more consistent and more informative than fixing the threshold at 10% of the household's income (Boardman, 2010).

There are two other widely used ways to set the energy poverty line. Barnes et al. (2011) proposed setting the energy poverty line at the point from which households' energy consumption starts to rise with an increase in income. Healy and Clinch (2004) and Sovacool (2012) simply considered households to be in energy poverty if they report being unable to afford basic heating in winter.

In this paper, we use the measurement proposed by Boardman (2010). We take twice the median proportion of energy expenditure in household income as the energy poverty line, denoted as α. The proportion of energy expenditure is defined as:

$$\frac{E_i}{I_i} = \frac{\sum_{e=1}^{m}(X_{ie} \cdot P_e - R_{ie})}{I_i} \quad (1)$$

where E_i is the heating energy expenditure of household i; I_i is the annual income of household i; m is the number of types of energy; X_{ie} is the quantity of energy type e consumed by household i; P_e is the price of energy e; and R_{ie} is the subsidy for energy e received by household i. If $\frac{E_i}{I_i} > \alpha$, household i is defined to be in energy poverty. $I_i \times \alpha$ is the threshold of expenditure on energy.

We adopt the Energy Affordability Gap (EAG) index proposed by Fisher, Sheehan and Colton (Hills, 2012) to capture the energy poverty gap, and we use the FGT class (Foster et al., 1984) to capture the breadth and the depth of energy poverty.

The EAG index calculates the difference between actual expenditure and the threshold of expenditure on energy as follows:

$$EAG_i = E_i - I_i \times \alpha \quad (2)$$

EAG_i measures the energy poverty gap of household i. The total energy poverty gap of the society and the average energy poverty gap are defined in Equations (3) and (4) respectively:

$$EAG = \sum_{EAG_i \geq 0} EAG_i = \sum_{E_i \geq I_i \times \alpha} (E_i - I_i \times \alpha) \quad (3)$$

$$\overline{EAG} = \sum_{E_i \geq I_i \times \alpha} (w_i/N) \; (E_i - I_i \times \alpha) \quad (4)$$

where w_i represents the weight of household i. In this paper, each household takes an equal weight, so $w_i = 1$. N is the number of households. EAG and $\overline{EAG}$ measure respectively the total cost and the average cost to the society to eliminate energy poverty.

The FGT class measures the breadth and depth of energy poverty by the following formula:

$$P_\theta = \sum_{E_i \geq I_i \times \alpha} (w_i / N) \left[\frac{E_i - I_i \times \alpha}{I_i}\right]^\theta \tag{5}$$

where θ is a parameter that takes a value of 0 or 1.

When $\theta = 0$,

$$P_0 = \sum_{E_i \geq I_i \times \alpha} (w_i / N) \tag{6}$$

P_0 measures the breadth of energy poverty.

When $\theta = 1$,

$$P_1 = \sum_{E_i \geq I_i \times \alpha} (w_i / N) \left[\frac{E_i - I_i \times \alpha}{I_i}\right] \tag{7}$$

P_1 calculates the average distance between the threshold expenditure and the expenditures of households in energy poverty. A greater distance indicates more serious energy poverty. So, P_1 measures the depth of energy poverty.

3. Survey and Data

We use household survey data to calculate the indices of energy poverty, including breadth (defined in Equation 6), depth (defined in Equation 7), and energy poverty gap (defined in Equation 2). The data are from the Chinese Residential Energy Consumption Survey 2016 (CRECS 2016), conducted by the Department of Energy Economics at Renmin University of China. The survey covers rural areas in Beijing and Hebei province. In Beijing, 183 villages were randomly selected, and about 4000 households were interviewed. In Hebei, 550 households were randomly selected for survey in person. The survey collected (1) information at the village committee level, including village participation status, subsidy scheme, and energy price; (2) social and economic characteristics at the household level, including household size, age, income, and education level; and (3) household heating behavior, including program participation status, energy consumption before and after the program, subjective evaluation of the program, etc.

Considering that the transition mainly affects heating energy and heating cost, and that heating cost is the main energy cost for the areas studied in this paper, we focus on heating energy poverty.[6] To evaluate the effect of the program on heating energy

[6] Heating energy is part of total energy consumed by households. So the ratio of heating energy expenditure to income is smaller than the ratio of energy expenditure to income. Because they are highly correlated, the conclusions of this paper remain stable to the definition of energy as total energy or heating energy.

poverty, we first calculate the participants' heating energy expenditure before and after the program. In the Hebei survey, this information is directly reported by the households. In the Beijing survey, such information is not reported, so we calculate it by multiplying heating energy consumption by price and deducting the subsidy received by the household. The information on energy consumption is reported by households. The prices of electricity and gas are obtained from the local price schedule issued by the Development and Reform Commission of Beijing. There is no official price schedule for coal and firewood, so we take the median of the reported prices from the village level survey. As for the subsidies, according to the policy documents, participating households receive a subsidy of 0.2 yuan per kWh for off-peak electricity consumption (two-thirds of the off-peak electricity price), up to 10,000 kWh per household; 0.38 yuan per m^3 for natural gas consumption (one sixth of the first tier natural gas price), up to 820 m^3 per household; and 200 yuan per ton for clean coal (one fourth of the clean coal price), up to 4.5 tons per household. Details on the subsidy scheme are presented in Appendix A, and details on prices with subsidies are presented in Appendix B. For non-participants in the programs, we assume that the heating expenditure remain unchanged.

The sample included households[7] and villages that were and were not participating in the heating transition program. The number of households participating in *coal to electricity* and *clean coal replacement* in Beijing is relatively large, accounting for 23% and 42% of the sample, respectively. In Hebei, 46% of households were participating in *coal to gas*, and the number of households participating in other programs was small. Therefore, in Hebei we focus only on the *coal to gas* program.

Table 1 presents the summary statistics of the key variables for the energy poverty measurement, including income, heating energy expenditure, and the ratio of expenditure to income. Considering that effects on energy poverty vary across programs and regions, we distinguish the three programs and the regions in the following analysis. As shown in the Beijing panel of Table 1, the average income is 92.65, 90.92, and 73.66 thousand yuan for the Beijing households that are enrolled in *coal to electricity, coal to gas* and *clean coal replacement*, respectively. The heating expenditures are 2.47, 1.80, and 2.84 thousand yuan before participation, and 3.21, 2.97, and 2.54 thousand yuan after participation. That is, the heating expenditure increases 0.74 and 1.17 thousand yuan for *coal to electricity* and *coal to gas,* respectively, while it decreases 0.29 thousand yuan for *clean coal replacement*. The ratios of heating expenditure to income are 5.39%, 3.89%, and 7.12% before and 6.37%, 5.87%, and

[7] While participation is mandatory for all households in participating villages, some households still make some use of traditional coal and firewood.

6.43% after. The ratio changes by 0.97, 1.98, and -0.68 percentage points, which are changes of 18.00, 50.90, and 9.55 percent. On average, the heating transition program in Beijing increased the ratio of heating energy expenditure to income from 5.94% to 5.98%.

As shown in the Hebei panel of Table 1, the average income is 61.07 thousand yuan for households that participate in *coal to gas.* The heating expenditures are 2.48 and 4.07 thousand yuan before and after the *coal to gas* program, with an increase of 1.59 thousand yuan. The ratio of expenditure to income is 6.54% and 10.85% before and after the program, with a change of 4.31 percentage points, which is a 65.90 percent change. On average, the program in Hebei increased the ratio of heating energy to income from 6.55% to 8.65%.

The comparison of Beijing and Hebei in Table 1 shows that the heating expenditure in Beijing was higher before the program but lower afterward, compared to Hebei. This indicates that the program increases heating expenditure in Hebei more than in Beijing. In addition, households' income level in Beijing is much higher than in Hebei. So, although the heating expenditure before the program is higher in Beijing, the ratio of heating expenditure to income is lower in Beijing both before and after the program.

4. Graphic Findings on Energy Poverty

Based on the methodology and the survey data described above, in this section we measure the breadth and the depth of energy poverty and the energy poverty gap before and after the program in Beijing and Hebei. We also explore the reasons why the heating transition program worsened energy poverty.

4.1. Energy Poverty Breadth, Depth, and Gap

The energy poverty line is set to be two times the median ratio of the household heating expenditure to income. As calculated in the previous section, the median of the ratio is 3.67% and 4.00% before the program for Beijing and Hebei respectively. Therefore, the energy poverty line in this paper is set to be 7.33% and 8.00% for Beijing and Hebei, respectively. The indicators of energy poverty are calculated based on this energy poverty line. The results are summarized in Figure 1.

Table 1: Summary Statistics of Energy Expenditure and Income

Panel A. Beijing

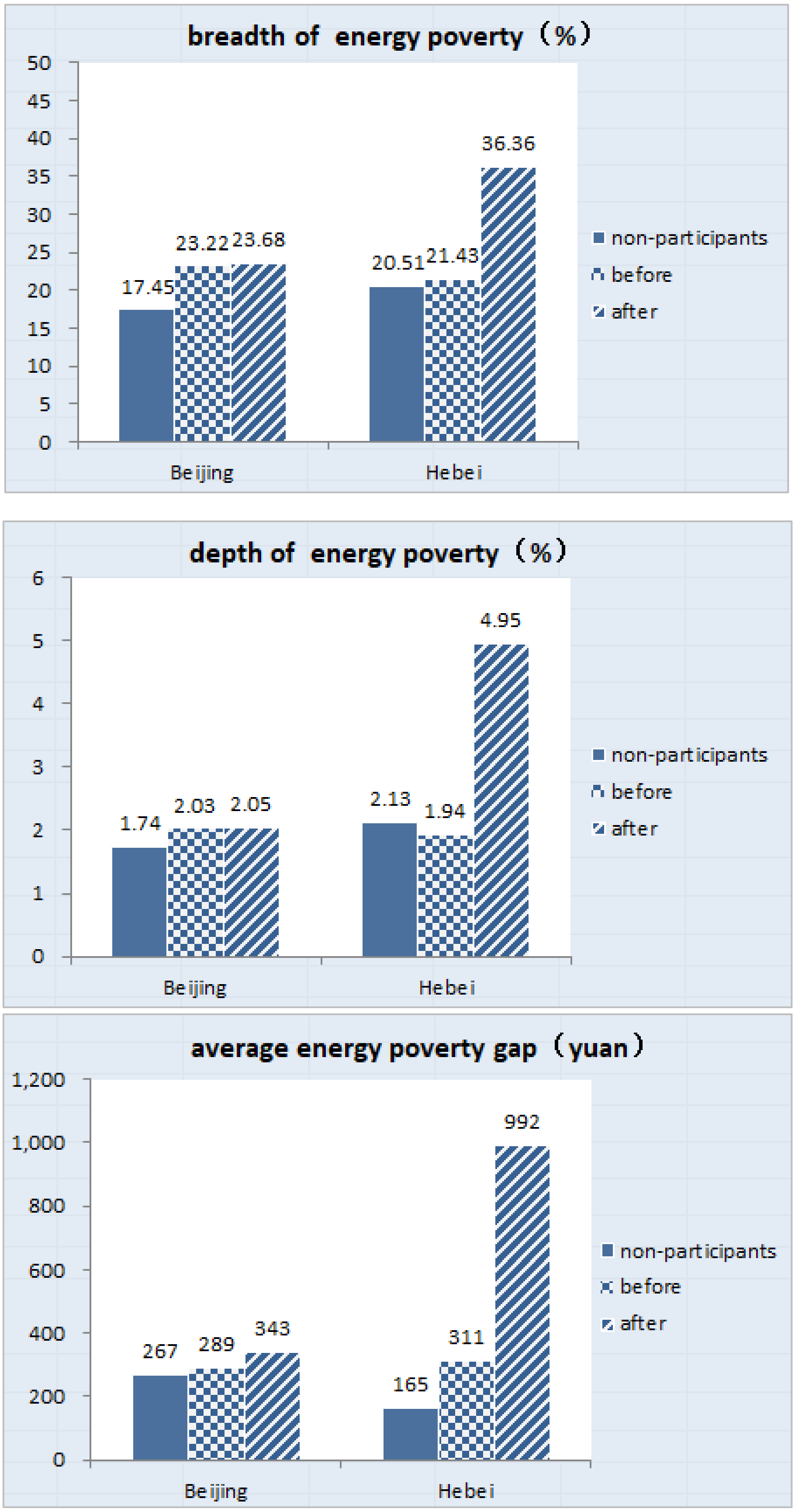
		Participants			Non Participants	Average
		Coal to Electricity	*Coal to Gas*	*Clean Coal Replacement*		
No. of Obs. (1585)		374	71	671	487	
Income	(thousand yuan)	92.65	90.92	73.66	88.83	83.56
Before	Expenditure (thousand yuan)	2.47	1.80	2.84	2.27	2.53
	Ratio of expenditure to income (%)	5.39	3.89	7.12	5.23	5.94
After	Expenditure (thousand yuan)	3.21	2.97	2.54	2.27	2.64
	Ratio of expenditure to income (%)	6.37	5.87	6.43	5.23	5.98

Panel B. Hebei

		Participants	Non Participants	Average
		Coal to Gas		
No. of Obs. (310)		143	156	
Income	(thousand yuan)	61.07	54.36	58.93
Before	Expenditure (thousand yuan)	2.48	1.82	2.20
	Ratio of expenditure to income (%)	6.54	6.50	6.55
After	Expenditure (thousand yuan)	4.07	1.82	2.95
	Ratio of expenditure to income (%)	10.85	6.50	8.65

Notes: After dropping observations with missing values or outliers in key variables (e.g., total energy consumption and income), we have 1585 observations in Beijing and 310 observations in Hebei. Income and expenditure are both household annual values. The sum of participants and non-participants in Beijing exceeds the total number of observations, because some participants participate in more than one program. In the Hebei sample, we have full information for only 9 and 2 households in the programs of *coal to electricity* and *clean coal replacement*, so in Hebei we only investigate the program of *coal to gas*.

Figure 1: Overall Energy Poverty



The overall energy poverty breadth, depth, and gap in Beijing have all increased slightly. Among the 1098 participant households in Beijing, the breadth of energy poverty is 23.22% and 23.68% before and after the program, respectively. The energy poverty depth increases from 2.03% to 2.05%. The energy poverty gap increases from 289 to 343 yuan, which is an 18.69 percent increase. Among the 487 households who do not participate in any program, the energy poverty breadth, depth, and gap are all smaller than that of participants.

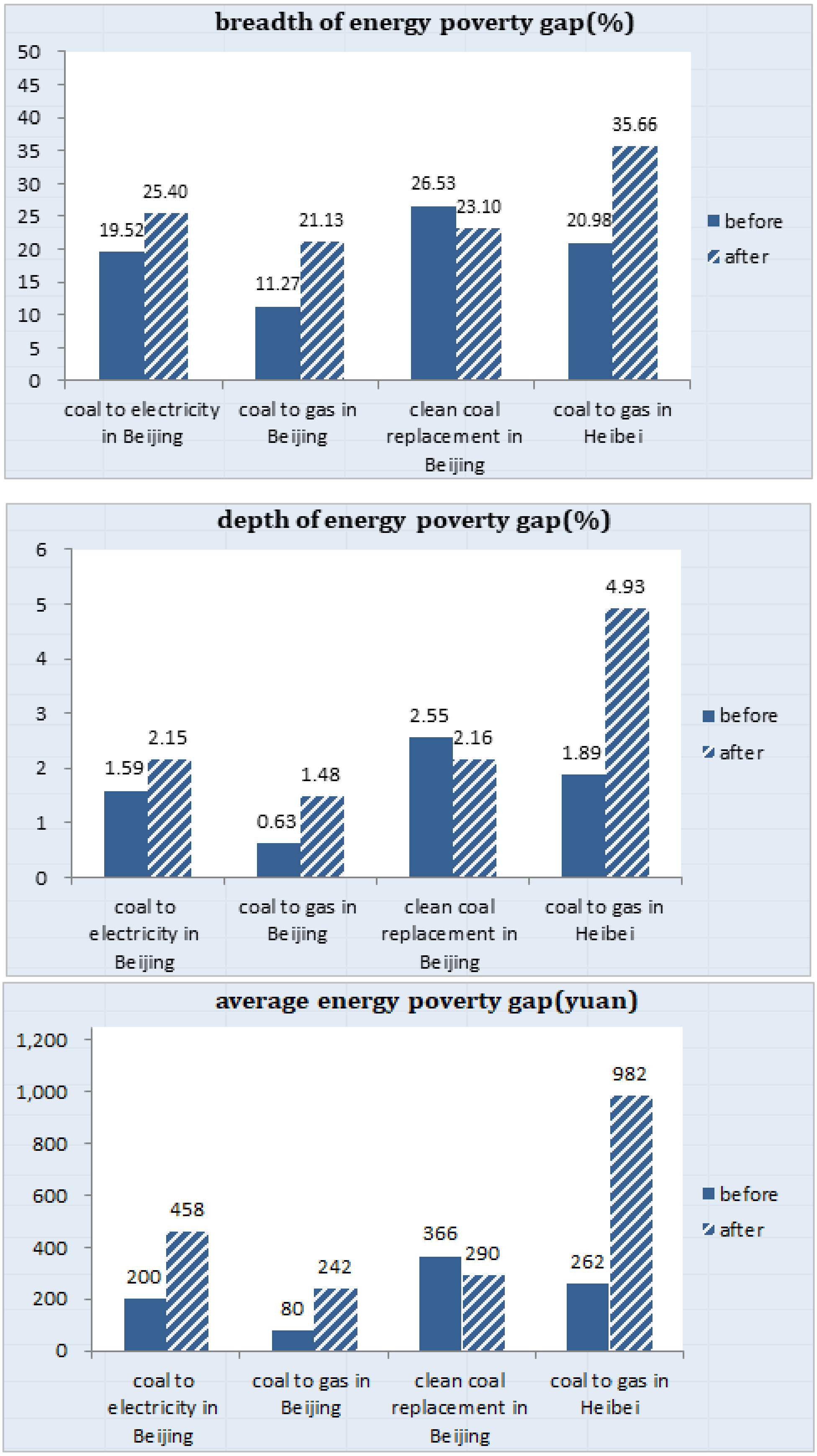
The overall energy poverty breadth, depth, and gap in Hebei also have all increased, and the magnitudes of the changes are much larger than those of Beijing. Among the 154 households who participate in the program in Hebei, the breadth of energy poverty increases from 21.43% to 36.36%, which is a 70 percent increase. The energy poverty depth increases from 1.94% to 4.95%, and the energy poverty gap increases from 310 to 992 yuan before and after the program. The depth increases by 155 percent, and the gap increases 2.19-fold. The breadth of energy poverty among the non-participants is almost the same as that of the participants, and the energy poverty gap is smaller.

By comparing Beijing and Hebei, we find that, although the energy poverty situation in Hebei is similar to Beijing before the program, the indicators of energy poverty become higher than Beijing after the program. The possible reasons could be as follows. First, households in Hebei have much lower income than households in Beijing, as shown in the previous section. So, an increase of energy expenditure has a larger effect on energy poverty for households in Hebei. Second, due to the differences in the local price and subsidy schemes, the price of clean energy in Hebei is higher than in Beijing. For example, in Hebei, the price of electricity is about 6% higher and natural gas is 5% higher than Beijing. Third, the three programs have different effects on energy poverty, so the participation status may lead to different average effects. We therefore explore the heterogeneity of the effects across the programs in the next subsection.

4.2 Heterogeneous Effects Across Programs

Given that *coal to electricity*, *coal to gas*, and *clean coal replacement* have different costs and subsidy schemes, they have different effects on energy poverty. In this section, we explore the heterogeneous effects of the three programs. As shown by Figure 2, *coal to electricity* and *coal to gas* aggravate energy poverty, while *clean coal replacement* alleviates energy poverty. The *coal to gas* program has a larger negative impact than the *coal to electricity* program, in terms of the breadth, depth, and gap of energy poverty. For participants in the *coal to gas* program, the energy poverty breadth, depth, and gap increased by 9.86 percentage points, 0.85 percentage points, and 162 yuan, respectively, which is an 87.49, 137.92, and 202.58 percent change in Beijing. Breadth, depth, and gap increase by 14.68 percentage points, 3.04 percentage points and 721 yuan in Hebei, which is a 69.97, 160.85, and 275.15 percent change. For *coal to electricity*, these three indicators increase by 5.88 percentage points, 0.56 percentage points and 258 yuan, respectively, which is a 30.12, 35.22, and 129.39 percent change, and for *clean coal replacement* these decrease by 3.43 percentage points, 0.39 percentage points and 76 yuan, which is a 12.93, 15.29, 20.84 percent change in Beijing.

Figure 2: Energy Poverty Under Different Programs

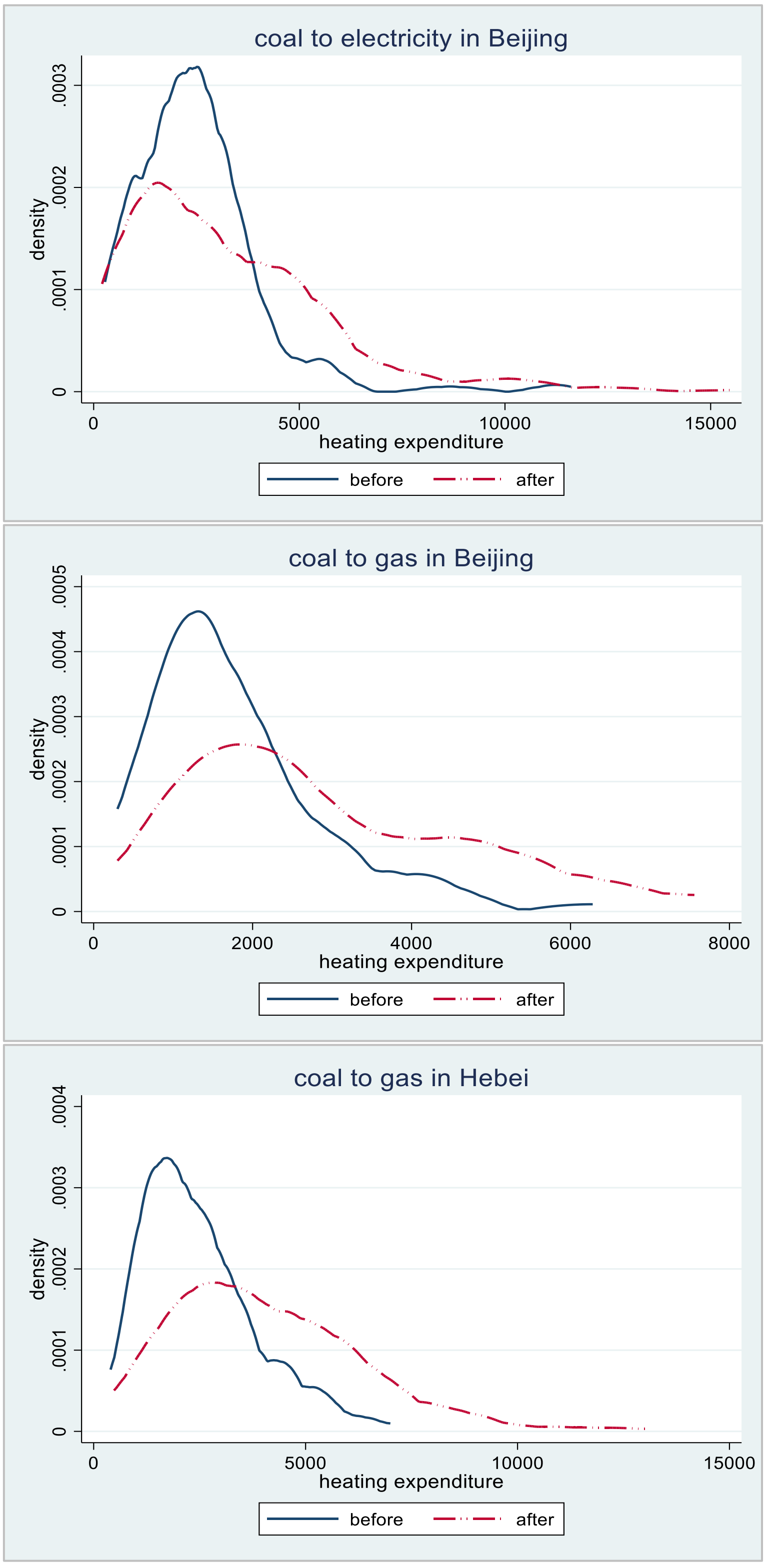


4.3 Reasons for the Effects on Energy Poverty

The heating energy program worsens the energy poverty problem, because the household heating energy transition from coal to electricity and gas is costly and mandatory, and the supporting subsidy is not enough to cover the cost. In this section, we discuss these reasons in more detail.

Heating by electricity and gas costs more than heating by coal. Under the current energy prices and heating technologies, electricity and natural gas heating cost more than coal to achieve the same heating effect. According to the survey, Beijing households on average consumed 1.82 tons of coal per heating season, which cost 1.22 thousand yuan on average, before the program. After the program, households that participate in *coal to electricity* consume 6791 kWh of electricity for heating per heating season, which costs on average 3.70 thousand yuan without subsidy; households that participate in *coal to gas* consume 1409 m^3 of gas on average, which costs 3.32 thousand yuan without subsidy. Figure 3 plots the distribution of household heating expenditures using different energy sources. From coal to electricity or gas, the heating expenditures shift to the right, indicating that heating with electricity and gas is more expensive than coal.

Figure 3: Heating Expenditure with Electricity and Gas



Notes: The plots depict the kernel density of heating expenditure in Beijing and Hebei before and after different programs. The solid line represents the distribution of the heating expenditure before the program, and the dotted line represents that after program.

The subsidies for electricity and gas are not enough to cover the additional cost. According to the estimation results in Xie et.al. (2020), the average subsidy received by a household that participates in *coal to electricity*, *coal to gas* and *clean coal replacement* is 0.93, 1.15 and 1.76 thousand yuan, accounting for 55.71%, 49.60% and 119.79% of the average additional expenditure. This indicates that the current subsidies for electricity and gas heating can only cover about half of the extra expenditure caused by the transition.

The mandatory implementation of the program leaves the covered households no option to participate or not. Because heating with electricity and gas are more expensive and the subsidies are insufficient, many households would have chosen not to participate if they had that option. However, all selected households are required to make the transition. Village leaders are responsible for ensuring participation, using means such as banning the sale of coal in the village. The mandatory feature means that energy poverty worsened more than it would have if households had a choice.

5. Regression Analysis

The previous sections have shown that the heating energy transition program put more households into energy poverty. Because the effects vary across households, we further explore the characteristics of the cohorts that are more likely to be in energy poverty and those that are negatively affected by the program to a larger extent.

We employ econometric models for the analysis. The explained variable is the ratio of heating energy expenditure to income. We use this instead of the dummy variable for energy poverty, because the value of the energy poverty dummy is based on the comparison of the ratio and the energy poverty line. Using an energy poverty dummy would omit more detailed information on the ratio. As shown in Appendix C, the dummy variable yields similar findings, but with less significance because of less information in the dependent variable.

The explanatory variables are household characteristics and housing characteristics, including income, household size, household structure, education, and size, age, and warmth retention of the houses. The detailed definitions of the variables are presented in Table 2. The summary statistics are presented in Table 3. In Panel A, the four columns respectively present the full sample and the samples of participants in Beijing in c*oal to electricity*, *coal to gas*, and *clean coal replacement*. Panel B presents the Hebei c*oal to electricity* program.

Table 2: Definition of Variables

variable	definition
Explained Variable	
ratio of heating expenditure to income	household annual heating expenditure divided by household annual income
energy poverty	a dummy variable, which takes a value of one if the household's ratio of heating expenditure to income is more than twice the median ratio, zero otherwise.
Explanatory Variable	
Household Characteristics	
income	household annual income (thousand yuan)
household size	number of household members
elder	a dummy variable, which takes a value of one if the household has an elder over 60, zero otherwise.
children	a dummy variable, which takes a value of one if the household has a child younger than 15, zero otherwise.
education	Education level of household head, which takes a value of one if the education level of household head is illiteracy, uneducated or primary school; two if the education level is junior high school; three if the education level is high school (including vocational high school); four if the education level is college, university, master or doctor
Housing Characteristics	
house size	housing area (100 m^2)
house age	Number of years from the construction of the house to the survey year
warmth retention	a dummy variable, which takes a value of one if the household has done warmth renovation or has double glazing, zero otherwise.

Table 3: Summary Statistics of Regression Variables

Panel A. Beijing

	Full Sample	*Coal to Electricity* Participants	*Coal to Gas* Participants	*Clean Coal Replacement* Participants
Explained Variables				
Before				
energy poverty	0.214	0.200	0.175	0.267
expenditure ratio	5.953	5.529	3.878	7.109
After				
energy poverty	0.216	0.254	0.221	0.231
expenditure ratio	5.990	6.502	5.948	6.426
Explanatory Variables				
income	82.743	93.416	90.853	72.646
household size	3.66	3.761	3.294	3.598
elderly	0.578	0.639	0.500	0.576
children	0.396	0.424	0.412	0.359
education	1.971	1.934	2.000	1.903
house size	1.638	1.757	1.369	1.742
house age	21.222	21.382	18.191	22.179
warmth retention	0.7	0.69	0.735	0.689
No. of observations	1483	335	68	637

Panel B. Hebei

	Full Sample	*Coal to Gas* Participants
Explained Variable		
Before		
energy poverty	0.232	0.228
expenditure ratio	7.052	6.856
After		
energy poverty	0.308	0.370
expenditure ratio	9.295	11.235
Explanatory Variables		
income	55.709	59.069
household size	3.323	3.543
elderly	0.335	0.346
children	0.285	0.339
education	2.167	2.220
house size	1.410	1.454
house age	21.209	21.087
warmth retention	0.502	0.543
No. of observations	263	127

We first investigate the characteristics of households that were more likely to have a high ratio of heating expenditure to income before the program. We adopt a Multiple Linear Regression and include all the observed households in the regression. We run the regression separately for Beijing and Hebei and present the regression results in Table 4. It shows that before the initiation of the heating energy transition program, households in Beijing with lower income and education level and those who live in larger and older houses tended to have a larger heating expenditure-to-income ratio, and therefore were more likely to be in energy poverty. The regression results also show that households with fewer members tended to have a smaller ratio, indicating the existence of economy of scale in heating. The coefficient of warmth retention is positive and statistically significant, showing the positive correlation between houses with better warmth retention and a higher heating expenditure ratio. This is counterintuitive, because better warmth retention is supposed to save heating energy. One possible reason could be reverse causality, where households with high heating expenditure tend to add insulation and take other steps to save on heating expenditure. Another reason could be simultaneous causality, where households with high heating expenditure are those who pursue comfort and therefore are more likely to improve the warmth retention of the house. In Hebei, the findings are similar to Beijing: households with lower income and those that have elderly members were more likely to be in energy poverty before the program.

Table 4: Heating Expenditure Ratio Before the Energy Transition Program

	Beijing	Hebei
Household Characteristics		
income	-0.031***	-0.088***
	(0.005)	(0.015)
household size	-0.681***	0.292
	(0.167)	(0.300)
elderly	0.315	3.697**
	(0.467)	(1.529)
children	0.297	0.177
	(0.407)	(1.338)
education	-0.725***	-0.233
	(0.270)	(0.551)
Housing Characteristics		
house size	0.480***	-0.994
	(0.170)	(1.001)
house age	0.038*	-0.008
	(0.020)	(0.072)
warmth retention	0.704*	1.953*
	(0.405)	(1.011)
Constant	10.03***	10.77***
	(0.872)	(2.683)
Observations	1,483	263
R-squared	0.160	0.226

Notes: OLS estimation. The explained variable is the ratio of heating energy expenditure to income before the program. *, ** and *** indicate significance levels of 10%, 5% and 1% respectively. Robust standard errors in parentheses.

We then investigate the characteristics of households that are more likely to have a high ratio after the program. We distinguish among the programs and summarize the regression results in Table 5. Each column in Table 5 includes the participants in one program. Similar to the findings before the program, the results after the program show that participants who have a high expenditure ratio are those with lower income, fewer members, lower education, and larger houses. One different finding is that the coefficient of warmth retention is negative and statistically significant in the regression for *coal to gas* in Beijing , while it is positive, small, and not statistically significant in other regressions after the reform. A possible reason is that the reverse causality and co-causality are alleviated in the after-program regressions, because the program brought a shock to heating expenditure and the response of improving warmth retention (e.g., adding or retrofitting insulation to old houses) takes time.

Table 5: Heating Expenditure Ratio After the Energy Transition Program

	Coal to Electricity in Beijing	*Coal to Gas* in Beijing	*Clean Coal Replacement* in Beijing	*Coal to Gas* in Hebei
Household Characteristics				
income	-0.023***	-0.014**	-0.054***	-0.162***
	(0.007)	(0.006)	(0.007)	(0.031)
household size	-0.828**	-1.908*	-0.581**	-0.202
	(0.395)	(1.016)	(0.248)	(0.567)
elder	-0.739	0.647	-1.024	1.510
	(1.078)	(1.808)	(0.876)	(2.899)
children	-0.132	2.147	0.938	-3.488**
	(0.791)	(1.711)	(0.658)	(1.342)
education	-1.212*	-2.670	-1.011**	0.579
	(0.695)	(1.613)	(0.472)	(1.311)
Housing Characteristics				
house size	0.663	1.888*	0.832***	0.603
	(0.544)	(1.105)	(0.293)	(1.581)
house age	0.068	-0.130**	0.030	-0.053
	(0.053)	(0.057)	(0.036)	(0.102)
warm retention	0.389	-3.241**	0.938	0.321
	(1.127)	(1.361)	(0.677)	(1.990)
Constant	11.72***	19.79***	11.86***	20.95***
	(2.431)	(6.023)	(1.314)	(5.541)
Observations	335	68	637	127
R-squared	0.152	0.412	0.175	0.317

Notes: OLS estimation. The explained variable is the ratio of heating energy expenditure to income after the programs. We distinguish the programs and the regions. Each column shows the results for participants in one program of one region. *, ** and *** indicate significance levels of 10%, 5% and 1% respectively. Robust standard errors in parentheses.

We further explore whether the energy transition program has heterogeneous effects across households with different characteristics. We run regressions of the change in the ratio before and after the program on characteristics of households and houses. Results are summarized in Table 6. Similar to previous findings, households with lower income are more likely to be worse off due to the *coal to gas* program. These findings show that low-income households not only have a high expenditure ratio and easily fall into energy poverty, but also are burdened by a greater negative impact from these programs. The coefficient for warmth retention is negative and statistically significant in the regression for coal to gas in Beijing, which provides support for the results in Table 5. For the other characteristics, the coefficients are not statistically significant, implying the universal influence of the program across households with different household characteristics and housing characteristics, except for income and warmth retention.

Table 6: Heating Expenditure Ratio Change After the Transition Program

	Coal to electricity in Beijing	*Coal to gas* in Beijing	*Clean coal replacement* in Beijing	*Coal to gas* in Hebei
Household Characteristics				
income	-0.003	-0.008*	0.004	-0.068***
	(0.002)	(0.004)	(0.003)	(0.018)
household size	0.041	-0.052	0.104	-0.216
	(0.210)	(0.759)	(0.128)	(0.427)
elder	0.0145	1.937	-0.256	-2.301
	(0.762)	(1.285)	(0.494)	(2.140)
children	0.119	0.0275	-0.458*	-1.755
	(0.516)	(1.204)	(0.273)	(1.089)
education	-0.299	-0.118	0.060	-0.041
	(0.425)	(1.129)	(0.212)	(0.893)
Housing Characteristics				
house size	0.529**	0.278	0.071	1.217
	(0.266)	(0.797)	(0.138)	(1.225)
house age	0.0153	-0.147***	-0.018	0.096
	(0.028)	(0.052)	(0.020)	(0.100)
warm retention	-0.299	-3.008***	-0.166	-0.364
	(0.759)	(0.994)	(0.341)	(1.658)
Constant	0.581	6.704	-0.751	7.046
	(1.617)	(4.485)	(0.824)	(5.312)
Observations	335	68	637	127
R-squared	0.012	0.283	0.012	0.139

Notes: OLS estimation. The explained variable is the change of expenditure ratio after the programs. Each column shows the results for each treatment group. *, ** and *** indicate significant levels of 10%, 5% and 1% respectively. Robust standard errors in parentheses.

6. Conclusion

Heating is a necessity in northern winters. When heating expenditure accounts for a high proportion of expenditures, households need to pay a higher proportion of their income to meet this basic need; as a consequence, they must reduce other consumption. After the household heating energy transition program was piloted in Beijing in 2013 and then rolled out to neighboring provinces, the heating expenditures of participating households that switched to gas or electricity increased sharply, and the problem of energy poverty has been intensified in these areas.

Using household-level questionnaires in Beijing and Hebei, this paper studies the increase in energy poverty of rural households through the heating energy transition program. The results show that, after the program, the overall breadth of energy poverty in the surveyed areas near Beijing remains basically unchanged. By contrast, the breadth of energy poverty of participants in Hebei increased from 21.43% to 36.36%. The depth of energy poverty in the two places has risen, with Hebei increasing more. The *coal to electricity* and *coal to gas* programs exacerbated energy poverty, though *clean coal replacement* alleviated energy poverty. Further, regression results show that households with lower income, smaller household size and lower education, and those with larger housing areas are more likely to fall into energy poverty. In addition, low-income households are negatively affected by the *coal to gas* program to a larger degree.

In addition to fuel cost, the heating energy transition program also involves the costs of infrastructure construction and the replacement of heating equipment. Due to the subsidy scheme, households do not bear the cost of infrastructure construction, but they do bear a portion of heating equipment replacement. When the cost of equipment replacement is taken into consideration, the energy poverty problem is more serious.

The main reason for the increase in energy poverty is that the household heating energy transition from coal to electricity and gas is costly and mandatory, and the supporting subsidy is insufficient to cover the increasing cost. Among the programs, although the *clean coal replacement* program is also mandatory, its replacement energy, clean coal, is much cheaper than electricity and gas, and does not involve the cost of infrastructure construction and heating equipment replacement. This implies that *clean coal replacement* would a good transitional measure before eventually achieving heating with coal or electricity, if the government is fiscally constrained in the short term.

These findings call the attention of policy makers to low-income households when designing and implementing policies. Without identifying the likely heterogeneous effects, a mandatory "one policy for all" is likely to hurt low-income households more. Low-income households need special attention during the implementation of policies. According to the survey, the subsidies for electricity and natural gas are insufficient and were not in place in time in some cases.

Furthermore, due to the huge financial pressure caused by the large-scale subsidies, it is foreseeable that the subsidy will not last long. When there is no subsidy in Beijing, the energy poverty breadth will further increase by 2.8 percentage points. Considering the limited financial resources and the unsustainable subsidies, encouraging technological innovation to improve the efficiency of electricity and gas heating and reduce the cost of clean heating would be the key to achieving affordable, clean heating.

References

Barnes, D. F., Khandker, S. R., and Samad, H. A. (2011). Energy poverty in rural Bangladesh. *Energy Policy, 39*, 894–904.

Boardman, B. (1991). Fuel poverty: From cold homes to affordable warmth. Pinter Pub Limited.

Boardman, B. (2010). Fixing fuel poverty: Challenges and solutions. Earthscan. London.

Chaton, C., Lacroix, E., 2018. Does France have a fuel poverty trap? *Energy Policy, 113,* 258–268.

Foster, J., Greer, J., and Thorbecke, E. (1984). A class of decomposable poverty measures. *Econometrica: Journal of the Econometric Societ*y, 761–766.

Foster, V., Tre, J.-P., Wodon, Q. (2000). Energy prices, energy efficiency, and fuel poverty. Latin America and Caribbean Regional Studies Programme. Washington, DC: World Bank.

Guertler, P. (2012). Can the Green Deal be fair too? Exploring new possibilities for alleviating fuel poverty. *Energy Policy, 49,* 91–97.

Healy, J. D., and Clinch, J. P. (2004). Quantifying the severity of fuel poverty, its relationship with poor housing and reasons for non-investment in energy-saving measures in Ireland. *Energy Policy, 32*, 207–220.

Hills, J., 2011. Fuel poverty: the problem and its measurement: Interim Report of the Fuel Poverty Review. Case Report, Centre for Analysis of Social Exclusion, LSE.

Hills, J. (2012). Getting the measure of fuel poverty: Final Report of the Fuel Poverty Review. Case Report, Centre for Analysis of Social Exclusion, LSE.

Isherwood, B., and Hancock, R. (1979). Household expenditure on fuel: Distributional aspects. London: Economic Adviser's Office, DHSS.

Jenkins, D. (2010). The value of retrofitting carbon-saving measures into fuel poor social housing. *Energy Policy, 38*, 832–839.

Jian-ping, Y., 2013. Energy poverty situation and problem analysis in rural China. *Journal of North China Electric Power University (Social Sciences), 3.*

Li, K., Liu, C. and Wei, Y. (2011). Analysis to China's energy poverty. *China's Energy, 8*, 1–9.

Li, K., Lloyd, B., Liang, X.-J., and Wei, Y.-M. (2014). Energy poor or fuel poor: What are the differences? *Energy Policy, 68*, 476–481.

Mohan, G., Longo, A., and Kee, F. (2018). The effect of area based urban regeneration policies on fuel poverty: Evidence from a natural experiment in Northern Ireland. *Energy Policy, 114*, 609–618.

Mould, R., and Baker, K. J. (2017). Documenting fuel poverty from the householders' perspective. *Energy Research & Social Science, 31*, 21–31.

Pachauri, S., and Spreng, D. (2004). Energy use and energy access in relation to poverty. *Economic and Political Weekly*, 271–278.

Sovacool, B. K. (2012). The political economy of energy poverty: A review of key challenges. *Energy for Sustainable Development, 16*, 272–282.

Xie, L. Wei, C., Zheng, X., Wu, W., and Feng, Z. (Forthcoming in 2020). Who Benefits from the Household Energy Transition Program in China? A Benefit and Cost Analysis Based on Survey Data. Gothenburg, Sweden, and Beijing, PRC: Environment for Development Discussion Paper Series.

Zhang, X., Jin, Y., Dai, H., Xie, Y., and Zhang, S. (2019). Health and economic benefits of cleaner residential heating in the Beijing–Tianjin–Hebei region in China. *Energy Policy, 127*, 165–178. https://doi.org/10.1016/j.enpol.2018.12.008

Appendices

Appendix A

Subsidy Scheme in Beijing

Coal to Electricity – Time of Use pricing is implemented for the participating households and off-peak price is subsidized. During the off-peak period (21:00 to 6:00), the electricity price is 0.3 yuan per kWh without subsidy, and the subsidy is 0.2 yuan/kWh, of which 0.1 yuan/kWh is from the municipal government and the other 0.1 yuan/kWh is from the district government. The cap is 10,000 kWh per household. In addition, there is a municipal equipment subsidy which is 1/3 of the purchase cost for energy storage type electric heaters, with a cap of 2.2 thousand yuan; 100 yuan per square meter for air source heat pump and ground source heat pump, with a cap of 12 thousand yuan. The district government can increase the subsidies based on their financial capacity. Further, the government pays all outdoor electricity line expansion expenses, and subsidizes the indoor line expansion.

Coal to Gas – Participating households enjoy a subsidy of 0.38 yuan per m^3 for natural gas, with a cap of 820 m^3. The government subsidizes 1/3 of the equipment price, with a maximum amount of 2.2 thousand yuan per household. For the gas pipeline, the government pays the construction cost and the village pays the renovation cost.

Clean Coal Replacement – The government subsidizes 200 yuan per ton for clean coal, with a maximum amount of 4.5 tons per household.

Subsidy Scheme in Hebei

Coal to Electricity – Electricity price and line subsidy schemes are the same as Beijing. There is a small difference in the equipment subsidy scheme, which is that the government subsidizes 5 thousand yuan for participating households with direct electric heating or air energy heat pump heating.

Coal to Gas – Participating households enjoy a subsidy of 1 yuan per m^3 for natural gas, with a cap of 1200 m^3. For pipeline transformation and equipment purchase, the government subsidizes 70% of the purchase and installation investment of gas equipment, with a maximum amount of 2.7 thousand yuan.

Clean Coal Replacement – The government subsidizes 300 yuan per ton for clean coal.

Appendix B

Table B1: Energy Prices in Rural Areas of Beijing

Energy type	Unit	Price before	Price after (with subsidy)
Electricity	yuan/kWh	Peak period: 0.4883 (first tier) 0.5883 (second tier) Off-peak period: 0.3	Subsidize 0.2 yuan per kWh for off-peak consumption, up to 10,000 kWh per household
Natural gas	yuan/m^3	2.28 (first tier) 3.5 (second tier) 3.9 (third tier)	Subsidize 0.38 yuan per m^3, up to 820 m^3 per household
raw coal	yuan/ton	650	No subsidy
Bituminous coal: briquette	yuan/ton	675	No subsidy
Bituminous coal: honeycomb coal	yuan/ton	743	No subsidy
Anthracite: briquette	yuan/ton	750	Subsidize 200 yuan per ton, up to 4.5 ton per household
Anthracite: honeycomb coal	yuan/ton	800	Subsidize 200 yuan per ton, up to 4.5 ton per household
Firewood	yuan/ton	0.3	No subsidy

Notes: Information on prices of electricity and natural gas is from Beijing Municipal Commission of Development and Reform. Information on prices of coal and firewood is from the village survey of CRECS 2016 Beijing.

Appendix C

We rerun the regressions in Tables 4 through 6 with a new dependent variable: the energy poverty dummy. Given the dummy dependent variable, we adopt logit estimation. The estimated marginal effects of the explanatory variables are summarized in the following tables. The findings are similar to Tables 4 through 6, but the significance of the estimation is negatively affected. The reason is as explained in the main text: the energy poverty dummy is constructed from the expenditure ratio and contains less information than the continuous variable of expenditure ratio.

Table C1: Energy Poverty before the Heating Energy Transition Program

	Beijing	Hebei
Household Characteristics		
income	-0.007***	-0.011***
	(0.0004)	(0.001)
household size	-0.002	0.017
	(0.009)	(0.021)
elderly	0.004	0.037
	(0.018)	(0.036)
children	0.007	-0.040
	(0.025)	(0.052)
education	0.005	0.031
	(0.012)	(0.029)
Housing Characteristics		
house size	0.039***	0.037
	(0.011)	(0.030)
house age	-0.0007	-0.001
	(0.0007)	(0.002)
warmth condition	0.008	0.041
	(0.017)	(0.037)
Constant	3.398***	2.659
	(1.416)	(2.275)
PseudoR^2	0.394	0.430
Wald *c*2	121.39***	24.35***
Observations	1,483	263

Notes: Logit model. The explained variable is whether a household was in energy poverty before the program. The reported results are marginal effects. *, ** and *** indicate significance levels of 10%, 5% and 1% respectively. Robust standard errors in parentheses.

Table C2: Energy Poverty after the Heating Energy Transition Program

	Coal to Electricity in Beijing	*Coal to Gas* in Beijing	*Clean Coal Replacement* in Beijing	*Coal to Gas* in Hebei
Household Characteristics				
income	-0.005***	-0.007***	-0.007***	-0.011***
	(0.0005)	(0.001)	(0.001)	(0.002)
household size	0.0002	0.049	-0.018	0.026
	(0.020)	(0.053)	(0.013)	(0.029)
elderly	0.018	0.177**	-0.034	-0.044
	(0.046)	(0.073)	(0.027)	(0.065)
children	0.013	-0.005	0.062*	-0.057
	(0.063)	(0.155)	(0.037)	(0.076)
education	-0.014	0.029	-0.013	-0.013
	(0.029)	(0.058)	(0.020)	(0.041)
Housing characteristics				
house size	0.015	0.077	0.033*	-0.036
	(0.019)	(0.056)	(0.018)	(0.049)
house age	0.003	-0.004	3.34e-05	4.55e-06
	(0.002)	(0.004)	(0.001)	(0.003)
warmth condition	0.058	-0.183***	0.005	0.071
	(0.042)	(0.047)	(0.026)	(0.069)
Constant	1.370	1.823	5.828***	27.445**
	(1.057)	(5.762)	(3.572)	(40.251)
PseudoR^2	0.289	0.563	0.350	0.428
Wald $c2$	62.40***	21.64***	45.31***	21.98***
Observations	335	68	637	127

Notes: Logit model. The explained variable is whether a household is in energy poverty after the program. The reported results are marginal effects. Each column shows the results for participants in one program. *, ** and *** indicate significance levels of 10%, 5% and 1% respectively. Robust standard errors in parentheses.

Table C3: Energy Poverty Change after the Program

	Coal to electricity in Beijing	*Coal to gas* in Beijing	*Clean coal replacement* in Beijing	*Coal to gas* in Hebei
Household Characteristics				
income	-0.003***	-0.004***	-0.001***	-0.001
	(0.0005)	(0.002)	(0.0004)	(0.0008)
household size	0.039**	0.057	0.009	-0.014
	(0.019)	(0.041)	(0.010)	(0.029)
elderly	0.069	0.162**	0.015	-0.174**
	(0.048)	(0.068)	(0.024)	(0.082)
children	-0.064	0.033	-0.052	-0.019
	(0.058)	(0.120)	(0.032)	(0.085)
education	0.024	0.073	-0.001	-0.087*
	(0.030)	(0.057)	(0.014)	(0.046)
Housing characteristics				
house size	-0.052**	-0.009	0.010*	-0.053
	(0.023)	(0.048)	(0.006)	(0.045)
house age	0.003	-0.0003	-0.001	0.003
	(0.002)	(0.004)	(0.001)	(0.003)
warmth condition	0.006	-0.105	0.003	0.061
	(0.042)	(0.066)	(0.023)	(0.0676)
Constant	0.279	0.049	0.177**	2.631
	(0.224)	(0.115)	(0.121)	(3.270)
PseudoR^2	0.199	0.313	0.075	0.101
Wald *c*2	44.67***	12.93	19.58**	12.75
Observations	335	68	637	127

Notes: Logit model. The explained variable is the change of household energy poverty state from before the program to after the program. The reported results are marginal effects. Each column shows the results for participants in one program. *, ** and *** indicate significance levels of 10%, 5% and 1% respectively. Robust standard errors in parentheses.