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Coal taxation reform in China and its distributional effects on residential consumers

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ABSTRACT

There is an ongoing reform in coal taxation in China, from a quantity-based to a price-based approach. While the coal tax could play an important role in resource conservation and air pollution reduction, its distributional effect is not well studied. This paper investigates the distributional effect of China's coal taxes on households before and after the reform. We find that about 30 percent of rural households and six percent of urban households are directly affected by the coal taxes, and that the directly affected households tend to be poor. We also find that provinces are affected differently by the coal taxes; the provinces that are more affected tend to have lower household income. By the Suits Index, we find that both the quantity-based and price-based coal taxes are regressive for residential consumers in China, and that the coal taxation reform had little effect on the regressivity of the coal tax. By simulation, we find that the regressivity of the coal tax could be reduced if the tax rate were set to be positively correlated with provincial household income.

1. Introduction

Coal plays an important role in climate change and air pollution. It accounts for around 30 percent of the primary energy consumption in the world but almost half of the world's CO2 emissions. As the largest consumer of coal in the world, China accounted for around half of the world's coal consumption in the last decade. In China, coal comprises almost 60 percent of the country's primary energy consumption, far exceeding the 27 percent share of coal in the world average (BP, 2018). China's heavy reliance on coal has caused increasingly severe environmental consequences, including air pollution and greenhouse gas emissions. According to BP (2018), around 80 percent of the carbon emissions in China are from coal consumption, while the world average is 40 percent.

In recent years, China has taken a number of measures to cut its coal consumption, particularly in light of the increasing spotlight on high levels of air pollution in the country's major cities. For instance, China decided to close coal-fired power and heating plants located in Beijing's municipal area, in an effort to improve air quality in the capital. On the residential consumption side, the government encourages or mandates that both urban and rural households in and around big cities change their heating energy from coal to natural gas or electricity. Meanwhile, to accelerate the transformation of China into a low-carbon economy, a nationwide coal taxation reform took effect in 2014. The reform removed various types of pre-existing fees on coal and instead imposed a tax. The tax rate is set between 2 and 10 percent, up to the choice of the provinces. Although a high rate can alleviate the fiscal burdens of local government, most provinces opted for a low tax rate between two and three percent. The possible reasons include protecting local coal businesses and concern about the distributional effects of the reform.

A common argument against a higher tax rate is the potential for regressive consequences, where the poor are hit hardest and bear an unfair tax burden. Does this argument generally hold? The literature on China's coal tax reform is limited, and previous studies on resource or energy taxes in other countries have mixed findings. This study, therefore, investigates the distributional impact of the coal taxation reform on residential consumers.

We study coal use at the household level. Household coal use is described as "scattered coal"[1]; it includes coal used by rural and urban residents for home heating, cooking, heating water, etc. Although

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[1] The concept of scattered coal is not clearly defined and has different expressions in academic literature and policy documents. For a discussion of coal use classification, please see Appendix A.

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household coal accounts for only 2% of the total coal consumption in China (China Energy Statistical Yearbook, 2018), it causes a large negative impact on human health, due to its high pollution intensity. Household coal is a kind of raw coal that has not been processed and washed according to strict standards (Zhi et al., 2015). It combusts inefficiently and the emissions are not filtered before being discharged into open air, due to the limitations of household heating or cooking devices. Therefore, household coal emits five to ten times more air-borne pollutants per unit than industrial coal. It has become an important source of air pollution in Northern China in winter.

We also care about household coal because it takes a substantial share of total household expenditure for low-income households, especially those in cold and rural areas. According to the Chinese Residential Energy Consumption Survey (CRECS) for 2012, 2013 and 2014, the household expenditure share on coal varies a lot among provinces, and is much higher for rural households than urban households. The average expenditure on coal is 7.6 percent of total household expenditure for households that use coal, and the share is 3.9 percent and 8.0 percent for urban and rural households respectively.

Coal taxation in China started in 1984, along with taxation of crude oil and natural gas. The goal of the taxes on these fossil resources was to promote efficient levels of extraction and efficient allocation of national resources. The taxes were charged based on quantity extracted (a given number of yuan per ton), for simplicity. Besides the coal tax, firms were also charged several kinds of fees, such as a mineral resources compensation fee, a price adjustment fund, etc.

Effective December 1, 2014, the Ministry of Finance and the State Administration of Taxation released the "Notification of the Coal Resource Taxation Reform" with the stated goals of promoting resource conservation and environmental protection and reducing the tax burden on enterprises. The announcement stated that a price-based coal tax (a given percentage of the price per ton) will replace the quantity-based tax, and that provincial governments are responsible for setting the tax rate within the range of two to ten percent. Firms that sell raw or washed coal are charged at the tax rate set by the provincial government. Firms that produce coal using new technologies or from depleted coal mines enjoy a 30 to 50 percent discount. Meanwhile, all fees related to fossil resources were eliminated.

As depicted in Fig. 1, the tax rates in Heilongjiang, Jilin, Liaoning, Beijing, Henan, Hebei, Jiangsu, Anhui, Jiangxi, Fujian, and Hubei are 2%, while the tax rates are set at 2.5% for Guangxi, Gansu, Sichuan and Hunan. The local governments in Chongqing, Shandong, Guizhou and Yunnan set the tax rate at 3%, 4%, 5% and 5.5%, respectively. For coal-rich provinces, the tax rates are relatively higher: the tax rates in Xinjiang, Qinghai and Shaanxi are 6%. The tax rates in Ningxia, Shanxi and Inner Mongolia are 6.5%, 8% and 9%. Given the variations in tax rate and income across provinces, consumers in different provinces are affected differently.

Utilizing a comprehensive dataset on household energy consumption, we investigate the distributional effects of the coal taxes before and after the reform, at household level, which is a much finer level than most previous studies. Households are affected by a coal tax in both direct and indirect ways. For households that directly consume coal, e.g., use coal for cooking or heating, they directly face the price change when a tax is applied, and therefore are directly affected by the reform. Households that do not use coal can also be affected, because coal is an important input for the generation of power and the production of many consumption goods. The tax on coal could be transferred to many sectors through product price adjustment and thereby could indirectly affect the consumers of those goods. In this paper, we focus on the direct effect, which is also called the first-order equity impact.

We find that nearly 30 percent of rural households and six percent of urban households are directly affected by the coal tax. The affected households tend to be poor. Provinces with greater coal consumption, higher coal price, and a higher tax rate are affected to a larger degree, and they tend to have lower household income. Both the quantity-based and price-based coal taxes are regressive, and the magnitudes of the regressivity, measured by the Suits Index, are similar. By simulation, we find that the price-based coal tax could reduce regressivity if the tax rate were positively correlated with household income.

The remainder of the paper is organized as follows. Section 2 reviews related literature. Section 3 introduces the data. Section 4 describes the methodology to measure the progressivity/regressivity of a tax. Section 5 presents the findings. Section 6 concludes.

2. Literature review

There is a large literature on the distributional effects of taxes. The concept of regressivity or progressivity is commonly used for the analysis (e.g., Suits, 1977; Carlson and Patrick, 1989; Fourie and Owen, 1993; Remler, 2004; Gospodinov and Irvine, 2009; Owen and Noy, 2017). The literature on the distributional effects of carbon, resource, and energy taxes yields mixed findings. Energy and carbon taxes are found to be regressive in most developed countries, such as the United States (Mathur and Morris, 2014), Canada (Hamilton and Cameron, 1994), Australia (Cornwell and Creedy, 1996), the Netherlands (Kerkhof et al., 2008), and Denmark (Wier et al., 2005), France and Spain (Symons et al., 2000), although they are found to be progressive for the UK and Italy (Symons et al., 2000; Tiezzi, 2005). Sterner, 2012 studied the carbon tax in seven European countries and found a very small regressivity of the tax; he therefore concluded that the carbon tax is approximately proportional. In developing countries, the findings also vary across samples. Yusuf and Resosudarmo (2007) analyzed the distributional impact of a carbon tax in Indonesia and suggested that the introduction of such a tax was not necessarily regressive. Brenner et al. (2007) studied proposed carbon charges on the use of fossil fuels in China and suggested that the charges would be progressive, while Jiang and Shao (2014) found that a carbon tax in China would be significantly regressive.

The difference in distributional effects of a resource or carbon tax is related to the differences in tax base, expenditure patterns, and price elasticity of demand across regions. For example, Barker and Kohler (1998) distinguished energy between household use and transportation use, and found that carbon taxes based on energy for household use were regressive in most EU countries, while those based on transportation use were slightly progressive. Jiang et al. (2015) found that the removal of electricity subsidies has a regressive effect, while the removal of transport fuel and coal subsidies have the strongest and the weakest progressive effects respectively.

The distributional effect of a resource or carbon tax is also affected by considering the factor price changes caused by the tax and how the tax revenue is recycled back to the economy (e.g., Bureau et al., 2010; Beck et al., 2015; Gonzalez, 2012). This is referred as the indirect impact or the second-order equity impact. Dissou and Siddiqui (2014) found that carbon taxes tend to increase inequality through commodity price changes and decrease inequality through factor price changes. Klenert and Mattauch (2016) analyzed the distributional effects of a carbon tax reform in a two-sector model and found that the reform is progressive if the revenues are recycled as uniform lump-sum transfers and regressive otherwise.

In this paper, we study the distributional effect of China's coal taxes on households before and after the reform, utilizing detailed coal use data from thousands of households all over the country. Literature on this specific topic is limited. One possible reason is that the heavy use of coal is not a world-wide phenomenon. When Brenner et al. (2007) and Jiang and Shao (2014) studied China's carbon tax, they were considering a different coal tax than the one we study here. While there is a large Chinese literature on China's resource taxes, these studies mainly focus on the optimal tax rates under different scenarios, the effect of a tax on the whole economy or industrial sectors, or the provincial differences in the effects (e.g., Lin, 2008; Xu et al., 2015; Cao et al., 2011; Guo et al., 2011; Xu, 2007). Distributional effects on residential

Fig. 1. Spatial distribution of coal tax rate (Data source: Chinese Residential Energy Consumption Survey 2012, 2013 and 2014).

consumers are not considered in this line of literature.

3. Data

The main datasets are from the Chinese Residential Energy Consumption Survey (CRECS) 2012, 2013 and 2014, conducted by the department of Energy Economics at Renmin University of China. CRECS is the first national household energy consumption survey in China. It collects detailed information on (1) household energy prices and consumption, including coal, oil, natural gas, electricity, etc.; (2) the ownership of energy-using appliances and detailed energy consumption habits of a household; (3) household characteristics, including annual household income, age and education of household members, etc.; and (4) characteristics of housing, including size, age, infrastructure, etc.

Fig. 2. Spatial distribution of coal consumption (Data source: Chinese Residential Energy Consumption Survey 2012, 2013 and 2014).

In the three years of 2012 through 2014, 8717 households in 31 province-level administrative units were randomly sampled. Taiwan, Macao, and Hong Kong are not included in the sampling. Tibet is sampled, but excluded from the analysis, because the income variable is missing in all observations in Tibet. This results in a sample of 7241 households in 30 province-level administrative units. The number of observations in a province ranges from 25 to 759 households, based on the variation on population.

Fig. 2 depicts the spatial distribution of household coal consumption. It shows that the coal consumption in the north is much higher than that in the south and the southeast coastal provinces. The average annual household coal consumption of Qinghai, Gansu and Hebei reaches 1588, 1131 and 941 kg (kg), respectively. For the southeast coastal areas, such as Guangdong, Zhejiang and Fujian, the household coal consumption is only about 1 kg, indicating that the majority of the households in those areas do not directly consume coal.

Fig. 3 depicts the spatial distribution of household annual income. It shows that the average household income in the eastern coastal region is higher than that of the inner mainland. Beijing has the highest household income, followed by Shanghai, Guangdong and Jiangsu, where the average annual household incomes are more than 100 thousand yuan. In contrast, Guangxi, Hebei and Yunnan have the lowest household income, which is less than 45 thousand yuan per year.

Fig. 4 depicts the spatial distribution of coal price. Most households reported the price they paid for coal in the survey for 2014, but only a small portion of households did so in the surveys for 2012 and 2013. Based on the fact that coal prices within a region are similar, for 2014 we fill in the missing data using the average household-reported coal price in the same province, or the average coal price of the whole sample for the provinces where no price information is available. We then calculate the corresponding prices in 2012 and 2013 based on the prices in 2014, using the Retail Price Indices by Category and Region (2013, 2014) from the China Price Statistical Yearbook. This shows that the coal prices are lower in provinces with greater coal production, such as Shanxi, Shaanxi and Inner Mongolia. The coal prices in Beijing, Henan, Anhui, Zhejiang, Sichuan and Yunnan are relatively high. Compared with Figs. 2 and 3, Fig. 4 shows that the coal prices tend to be lower for provinces with higher coal consumption and lower household income, such as the northern part of China: Heilongjiang, Jilin, Hebei, etc.

Table 1 provides the summary statistics of the variables of coal price, household annual income, and household coal consumption. Coal consumption and income show large variation across households, while the coal price variation is relatively small, as expected.

4. Methodology: Suits Index

We use the Suits Index to measure the progressivity/regressivity of the coal taxes. The Suits Index is a measurement developed by Daniel B. Suits (1977) and has been one of the most widely used instruments to assess the progressivity/regressivity of a tax. As illustrated in Fig. 5, the Suits Index compares a cumulative frequency distribution of tax liabilities with a similar distribution of household income. One can conclude that the coal tax is regressive (progressive) if the percentage of the total tax burden is always higher (lower) than the corresponding percentage of total income. That is, the percentage curve of the total tax burden (i.e., the Lorenz curve) is above (below) the diagonal line for a regressive (progressive) tax. The Lorenz curve of a proportional tax would follow the diagonal line.

The Suits Index is calculated as $S = 1 - \left(\frac{L}{K}\right)$, where L is the area under the Lorenz curve and K is the area under the straight 45-degree line. The range of the Suits Index is between −1 (extreme of regressivity) and 1 (extreme of progressivity). For a proportional tax, $L = K$, which implies that the Suits Index is zero. For a progressive (regressive) tax, the Suits Index takes on positive (negative) values. A larger absolute value of a Suits Index indicates a larger degree of regressivity (if negative) or progressivity (if positive).

5. Findings

5.1. About 30 percent of rural households and six percent of urban households are directly affected by coal taxes

We compare the penetration rate of coal between urban and rural households. As shown in Table 2, 1323 out of 4486 surveyed rural households (about 30 percent) and 165 out of 2755 surveyed urban households (about six percent) use coal. This indicates that a larger portion of rural households are directly affected by coal taxes, compared to urban households.

5.2. Directly affected households tend to be poor

The survey data show that the average income of rural households is 42.45 thousand yuan, while the average income of urban households is 100.31 thousand yuan, more than twice that of the rural households. Together with Table 2, this implies that coal taxes are more likely to directly affect poor households.

Next, we compare the income of households that use coal with those that do not, for the urban and rural households respectively. As shown in Table 3, coal users and non-users have different household income, and the differences are statistically significant, for both rural and urban households. On average, the per capita annual income of rural households that do not use coal is 36 percent higher than that of rural households that use coal, while urban households that use coal have about half the income of urban non-coal users.

We also compare the size of the residence. As shown in Table 3, in rural areas, living space is larger for households that do not use coal, while the finding is the opposite in urban areas. A possible explanation is that rural households living in large houses are likely to be those with higher income, and they are more likely to use electricity or gas, rather than coal. In contrast, urban households that use coal usually live in suburbs or towns rather than cities and are more likely to live in houses than in apartments, which are generally smaller than houses but more modern in construction and appliances.

5.3. Conditional on use of coal, households that consume more coal tend to be those with relatively higher income

We further explore the relationship between household coal consumption and household annual income, conditional on the use of coal. We distinguish urban and rural households, and plot them separately in Fig. 6. The dots in Fig. 6 are households that consume coal. The lines are linearly fitted. The slopes show the relationship between income and coal consumption. To avoid the influence of outliers, we exclude the households within the top 5th percentile of income.

The fitted line for rural households has a slope of 0.00442, statistically significant at the 5% significance level ($p = 0.014$), while the fitted line for urban households has a slope of 0.0074 and is not statistically significant ($p = 0.114$). The slope of the urban line is about twice that of the rural line, so the insignificance is likely due to the small sample size of the urban households and the greater noise in coal consumption in urban areas. The positive sign of the slopes indicates that, conditional on the use of coal, households with higher income tend to consume more coal.

To quantitatively investigate how income affects the use of coal in both extensive and intensive margins, we perform a regression analysis. Extensive margin refers to whether the household consumes coal, and intensive margin refers to the quantity of coal consumption conditional on the use of coal. The regressions are presented below.

$$C_{it} = \beta_0 + \mathbf{X}_{it}'\boldsymbol{\beta}_2 + \mathbf{Z}_{.t}'\boldsymbol{\beta}_3 + \varepsilon_{it} \tag{1}$$

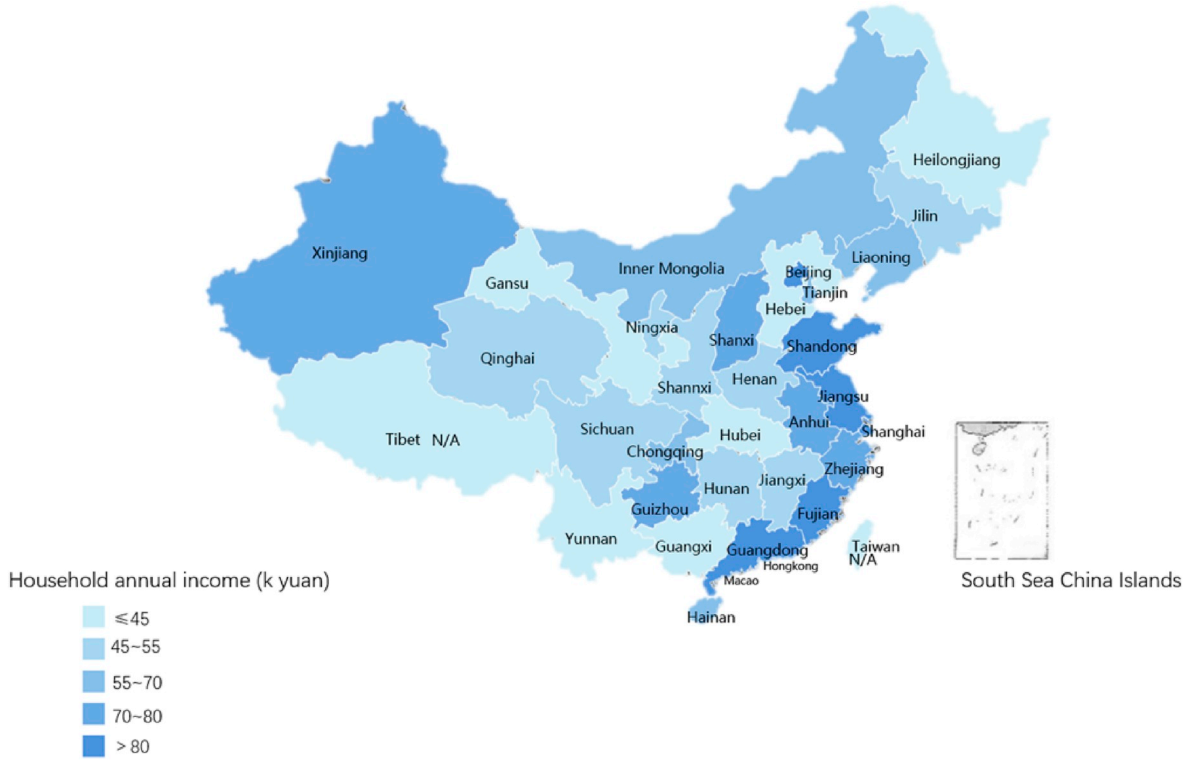


Fig. 3. Spatial distribution of household annual income (Data source: Chinese Residential Energy Consumption Survey 2012, 2013 and 2014).

Fig. 4. Spatial distribution of coal price (Data source: Chinese Residential Energy Consumption Survey 2014, China Price Statistical Yearbook 2013, 2014).

$$ln(Y_{it}) = \alpha_0 + \boldsymbol{X}_{it}'\boldsymbol{\alpha}_2 + \boldsymbol{Z}_{it}'\boldsymbol{\alpha}_3 + v_{it} \tag{2}$$

where C_{it} is a dummy variable, which equals 1 if household i consumes coal at time t, otherwise 0; Y_{it} is coal quantity consumed by household i at time t, conditional on the use of coal; $\boldsymbol{X}_{it}$ is a vector of characteristics of household i at time t including log of household income, household size and years of education of the household head; $\boldsymbol{Z}_{it}$ is a vector of characteristics of the dwelling in which household i lives at time t, including whether the dwelling is in an urban area, whether it has

Table 1
Summary statistics.

Variable	Obs.	Mean	Std. Dev.	Min	Max
Coal consumption (kg)	7241	265.08	849.54	0	16200
Coal price (yuan/kg)	7241	0.98	0.27	0.5	1.63
Annual income (thousand yuan)	7241	64.47	144.35	0	5000

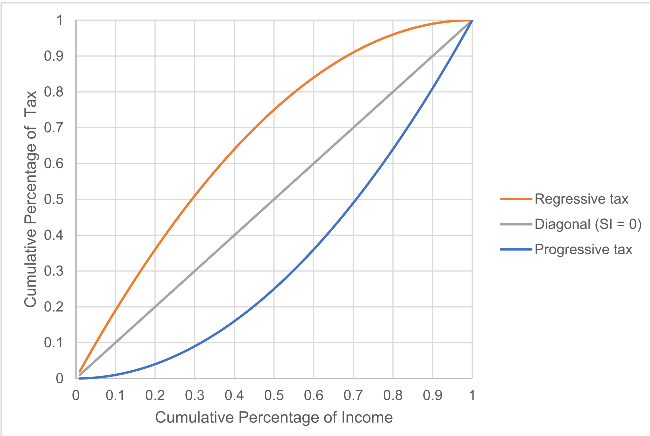


Fig. 5. Illustration of the suits index.

Table 2
Number of households that use coal and do not use coal.

	Households do not use coal	Households use coal	Total
Rural	3163	1323	4486
Urban	2590	165	2755
Total	5753	1488	7241

Table 3
Comparison between households that use and do not use coal.

No. of ob.	Rural households			Urban households		
	Not use coal	Use coal	Diff.	Not use coal	Use coal	Diff.
	3167	1313		2582	165	
Income	18043.91	13277.36	4766.55**	43264.04	20519.35	22744.69***
Area	54.43	45.58	8.85***	40.77	50.49	−9.72***

Notes: income is household annual income per capita, in units of yuan; *area* is per capita area of a residence, in units of square meters. *** and ** indicate that the difference is statistically significant at the 1% and 5% significance levels.

central heating,[2] and the size of the residence; and $\varepsilon_{i,}$ and v_{it} are the error terms. The summary statistics of the variables which are not included in Table 1 through 3 are presented in Table 4 below.

We estimate Equations (1) and (2) using a Logit model and an Ordinary Least Squares (OLS) model, respectively. Estimation results are presented in the first two columns of Table 5. In the next two columns, we add in dummies of year, province, and province by year. Year dummies absorb the effects of factors that are common to all the households, such as macro economy shocks. Province dummies absorb the effects of factors that are province-specific and time-invariant, such as climate, culture, and infrastructure. Province-by-year dummies absorb the effects of factors which vary only at the level of province and year, such as household energy price. We do not include individual fixed effects, because the dataset is repeated cross-sectional at individual level, rather than a panel.

The estimated coefficients of log income in the extensive margin regression (columns (1) and (3)) are negative, indicating that households with lower income are more likely to use coal. This is consistent with the finding in section 5.2, which is that directly affected households tend to be poor. The estimated coefficients of log income in the intensive margin regression (columns (2) and (4)) are positive, indicating that, conditional on the use of coal, households with higher income use more coal. This is consistent with the finding in section 5.3, which is that households that consume more coal tend to be those with relatively higher income. The estimated coefficients of urban in both the extensive and intensive margins are negative, indicating that rural households are more likely to use coal, and consume more conditional on use. This is consistent with the finding in section 5.1. In addition, the regression results show that, compared to the households that do not directly consume coal, the households that consume coal tend to have more household members and are less likely to have central heating; conditional on the use of coal, more coal is consumed if there are more members in the household and if there is no central heating installed.

5.4. Provinces with greater coal consumption, higher coal price, and a higher tax rate are affected to a larger degree, and they tend to have lower household income

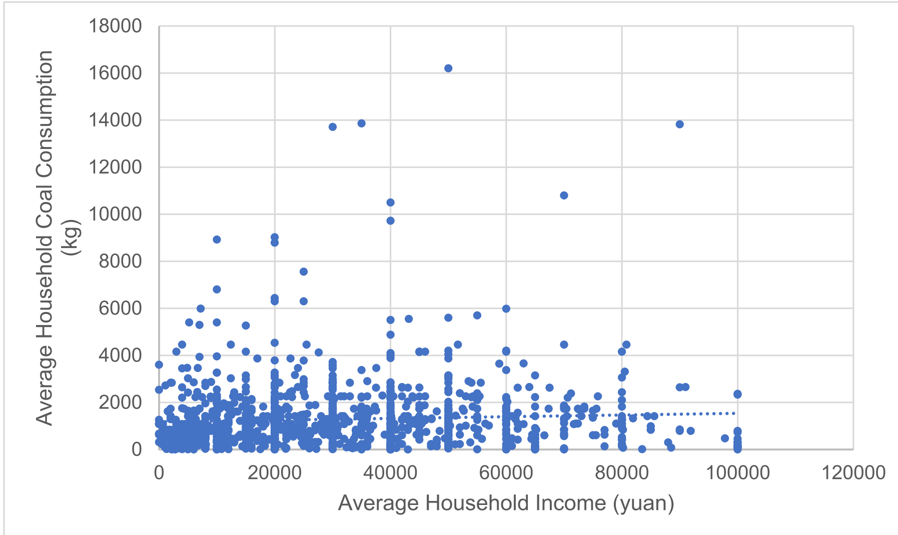
Before the coal tax reform, the amount of tax was determined by the amount of coal consumption. As shown by Fig. 7, average household coal consumption and average household income are roughly negatively correlated. The provinces with lower income are those in the north and inner regions, and they tend to have high coal consumption. As a result, households in these provinces are affected to a larger degree due to greater consumption of coal. By contrast, the majority of households in the southeastern coastal areas do not use coal at home, so they are not directly affected by the coal tax.

Since the reform, the total amount of tax paid by households also has been determined by the coal price and the tax rate. Fig. 8 depicts the average household coal consumption, household income, coal price, and coal tax in each province. It shows that the provinces paying the most coal tax are Qinghai, Ningxia and Shaanxi, which tend to have lower household income. It also shows that there is little correlation between coal consumption and coal price or coal tax rate, and that there is little variation in coal price across provinces. This implies that the difference in tax burden will mainly come from the difference in coal consumption, rather than the differences in coal price and coal tax rate.

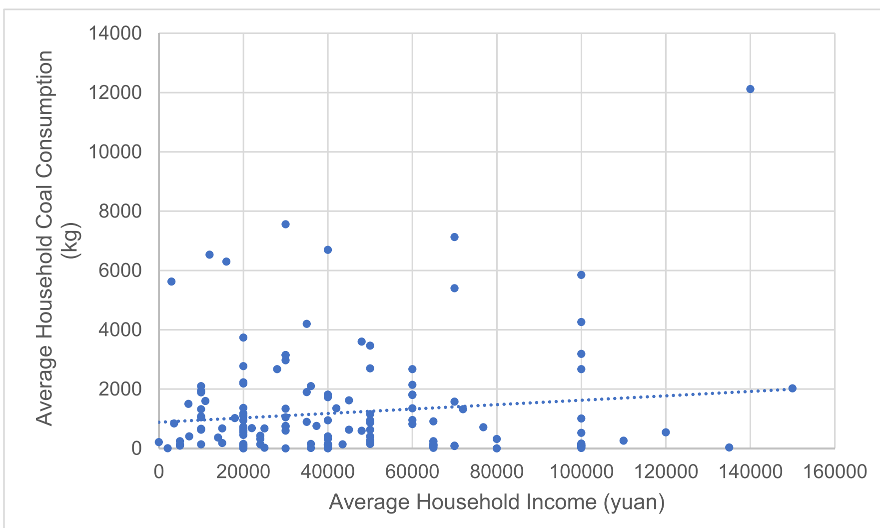
5.5. The quantity-based tax (the tax before the reform) was regressive

To explore the regressivity of the coal tax before the reform, we plot as the red curve in Fig. 9 the cumulative percentage of coal tax paid by households against the cumulative percentage of household income. This shows that the curve lies above the diagonal line. A further

[2] Central or "district" heating is made available in northern China, although not all dwellings in those areas have a connection to central heating installed. This analysis does not consider the role of coal in providing central heating. Households that have central heating are expected to use less "scattered" coal for home heating.



(a) Rural households



(b) Urban households

Fig. 6. The relationship between household income and quantity of coal consumption (conditional on coal use) in rural (a) and urban (b) areas.

Table 4
Summary statistics.

Variable	Obs.	Mean	Std. Dev.	Min	Max
Household size (number of household members)	7163	2.873	1.374	0	16
Education of household head (year)	6963	8.620	4.528	0	22
Central heating (yes = 1, no = 0)	6550	0.195	0.396	0	1

Notes: This table reports the summary statistics of the variables which are included in the regressions but not reported in Table 1 through 3.

calculation shows that the Suits Index is −0.6796. This indicates that the coal tax before the reform was regressive: poor households faced a relatively higher tax burden compared with their income.

5.6. The coal tax reform does not change the first-order equity impact of the coal tax

To assess the regressivity of the tax after the reform, we now plot, for the price-based coal tax, the cumulative percentage of coal tax against the cumulative percentage of household income.[3] For the five provinces that do not produce coal and therefore do not have a reported coal tax rate, we assume their tax rate is the average of the 25 coal producing provinces. Our rationale is that those provinces which do not produce coal import it from other provinces, so they are also affected by the tax-induced coal price change in the coal-exporting provinces.

We plot the curve in blue in Fig. 9. It shows that the coal tax after the reform is still regressive. The Suits Index is −0.6793, very similar to the Suits Index of the tax before the reform. This indicates that the price-based coal tax under the current scheme has the same distributional effect as the quantity-based coal tax before the reform.

[3] To calculate the tax burden of a price-based tax, the price used for the calculation should not include the tax. However, the price we have is the price faced by households, which includes the tax. We do not observe the coal price without tax, because the coal tax is levied at the mining sites, rather than at the household level. By assuming that the embedded household tax rate is the same as that at the mining sites, we calculate the Suits Index based on the price that does not include the tax. We find that the Suits Index is −0.6792, very similar to the index without deducting the tax from the price, which is −0.6793.

Table 5
Extensive and Intensive Margin regression outcome.

	(1)	(2)	(3)	(4)
	Extensive Margin	Intensive Margin	Extensive Margin	Intensive Margin
	(Logit)	(OLS)	(Logit)	(OLS)
Log of income	−0.128***	0.0833	−0.0801*	0.179***
	(0.0331)	(0.0604)	(0.0478)	(0.0536)
Household size	0.107***	0.147***	0.146***	0.0260
	(0.0246)	(0.0313)	(0.0338)	(0.0267)
Education	0.0185**	−0.0329**	−0.00785	−0.0210*
	(0.00931)	(0.0148)	(0.0126)	(0.0116)
Urban	−1.359***	−0.290	−0.504***	−0.0420
	(0.112)	(0.179)	(0.147)	(0.174)
Central heating	−1.889***	−1.061***	−3.183***	−0.975**
	(0.210)	(0.407)	(0.253)	(0.392)
Area of residence	0.000891**	0.00268***	0.00265***	0.00429***
	(0.000437)	(0.000488)	(0.000662)	(0.000599)
Constant	−0.156	5.044***	−1.107	3.653***
	(0.314)	(0.594)	(1.023)	(0.653)
Year dummies			✓	✓
Province dummies			✓	✓
Year by province dummies			✓	✓
Observations	6172	1166	5241	1166
R-squared		0.064		0.499

Notes:Logit model and Ordinary Least Square (OLS) model. Estimation results of equations (1) and (2) are presented in the first two columns. The next two columns add in dummies of year, province, and year by province. The dependent variable in column (1) and column (3) is a dummy variable, which equals one if the household consumes coal, and zero otherwise. The dependent variable in column (2) and column (4) is log of coal quantity consumed, conditional on the use of coal. Robust standard errors are in parentheses. ***, **, and * indicate that the estimate is statistically significant at the 1%, 5%, or 10% significance level, respectively.

5.7. *The tax reform could reduce regressivity if the tax rate were positively correlated with provincial household income*

Since the tax rate is set by the government and varies across provinces, we experiment with different tax rate scenarios, in order to explore whether changing the current coal tax rate scheme can reduce the regressivity of the tax.

In scenario (1), we set a uniform tax rate which is at the average tax rate of 6%, and find the Suits Index to be −0.6800. In scenario (2), we set the tax rate to be positively correlated with the average household income in each province. We first rank the provinces based on the average household income, and then set the tax rate to be $0.02 + 0.002*(i - 1)$, where i is the ordinal number of the province's rank, which is 1, 2 … 30. So, the simulated tax rate is between 2% and 7.8%, with the province with the lowest (highest) income having the lowest (highest) tax rate. We find the Suits Index to be −0.6642, indicating that this tax rate scheme can make the tax less regressive. In scenario (3), we set the tax rate to $0.02 + 0.003*(i - 1)$, so that the tax rate is correlated with the average household income to a larger extent. We find that the Suits Index is −0.6602, which indicates less regressivity, as expected. In scenario (4), we look for the correlation coefficient between tax rate and income that can make the coal tax progressive. By trials, we find that, as the correlation between household income and tax rate gets larger, the Suits Index gets less regressive, but at a diminishing rate. When we set the coefficient of $(i-1)$ to be 0.03, which leads to a coal tax of 100% for the province that has the highest household income, the index is −0.6432, still far below zero – i.e., still regressive.

Table 6 summarizes the above findings. We see the potential to reduce the regressivity of the coal tax, if the tax rate scheme is set appropriately. However, the room for improvement is limited, because the negatively correlated relationship between coal consumption and household income dominates in the distributional effect of the tax, consistent with the findings in section 5.4.

The regressivity curves for the price-based coal taxes are shown in Fig. 10. We zoom out the graph when the cumulative percentage of income is between 0.2 and 0.4, making clear the differences among the three curves. This shows that, when the correlation increases, the curve shifts down, indicating a reduction in regressivity, but the reduction is limited.

6. Conclusion and policy implications

Household energy consumption is an important indoor pollution source in developing countries, particularly in areas where coal comprises a significant proportion of household energy use. Given the enormous health burden imposed by indoor pollution, the literature has started to evaluate the effectiveness of various policy tools available to combat air pollution in China and other industrializing countries (such as India). However, the distributional effects of such policy tools have been paid little attention in the literature so far.

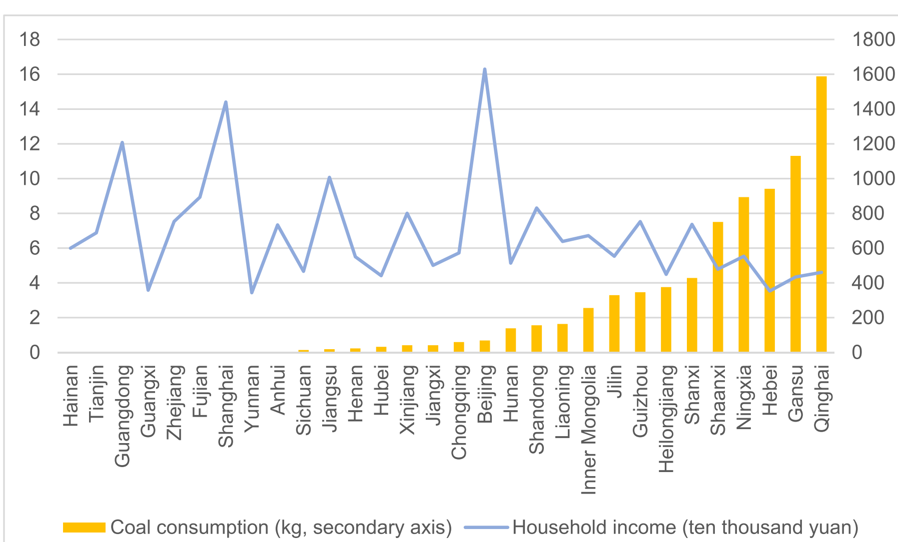


Fig. 7. Average household coal consumption and household income of each province.

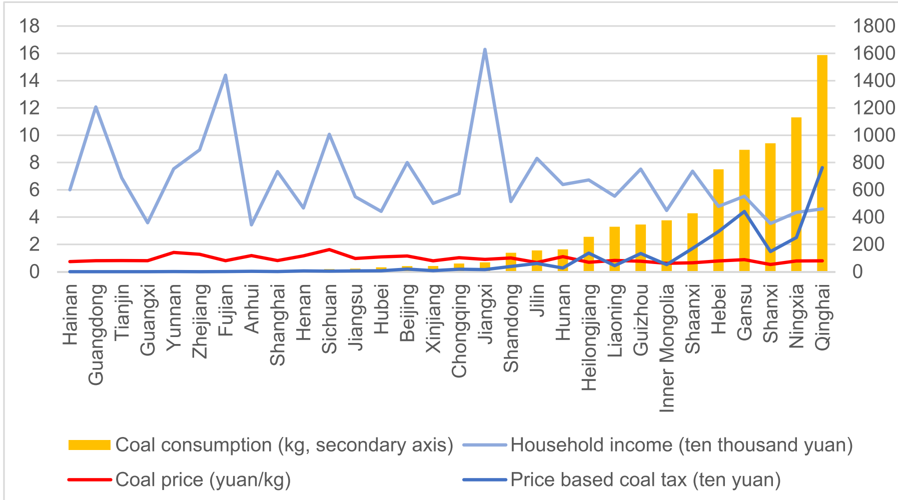


Fig. 8. Average household coal consumption, income coal tax and coal price.

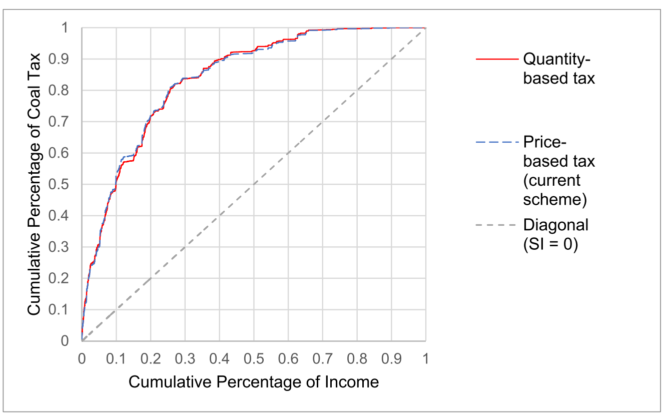


Fig. 9. Regressivity curves for the quantity-based coal tax and the price-based coal tax in current scheme.

In this paper, we investigate the distributional effects of China's coal tax before and after the change to a price-based tax scheme, utilizing detailed household coal consumption data covering most of the provinces in China. We find that nearly 30 percent of rural households and six percent of urban households are directly affected as users of coal. Compared to the households that do not directly consume coal, they tend to have lower income. Rural families that consume coal tend to have a smaller residence (implying lower income in the rural context), while urban families that consume coal tend to have a larger residence (implying that they do not live in a modern apartment). Households that consume coal also tend to have more household members and are less likely to have central (district) heating. We also find that provinces with greater coal consumption, higher coal price, and a higher tax rate are affected to a larger degree and those provinces tend to have lower average income. Therefore, when we use a Suits Index to measure the regressivity/progressivity of the coal tax, we find a negative Suits Index (indicating regressivity) for both quantity-based and price-based coal taxes; the indices are −0.6796 and −0.6793, respectively. By simulation, we also find that a price-based tax could reduce the regressivity of the tax (relative to both the old quantity-based system and the current price-based system) by setting tax rates to be positively correlated with provincial average income. However, the room for improvement is limited, because the negative correlation between coal consumption and household income dominates.

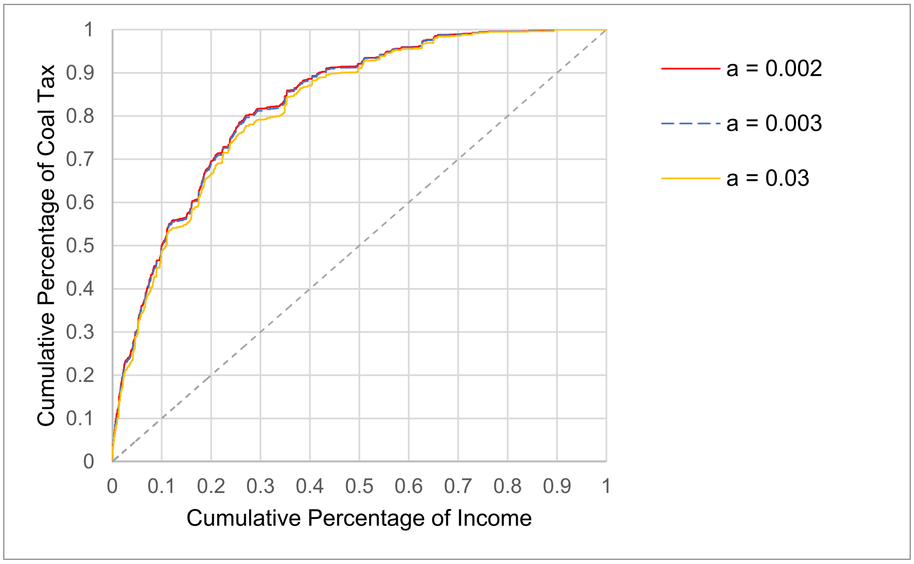
These findings should call the attention of policy makers to the fact that both quantity- and price-based coal taxes in China hardest hit the poor and rural people, who are more likely to be affected by indoor air pollution and suffer from energy poverty. That is, although a coal tax may be effective for energy conservation, mitigation of climate change, and household energy transition, its regressive distribution effects should be considered, and measures should be taken to alleviate the regressive consequences.

This implication does not only apply to coal tax, but also to other price-based mechanisms. For example, while appropriate price-based mechanisms are potentially effective parts of the climate policy toolkits available to developing countries, both their effectiveness and their distributional effects should be evaluated during policy selection, design and implementation. If the poor will bear an unfair tax burden, policy makers should make tradeoffs between effectiveness and fairness. Another example is the broader context of the ongoing energy transition in developing countries, which includes encouraging households to switch away from dirty energy technologies and fuels (such as traditional stoves and coal) towards cleaner, more efficient ones (such as electricity and gas) that also improve household health. Economic incentives and price-based mechanisms are thought to be important tools for facilitating this much-needed switch. However, the distributional consequences of the policies should be assessed when making policy decisions. If effectiveness dominates the choice, at least some measures should be taken to improve fairness.

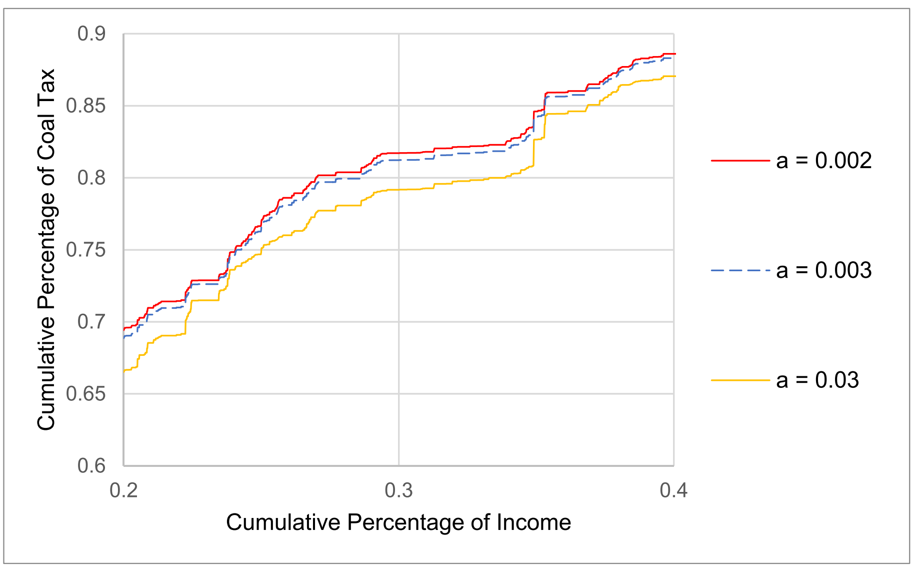
Table 6
Suits Index in different scenarios.

Tax Rate	Quantity Based	Price Based				
	0.008 yuan/ton	Current scheme	6% for all	$0.02 + a^*(i-1)$		
				a = 0.002	a = 0.003	a = 0.03
Suits Index	−0.6796	−0.6793	−0.6800	−0.6642	−0.6602	−0.6432

*Notes:*We set the tax rate to be positively correlated with average household income as $0.02 + a^*(i-1)$, where i is the ordinal number of the province's rank, which is 1, 2 … 30.



(a)



(b)

Fig. 10. Regressivity curves for the price-based coal taxes.

While this study has important policy implications, its limitation is that it assumes that coal consumption does not react to the coal price change caused by the taxation reform. That is, in this paper we focus on the first-order equity impact of the tax, and study the households that are directly affected by the coal tax. Given that the second-order equity impact is also important, we make assumptions or estimations on the coal price change and coal demand elasticity, simulate the coal consumption adjustment of households after the reform, and calculate the Suits Index of the price-based coal tax. Details of estimation and simulation are included in Appendix B .[4] We find that the regressivity of the price-based tax remain stable. Besides the coal quantity change, the tax can also affect households that do not directly consume coal, through changing the price of other goods which use coal as an input. The tax can also affect households through tax revenue redistribution. Due to the lack of data and the focus of this paper, we leave these topics for future research.

Author contribution

Ping Qin: Conceptualization, Investigation, Resources, Writing - Original Draft, Supervision. **Xiaobing Zhang**: Methodology, Formal analysis, Investigation, Writing - Original Draft. **Lunyu Xie**: Methodology, Formal analysis, Investigation, Writing - Original Draft, Writing - Review & Editing, Supervision, Acquisition of the financial support for the project leading to this publication. **Peilin Chen**: Software, Formal analysis, Investigation, Writing - Review & Editing, Visualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

[4] We put this in the appendix because, due to data limitation, we cannot empirically estimate the effect of the reform on household coal consumption, so we can only assume the price change and simulate coal consumption change based on assumptions about the price effect.

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Appendix C. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.enpol.2020.111366.

Appendix A

There are many ways to classify coal. According to processing method, coal is divided into raw coal, cleaned coal, granular coal, washed coal, and low-quality coal. According to quality composition, coal is divided into bituminous coal, anthracite, coking coal, and power coal. According to use, coal is divided into industrial coal and household coal. According to scale of use, industrial coal can be further divided into coal for concentrated combustion and scattered coal.

Household coal is scattered coal. It mainly includes coal used by rural and urban households for home heating, cooking, heating water, etc. Industrial scattered coal is mainly used in small coal-fired boilers and kilns in industry. The concept of scattered coal has different expressions in academic literature and policy documents, as summarized in Table A1.

Table A1
The concept of " scattered coal" expressed in relevant policy documents

Definition	Documents	Time	Department	Related content
Scattered coal	Beijing clean air action plan 2013–2017	2013.9	Beijing Municipal Government	"Promoting the reduction of scattered coal in rural areas", "dramatically reduced the use of scattered coal"
Dispersed, unprocessed raw coal	Strategic action plan for energy development (2014–2020)	2014.6	General Office of the State Council	"Significantly reduce direct coal combustion and encourage the use of cleaned coal and briquette in rural areas"
Coal burned separately as opposed to concentrated combustion	Action plan for clean and efficient use of coal (2015–2020)	2015.5	Ministry of Industry and Information Technology	"Develop heat supply methods such as cogeneration and central heating, and replace small and medium-sized coal-fired boilers with clean fuels such as natural gas and electricity."

Based on the information above, we summarize the characteristics of household coal as follows. In terms of quality, household coal is a kind of raw coal that has not been processed and washed according to strict standards. The quality is poor, and pollution intensity is high. In terms of use, the scale is small and the consumption is scattered, with the household as the unit.

Appendix B

To take coal consumption response into consideration in the analysis of the effect of the coal tax reform, we would need to quantify how the reform affected coal price and how the coal price change affected household coal consumption.

To explore the effect of the coal taxation reform on household coal price, we would need to observe household coal price before and after the reform, as well as all the factors that could affect the price. Due to the lack of data, we cannot empirically estimate the effect. For the purpose of simulation, we assume four scenarios of household coal price change: 10 percent decrease in household coal price, 5 percent decrease, 5 percent increase, and 10 percent increase.

As for the effect of coal price change on household coal consumption, previous literature has mixed findings. For example, based on the survey of 1866 rural households in Beijing, Xiao et al. (2017) found that coal price had little impact on the consumption of coal. The possible reason is that coal used for heating in rural Beijing has become a necessity. On the other hand, when exploring the influence of energy price change on energy consumption of farmers in northwest China, Pan and Zhang (2011) found that when coal price rises by 1%, per capita coal consumption decreases by 3%.

Utilizing the CRECS data used in the paper, we can estimate the coal demand elasticity through regressions. The regressions are similar to equations (1) and (2) in the text, with two differences. One difference is that we add in a price variable, instead of using the dummies of province, year, and province by year to capture the effect of price, because we need the coefficient of coal price for the estimation of demand elasticity. The other difference is that we add in the interaction term of price and household income to explore the heterogeneity in demand elasticity across households with different income. The estimation results are summarized in Table B1. It shows that households with higher income have smaller demand elasticity of coal, as expected. Based on the estimation results, we find that the demand price elasticity is −5.5 for a household with the average income of 64 thousand yuan.

Table B1
Extensive and Intensive Margin Regression Outcome

	(1)	(2)
	Extensive Margin	Intensive Margin
	(Logit)	(OLS)
Log of income	−0.145***	0.0849
	(0.0394)	(0.111)
Log of price	−5.265***	−5.473
	(1.440)	(3.530)

(continued on next page)

Table B1 (*continued*)

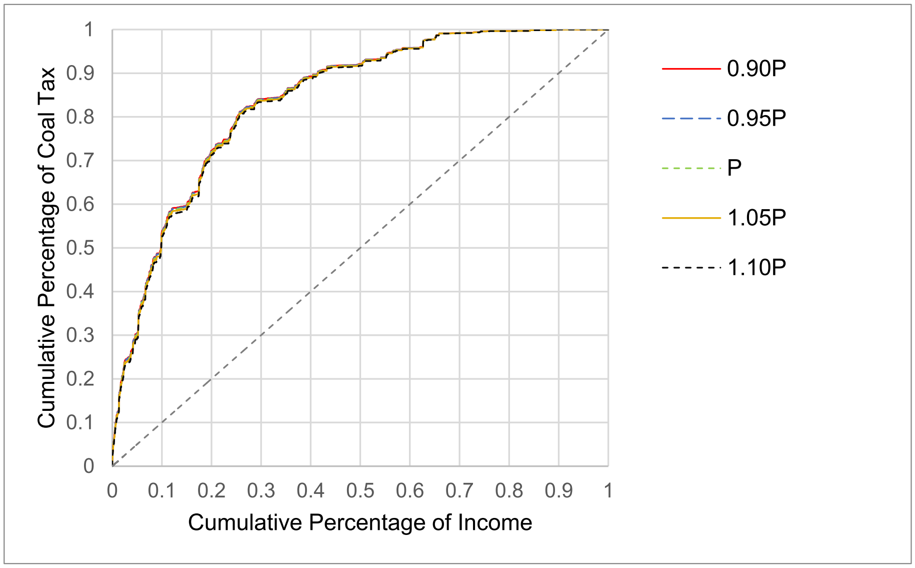
	(1)	(2)
	Extensive Margin	Intensive Margin
	(Logit)	(OLS)
Log of income * log of price	0.123	0.138
	(0.141)	(0.335)
Household size	0.0845***	0.129***
	(0.0260)	(0.0276)
Education of household head	0.0125	−0.0218
	(0.00996)	(0.0133)
Urban dummy	−1.276***	−0.130
	(0.115)	(0.161)
Central heating	−2.564***	−1.034***
	(0.231)	(0.359)
Residential area	0.00285***	0.00402***
	(0.000512)	(0.000494)
Constant	−0.518	3.955***
	(0.379)	(1.146)
Observations	6172	1166
R-squared		0.271

Notes:Logit model and Ordinary Least Square (OLS) model, including price variable and interaction term of price and household income in order to explore the heterogeneity in demand elasticity across households with different income. The dependent variable in column (1) is a dummy variable, which equals one if coal is consumed, and zero otherwise. The dependent variable in column (2) is the log of coal quantity consumed conditional on the use of coal. Robust standard errors are in parentheses. ***, **, and * indicate that the estimate is statistically significant at the 1%, 5%, or 10% significance level, respectively.

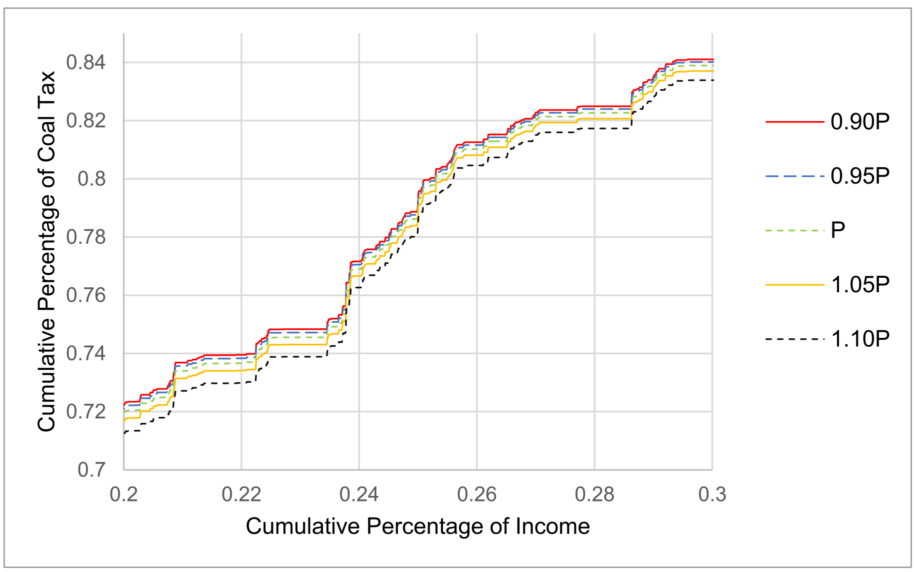
Based on the assumptions and estimations above, we simulate the coal consumption change after the reform and calculate the Suits Index for the four price change scenarios. The results are presented in Table B2 and Figure B1. It shows that if the reform leads to an increase (decrease) in household coal price, the regressivity of the coal will be alleviated (increased). The reason is that households with lower income have larger price elasticity in coal consumption, as shown in Table B1. Compared with households with higher income, they reduce (increase) coal consumption more when price increases (decreases), therefore the tax burden decreases (increases) more. This leads to the reduction (increase) in the tax regressivity. However, the change in the tax regressivity is small compared to the Suits Index without considering the coal consumption response, implying that the regressivity of the price-based tax remains stable.

Table B2
Suits Index in different situations

Scenarios in coal price change	10% down	5% down	5% up	10% up
Suit Index	−0.682	−0.681	−0.677	−0.672



(a)



(b)

Fig. B1. Regressivity curves for the price-based coal taxes in different scenarios.

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