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Household carbon inequality in urban China, its sources and determinants

Xinkuo Xu [a], Liyan Han [b,*], Xiaofeng Lv [c]

[a] School of Finance, Capital University of Economics and Business, Fengtai, 100070 Beijing, China
[b] School of Economics and Management, Beihang University, Haidian, 100191 Beijing, China
[c] School of International Business, Southwestern University of Finance and Economics, Chengdu, Sichuan, China

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ABSTRACT

Designing mitigation policies for households requires knowledge of household carbon distributions. This study surveys the household carbon inequality in urban China and analyzes its sources and determinants using weighted household survey data. Different from existing literatures studying carbon inequality on the international or regional level, we focus on the household aspect and first survey its characteristics by some comparisons. By ascribing household carbon emissions calculated by the Consumer Lifestyle Approach to several consumption categories with the method of Gini coefficient decomposition, we find that residential consumption with high carbon intensity is the most important source of household carbon inequality in urban China. Food consumption and the consumption of educational, cultural and recreational services are the next largest sources because of the consumed quantities or carbon intensity. The application of Shapley decomposition shows the determinants of household carbon inequality in urban China and their contributions, which are household demographic characteristics (59.74%), household employment and income (24.31%), household burdens (8.00%), and household assets and financial plans (7.95%). The policy implications of these results are also discussed.

1. Introduction

Designing mitigation policies requires knowledge of the distribution of carbon emissions. Quite a few studies have investigated the international inequality of carbon emissions, including Heil and Wodon (1997, 2000); White (2000, 2007); Sun (2002); Alcántara and Duro (2004); Hedenus and Azar (2005); Padilla and Serrano (2006); Duro and Padilla (2006); Ezcurra (2007); Kahrl and Roland-Holst (2007); Duro and Padilla (2008); Duro et al. (2010); Cantore and Padilla (2010); Steinberger et al. (2010); Cantore (2011); Duro (2010, 2012, 2013) and Padilla and Duro (2013). Clarke-Sather et al. (2011) studied the carbon inequality on the sub-national scale in China during 1997–2007, and they found that the interprovincial carbon inequality in China is not regional in character and is different from the carbon inequality on the global scale. These studies provided the gross information about the distribution of carbon emissions and referred to the abatement duties between different countries or regions. The distribution of carbon emissions between households is also needed to be concerned as the households in the same region shall bear different responsibilities for emission reduction. However, to our knowledge, the specific study of carbon inequality at the household level in China and some other areas is still limited.

As Duro (2013) defines the carbon inequality at the global scale as the inequality of per capita carbon emissions between different countries and Clarke-Sather et al. (2011) defines the interprovincial carbon inequality as the inequality of per capita carbon emissions between different provinces, this paper defines household carbon inequality as the inequality of household per capita carbon emissions. Household carbon inequality reflects the differences in household carbon emissions according to the natural attribute. Moreover, according to the social attribute, household carbon inequality reflects households' different obligations in emission abatement and their distinct sensibilities to mitigation policies.

There are four reasons for us to focus on household carbon inequality in urban China. Firstly, a major part of the energy requirements and related carbon emissions of an economy is allocated to the household sector, in fact, more than 80% for the U.S. (Bin and Dowlatabadi, 2005) and 75% for India (Pachauri and Spreng, 2002). This allocation is more than 40% for China (Liu et al., 2011), but rises in the income and wealth of households, changes in consumers' lifestyles and the consumption of carbon-intensive goods and services in urbanization cause increases in household CO_2 emissions in China (Feng et al., 2011). As a result, the need for the household sector to reduce its energy use and CO_2 emissions has been emphasized in mitigation policies (Hamamoto, 2013). Secondly, household carbon inequality refers to the environmental

* Corresponding author at: School of Economics and Management, Beihang University, Xueyuan Road, Haidian Distinct, 100191, Beijing, China.
E-mail address: hanly@buaa.edu.cn (L. Han).

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justice, which is an important social problem involved all humanity, especially the socio-economically disadvantaged ones (Occelli et al., 2016). Thirdly, mitigation policies should be distinct to households according to the extent of household carbon inequality, as the rich should have more duties in abatement than the poor. As Clarke-Sather et al. (2011) put it, “internal dynamics of carbon inequality have the potential to shape future energy policies”. Fourthly, because the poor and the rich have different abatement abilities, the extent of household carbon inequality will determine the effect of household mitigation policies. As Sauter et al. (2016) put it, “the more widespread pollution sources are, the larger are costs of implementing and monitoring environmental policies”.

The literatures referred to household carbon inequality have studied the differences in CO_2 emission across different household groups. Using the cross-sectional data, Golley and Meng (2012) and Andrich et al. (2013) surveyed the per capita carbon emissions of households with different income levels. These literatures found that the rich emit more per capita but the poor are more emission-intensive, which suggests that the existence of significant inequality among households in CO_2 emissions. However, their limitation in quantitative analysis impairs their impact on household mitigation policies. Rosas et al. (2010) and Wang and Shi (2009) observed the dynamic variations in direct and indirect CO_2 emissions of different income groups in different years. Moreover, other literatures, such as Duarte et al. (2012); Büchs and Schnepf (2013); Brand et al. (2013); Chancel (2014); Han et al. (2015) and so on, distinguished households into groups by more factors other than income and surveyed their differences in CO_2 emissions. But it is still confused about the contribution of each factor. As Roca and Serrano (2007) and Kerkhof et al. (2009) have estimated the emissions associated with the consumption patterns of different groups of households classified according to their level of expenditure, this paper also concerns about the contribution of each expenditure category on household carbon inequality. As a result, this paper quantitatively measures the household carbon inequality in urban China and moreover analyzes the contributions of consumption categories and household characteristics to this inequality.

According to the Consumer Lifestyle Approach (CLA) advanced by Bin and Dowlatabadi (2005), household carbon emissions are embedded in consumption patterns which are determined by household socio-economic characteristics. Correspondingly, this paper firstly measures the inequality of carbon emissions in representative urban households in China using the Gini coefficient. Secondly, this paper uses the method of Gini coefficient decomposition to survey the sources of this inequality, i.e., the contributions of consumption contents to household carbon inequality. Thirdly, it uses the method of Shapley decomposition to survey the determinants of this inequality, i.e., the contributions of household socio-economic characteristics to household carbon inequality. The relations of the three parts are showed in Fig. 1.

This paper proceeds as follows: Section 2 introduces the survey data used in this study and the CLA method (Bin and Dowlatabadi, 2005), which is utilized to calculate household carbon emissions. Furthermore, this section details the methodologies we apply to measure and decompose the inequality of household carbon emissions. Section 3 reports and discusses the main results obtained from the application of these inequality measure and decomposition methodologies, which explains the inequality of household carbon emissions in urban China, its sources and determinants. Section 4 gives the main conclusions of this work and discusses the policy implications of it.

2. Data and Methods

2.1. Data Sources

The survey data used in this study come from the Survey of Consumer Finance in China (2011), which was performed by the China Center for Financial Research (CCFR), Tsinghua University. A total of 5761 samples are selected to represent urban households from the 24 cities all around Mainland China, which are Beijing, Jinan, Shenyang, Shanghai, Guangzhou, Chongqing, Xian, Wuhan, Baotou, Jilin, Xuzhou, Nanchang, Haikou, Kunming, Urumqi, Luoyang, Shuozhou, Yichun, Anqing, Quanzhou, Guilin, Panzhihua, Baiyin and Zhuzhou. As a consumer finance survey, it contains the quotas of household consumption categories, which will be applied to calculate household carbon emissions. The survey also contains households' demographic characteristics, financial characteristics and certain other socio-economic characteristics of them; some of these characteristics can be utilized as the probable determinants of household carbon emissions. Based on Duarte et al. (2012); Büchs and Schnepf (2013) and Brand et al. (2013) and including many more household features, the probable determinants of the household carbon emissions in urban China that we choose contain the demographic characteristics of each household (the size, marital status, gender of the family head, and education), employment and income (the employment, unemployment, retirement, net income, and income expectation), burdens (being educated, pre-education, elders living together, or supported elders), and assets and financial plans (the deposits, housing ownership, car ownership, or heritage plans). The city a household lives in (*j*.city) is the control variable. These factors and their directions are shown in Table 1, and their summary statistics are shown in Table 2.

The selective dataset can be taken to represent households in urban China broadly. First, the survey stratifies cities above the prefecture level in Mainland China into three categories according to their size, economic development level, savings level, consumption level and consumption conditions. Second, the 24 sample cities selected all include the three categories in the seven regions of Mainland China (according to the economic development level and geographical features and adopted by some authorities). The weights of these cities refer to the proportion of the population in the Chinese City (Town) Life and Price Yearbook (2009). Thirdly, after the sample cities have been selected and the number of representative households in each sample city has been determined, these households are randomly sampled according to the community distribution and population distribution in each sample city.

However, the selective dataset has distinct population distributions from the real population distributions for urban households in the seven regions of China, as shown in Table 3. This distinction exists because the weights of the cities in the survey, which are based on the proportion of the population in the Chinese City (Town) Life and Price Yearbook (2009), set many sample households in the central and western regions of China. When calculating households' carbon inequality all around urban China, we replicate the samples with different multiples in the seven regions to make the population portions of the

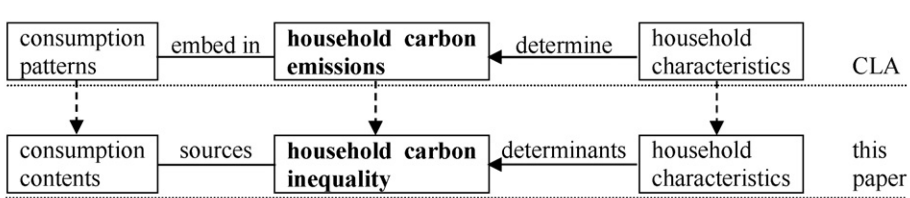

Fig. 1. Relations of this paper's three parts designed according to the CLA.

Table 1
Directions of the variables affecting household per capita emissions.
Source: own elaboration.

	Variables	Directions
Household demographic characteristics	*size*	The number of persons in a household
	marriage	The marital status of the head of a household (married = 1 or 0)
	gender	The gender of the head of a household (male = 1 or 0)
	education	The education level of the head of a household
Household employment and income	*employment*	The number of persons on work in a household
	unemployment	The number of unemployed persons in a household
	retired	The number of retired persons in a household
	netincome	The net income of a household
	incomeexpect	The income expectation of a household
Household burdens	*beingeducation*	The number of persons being educated in a household
	preeducation	The number of persons not enrolled in school in a household
	elderlivingtogether	The number of elders in a household
	eldertosupport	The number of elders a household needs to support
Household asset and finance plan	*deposit*	The deposit level of a household
	ownhouse	The housing ownership of a household
	owncar	The car ownership of a household
	heritageplan	The heritage plan of a household (have = 1 or 0)
	j.cities	The city a household lives in

representative households consistent with the real portions of the urban population in these regions. The adjustment multipliers of the sample households in different regions of China and the effects of the adjustments are also shown in Table 3.

2.2. Calculations of Household CO_2 Emissions

In this study, household carbon emissions contain both direct carbon emissions and indirect carbon emissions, which are imbedded in household consumption and can be calculated by the CLA (Bin and Dowlatabadi, 2005). The CLA is a method to explore the relationship between consumer activities and environmental impacts. It can reveal the total impacts of consumer activities on residents' energy use and CO_2 emissions, which are induced by both household consumer demands and the necessary economic activities to support these demands (Bin and Dowlatabadi, 2005). According to the CLA (Bin and Dowlatabadi, 2005; Feng et al., 2011), the CO_2 emissions of a household depend on both the CO_2 emissions intensities and volumes of its consumption.

Table 2
Summary statistics of the factors affecting household carbon emissions.
Source: own elaboration.

Variable	Obs	Mean	Std. dev.	Min	Max
size	5761	3.469	1.435	1	18
marriage	5761	0.6659	0.4717	0	1
gender	5761	0.4749	0.4994	0	1
education	5761	2.5131	0.7856	1	5
employment	5761	2.000	1.018	0	10
unemployment	5761	0.1499	0.4744	0	5
retired	5761	0.6318	0.9191	0	6
netincome	5761	5785	9.77E + 07	5000	5.00E + 09
incomeexpect	5761	3.505	0.8325	0	5
beingeducation	5761	0.3798	0.5947	0	6
preeducation	5761	0.1765	0.4329	0	6
elderlivingtogether	5761	0.7226	0.9705	0	6
eldertosupport	5761	1.836	1.432	0	9
deposit	5761	4.853	4.016	1	19
ownhouse	5761	6.722	4.571	1	17
owncar	5761	2.583	3.167	1	17
heritageplan	5761	0.1918	0.3938	0	1

Consumption in this study is divided into seven categories, namely, Food, Clothing, Household facilities, articles and services, Medicine and medical services, Transport and communication services, Educational, cultural and recreational services and Residence (Wei et al., 2007; Feng et al., 2011). Miscellaneous commodities and services are not included because they are hard to measure in a survey.

In a group, each consumption category corresponds to a quota of embedded CO_2 emissions (Wei et al., 2007; Feng et al., 2011). Based on China's input–output tables in 2002, Wei et al. (2007) used the basic input–output method by considering the intermediate input of imported goods to calculate the carbon emissions in urban China. Then they divided quota of CO_2 emissions embedded in each consumption category by the total spending volume of the category and get their carbon intensities, which are shown in Table 4.

Accordingly, the CO_2 emissions (kg) from consumption category t of household h, or e_t, and the total CO_2 emissions (kg) of the household h, or e_h, are calculated as follows (Kerkhof et al., 2009):

$$e_t = density_t consumption_{t,h} \tag{1}$$

$$e_t = \sum density_t consumption_{t,h} \tag{2}$$

where $density_t$ is the CO_2 emission intensity of consumption category t (t C/10^4 Yuan) and $consumption_{t,h}$ is the spending amount in consumption category t for household h (10^4 Yuan). The distributions of the households' per capita emissions in the selected sample cities of China are shown in Fig. 2.

2.3. Household Carbon Inequality's Measure and Decomposition by Sources

The measures of carbon inequality on the international or sub-national level provide some methods to evaluate the carbon inequality on the household level. Duro (2012) summarized and compared the application of the most frequently used inequality indices in an analysis of the international distribution of some environmental indicators: the Gini coefficient, the Theil index, the Atkinson indices, and the Variation coefficient. The Theil index is one type of the GE indices, and the Atkinson indices can be converted into the GE indices by a one-to-one function. Moreover, the Variation coefficient is the square of the GE(2). All the inequality indices have the similar functions though they have differently sensitivities to the same data.

The Gini coefficient, though with some shortcomings on distributive sensitivity compared with other inequality indicators, such as the Theil index or the Atkinson measure, is arguably the most popular and widely employed inequality measure and is employed in most studies on carbon inequality. Moreover, the Gini coefficient is thought to be the only inequality measure that is additively decomposable into terms corresponding to inequality for each source of emissions as well as its share in and rank correlation with total emissions (Grunewald et al., 2014). As a result, we choose the classical Gini coefficient to evaluate the inequalities in household carbon emissions and compare them with other inequalities.

Based on the work of Cantore and Padilla (2010); Cantore (2011) and Duro (2013), we estimate the Gini coefficient of international per capita carbon emissions. We follow Clarke-Sather et al. (2011) to estimate the Gini coefficient of sub-national per capita carbon emissions. Similarly, the Gini coefficient of household per capita CO_2 emissions, which we denote *Gini*, is calculated as follows:

$$Gini = \left[\frac{2}{N\sum_{i=1}^{N} y_i}\sum_{i=1}^{N} i*y_i\right] - 1 - \frac{1}{N} \tag{3}$$

where N is the number of households and y_i represents the per capita CO_2 emissions of the ith household; the y_i are ordered by the per capita CO_2 emissions.

Table 3
Distribution of the sample, real or adjusted urban population portion in the seven regions of China.
Source: own elaboration.

Region	Number of the sample households	Number of the sample population	Portion of the sample population	Portion of the real population	Portion bias of the sample population	Adjustment multiplier	Portion of the adjusted population	Portion bias of the adjusted population
Northeast China	720	2230	11.14%	11.48%	−2.77%	7	12.10%	5.46%
North China	628	2232	11.17%	13.93%	−19.80%	8	13.85%	−0.59%
East China	1303	4470	22.37%	28.79%	−22.30%	8	27.73%	−3.69%
South China	810	3364	16.83%	18.73%	−10.11%	7	18.26%	−2.50%
Central China	766	2722	13.62%	12.14%	12.24%	6	12.66%	4.35%
Northwest China	615	2008	10.05%	5.84%	71.94%	4	6.23%	6.57%
Southwest China	919	2958	14.80%	9.10%	62.70%	4	9.17%	0.84%
Total	5761	19,984	100%	100%	–	–	100%	–

Note: portions of the real population are calculated according to the urban population distribution in regions of China in 2010, which refers to The Sixth Census Data in China. The adjustment multipliers are determined by trial and error.

As Grunewald et al. (2014) has applied the method of the decomposition of Gini coefficient to investigate the sources of inequality in global CO_2 emissions, we use a similar method to survey the sources of household carbon inequality, which are carbon emissions embedded in the different consumption categories. This method of Gini coefficient decomposition was firstly introduced by Lerman and Yitzhaki (1984), who expressed the Gini coefficient of total income as a function of (i) the inequality within a given source, (ii) the share of this source in total income, and (iii) its rank correlation with total income. This method contains more information to survey the correlation between the total inequality and its sources, while most other decomposition rules, such as the popular Shorrocks rule (see Shorrocks (1984)), only indicate the inequality within a given source and its share in the total inequality but not the correlation between them. Lerman and Yitzhaki (1985) and Stark et al. (1986) advanced this method to analyze the impact that a marginal change in a particular source will have on inequality.

As in Lerman and Yitzhaki (1984, 1985) and Stark et al. (1986), the Gini coefficient of households' per capita carbon emissions, G, is calculated as follows:

$$G = \sum_{i=1}^{K} S_k G_k R_k \tag{4}$$

where S_k represents the share of per capita carbon emissions that is embedded in consumption category k. Furthermore, G_k is the Gini coefficient of the household per capita carbon emissions that are embedded in consumption category k, R_k is the Gini correlation between the per capita emissions embedded in consumption category k and the distribution of household per capita carbon emissions embedded in all consumption categories, and K is the order number of consumption categories.

Household carbon emissions in this study, which are calculated by the CLA (Bin and Dowlatabadi, 2005), come from different consumption categories. The effect of one consumption category upon the total inequality of household per capita carbon emissions depends on how important the carbon emissions from one consumption category are with respect to the total household carbon emissions (S_k); how equally or unequally distributed the carbon emissions from one consumption category are (G_k); and how the carbon emissions from one consumption category and the distribution of households' total carbon emissions are correlated (R_k) (Stark et al., 1986).

According to Lerman and Yitzhaki (1985) and Stark et al. (1986), the partial derivative of the Gini coefficient of households' per capita carbon emissions with respect to a percent change e in source k is equal to

$$\frac{\partial G}{\partial e} = S_k (G_k R_k - G) \tag{5}$$

where G is the Gini coefficient of the total carbon emissions inequality prior to the change in household carbon emissions. The percent change in inequality resulting from a small (percentage) change in the carbon emissions from consumption category k equals

$$\frac{\partial G / \partial e}{G} = \frac{S_k G_k R_k}{G} - S_k \tag{6}$$

2.4. Household Carbon Inequality's Decomposition by Determinants

To analyze the determinants of inequality, Fields and Yoo (2000) and Morduch and Sicular (2002) firstly introduced the decomposition method based on regression models. As their method has some limitations on the formals of equation and variables, Wan (2002, 2004) advanced a new decomposition method, which is then known as Shapley decomposition. The Shapley decomposition method, compared with the method of Fields and Yoo (2000) and Morduch and Sicular (2002) and the Shorrocks rule (see Shorrocks (1984)), has its advantage on decomposing inequality based on any formal of regression models and has begun to be widely employed in analyzing the contributions of the determinants of inequality in income or other welfare indicators (Wan, 2004; Shorrocks, 2013). To decompose the household carbon inequality in urban China into its determinants, we also use the Shapley decomposition method.

According to Wan (2004) and Shorrocks (2013), we first give out the determined formulation of the household per capita CO_2 emissions and then utilize the method of Shapley decomposition to decompose the inequality of household per capita CO_2 emissions into its determinants. The determined formulation of the household per capita CO_2 emissions is expressed as follows:

$$\ln(y) = \alpha + \boldsymbol{X\beta} + \varepsilon \tag{7}$$

where y is the household per capita carbon emissions, α is a constant, and $\boldsymbol{X}$ are the determinants of the household per capita carbon emissions, which are discerned from the probable determinants of household carbon emissions in urban China. These probable determinants are discussed in Section 2.1 and shown in Table 1. Lastly, $\boldsymbol{\beta}$ are the regression coefficients and εε is the residual. The Shapley decomposition of the inequality of household per capita CO_2 emissions is referred to

Table 4
Carbon intensity of different consumption categories in urban China.
Source: Wei et al. (2007).

Consumer expenditure	Carbon intensity of the related sectors (t C/104 Yuan)
Food	0.23
Clothing	0.17
Residence	2.82
Household facilities, articles and services	0.08
Transport and communication services	0.07
Medicine and medical services	0.18
Education, cultural and recreation services	0.43

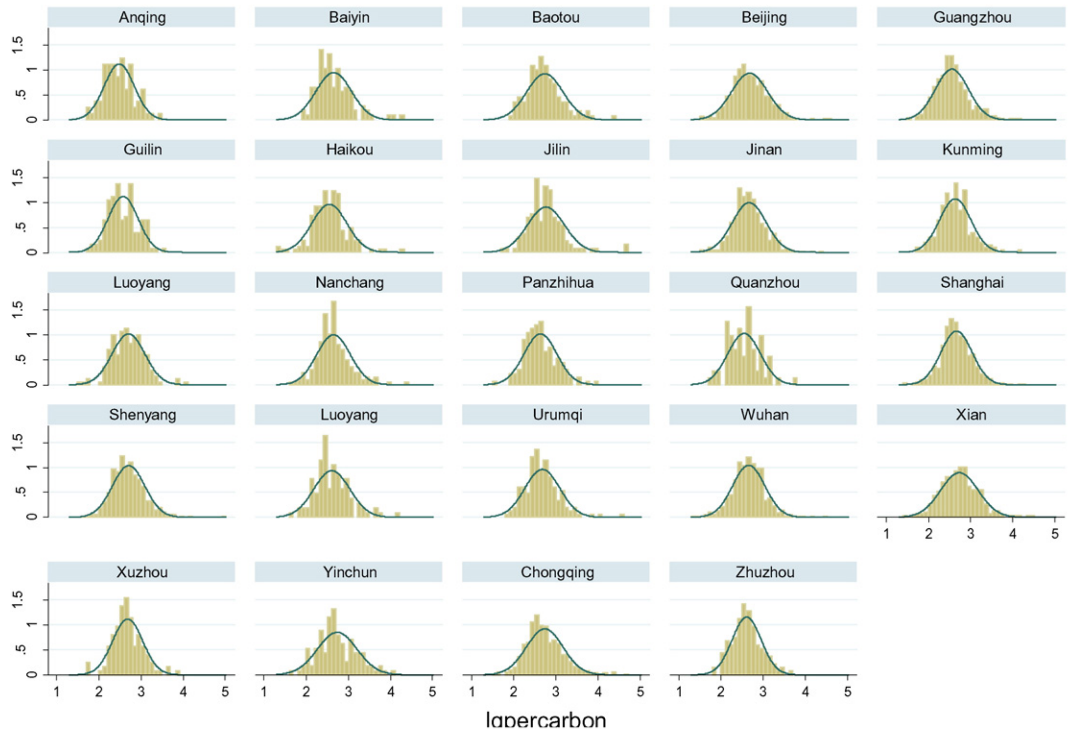

Fig. 2. Distribution of the logarithmic of household per capita CO_2 emissions in the sample cities of Mainland China.
Source: own elaboration.

Han et al. (2015). As Han et al. (2015) have utilized the Shapley decomposition method to analyze the determinants' contributions to household carbon emissions, we use this method to survey the determinants' contributions to the inequality of household carbon emissions.

3. Results and Discussion

3.1. Household Carbon Inequality in Urban China: Some Comparative Analysis

We use the weighted sample data described in Section 2.1 to calculate the Gini coefficient of household per capita carbon emissions in urban China, and its result is 0.5791. Some literatures have calculated the Gini coefficients of per capita carbon emissions from industries across countries or regions. For example, Padilla and Serrano (2006) took into account the CO_2 emissions from fossil fuels provided by the IEA and found the Gini coefficients of per capita carbon emissions across countries are between 0.58 and 0.68 from 1971 to 1999. Cantore and Padilla (2010) included emissions from technological change in industry and land use change and found the Gini coefficients of per capita carbon emissions across countries are between 0.42 and 0.58 from 1977 to 2007. Clarke-Sather et al. (2011) calculated carbon emissions by processing the data on energy consumption through the IPCC reference approach and found the Gini coefficients across provinces in China are between 0.43 and 0.44 from 1995 to 2005. The Gini coefficients in these studies are more than the standard for inequality, i.e., 0.4. This suggests the international or sub-national inequality in industrial carbon emissions and the different abatement responsibilities for countries or regions. The carbon emissions accounted by the CLA method in this paper includes emissions from household consumption. As a result, the Gini coefficient with a value of 0.5791 implies the significant household carbon inequality in urban China and the different abatement responsibilities for households according to their consumption behaviors.

The household carbon inequality in urban China was also compared with the household income or consumption inequality, which was calculated using the same weighted sample data described in Section 2.1. The Gini coefficients for household per capita consumption or income in urban China are 0.52 and 0.48 respectively. The inequality of household per capita carbon emissions is higher than the inequality for per capita consumption, both of which are higher than the inequality of household per capita income. This result suggests that the carbon inequality is comparable to the income or consumption inequality in households in urban China.

Then we analyze the regional features of the household carbon inequality in urban China; see Fig. 3. Firstly, household carbon inequalities are different for cities in urban China. The Gini indices of household per capita emissions in different Chinese sample cities vary from 0.44 to 0.73. By surveying the reasons for the inequality difference for different sample Chinese cities, we find that household carbon inequality is positively related to the average of household per capita carbon emissions in the cities; see Fig. 3. This indicates that the rise of household average per capita carbon emissions will increase the regional household carbon inequality in urban China. Secondly, the household carbon inequalities in South China are higher than in North China. The Gini coefficients of the household per capita emissions in the cities of South China are generally higher than that in the cities of North China. Thirdly, the household carbon inequalities in the cities divided by the seven regions of China are quite different. The Gini coefficients of the household per capita emissions in the cites of the East North or the West North can be as high as 0.64 to 0.73, while the Gini coefficients in the cities of North China, East China or Central China are low to 0.45. The regional features of the household carbon inequality indicate distinct mitigation policies in different regions.

3.2. Sources of the Household Carbon Inequality in Urban China

As the inequality of household per capita CO_2 emissions in urban China exists, we care about its sources. We apply the method of Gini coefficient decomposition to decompose the household carbon inequality in urban China into carbon emissions from different consumption categories, with the weighted sample data described in Section 2.1 and with

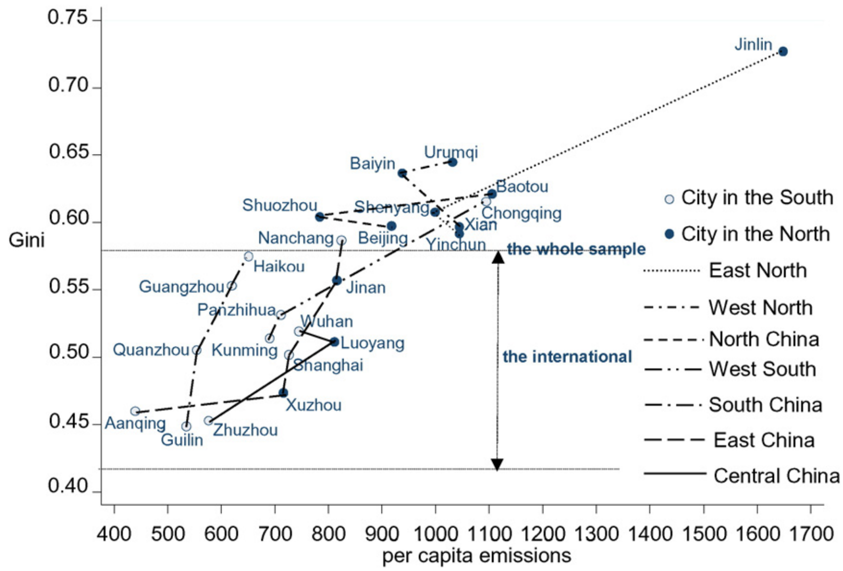

Fig. 3. Relation of household carbon inequality and the average of household per capita carbon emissions for different cities or regions in China.

the method advanced in Section 2.3. Table 5 shows the results of the indices in this decomposition. Fig. 4 shows the comparisons of some of these indices for the different sources.

Residential consumption is the main source of the carbon emissions that are embedded in household consumption in urban China, and it is also the main source of the household carbon inequality in urban China, as shown in Fig. 4. The results of S_k_e and Sh in Table 5 show that the carbon emissions from residential consumption account for 57.11% of the total carbon emissions from the weighted representative Chinese urban households. Furthermore, the household carbon inequality induced by residential consumption amounts to 61.72% of the total carbon inequality in the weighted representative households in urban China. The result of R_k in Table 5 shows that the Gini correlation of per capita carbon emissions from residences is 0.95 and is higher than the Gini correlations of per capita carbon emissions from all other sources, which never exceed 0.82. Additionally, a 1% change in residential consumption will cause a 4.61% change in the inequality of per capita emissions for the weighted representative households in urban China, which has a larger magnitude than all other carbon sources.

The major effect of residential consumption on the household carbon inequality in urban China occurs because residential consumption has much higher carbon intensity than the other consumption categories, not because of the share of residential consumption in the total consumption. The usage of electricity, fuel and heating in residences induces many direct and indirect carbon emissions. As shown in Table 4, the carbon intensity of residential units in urban China is 2.82 t C/10^4 Yuan, which is much higher than the carbon intensity of the other consumption categories, whose carbon intensities are no greater than 0.43 t C/10^4 Yuan. However, residential consumption only accounts for 10.41% of the total consumption (as shown in Table 5), which is higher than the consumption of transport and communication services but lower than the other five consumption categories. A proportional change in residential consumption will cause less change in the total consumption for the representative households from urban China, despite causing much larger changes in household carbon emissions and carbon inequality. As a result, abatement in residential consumption will have a relatively lower economic cost on mitigation policies for households in urban China.

Food consumption and the consumption of educational, cultural and recreational services are the second or third greatest sources of carbon inequality in the weighted representative households from urban China, as shown intuitively in Fig. 4. Table 5 shows that the inequality of households' per capita carbon emissions from food consumption or the consumption of educational, cultural and recreational services consists of 13.07% or 15.56% of the inequality of households' per capita carbon emissions from all consumption categories for the weighted representative households in urban China. However, their effects on the households' carbon emissions and carbon inequality are different. As food consumption accounts for 36.46% of the total consumption, the consumption of educational, cultural and recreational services only accounts for a proportion of 10.63%. This discrepancy exists because consuming educational, cultural and recreational services have higher carbon intensities than food consumption. As shown in Table 4, the carbon intensity of the consumption of educational, cultural and

Table 5
Gini decomposition by the sources of household carbon emissions in urban China.
Source: own elaboration.

Source	Sk_e	Sk_c	Gk	Rk	Sh	%Change
Food	17.38%	36.46%	0.5339	0.8155	13.07%	−4.32%
Clothing	5.14%	14.67%	0.6792	0.7919	4.77%	−0.37%
Residence	57.11%	10.41%	0.6590	0.9497	61.72%	4.61%
Household facilities, articles and services	1.78%	12.99%	0.7722	0.8056	1.92%	0.13%
Transport and communication services	1.88%	4.01%	0.6275	0.7880	1.61%	−0.28%
Medicine and medical services	1.59%	1083%	0.7662	0.6434	1.36%	−0.24%
Education, cultural and recreation services	15.12%	10.63%	0.7278	0.8195	15.56%	0.45%
Total	100%	100%	–	–	100%	–

Note: S_k_c represents the share of each consumption category in the total consumption, S_k_e represents the share of per capita carbon emissions from one consumption category in households' total per capita carbon emissions, G_k represents the Gini coefficient of households' per capita carbon emissions from one consumption type, R_k represents the correlation between this Gini coefficient and the distribution of households' total per capita carbon emissions, Sh represents the share of the inequality of each emission source in the total inequality and *%Change* represents the impact that a 1% change in one emission source would have on the total inequality.

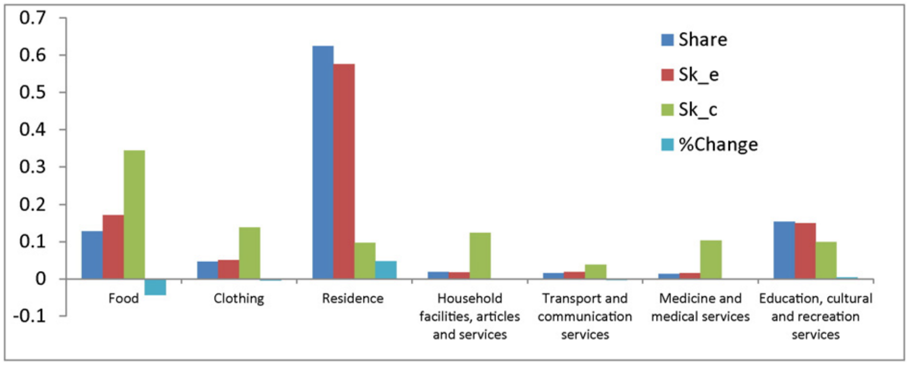

Fig. 4. Impact of different consumption categories on the inequality of household carbon emissions in urban China.
Source: own elaboration.

recreational services is 0.43 t C/10^4 Yuan, whereas the carbon intensity of food consumption is only 0.23 t C/10^4 Yuan. Thus, the different effects on household carbon inequality are determined by both the proportion and the carbon intensity of the corresponding consumption categories. As mitigation policies in the production sector will lower carbon intensity of goods and services, mitigation policies in the household sector should address the change in the consumption structure as well as lead households to consume low-carbon products.

The directions are also different for the changes in the consumption categories to impact the household carbon inequality in urban China. Whereas residential consumption, the consumption of household facilities, articles and services and the consumption of educational, cultural and recreational services, have positive effects on the household carbon inequality in urban China, the effects are opposite for food consumption, clothing consumption, the consumption of transport and communication services and the consumption of medicine and medical services. As shown in Table 5 and Fig. 4, the inequality of household per capita carbon emissions is projected to rise by 4.61%, 0.13% and 0.45% when residential consumption, the consumption of household facilities, articles and services or the consumption of educational, cultural and recreational services rises 1% for the weighted representative Chinese urban households. Conversely, the inequality of household per capita emissions is predicted to decline by 4.32%, 0.37%, 0.28% and 0.24% when food consumption, clothing consumption, the consumption of transport and communication services or the consumption of medicine and medical services experiences a 1% rise for the weighted representative Chinese urban households.

3.3. Determinants of the Household Carbon Inequality in Urban China

We utilize two regression models to discern the determinants of the household per capita CO_2 emissions in urban China with the weighted sample data described in Section 2.1. The results are shown in Table 6. Because the sampling mechanism is prone to non-randomly sampling from the population due to clustering, we should consider clustering standard error for inferences. Based on block bootstrap (i.e., Angrist and Pischke, 2008) with 1000 replications, we obtained robust standard errors for inferences, and found that the significance is almost not changed even if the robust standard errors are larger than the ones of Table 6. Like eq. (8.2.3) of Angrist and Pischke (2008), we also consider a mixed error, $e_{gi} = v_g + \eta_{gi}$, where v_g is a random variable indicating group effects, and $\eta_{gi}$is independent of v_g. Under $v_g \sim N(0,\sigma_g^2)$ and $\eta_{gi} \sim N(0,\sigma_\eta^2)$, we estimated the coefficients by ML, the estimation results are very similar to Table 6. For the sake of conciseness, we do not report these robustness analysis results. It should be highlighted that controlling city's heterogeneity by introducing city dummy variables plays an important role in achieving robustness of Table 6.

Table 6 illustrates the significant effects of households' demographic characteristics, employment and income, burdens and asset levels and financial plans on the household per capita carbon emissions in urban China, though not all of the variables selected to represent the factors are significant. The significant variables are the household size, marital status and gender of the family head, income, income expectations, numbers of the employed or retired, number of pre-education members or elders, deposits, housing ownership, car ownership and heritage plans. The education level, number of members in education and number of elders to support do not show significant effects. These results are partially in line with the findings of Golley and Meng (2012), who also surveyed the association between household characteristics and household carbon dioxide emissions in urban China. Furthermore, we enrich the findings of Duarte et al. (2012); Büchs and Schnepf (2013) and Brand et al. (2013), who analyzed the associations between household characteristics and carbon emissions in other countries.

Then, we apply the method of Shapley decomposition to analyze the determinants' contributions of households' carbon inequality in urban China, which involves the weighted sample data described in Section 2.1. The result is shown in Table 7. First, the household demographic characteristics, which make a contribution of 59.74%, are the most important determinants of the inequality of household per capita emissions in urban China. The household size has a value of 51.95% and contributes more than any other determinants we have found. Table 6 shows that the household size has the opposite effect on the household carbon emissions. Consequently, the smaller the size of a household is, the more per capita emissions a household has. People in small households emit more per capita, as they consume more or have higher carbon intensity in their consumption. Mitigation policies addressing the distribution of household carbon emissions should be concerned by the size of households in urban China. The marital status contributes 7.24% to the inequality of household per capita emissions. Indeed, married households have a coefficient of −0.0253, as model 1 in Table 6 shows, and they have lower per capita emissions than unmarried households. Therefore, the effect of marriage on the household carbon emissions should be examined to improve mitigation policies in areas with many unmarried households.

Secondly, household employment and income has a total contribution of 24.31% and is the second most important component of the household carbon inequality in urban China. The number of the employed has a contribution of 21.18% to the inequality of household per capita emissions. This fact suggests that changes in the number of the employed members will have a significant impact on households' consumption behaviors and carbon emissions, and then, such changes will affect the inequality in China's household carbon emissions. Table 6 shows that the opposite effect of the number of employed people is the most comparable with the effects of the numbers of members who are unemployed, retired or receiving an education. This result suggests that mitigation policies should care about changes in employment. Despite its important effect on consumption, income only has a contribution of 0.44% to the inequality of household per capita carbon

Table 6
Determinants of household per capita CO_2 emissions in urban China.
Source: own elaboration.

Variables	(1)	(2)
	lgpercarbon	lgpercarbon
Household demographic characteristics		
size	−0.1270***	−0.1260***
	(0.0033)	(0.0033)
marriage	−0.0253***	−0.0231***
	(0.0048)	(0.0048)
gender	0.0163***	0.0184***
	(0.0038)	(0.0038)
education	−0.0039	−0.0002
	(0.0028)	(0.0028)
Household employment and income		
employment	−0.0111***	−0.0099***
	(0.0032)	(0.0032)
unemployment	0.0032	0.0018
	(0.0050)	(0.0050)
retired	0.0132***	0.0130***
	(0.0034)	(0.0034)
netincome	−1.24e−10***	
	(0)	
lgincome		−0.0648***
		(0.0046)
incomeexpect	−0.0109***	−0.0080***
	(0.0023)	(0.0023)
Household burden		
beingeducation	−0.0035	−0.0030
	(0.0045)	(0.0044)
preeducation	0.0142***	0.0154***
	(0.0054)	(0.0054)
elderlivingtogether	0.0043*	0.0044*
	(0.0025)	(0.0025)
eldertosupport	0.0019	0.0025*
	(0.0015)	(0.0015)
Household asset and finance plan		
deposit	−0.0013***	−0.0010**
	(0.0005)	(0.0005)
ownhouse	−0.0010**	−0.0001
	(0.0005)	(0.0005)
owncar	−0.0041***	−0.0018***
	(0.0007)	(0.0007)
heritageplan	−0.0218***	−0.0209***
	(0.00483)	(0.0048)
Control variables		
2.city	0.114***	0.110***
	(0.0225)	(0.0225)
i.city	–	–
	(−)	(−)
24.city	0.0600***	0.0648***
	(0.0191)	(0.0191)
Constant	3.113***	3.380***
	(0.0190)	(0.0267)
Observations	36,890	36,890
R-squared	0.221	0.224

Standard errors in parentheses: ***p < 0.01, **p < 0.05, *p < 0.1.

emissions, as we utilize the normal value of income. Household income in the formal logarithm will have a contribution of 7.80% to the inequality of household per capita carbon emissions, as shown in Table 8.

Household burdens have a contribution of 8.00% to the household carbon inequality in urban China. In which, the number of elders has a contribution of 5.93%, whereas the number of child members has a contribution of 2.07%. Carbon emissions from the elders, who may have more wealth, more leisure time to consume or greater medical and residential costs, should receive more attention due to the arrival of an aging society in Mainland China.

Household assets and financial plans make a contribution of 7.95% to the household carbon inequality in urban China. As an indicator that is relatively easy to identify, the number of cars owned by households contributes 4.86% to the inequality of household per capita emissions.

Table 7
Shapley decomposition of household carbon emissions in urban China.
Source: own elaboration.

Factors	Shapley value	Per cent
Household demographic characteristics		59.74%
size	0.0143	51.95%***
marriage	0.0020	7.24%***
gender	0.0002	0.55%***
Household employment and income		24.31%
employment	0.0058	21.18%***
retired	0.0006	2.03%***
netincome	0.0001	0.41%***
incomeexpect	0.0002	0.69%***
Household burdens		8.00%
preeducation	0.0006	2.07%***
elderlivingtogether	0.0016	5.93%*
Household asset and finance plan		7.95%
deposit	0.0002	0.57%***
ownhouse	0.0002	0.67%**
owncar	0.0011	4.02%***
heritageplan	0.0007	2.69%***
All factors present	0.0276	100.00%

Standard errors in parentheses: ***p < 0.01, **p < 0.05, *p < 0.1.

Household heritage plans make a contribution of 2.84% to the inequality of household per capita emissions. The contribution of household assets and financial plans exists because Chinese urban households have much more wealth, including cars and financial assets, after 30 years of rapid economic growth in urban China. With the further development of the economy, household assets and financial plans should be considered in mitigation policies in urban China.

4. Conclusions and Policy Implications

4.1. Conclusions

First, the application of the Gini coefficient shows that the distribution of household carbon emissions in urban China is more unequal than the carbon distributions on the international or sub-national levels in recent decades. This finding suggests that household carbon inequality is an important aspect of all types of carbon inequality. Thus, the household carbon inequality should be accounted for (at least in urban China) when mitigation policies are enacted to address the distribution of carbon emissions on different levels. At the same time, we find that the carbon inequality is comparable to the income inequality in

Table 8
Shapley decomposition of household carbon emissions in urban China (household income in the logarithm formal).
Source: own elaboration.

Factors	Shapley value	Per cent
Household demographic characteristics		56.63%
size	0.0141	49.12%***
marriage	0.0020	7.06%***
gender	0.0001	0.45%***
Household employment and income		29.47%
employment	0.0057	19.76%***
retired	0.0006	2.06%***
netincome	0.0020	7.15%***
incomeexpect	0.0001	0.50%***
Household burdens		7.49%
preeducation	0.0006	1.94%***
elderlivingtogether	0.0016	5.55%*
Household asset and finance plan		6.40%
deposit	0.0001	0.44%***
ownhouse	0.0002	0.53%**
owncar	0.0008	2.92%***
heritageplan	0.0007	2.51%***
All factors present	0.0286	100.00%

Standard errors in parentheses: ***p < 0.01, **p < 0.05, *p < 0.1.

households in urban China. This suggests that household carbon inequality, which refers to environmental justice, is one aspect of all kinds of social inequality. We also find differences in the household carbon inequality exist in different cities or regions because the household carbon inequality will rise as the household per capita carbon emissions increase in an area. The regional features of the carbon emissions in urban China can provide comparisons of the carbon inequality in different areas and can be referred to by policymakers in any of the local regions or in the whole economy.

Second, the Gini coefficient decomposition shows that household carbon inequality can be ascribed to different consumption categories, and that the contributions and impacts of consumption categories are different according to their carbon intensities and shares in the total consumption. In our study, residential consumption is the most important source of the household carbon inequality in urban China, which is mainly because that the intensity of carbon emissions in residential consumption is high. The second most important source is the consumption of educational, cultural and recreational services because of these services' intensive carbon emissions. The third is food consumption because of its high proportion in households' total consumption. The directions are also different for the changes in the consumption categories to impact the household carbon inequality in urban China. Residential consumption, the consumption of household facilities, articles and services and the consumption of educational, cultural and recreational services, have positive effects on the household carbon inequality in urban China, while the effects are opposite for food consumption, clothing consumption, the consumption of transport and communication services and the consumption of medicine and medical services.

Third, the Shapley decomposition shows that household characteristics have quite different contributions to the household carbon inequality in urban China; this decomposition occurs after a regression analysis to discern the determinants of households' per capita CO_2 emissions. Households' demographic characteristics contribute 59.74% to the inequality of their per capita emissions. Among the pertinent components, the household size is the most important factor with a contribution of 46.29%. Household employment and income, which has a total contribution of 24.31%, is the second largest determinant of the household carbon inequality. Household burdens, which have a total contribution of 8.00%, and household assets and financial plans, which have a total contribution of 7.85%, also have some impact on the household carbon inequality.

4.2. Policy Implications

First, household carbon inequality should be emphasized in mitigation policies. On one hand, household carbon inequality affects the efficiency of mitigation policies. To achieve better effect of energy conservation and emissions reduction, mitigation policies on household sector should emphasize more on the households who have high per capita emissions and have more potential in abatement. On the other hand, household carbon inequality affects the fairness of mitigation policies. Household carbon inequality implies that households in the same country or area have different abatement responsibilities according to their levels of carbon emissions. As a result, households should be treated differently in a carbon tax, imposing quotas or command-and-control system.

Second, diverse measures should be taken to equalize consumption categories with different impacts on household carbon inequality. According to our study, close attention should be paid to residential consumption, food consumption and the consumption of educational, cultural and recreational services, which have high carbon intensities or high shares in households' total consumption. Moreover, when caring for the distributions of household carbon emissions in urban China, policymakers should focus on food consumption, clothing consumption, the consumption of transport and communication services and the consumption of medicine and medical services as they have positive effects on the household carbon inequality.

Third, mitigation policies based on household characteristics only need to concern some key household characteristics selected from determinants of household carbon emissions, which will make sense more feasible and cost-efficient. The key characteristics for Chinese urban households are household size and employment. Household income level, marriage, the number of elders and car ownership also has some effect. Education and house holding, though commonly concerned, are not included. The high-carbon households discerned by the key characteristics can be given priority for emissions-cutting technology and environmental education.

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