Atmospheric Pollution Research 8 (2017) 310–319

Contents lists available at ScienceDirect

Atmospheric Pollution Research

journal homepage: http://www.journals.elsevier.com/locate/apr

Original Article

Difference analysis of the relationship between household per capita income, per capita expenditure and per capita CO_2 emissions in China: 1997–2014

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ARTICLE INFO

Article history:
Received 11 July 2016
Received in revised form
27 September 2016
Accepted 28 September 2016
Available online 12 October 2016

Keywords:
Household per capita CO_2 emissions
Per capita income
Per capita expenditure
Panel data model
Difference analysis

ABSTRACT

Driven by the buoyancy of economy and continuous improvement of people's living standards, residential sector has gradually become the second largest CO_2 emissions source in China. Reducing the fast rising rate of CO_2 emissions in this sector is essential for realizing the target of carbon emission mitigation in China. The researches on the driving factors of residential CO_2 emissions have attracted scholars' attention recently, yet few studies can interpret the causality relationship between household per capita income-expenditure-CO_2 emissions at national and regional levels. Based on econometric techniques and a panel data set, this paper presents an investigation of the causality relationship, which combines household per capita income, per capita expenditure and per capita CO_2 emissions (hereafter referred to as PI, PE, and CE, respectively) on a national level and within three regions (namely, eastern, central, and western regions of China) from 1997 to 2014. Urban and rural areas are considered as well. The empirical results manifest a varied causality relationship in different regions. For example, PI and PE correspond to CE in eastern rural area, but this phenomenon does not occur in central rural area. In addition, urban and rural differences are displayed. There is no causality between PI and PE in western urban area, while a bidirectional causal relationship emerges in PI and PE for western rural area. Finally, this study proposes some policy implications to decrease the increase rate of household CO_2 emissions in China.

1. Introduction

China's CO_2 emissions account for 23.4% of the world's total emissions in 2014 (IPCC, 2014). CO_2 emissions produced by human activities have become a culprit of promoting global warming and environmental degradation (Zhi et al., 2015). Although the rapid development of industrialization has been regarded as the main reason of CO_2 emissions for a long time (Wang et al., 2012a,b; Wang and Feng, 2015), the improvement of people's life quality in recent years has greatly encouraged residential CO_2 emissions (Yuan et al., 2015; Wang et al., 2014), which has gradually become the main growth source of CO_2 emissions (Wang and Liu, 2015). Now, the residential sector is the second-largest energy consumer in China after the industrial sector, and then the transport sector comes next (Nie and Kemp, 2014). Likewise, the CO_2 emissions from this sector present an identical trend, with a noticeable average annual increase rate of 7.49% (see Fig. 1). Fig. 2 shows the average of household per capita CO_2 emissions in urban and rural areas of China's 30 provinces between 1997 and 2014. Hence, in the process of constructing a resources-saving and environment-friendly society, the part of household CO_2 emissions should be considered seriously.

Generally, per capita income and per capita expenditure of residents have been deemed as important indicators of residential consumption level. On balance, from 1997 to 2014, household per capita income in China urban and rural areas has experienced a phenomenal rise, with the average annual growth rate of 8.53% and 7.00% respectively, accompanied by unbalanced development among different provinces (Fig. 3). From Fig. 4, a higher household per capita expenditure level appears in urban areas, whereas the

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Peer review under responsibility of Turkish National Committee for Air Pollution Research and Control.

http://dx.doi.org/10.1016/j.apr.2016.09.006

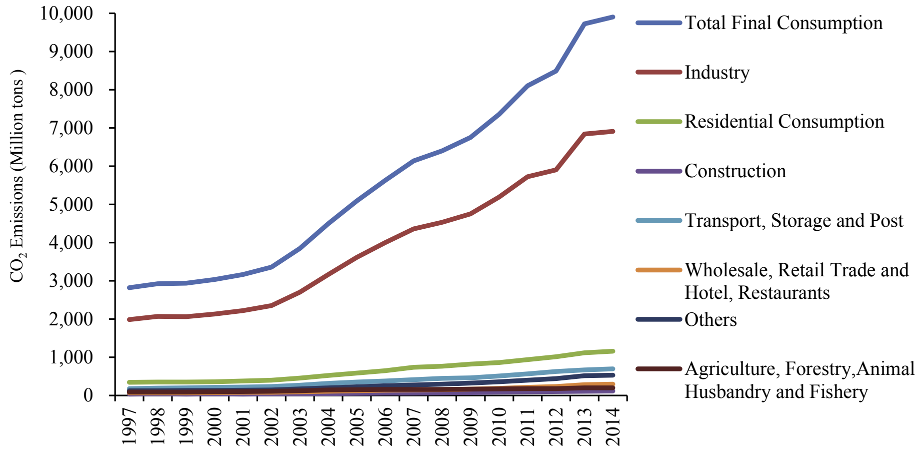

Fig. 1. Residential CO_2 emissions from final energy consumption in China from 1997 to 2014.

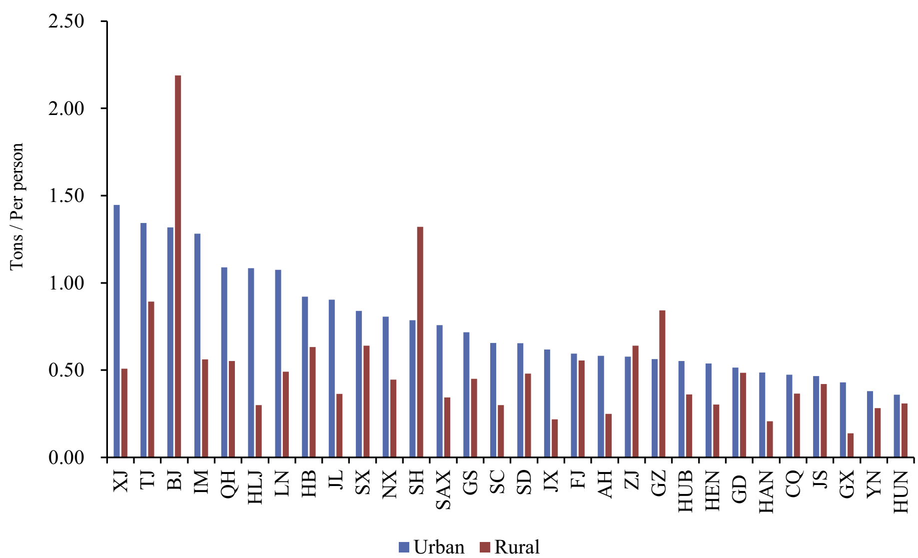

Fig. 2. The average household per capita CO_2 emissions of China's 30 provinces from 1997 to 2014.

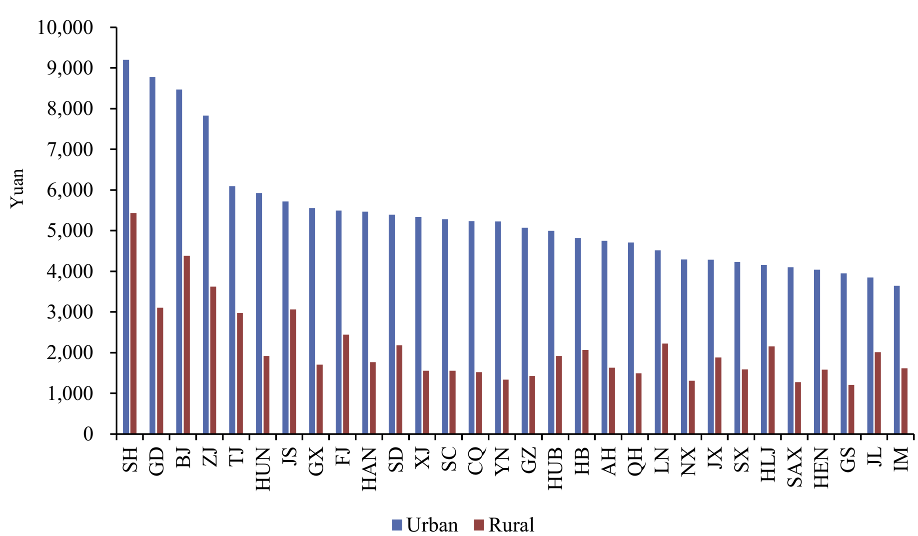

Fig. 3. The average household per capita income of China's 30 provinces from 1997 to 2014.

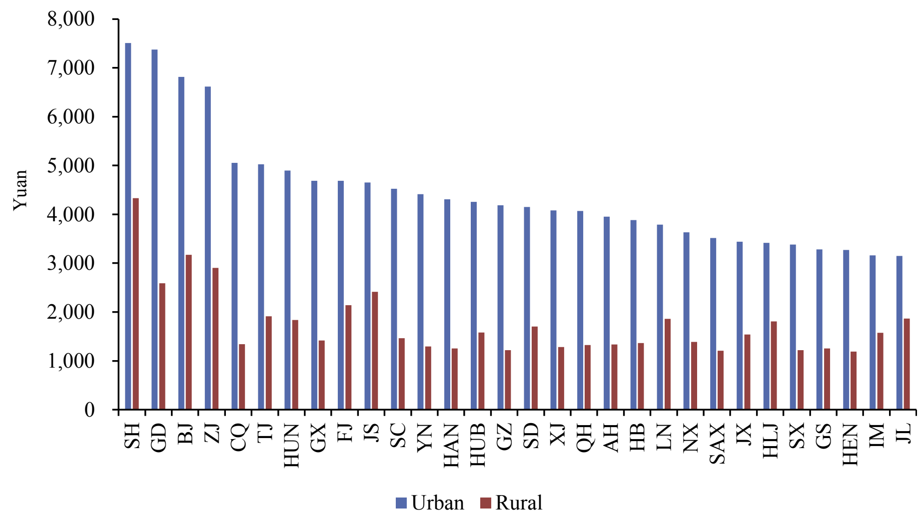

Fig. 4. The average household per capita expenditure of China's 30 provinces from 1997 to 2014.

consumption level of rural areas remains low. Although various factors affect household CO_2 emissions, such as housing types (public housing, HA subsidized sales flats, private housing, and other housing), floor space (house area in square meters), energy price (Chuang et al., 2011; Nie and Kemp, 2014; Liu and Zhao, 2015), the factor of household per capita expenditure has not been adequately studied in China. This paper selects a new perspective of household consumption level to study the differences of the causal relationship between household per capita income, per capita expenditure and per capita CO_2 emissions in China during the period of 1997–2014, which is the main objective of this study.

The remainder of this paper is organized as follows. Section 2 provides a brief literature review mainly on household energy consumption and CO_2 emissions. Section 3 introduces the applied methodology. Section 4 represents the data sources. Results and discussions are given in Section 5, and the conclusions and policy implications are summarized in Section 6.

2. Literature review

With the intensification of global warming effect, increasing scholars show solicitude for carbon emission, carbon footprint, and carbon convergence analysis (Patthanaissaranukool and Polprasert, 2016; Serino and Klasen, 2015; Acar and Lindmark, 2016). Recently, certain researchers have been focusing on studying the CO_2 emissions in residential sector. Literature review is concerned with relevant articles that probe the driving factors of residential energy consumption and CO_2 emissions in different geographies. For instance, Das and Paul (2014) found that population played a significant role in the rise of household CO_2 emissions in India. Based on a demographics analysis, Roberts (2008) concluded that the expansion of household size brought about the growth of electricity demand in UK. There are also many studies related with residential CO_2 emissions in the Chinese context (Peters et al., 2007; Guan et al., 2009). Han et al. (2015) studied the contributing factors of household embedded carbon emissions in urban China, and reached the conclusion that household income was the most important determinant. Besides, some researchers pay attention to residential building energy consumption (Chen et al., 2008; Ouyang et al., 2009; Ding et al., 2012). Some other scholars study on household transport-related CO_2 emissions (Wang and Liu, 2015). As for the research methods of residential energy consumption and carbon emissions, decomposition analysis (including index decomposition analysis and structural decomposition analysis), input and output analysis (Qu et al., 2013), consumer lifestyle approach (Feng et al., 2011), quantitative analysis (Xu et al., 2015) are the four main basic methods for residential carbon emissions analysis. For example, applying additive Logarithmic Mean Divisia Index (LMDI-I) analysis method, Zha et al. (2010) studied the energy related carbon dioxide emissions in China's residential sector during the period of 1991–2004. According to their research, income effect in urban areas was always larger than that in rural areas and contributed to the fast rise. From a region perspective, Tian et al. (2014) applying the multi-region input–output model (MRIO) and structural decomposition analysis (SDA) researched the regional disparity of carbon footprint, figuring that the regional carbon footprint increased with the growth of regional income. Using weighted household survey data, Xu et al. (2016) surveyed the household carbon inequality in urban China and analyzed its sources and determinants. They found that residential consumption with high carbon intensity was the most important source, and the determinants of household carbon inequality were household demographic characteristics, household employment and income, household burdens, and household assets and financial plans. Furthermore, some studies have dealt with the causal relationship between variables. In this regard, the causality relationships between CO_2 emissions, energy consumption and economic growth were documented well in the literature; which were studied by Ozturk and Acaravci (2010) for Turkey, by Alam et al. (2011) for India, by Hwang and Yoo (2014) for Indonesia and by Begum et al. (2015) for Malaysia. To date, however, there is a void in the literature on examining the relationship between household per capita income, expenditure and CO_2 emissions by considering the case of China.

From the literature review, it can be clearly seen that previous studies are confined to these approaches, e.g., decomposition analysis method, input–output method, consumer lifestyle approach and quantitative analysis, to investigate factors influencing household energy consumption and CO_2 emissions. But, panel data model has rarely been applied to the field of studying residential CO_2 emissions in China. Thus, this paper constructs a panel data model to indagate the impact of residential consumption level on CO_2 emissions in China, which differs from other researches. And another novel aspect is exploring the differences of the causality relationship between household per capita income-per capita expenditure-per capita CO_2 emissions at national and regional levels, from a systemic point of view.

Therefore, this analysis aims to fill the research gap for China and develop a comprehensive picture of the relationship between selected variables. The conclusions of this study can more effectively guide the direction of reducing CO_2 emissions in residential sector.

3. Methodology

3.1. Estimation of CO_2 emissions

Following the IPCC 2007 guideline, the formula used to calculate household direct CO_2 emissions is based on energy consumption, carbon emission coefficients and the conversion coefficient as follows:

$$CE_{iz}^{t} = \sum_{j} E_{ijz}^{t} \times K_j \times \frac{44}{12} \quad (1)$$

where CEt iz represents the household CO_2 emissions for province i in area z (urban or rural) in year t (Million tons (Mt)), Et ijz refers to the j th kind of energy consumption in area z of province i in year t (Mt or Billion cubic meters), K_j is carbon emission coefficient of the j th kind of energy, and the factor 44/12 is the ratio of molecular weights of CO_2 and C. Total household CO_2 emissions divided by the corresponding population will obtain the household per capita CO_2 emissions.

In this paper, eleven types of energy are calculated, that is, raw coal, briquette, coke, coke oven gas, gasoline, kerosene, diesel oil, liquefied petroleum gas, natural gas, heat and electricity. The CO_2 emission coefficients of the 9 different types of fossil fuels can be estimated based on average low calorific value, carbon content and oxidation rate, as observed in Table 1. More specifically, multiply the corresponding value of average low calorific value, carbon content and oxidation rate together, and we will get the CO_2 emission coefficient, noticing the conversion between units. The carbon emission coefficients of fossil fuels are often supposed to be constant over time (Ang and Pandiyan, 1997). The underlying reason is that the quality of fuels will not vary by much in a short period (Zha et al., 2010).

The heat is first needed to convert into standard coal (Mt), and then turn into CO_2 emissions (Yang et al., 2015a). The conversion factor from physical units to coal equivalent of heat is 0.03412 (kg tce/million joule), in the light of China Energy Statistical Yearbook Appendix IV (2014). According to the recommended value by the Energy Research Institute National Development and Reform Commission, the carbon emission coefficient of standard coal equivalent is 0.67 (t C/tce). The CO_2 emission factors for electricity (summarized in Table 2) refer to the Provincial Greenhouse Gas Listing Compilation Guidelines published by China's National Development and Reform Commission (Yang et al., 2015a).

Table 2
Electricity CO_2 emission factors for different regions of China.

Region	CO_2 emission factor
Northern China	1.246 kg/kW h
Northeastern China	1.096 kg/kW h
Eastern China	0.928 kg/kW h
Central China	0.801 kg/kW h
Northwestern China	0.977 kg/kW h
Southern China	0.714 kg/kW h
Hainan province	0.917 kg/kW h

3.2. Panel data model

Panel data models are first introduced into econometric analysis by Balestra and Nerlove (1966). Panel data model has many advantages over time series and cross-sectional data models, such as the capability of controlling individual heterogeneity, more reliable and stable parameter estimation, reducing the effects of collinearity among variables, raising the degree of freedom, improving the estimation efficiency and allowing for more informative data (Baltagi, 2005; Al-mulali, 2012). Accordingly, this paper adopts panel data model to capture the relationship between household per capita income, per capita expenditure and per capita CO_2 emissions in China.

The panel data models usually include three types, namely, pooled regression model, variable intercepts and constant coefficients model, and variable intercepts and variable coefficients model.

The formulas of these three categories models are as follows:

$$Y_{it} = \alpha + \beta\,\chi_{it} + \mu_{it} \ldots (i = 1,\ 2, \ldots, N;\ t = 1,\ 2, \ldots, T) \quad (2)$$

$$Y_{it} = \alpha_i + \beta\,\chi_{it} + \mu_{it} \ldots (i = 1,\ 2, \ldots, N;\ t = 1,\ 2, \ldots, T) \quad (3)$$

$$Y_{it} = \alpha_i + \beta_i\,\chi_{it} + \mu_{it} \ldots (i = 1,\ 2, \ldots, N;\ t = 1,\ 2, \ldots, T) \quad (4)$$

where α_i refers to the intercept, β_i is expressed as a coefficient vector, andμ_{it} is the error term.

To determine which specific model should be used, the covariance analysis is employed to test the following two hypotheses.

$$H_1 : \beta_1 = \beta_2 = \ldots = \beta_N \quad (5)$$

Table 1
The CO_2 emission coefficients of different types of fossil fuels.

Fuel	Average low calorific Value[a]	Carbon content[b]	Oxidation rate[c]	CO_2 emission coefficient[d]
Raw coal	20,908 (kJ/kg)	26.37 (t ton/TJ)	0.94	1.9003 (kg CO_2/kg)
Briquette[e]	20,700 (kJ/kg)	26.6 (t ton/TJ)	1	2.0189 (kg CO_2/kg)
Coke	28,435 (kJ/kg)	29.5 (t ton/TJ)	0.93	2.8604 (kg CO_2/kg)
Coke Oven Gas[f]	17,900 (kJ/m^3)	12.1 (t ton/TJ)	0.99	0.7863 (kg CO_2/m^3)
Gasoline	43,070 (kJ/kg)	18.9 (t ton/TJ)	0.98	2.9251 (kg CO_2/kg)
Kerosene	43,070 (kJ/kg)	19.5 (t ton/TJ)	0.98	3.0179 (kg CO_2/kg)
Diesel oil	42,652 (kJ/kg)	20.2 (t ton/TJ)	0.98	3.0959 (kg CO_2/kg)
Liquefied petroleum gas	50,179 (kJ/kg)	17.2 (t ton/TJ)	0.98	3.1013 (kg CO_2/kg)
Natural gas	38,931 (kJ/m^3)	15.3 (t ton/TJ)	0.99	2.1622 (kg CO_2/m^3)

[a] Notes: Source: China Energy Statistical Yearbook (2013).
[b] Source: Guidelines for Greenhouse Gas Inventories, Province (Trial).
[c] Source: Guidelines for Greenhouse Gas Inventories, Province (Trial).
[d] Source: The CO_2 emission coefficient is calculated via the average low calorific value, carbon content and oxidation rate.
[e] Source: Yang et al., 2015a.
[f] Source: Xu et al., 2014.

$$H_2 : \alpha_1 = \alpha_2 = \ldots = \alpha_N \tag{6}$$

$$\beta_1 = \beta_2 = \ldots = \beta_N$$

If assumption H_2 is accepted, Eq. (2) is available. Otherwise it is necessary to test H_1. If H_1 is then accepted, Eq. (3) is selected. Otherwise, Eq. (4) is chosen.

3.3. Panel data model selection

As mentioned above, panel data models can be divided into three types: mixed effects, fixed effects and random effects models. Due to the discrepancy of panel data, it is momentous to take appropriate panel data models to explore the relationship between per capita income-per capita expenditure-per capita CO_2 emissions in residential sector.

Following is the detailed procedures of selecting the suitable panel data model.

Firstly, the Likelihood ratio test is employed to determine whether mixed effects model or fixed effects model is fit for the empirical analysis. When the p-value of the F-test statistic is less than a specified level of significance (i.e., 1%, 5% and 10%), the null hypothesis will be rejected and a fixed effects model is available. Otherwise, the mixed effects model will be chosen for the research. Secondly, the Hausman test will be used to select between fixed effects and random effects model. If the Hausman test value is large, the corresponding p-value is less than the preset level of significance, and thus a fixed effects model will be established. If this is not the case, a random effects model will be constructed.

For the case of national level and the three regions, the results of Likelihood ratio test and Hausman test indicate that the fixed effects model is appropriate to conduct the empirical analysis (Table 3). The estimation results are presented in Table 8.

3.4. Granger causality test

Cointegration test demonstrates that there is a long-run cointegrating relationship between variables, but it does not reveal the orientation of the causal relationship (Hatzigeorgiou et al., 2011). Granger causality tests are broadly used to investigate the direction of causality between variables. Ordinarily, a prerequisite for Granger causality test is that the economic time series must be stationary, otherwise a spurious regression will occur. When X and Y are stationary sequences, X is supposed to be Granger-cause Y, if it can pass a series of t-tests and F-tests on lagged values of X (lagged values of Y also included). These X values provide statistically significant information about future values of Y (Wang et al., 2016a).

Therefore, Granger causality tests are carried out to explore the causality relationship between selected variables. The results of Granger causality test are presented in Tables 6 and 7.

4. Data sources

The variables used in this paper are per capita income, per capita expenditure and per capita CO_2 emissions of urban and rural residents in China's 30 provinces. Thus, the panel data set is comprised of cross-province observations containing urban and rural areas in China over the period of 1997–2014. For convenience, henceforth, household per capita income, per capita expenditure and per capita CO_2 emissions will be called PI, PE and CE, respectively.

The data of PI, PE and population for both urban and rural areas is obtained from China Statistical Yearbook (1998–2015) (National Bureau of Statistics of China, 1998–2015a). And the final energy consumed by households is collected from the Energy Balance Table of China Energy Statistical Yearbook (National Bureau of Statistics of China, 1998–2015b). Based on the final consumption of diversified fuels and their corresponding CO_2 emission coefficients, household CO_2 emissions for the 30 administrative regions are calculated. PI and PE in the researching period are all converted into 1995 constant price (Chinese Yuan). The software applied to the overall analysis is Eviews 7.0.

According to the National Bureau of Statistics of China, the 30 provinces are divided into eastern, central and western regions (Fig. 5) (Xu and Lin, 2016).

5. Results and discussions

5.1. Unit root test

Ordinarily speaking, most sequences of economic variables are non-stationary. If a non-stationary sequence is used to conduct a regression analysis, the spurious regression would occur. Hence, it is indispensable to test the stationary of the variable series. If the sequences are non-stationary but proved to be integrated of the same order, the regression results are reliable (Yang et al., 2015b,c). If a variable must be differenced d times to be stationary, it is integrated of order d, written as I (d). Specially, if a stationary variable is integrated of order zero, that is I (0); and a variable that is differenced once to be made stationary is integrated of order one, recorded as I (1) (Liddle, 2011).

There are mainly five approaches for unit root test of panel data, including the LLC test proposed by Levin et al. (2002), the IPS test proposed by Im et al. (2003), the ADF test proposed by Maddala and Wu (1999), the PP test proposed by Choi (2001), and that proposed by Hadri (2000). The null hypothesis of the LLC, IPS, ADF and PP is that there is a unit root, but the null hypothesis for Hadri is that there is not (Wang et al., 2016b).

To overcome the errors inherent in certain test method, this study chooses four types of unit root test, viz., LLC, IPS, ADF and PP, to evaluate the stability of the variables. The results of these unit root tests are exhibited in Table 4. As shown in Table 4, although most of variables are non-stationary in level, their first-difference

Table 3
The results of panel data model selection.

	Nation		Eastern region		Central region		Western region	
	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Hausman test	38.4694***	29.7963***	9.4666***	7.9103**	17.7725***	5.0846*	8.3411**	11.5764***
Likelihood ratio test	112.6544***	33.9769***	441.5256***	196.6658***	285.9767***	191.0311***	375.7250***	255.5733***
Model Type	FE	FE	FE	FE	FE	FE	FE	FE

Note: FE is fixed effects model.
*p < 0.1; **p < 0.05; ***p < 0.01.

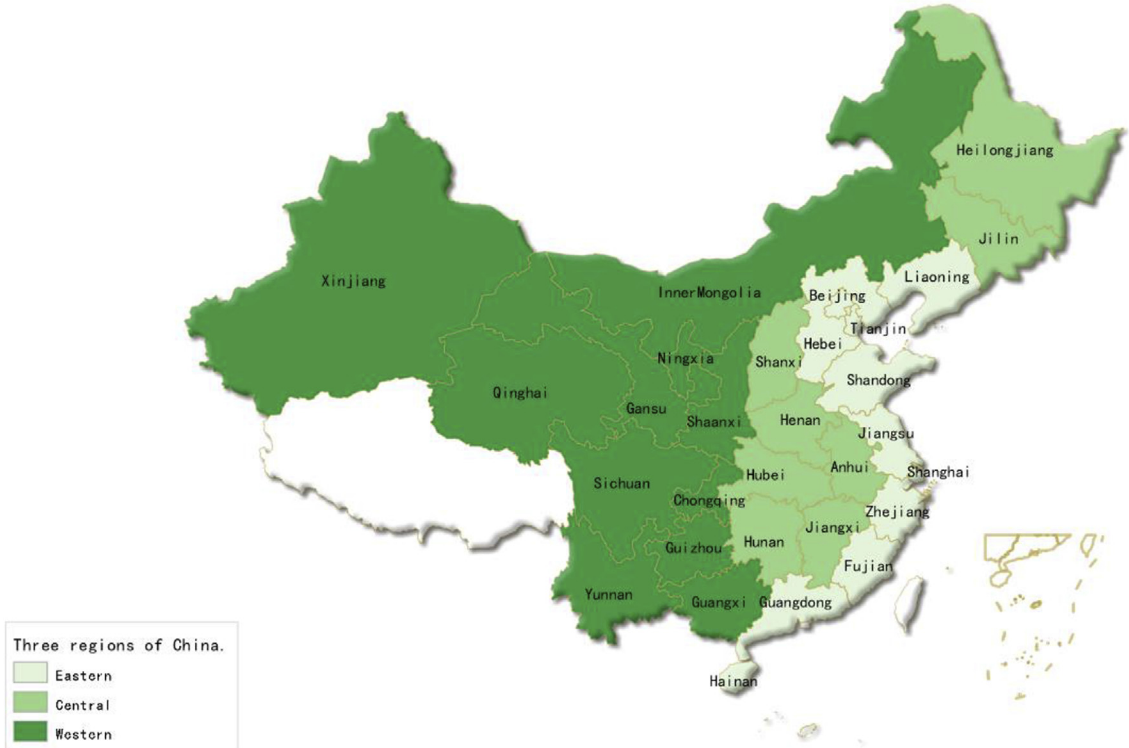

Fig. 5. The three regions of China. Notes: Tibet Autonomous Region is not included in this study due to incomplete data.

sequences are stationary, indicating that they are first-order integrated series, denoted as I (1).

5.2. Cointegration test

If the sequences are cointegrated, there exists cointegration relationship between them. The methods of cointegration test for panel data contain the Pedroni test (Pedroni, 1999, 2004) and the Kao test (Kao, 1999). The null hypothesis of the Pedroni test and Kao test is that there is no cointegrational relationship between variables (Wang et al., 2016b). Applying a Monete Carlo model, Luciano compared these cointegration test methods, reporting that when the time span T is small ($T < 20$), the Kao test is superior to the Pedroni test, while when T is large ($T > 20$), Pedroni test

Table 4
Results of panel unit root tests.

Region		Variable	Levin-Lin-Chu test		IPS test		ADF-Fisher test		PP-Fisher test	
			Level	First-order	Level	First-order	Level	First-order	Level	First-order
National	Urban	CE	0.8132	−8.2095***	2.4834	−13.0042***	50.5442	266.6600***	57.4992	652.9720***
		PI	13.2594	−7.9396***	16.4526	−4.0258***	2.3201	102.8020***	0.0360	153.0230***
		PE	13.2594	−8.2712***	16.4525	−4.2504***	2.3202	106.7600***	0.0360	153.0220***
	Rural	CE	9.1867	13.1880***	8.6967	−12.2683***	38.7423	261.8130***	31.8129	313.0440***
		PI	11.2488	−8.0545***	15.2406	−4.5963***	5.4566	107.1740***	0.0691	156.0330***
		PE	11.2489	−8.0545***	15.2407	−4.5962***	5.4565	107.1740***	0.0691	156.0330***
Eastern	Urban	CE	1.6263	19.4239***	2.9161	−12.7613***	9.0284	93.1562***	17.9912	122.0240***
		PI	8.6721	−4.6118***	10.8489	−2.1905**	0.5120	36.9790**	0.0054	60.7360***
		PE	8.6721	−4.9151***	10.8489	−2.5626***	0.5119	40.9376***	0.0054	60.7365***
	Rural	CE	4.6145	−7.3960***	4.6291	−8.5027***	27.2985	109.4510***	15.1323	119.0350***
		PI	6.8614	−5.2147***	9.2511	−2.9327***	1.7993	41.0810***	0.0120	62.4857***
		PE	6.8616	−5.2147***	9.2511	−2.9327***	1.7992	41.0810***	0.0120	62.4861***
Central	Urban	CE	0.6996	−6.0459***	0.8513	−4.8270***	21.3048	51.0668***	21.1244	311.0370***
		PI	5.1470	−6.0706***	6.2967	−4.1598***	1.0786	49.4491***	0.0154	79.9875***
		PE	5.1471	−6.0706***	6.2967	−4.1598***	1.0786	49.4492***	0.0154	79.9881***
	Rural	CE	3.6014	−8.6493***	5.4476	−5.8559***	1.3972	63.8391***	1.1661	89.5914***
		PI	3.9284	−3.4739***	5.5072	−1.4654*	3.6306	33.0386***	0.0270	40.5519***
		PE	3.9284	−3.4739***	5.5073	−1.4654*	3.6305	33.0393***	0.0270	40.5561***
Western	Urban	CE	1.3920*	12.3805***	0.3923	−9.8187***	20.2110	119.3700***	18.3836	180.9970***
		PI	8.6922	−5.6505***	11.0729	−3.2901***	0.7296	44.1255***	0.0153	50.2742***
		PE	8.6921	−5.6504***	11.0729	−3.2901***	0.7297	44.1250***	0.0153	50.2735***
	Rural	CE	7.2486	−7.7656***	5.1426	−6.7195***	10.0466	88.5225***	15.5145	104.4170***
		PI	8.3814	−5.4100***	11.3964	−3.3539***	0.0268	44.9959***	0.0301	57.1758***
		PE	8.3814	−5.4098***	11.3964	−3.3537***	0.0268	44.9941***	0.0301	57.1735***

Note: *$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

Table 5
The results of panel cointegration test.

Cointegration test	Nation		Eastern region		Central region		Western region	
	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
ADF stat	−1.7627**	−4.1406***	−10.4420***	−1.7092**	1.9604**	−4.7249***	−1.3925*	−5.0075***
Residual variance	87343.62	18282.48	48401.73	35790.71	215806.9	3041.842	32093.37	11852.12
HAC variance	37573.28	17613.99	47525.76	33906.44	19054.41	2612.973	28684.22	12109.21

Note: *p < 0.1; **p < 0.05; ***p < 0.01.

outperforms Kao test (Gutierrez, 2006). Thus, the Kao test is adopted in this paper. The results of Kao test are shown in Table 5. It is evident that there is a long run equilibrium relationship between each explanatory variable and per capita CO_2 emissions significantly at 10% or a higher level.

5.3. Granger causality test

Employing the first-order sequences of variables within the theoretical framework of Granger causality test, this study intends to capture the causality relationship between household per capita income, per capita expenditure, and per capita CO_2 emissions for the three regions of China. Results of the Granger causality test are reported in Tables 6 and 7. Table 6 shows the original results of Granger causality test, and the verbal descriptions of these results are listed in Table 7.

At national level, test results demonstrate the existence of a unidirectional causality from PI and PE to CE. During the initial stage of China's reform and opening-up, Chinese government developed the economy vigorously in an extensive mode, and did not give full play to the advantages of high-tech and service industry. Yet whilst this mode of economic growth can promote the level of households' income and expenditure, it can also increase energy consumption, thereby producing significant augment in CO_2 emissions (Wang et al., 2015). Obviously, there is a Granger causality running from PI to PE with a feedback, which indicates PI and PE interact on each other.

Eastern region shows PI and PE can drive CE, but the opposite does not hold true. To decrease CE, people in this area had better transform their lifestyles and consumption behaviors. There is no causality relationship between PI and PE in any direction, which illustrates PI is not affected by PE, and vice versa.

The test results provide evidence of the existence of monodirectional Granger causality from PI and PE to CE in central urban area, but neither PI nor PE causes movements in CE in central rural area. Thus, the local government can purse economic growth through the policy of stimulating consumption in central rural area. As to the causal interactions between PI and PE, the evidences attest to a two-way causality significantly at 5% level for both urban and rural areas. This means that the increase of PE will boost economic growth, and then with corresponding growth in PI, which conforms to the hypothesis of the “Three Carriages” in economics. Conversely, the rise of PI will lead to the increase of PE.

In western region, a single-track causality ranges from PI and PE to CE in urban and rural areas, but without any feedback effect. The test results support the occurrence of bidirectional causality between PI and PE in western rural area, whilst there is no causal relationship between the two variables in western urban area.

Another interesting result is that CE does not proceed to PI and PE in this study. The overall results indicate that, CO_2 emissions reduction policies are likely to have no adverse effect on the growth of household's income and expenditure in China. Therefore, the government of China may follow energy efficiency and carbon emission reduction policies without impeding the growth potentiality of PI and PE. This finding is mostly consistent with the work of Alam et al. (2011), but different from the study of Dinda and Coondoo (2006). According to the existing literature, the direction of the causality between variables is both research methods and periods dependent.

The reasons of the differences between regions lie in geographic conditions, resource endowments and industrial structure. For instance, due to strict environmental regulation, eastern region has been transferring energy-intensive industry to central and western regions, resulting in the changes of industrial structure in these regions. As we know, a higher consumption level presents in urban areas. Household appliances are widely used in cities, and thus, a higher proportion of carbon emissions is from electricity consumption for urban households. In contrast, the consumption level of rural households remains relatively low. In virtue of the abundant resource and low price, coal is extensively used for cooking and heating in rural areas (Li et al., 2016).

5.4. National analysis

The estimation results of panel data model at national level are illustrated in Table 8. Clearly, all variables in urban and rural areas are statistically significant at 1% level on national level. The coefficients of household per capita income are positive. This result coincides with the view of Li et al. (2016), who confirm that per capita income is the most important explanatory variable for household per capita CO_2 emissions. Besides, the result is

Table 6
Panel Granger causality test results between the three variables in different regions.

Region	Result	National	Eastern	Central	Western
Urban	PI → CE	11.0592**	6.2105**	16.5295***	39.0227**
	PE → CE	11.1606**	6.2079**	16.5500***	36.7192**
	PI → PE	5.9744**	–	4.5957**	–
	PE → PI	5.9966**	–	4.6086**	–
	CE → PI	–	–	–	–
	CE → PE	–	–	–	–
Rural	PI → CE	13.9933***	76.1357**	–	7.3085***
	PE → CE	14.5166***	58.9120**	–	7.2859***
	PI → PE	4.9462**	–	5.2724**	4.6629**
	PE → PI	5.0374**	–	5.4211**	4.6831**
	CE → PI	–	–	–	–
	CE → PE	–	–	–	–

Note: *p < 0.1; **p < 0.05; ***p < 0.01.

Table 7
The verbal descriptions of panel Granger causality test results.

Region	Result	National	Eastern	Central	Western
Urban	PI CE	Unidirectional	Unidirectional	Unidirectional	Unidirectional
	PE CE	Unidirectional	Unidirectional	Unidirectional	Unidirectional
	PI PE	Bidirectional	–	Bidirectional	–
Rural	PI CE	Unidirectional	Unidirectional	–	Unidirectional
	PE CE	Unidirectional	Unidirectional	–	Unidirectional
	PI PE	Bidirectional	–	Bidirectional	Bidirectional

consistent with the conclusion of Wang and Liu (2015), showing that per capita disposable income is the main driver of increasing household daily travel CO_2 emissions.

However, the parameters of household per capita expenditure are negative at national level. With other conditions unchanged, a 1% increase in PE are associated with 0.6425% and 1.0693% decrease in household per capita CO_2 emissions in urban and rural areas, respectively. This finding is not in line with the result of Papathanasopoulou (2010), who argues that household expenditure contributes to the increase of CO_2 emissions in Greece between 1990 and 2006. With the explosive growth of per capita expenditure, people's consumption modes have transformed, tending to consume more advanced commodities and services. That is to say, people have changed the consumption concepts and laid stress on the quality of life characterized with buying commodities of high quality and emphasizing service experience in the course of consumption, which will impose more pressure on the mitigation of CO_2 emissions (Zha et al., 2010). Given the peculiar situation of China, a typical urban-rural dualistic structure gives rise to the disparities of people's lifestyles and consumption behaviors. For example, the activities of cooking and water heating in residential daily-life primarily burn electricity and natural gas in urban areas, while most rural residents are still using traditional biomass fuels such as stalks and firewood (Fan et al., 2012). For consumption behaviors, urban households prefer more wholesome diet and comfortable living environment, and consume more extravagant goods. Comparatively speaking, rural residents are very thrifty and inclined to put money in the bank. Thus, the distinctions between urban and rural residents should be deserved special attention when studying the residential CO_2 emissions.

5.5. Regional analysis

The vast territory of mainland China presents great discrepancies among the eastern, central and western regions, and the level of household per capita income and per capita expenditure also vary across different regions. Therefore, this paper takes regional analysis into account.

In the eastern region, all the independent variables of urban and rural are statistically significant at the 1% levels (Table 8). In eastern urban area, household per capita income and per capita expenditure affect per capita CO_2 emissions with coefficient of 0.8623 and −0.7832 respectively. Household per capita income in rural area has stronger explanatory power with parameter of 2.6306. The coefficient of per capita expenditure in rural area is −2.5666, indicating an inhibitory effect on per capita CO_2 emissions in this area. The reason causing the differences between eastern urban and rural areas is the more steady income levels and consumption patterns in eastern urban area. By comparison, the economy in eastern rural area is in the stage of rapid development, and people are apt to consume more energy in this transformation period.

The coefficients of explanatory variables show obvious disparities between urban and rural areas in central region (Table 8). Household per capita income is statistically significant with per capita CO_2 emissions in central urban area (4.1840), the highest amongst the three regions. Household per capita income explains per capita CO_2 emissions in rural area with the coefficient of 0.6823. As for household per capita expenditure, the figure is the lowest in central urban area (−4.7165). The implementation of the Mid-China Rising Strategy has brought per capita income and per capita expenditure of central urban residents to a new level, exerting a large impact on per capita CO_2 emissions in this area. Nevertheless, the economic development in central rural area is backward.

In western region, all independent variables are statistically significant at the 1% level (Table 8). The coefficients of household per capita income and per capita expenditure are 0.9773 and −0.8857, respectively, in western urban area. Noticeably, the western rural area is quite different from the national aggregate case, the eastern and central regions. The coefficient of household per capita income is negative in western rural area (−2.4508), whereas the figure for household per capita expenditure is positive in this area. Because of the unique pastoral culture in western region, households customarily live in yurts and use traditional energy (such as animal manure, straw, and kerosene), thus engendering differences with other regions.

6. Conclusions and policy implications

Deploying a comprehensive conceptual framework incorporating a unit root test, a cointegration test, a panel data model, and the Granger causality test, this paper establishes a residential carbon emission model and researches the causal relationship between household per capita income, per capita expenditure and per capita CO_2 emissions in China during the period of 1997−2014. On the basis of econometric tests, the fixed effects model is constructed for empirical analysis. Considering regional discrepancies, China's 30 provinces are divided into three regions.

The results of per capita CO_2 emissions show a large disparity in the three regions and urban-rural areas. Household per capita CO_2 emissions in China ranges from 0.2773 tons to 0.8441 tons over the sample period. In eastern urban area, the household per capita CO_2 emissions are the largest from 0.6115 tons to 1.0677 tons. This phenomenon is greatly caused by the surging development of economy in eastern urban area. Whereas household per capita CO_2 emissions are the smallest in central rural area running from 0.1942 tons to 0.5955 tons (Fig. 6), which is due to the retarded economy in this area.

Table 8
The results of panel estimation.

Region	Nation		Eastern region		Central region		Western region	
	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural
Constant	367.7770***	640.2432***	−642.3981***	1208.1700***	707.7587***	464.5928***	280.4136***	−138.5403***
PI	0.7448***	1.4323***	0.8623***	2.6306***	4.1840***	0.6823***	0.9773***	−2.4508***
PE	−0.6425***	−1.0693***	−0.7832***	−2.5666***	−4.7165***	−0.287**	−0.8857***	3.0767***
R^2	0.8810	0.8154	0.9891	0.9594	0.9585	0.9401	0.9747	0.9520
Adjusted R^2	0.8737	0.8042	0.9884	0.9567	0.9557	0.9361	0.9731	0.9489
F-statistic	121.2984***	72.3914***	1404.5410***	363.9763***	343.6466***	233.7254***	594.7730***	306.0091***
Sum squared resid	35913472	21896584	197.2638	197.5350	143.5354	140.6364	197.3943	197.6030
Obs.	540	540	198	198	144	144	198	198
Individuals	30	30	11	11	8	8	11	11
Estimation methods	FE	FE	FE	FE	FE	FE	FE	FE

Note: FE is fixed effects model.
*$p < 0.1$; **$p < 0.05$; ***$p < 0.01$.

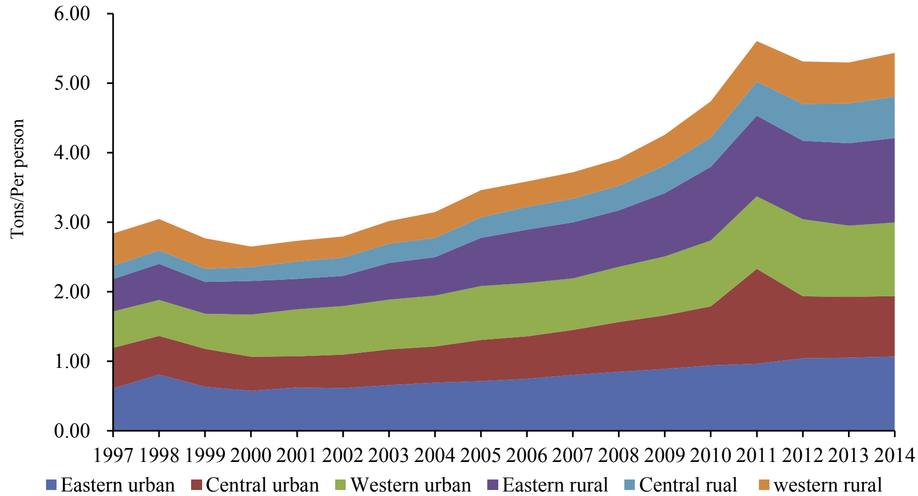

Fig. 6. The average household per capita CO_2 emissions in different regions from 1997 to 2014.

The impact of household per capita income on per capita CO_2 emissions denotes a positive effect significantly at 1% level, except western rural area (−2.4508). Household per capita expenditure decreases per capita CO_2 emissions in most regions, apart from the western rural area where the coefficient is positive (3.0767). The differences between western region and other regions rest with the unique pastoral culture in this region.

The causality relationships vary in different regions and urban-rural areas. At national level, the test results support the existence of one-way causality relationship from PI and PE to CE, and there is a Granger causality relationship ranging from PI to PE with a feedback. Eastern region shows PI and PE can drive CE, but the opposite does not hold true. There is no causality relationship between PI and PE in any direction. For central urban area, there is unidirectional Granger causality from PI and PE to CE, but neither PI nor PE causes movements in CE in central rural area. For western region, the test results imply bidirectional causality between PI and PE in western rural area. Howbeit this conclusion cannot extend to western urban area.

Along with the speedy growth of economy, residential CO_2 emissions will inevitably continue to grow, so it is necessary to adopt measures to mitigate CO_2 emissions in this sector. Based on the conclusions of this research, the following policy implications are proposed:

(1) Consumption behavior

With the betterments of living standards, people are likely to consume more energy to enjoy a comfortable life, which brings a challenge for energy conservation and carbon emission abatement. Thus, changing the consumption behavior of residents can considerably reduce environmental degradation. To avoid excessive consumption in residential sector, households need to alter the consumption composition of goods and services, switch to less carbon-intensive consumption patterns, and advocate moderate and green consumption. In addition, government plays a significant external driving role in shifting consumption behaviors (Zacarias-Farah and Geyer-Allély, 2003). The government must consider the substantial effect of household consumption on CO_2 emissions, when it encourages consumption. Simultaneously, government departments need to intensify the public to raise the consciousness of energy conservation and low carbon. Moreover, the enforcement of China's new Environmental Protection Law should be reinforced (Yang et al., 2015b,c).

(2) Energy efficiency

In order to decrease CO_2 emissions and enhance the quality of environment, Chinese government has advocated establishing ecological civilization since 2007 (Yang et al., 2013). Household CO_2 emissions abatement is still an integral part of reducing CO_2 emissions in China. Currently, most appliances are used in people's daily life, but the energy utilization efficiency of these appliances is not very high. Consequently, promoting the efficiency of energy has been and will still be an effective measure to mitigate CO_2 emissions in residential sector. Governments should be devoted to improving energy efficiency and fostering the rapid development of low-carbon techniques (Wu et al., 2015). For instance, releasing efficiency standards of appliances, which adopt advanced low-carbon techniques, can effectually cut down household CO_2 emissions.

In fact, due to further development of economy in China, residential CO_2 emissions will keep growing for the time to come. These results are conducive to update the existing literature in the aspects of energy and environment, and deserve particular attention from policy makers. To be sure, this research is preliminary. With vast territory in China, residents have their own lifestyles and energy-use features in specific place, so concrete regional analysis, provincial analysis, municipal level analysis, and even district level analysis on residential CO_2 emissions may be more meaningful for local policy-making.

Acknowledgements

We would like to thank the anonymous reviewers for their valuable and constructive comments on the earlier manuscript, which helped improve the quality of this paper. Any remaining errors are, of course, our own responsibility. We are also grateful to Dr. Juan Wang for her guidance and suggestions, and to postgraduate Cancan Zheng for her linguistic supports. This research is supported by the Ministry of Education of Philosophy and Social Major Science Project (15JZD021), the Ministry of Education of Humanities and Social Science Research Fund Plan (15YJA790091) and the National Natural Science Foundation of China (71373172).

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