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THE GREENNESS OF CHINESE CITIES: CARBON DIOXIDE EMISSION AND ITS DETERMINANTS

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DISCUSSION PAPER 16.12

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Abstract: This paper investigates carbon dioxide (CO_2) emission and its determinants in 286 Chinese cities. The findings strongly support an inverted U-shaped relationship between per capita CO_2 emission (PCE) and urban development. However the realization of this relationship depends on stringent governmental policy interventions. The regression analysis in this paper shows that city size is positively correlated with CO_2 emission efficiency, but negatively correlated with PCE. This result suggests that population restrictions in large cities tend to increase CO_2 emission. It is also shown that regional development programs are likely to encourage economic activities in regions with low CO_2 emission efficiency and may have significant environmental consequences in the future.

Keywords: CO_2 emission; greenness; urban development; Chinese cities
JEL codes: O53, Q53, Q58, R11

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1. Introduction

China has experienced impressive industrialization and urbanization over the past three decades. Urban population increased from less than 20% in 1980 to 52% in 2012. Urbanization is always considered as an important driver of economic growth and structural transformation. However accompanying the industrialization and urbanization was an increase in China's total energy consumption from 586 million tons of standard coal equivalent (TSCE) in 1980 to 3312 million TSCE in 2011(*China Energy Statistical Yearbook*, 2012). Dhadal (2009) estimated that urban share of China's total commercial energy use was 84% in the year 2006. As the world largest CO_2 emitter China is facing intense international pressure over CO_2 emission reduction. During the 2009 Copenhagen conference the Chinese government pledged a CO_2 emission intensity (tons of CO_2 emission per unit of GDP) reduction of 40%-45% from 2005 to 2020. In addition China targets a 17% reduction in CO_2 intensity during the 12th Five Year Plan (FYP, 2011-2015). In 2014 the Chinese government further pledged to end the CO_2 emission growth before 2030.

Cities differ greatly in CO_2 emissions due to their characteristics. Therefore the spatial distribution of population and economic activities across diverse cities is one of the key factors that affect CO_2 emissions (Kahn, 2006; Zheng et al., 2011). Using US household survey data Glaeser and Kahn (2010) found that cities with higher population density, warmer winter and cooler summer tend to produce lower CO_2 emissions. Based on Chinese urban household survey data across 74 cities in 2006, Zheng et al. (2011) documented that average city household CO_2, emissions are 69% higher in the northeastern region and 17% lower in the west. They also found that colder winter resulted in higher CO_2 emissions in the northeastern cities due to government-provided centralized home heating. Many studies (Hu and Wang, 2006; Shi et al., 2010; Yeh et al., 2010; Wei et al, 2012; Zhang and Choi, 2013) have documented that the eastern region has higher energy efficiency or CO_2 emission efficiency than the central and the western regions. Therefore reallocating economic activities and populations from high-energy efficiency and CO_2 emission efficiency regions to lower efficiency places may deteriorate CO_2 emissions in China. Unlike developed economies, China's central and local governments play important roles in the urbanization process. Therefore China's urban development policy may have significant impacts on CO_2 emissions. There are three major regional development programs that may reallocate economic activities to different regions. These programs are the Western Development Program initiated in 2001, the Rising of the Central China Program and the Northeastern Revitalization Program. The latter two were both launched in 2004.

Figure 1 shows the evolution trend of regional shares in output (gross regional product, GRP) and fixed investment for the period 1990-2011. Benefiting from preferential opening policy and geographical factors, the eastern region experienced fast economic growth driven by export-oriented and labor-intensive industries. Therefore output share in the eastern region maintained an increasing trend until its peak point in 2006, and then underwent a trend of decline after 2006. Furthermore the share of fixed asset investment in the eastern region declined from its peak of 50.6% in 2002 to 42.6% in 2011. In contrast the other three regions, namely the central region, the western region, and the northeastern regions have all experienced substantial share growth in terms of output and fixed asset investment since 2005. These observations suggest that the regional policy has already been effective in guiding the allocation of industrial activities and population movement across the regions.

Due to the limitation of energy consumption and CO_2 emission data, most studies on urban CO_2 emission in China use partial samples of cities. For example, Dhakal

(2009) covered 35 largest cities, and Zheng et al. (2011) considered 74 cities. Furthermore most researchers only use income and population size to estimate China's CO_2 emissions and neglected that the spatial distribution of economic activities across diverse cities may also be a key determinant of CO_2 emissions (Glaeser and Kahn, 2010; Zheng et al., 2011). In this article we construct a novel CO_2 emission data set across 286 prefectural and above (PAA) level cities covering the years of 2002-2011 and estimate how urban development affects China's CO_2 emissions.

This paper makes three main contributions to the literature on the investigation of China's urban CO_2 emissions. First we construct a novel PAA level city panel data set of energy use and CO_2 emissions covering the years 2002-2011 which broadly coincides with the 10^{th} FYP (2001-2005) and the 11^{th} FYP (2006-2010). Our city level panel data sample is much larger than the provincial panel data or time series data popularly used in the existing literature. Therefore our sample could provide more information and new insights into China's CO_2 emissions. This data set not only allows us to estimate the spatial differences in urban CO_2 emissions but also provides a basis to check the effects of policy changes between the 10^{th} and the 11^{th} FYP. Second, we contribute to the discussion of the environmental Kuznets curve (EKC) hypothesis. We use this new data set to investigate the driving forces of urban CO_2 emissions and present some interesting results that differ from previous studies. Third, we find that regional development programs are likely to encourage economic activities in regions with low CO_2 emission efficiency. The environmental consequences of China's current regional development programs are significant.

The remainder of the paper is organized as follows. Section 2 introduces the research method, which includes the DEA based estimation of CO_2 emission efficiency. Section 3 describes the variables and data. Section 4 is a preliminary analysis of CO_2

emission efficiency and PCE. Section 5 further investigates the determinants of CO_2 emission efficiency and PCE. Section 6 concludes the paper.

2. Research Method

In the existing literature PCE and CO_2 emission intensity are the most popular indicators which are employed for CO_2 emission research. Considering that China is a developing country, both economic growth and environmental protection are important objectives of urban development. How to improve CO_2 emission efficiency, namely to produce more outputs with less CO_2 emissions, is more meaningful for greenhouse gas (GHG) abatement. However both PCE and CO_2 emission intensity are single factor measures of CO_2 emission efficiency. To further investigate the relationship between spatial relocation of economic activities and CO_2 emissions we construct a total factor CO_2 emission efficiency index (TFEEI) with the data envelopment analysis (DEA) approach. TFEEI takes into account of multiple factors and is hence a better measure of CO_2 emission efficiency.

Assume there are N cities (decision making unit, DMU) in China and each city has three types of factors, namely inputs, desirable outputs, and undesirable outputs. They are denoted by three vectors: $x \in R_{+}^{M}$, $\in R^{s_1}$, and $b \in R^{s_2}$, respectively. The production possibility set (PPS) can then be defined as follows:

$$P = \{(x, \ g, \ b) | x \geq X\lambda, \ g \leq G\lambda, \ b \geq B\lambda, \ \lambda \geq 0\} \quad (1)$$

where $\lambda \in R^{n}$ is a non-negative intensity vector, indicating the above definition corresponds to the constant returns to scale (CRS) technology. *X*, *G*, and *B* denote $(m \times n)$ matrix of inputs, $(s_1 \times n)$ matrix of desirable outputs, and $(s_2 \times n)$ matrix of undesirable outputs, respectively. Based on this PPS we can define a non-radial, non-oriented slack based measure (SBM) of environmental efficiency：

$$\rho^* = \min \frac{1-\frac{1}{m}\sum_{i=1}^{m}\frac{s_{i0}^x}{x_{i0}}}{1+\frac{1}{s_1+s_2}\left(\sum_{r=1}^{s_1}\frac{s_r^g}{g_{r0}}+\sum_{r=1}^{s_2}\frac{s_r^b}{b_{r0}}\right)} \quad (2)$$

s.t. $x_0 = X\lambda + s_0^x$

$g_0 = G\lambda - s_0^g$

$b_0 = B\lambda + s_0^b$

$s_0^x \geq 0$, $s_0^g \geq 0$, $s_0^b \geq 0$, $\lambda \geq 0$

where vectors $s_0^x \in R^m$ and $s_0^b \in R^K$ are slack variables of inputs and undesirable outputs, and represent excesses in inputs and undesirable outputs. Vector $s_0^g \in R^M$ is a slack variable of good outputs, and corresponds to shortages in good outputs. The objective value in equation (2) satisfies $0 < \rho^* < 1$. Suppose $(\rho^*, \lambda^*, s^{x*}, s^{g*}, s^{b*})$ is the optimal solution to above program, $\rho^* = 1$ indicate that all slack variables are 0, namely $s^{x*} = 0$, $s^{g*} = 0$, $s^{b*} = 0$, the DMU(x_0, g_0, b_0) is efficient in the presence of undesirable outputs. An inefficient DMU can be transformed into an efficient one by deleting excesses in inputs and bad outputs and shortages in good outputs. The TFEEI of undesirable outputs for the *ith* DMU at time *t* can be defined as:

$$\text{TFEEI}_{i,t} = 1 - \frac{s_{i,t}^b}{b_{i,t}} = 1 - AP_{i,t} \quad (3)$$

where *AP* denotes abatement potential which expresses the proportion that can be reduced by efficiency improvement toward the production frontier. Both values of TFEEI and *AP* are between 0 and 1. By solving equation (2) we can estimate CO_2 emission slacks and then calculate the CO_2 emission efficiency and abatement potentials for each city between 2002 and 2011. For the comparability across different periods, global DEA approach is applied in the calculation (Wang and Feng, 2015). In this study the input factors include capital, labor, and energy. The desirable output is gross city product (GCP) while the undesirable output is CO_2 emission.

3. Data and variables

By 2014, there were 288 cities at the PAA level in China. As most data for the cities of Lasa and Rikaze are not available, we use a panel dataset across 286 cites between 2002 and 2011. The data are drawn from official publications of the Chinese statistical agency. The two major sources are the *China City Statistical Yearbook* (NBSC, 2003-2012a) and *China Urban Construction Statistical Yearbook* (NBSC, 2003-2012b).

3.1 Energy consumption

Our estimation of CO_2 emissions for the cities is based on the energy consumption. Therefore we need to estimate energy consumption first. Similar to Glaeser and Kahn （2010）and Zheng et al. (2011), we consider four main sources of energy consumptions and CO_2 emissions. These are electricity, coal gas and liquefied petroleum gas, transportation, and heating. Data of electricity, coal gas and liquefied petroleum gas consumption in each city can be directly obtained from the annual *China City Statistical Yearbook.* In the northern Chinese cities, winter heating is provided by the centralized heating systems between November 15 and March 15. Coal is burned to provide winter heating by small and medium industrial boilers. *China Urban Construction Statistical Yearbook* provides data about central heating by cities. We adopt a 70% thermal efficiency rate according to *GB/T 15317-2009 Monitoring and testing for energy saving of coal fired industrial boilers.* Coal consumption for winter heating can be estimated with heat values, thermal efficiency, and average low calorific value (20908 kjoule/kg). As centralized heating systems are not provided in the southern Chinese cities, heating through electricity consumption is always used as a replacement.

Transportation accounts for a large share of energy consumption in cities. No energy consumption data of transportation is directly available at the city level. However the *China City Statistical Yearbook* provides detailed freight traffic (ton-kilometer) and passenger traffic (passenger-kilometer) of transport by road, railway, waterway, and aviation. Freight ton-kilometres (passenger-kilometres) refers to the sum of the product of the volume of transported cargo (passengers) multiplied by the transport distance. It is an important indicator to reflect the achievement of the transportation industry. This is an important indicator to show the total results of the transport and to serve as the main basic data for calculating the efficiency, labour productivity and unit cost of transport. Following Li et al. (2013), assuming that energy consumptions of different transportation modes are proportionate to each other. Li et al. (2013) derived sets of ratios between different transportation modes, which are applied directly in this paper. The *China Statistic Yearbook* provides data of all types of energy consumption by the transportation sector. Then we can calculate the energy intensities of each transportation mode. With city level freight traffic, passenger traffic and energy intensities we can estimate the energy consumption by the transportation sector in each city. Consumption of all these four type energies is converted using the standard conversion factors in *China Energy Statistical Yearbook.*

3.2 CO_2 emissions

CO_2 emissions are generated by the consumption of energy in cities. In line with the estimation of energy consumption, the formula to estimate CO_2 emissions can be presented as follows:

$$Emissions_{co2} = \delta_1 * Transportation + \delta_2 * Electricity + \delta_3 * Heating + \delta_4 * Fuel \quad (4)$$

CO_2 emissions from fuel and heating can be computed directly by using the conversion factors from IPCC2006 and the data of coal gas, liquefied petroleum gas, and heating coal consumption. The estimation of CO_2 emissions by the transportation sector is similar to the estimation of energy consumption and all conversion factors are drawn from IPCC2006.

The computation of CO_2 emissions from electricity usage is more complicated than that from other energy consumption. Chinese cities differ greatly with respect to their natural resources that are used to produce electricity. Coal-fired power plants may have a higher emission factor than power plants that use renewable energies. Therefore the electricity conversion factor differs across regions in China. China's state power grid consists of six regional power grids. In recent years the baseline emission factors for each regional power grid were estimated and reported by the National Coordination Committee on Climate Change. As noted by Glaeser and Kahn (2010), electricity usage in the same regional power grid is substitutable. For this reason we use regional baseline emission factors to convert electricity consumption into CO_2 emissions.

3.3 Other Variables

(1) Output and labor

Nominal gross city product (GCP) is deflated by a province-specific GRP deflator with 2002 as the base year. In the absence of working hour data at the PAA level, following most studies, we use the number of employees as a proxy for the labor force.

(2) Capital stock

The capital stock of each city is estimated using annual fixed investment data with the perpetual inventory method. Data on fixed investment is available for all cities between 2002 and 2011. However the investment deflators have to be constructed at the provincial level. Therefore data on fixed investment is deflated using province-specific investment deflators with 2002 as the base year. As to the depreciation rate, Henderson et al.（2007） adopts a depreciation rate of 4% for all provinces, while Brandt et al.

(2013）uses 7%. We adopt a province-specific depreciation rate derived by Wu (2009). Then, the initial value of the capital stock for each city in 2002 can be constructed as

$$K_j = \frac{I_j}{\delta j + g_j} \tag{5}$$

where I denote the real value of fixed investment in 2002, δ is the depreciation rate and g_j is the average growth rate of real fixed investment between 2002 and 2011 for city j. With the initial value of capital stock, depreciation rate, and real fixed investment data; we can calculate capital stock for each city during 2002-2011 period using the following formula: $K_{j,t} = K_{j,t-1}(1 - \delta j) + I_{j,t}$.

(3) Population

In China, the actual residential population data is not available for most years in PAA city levels. We find that the *China City Statistical Yearbook* provides registered population for all cities over the period 2002-2011, and the *China Statistic Yearbook for Regional Economy* provides both actual residential population and registered population after 2010. The fifth population census also provides actual residential population and registered population data for 2000. We find that the two variables are quite the same except for a few megacities. The actual residential population number is highly correlated with registered one. For example, the correlation coefficients of the two are 0.991 and 0.924 in 2000 and 2010 respectively. Therefore, we use registered population number in our analysis. Furthermore, we also construct a new data set for actual residential population number of 2002-2011 by assuming that the growth rate of the ratio between residential population and registered population remains the same. The results using constructed actual residential population are also provided in the appendix for the purpose of robustness checks. Table 1 shows the descriptive statistics for all the input and output variables, and reveals substantial heterogeneity across cities.

Table 1 Descriptive statistics of input and output variables

Variables	Samples	Mean	S. D.	Min	Max
Labor（10,000 workers）	2860	42.8	81.4	4.9	1045.0
Capital stock（100 million Yuan）	2860	1105.0	2823.6	1.9	43255.7
Energy consumption (10,000 TSCE）	2860	200.8	357.3	0.8	4545. 7
GCP（100 million Yuan）	2860	441.1	1024.9	4.5	14660.5
CO_2 emissions（10,000 tons）	2860	881.4	1435.4	18	16593.9

Source: Authors' own calculation.

4. Preliminary analysis of CO_2 emissions in Chinese cities

For the purpose of comparison, we use both TFEEI and PCE in our analysis. Table 2 shows the estimated average TFEEI and PCE values of the top and bottom 10 cities during 2002-2011. In our sample period, Jiayuguan is the 'dirtiest' city with an average PCE of 30.17 tons per year, while Longnan is the 'cleanest' city with an average PCE as of 0.53 tons per year. The average emissions of Jiayuguan are approximately 56 times that of Longnan. In top ten PCE cities, all are specialized in heavy or chemical industries which are highly energy-intensive. Our city level sample shows much more disparities in PCE than provincial samples used in other studies (such as Du et al., 2012).

The rank of TFEEI is quite different from that of PCE. Erdos is the most efficient city in CO_2 emissions in terms of TFEEI (the highest value) and Fuxin has the lowest TFEEI value (0.12) in our sample. According to our DEA estimation Erdos lies on the frontiers for 6 times out of ten. This makes Erdos the most efficient city in terms of CO_2 emissions with an average score of 0.946 in our sample period. Changde and Dongguan rank second and third respectively. However, the average TFEEI value for all cities is only 0.342, which implies that there is great potential in CO_2 abatement.

Table 2 Top and bottom ten cities in terms of TFEEI and PCE, 2002-2011

city	PCE	Rank in PCE	city	TFEEI	Rank in TFEEI
Top ten performers					
Jiayuguan	30.17	1	Erdos	0.831	1
Daqing	24.83	2	Dongguan	0.759	2
Shizuishan	22.81	3	Changde	0.706	3
Wuhai	21.46	4	Dongying	0.682	4
Erdos	19.79	5	Yuxi	0.680	5
Jiaozuo	17.75	6	Putian	0.665	6
Jinchang	16.94	7	Daqing	0.659	7
Sanmenxia	15.12	8	Maoming	0.640	8
Liaoyang	14.88	9	Bozhou	0.623	9
Baiyin	14.73	10	Yan'an	0.622	10
Bottom Ten performers					
Zhaotong	1.46	277	Kaifeng	0.158	277
Anshun	1.44	278	Huangshi	0.157	278
Lincang	1.33	279	Hengyang	0.154	279
Suining	1.23	280	Jiaozuo	0.153	280
Bozhou	1.04	281	Guangyuan	0.137	281
Suizhou	0.87	282	Hanzhong	0.134	282
Baoshan	0.82	283	Mudanjiang	0.133	283
Bazhong	0.72	284	Jixi	0.130	284
Shangluo	0.71	285	Hegang	0.125	285
Longnan	0.53	286	Fuxin	0.120	286

Source: Authors' own calculation.

Since China is a large country with diverse regions, following most studies, we divide our samples into four city groups according to their regional locations, namely the eastern cities (87), the central cities (81), the western cities (84) and the northeast cities (34). We plot the average PCE and TFEEI from 2002-2011 by regions in Figure 2. The northeastern cities have the highest PCE in our sample period, followed by the eastern and the western cities, while the central cities have the lowest emissions in most years. However, the eastern cities are much more efficient in CO_2 emissions than other cities, while the northeastern cities are the least efficient ones in the four city groups.

All four regions have a sharp PCE increase from 2002 to 2011. The western cities have the largest increase of about 137% (from 3.84 tons per capita (tpc) in 2002 to 9.12 tpc in 2011), while the northeastern cities have the lowest increase of 57.8% (from 6.81 tpc in 2002 to 10.74 tpc in 2011). However the TFEEI values of the eastern, the central and the western cities experienced a significant U-shape change during 2002-2011 with a turning point in 2004 or 2005, which may be the result of policy differences between the 10th FYP and the 11th FYP. The northeastern cities have the greatest TFEEI improvement of 0.217 and the western cities have the lowest TFEEI increase of 0.132.

Of all four regions, the northeastern region is quite different from the other three regions. Since it features the coldest winters in China winter heating is one major source of its CO_2 emissions. According to our estimation CO_2 emissions from heat supply account for approximately one third of total emissions in the northeastern cities, while this value is only 9%，6% and 14% in the eastern, the central and the western cities respectively. At the same time the northeastern region has many state-owned heavy and chemical firms which use outdated technology. These may be the key reasons behind the lower CO_2 emission efficiency in the northeast cities.

Figure 3 shows the kernel density distribution of PCE and TFEEI in selected years. The decline of distribution peak shows that PCE follows a divergence trend from 2002 to 2011. However TFEEI initially shows a divergent trend during 2002-2006 and then tends to converge during 2006-2011. The kernel densities also show that the mean and variance of both PCE and TFEEI have maintained an increasing trend since 2002.

Kernel density distribution plot is a good approach to show the current distribution of variables in particular. However, it cannot forecast the future trend of variables. To examine the long-run trend of spatial distribution of CO_2 emissions across Chinese cities, we adopted a continuous dynamic distribution approach developed by Johnson (2005). If we use $f_t(x)$ to denote the distribution density function of variable *x* at time t. Assuming that the process of the evolution of the distribution is time-invariant and first-order, the distribution density function of variable *x* at t+τ (τ>0) can be described as $f_{t+\tau}(z) = \int_0^\infty g_\tau(z|x) f_{t+\tau}(x) dx$, where $g_\tau(z|x)$ is the conditional density of *z* on *x*.

Thus the ergodic distribution (denote as $f_\infty(z)$) can be estimated with $f_\infty(z) = \int_0^\infty g_\tau(z|x) f_\infty(x) dx$ (see Johnson, 2005; and Juessen, 2009 for further details). Because the continuous state space approach estimates the relative position change, the values of PCE and TFEEI of each city are divided by the yearly average value to get relative PCE and relative TFEEI. In this paper, we use adaptive kernel method with flexible bandwidth and annual transitions.

Figures 4 and 5 plot the estimated ergodic distribution of relative PCE and TFEEI respectively. We observe that the distribution of relative PCE is multimodal with four modes at its mean value (u), 1.8u, 4u and 5u. However, the mode at mean value has much high density than the other three modes. This result implies that PCE across Chinese cities converges to clubs obviously in the long run. But most cities converge at the mean value. Figure 5 however shows that the ergodic distribution of relative TFEEI is bimodal with modes at 0.75 mean value (0.75δ) and 1.5 δ respectively. The convergence clubs of relative PCE and TFEEI have important policy implications. Because the Chinese government allocates reduction targets to different regions, thus the reduction targets should be allocated according to their corresponding PCE and TFEEI distribution and long run trends. For example, the cities converge to high PCE and low TFEEI should be assigned tougher reduction targets in designing CO_2 reduction allocation plan.

5. The determinants of urban CO_2 emissions

Chinese cities differ greatly in PCE as it is shown in Table 1. To investigate the driving forces of CO_2 emissions we consider the following econometric model:

$$Emissions_{i,t} = \varphi_0 + \varphi_1 \ln(Income_{i,t}) + \varphi_2 \ln(Income_{i,t})^2 + \varphi_3 \ln(Energyintensity_{i,t}) + \varphi_4 \ln(Size_{i,t}) + Z_{i,t}\beta + \eta_i + \varepsilon_{i,t} \quad (6)$$

where $Emissions_{i,t}$ is either TFEEI or PCE of city i in year t, and $\ln(Income_{i,t})$ is the natural logarithm of per capita GCP in real terms (based on 2002 prices). $\ln(Size_{i,t})$ represents the natural logarithm of city population size; $\ln(Energyintensity_{i,t})$ denotes natural logarithm of energy intensity. $Z_{i,t}$ denotes a vector of exogenous variables, including capital intensity, industry structure, population density, trade openness, and foreign direct investment over output ratio; φ_0 is a constant item, φ_1, φ_2, and φ_3 are scalars to be estimated and β is a vector of parameters. η_i is city fixed effects and $\varepsilon_{i,t}$ is the error term. As TFEEI is bounded between 0 and 1, we use a doubly censored Tobit model. As to the PCE regression, we use Hausman test to determine whether the fixed effect (FE) estimators or the random effects (RE) estimators are preferred. The independent variables are constructed as follows:

Income denoted as $\ln(Income)$: The relationship between CO_2 emissions and income is found to be non-linear and follows an inverted U-shape relationship known as the environmental Kuznets curve (EKC) (Stern, 2014). This suggests that CO_2 emissions first rise with income up to some point and then declines after some threshold level is reached. Considering that non-linear relationship may also exist between TFEEI and income, the quadratic term of income is included in both PCE and TFEEI regression.

Energy intensity denoted as $\ln(Energyintensity)$: Following Auffhammer and Carson (2008) and Du et al. (2012) we use natural logarithm of energy intensity (energy consumption per unit GCP) to proxy for heterogeneity and variation in technological progress across cities.

City size denoted as Ln(*size*): City size may affect CO_2 emissions through transportation and public facility sharing. However there is no consensus on the effect of city size on CO_2 emissions (Borck and Pflüger, 2013).

Urban density denoted as ln(*density*): The natural logarithm of urban population per square kilometer in a city which is a proxy for urban density. As is discussed in section 1, high urban population density may reduce energy consumption and hence CO_2 emissions (Glaeser and Kahn, 2010; Qin and Wu, 2015). It is also argued that denser cities may be less green because of relocation effects on firm and labor (Gaigne´ et al., 2012; Oliveira et al., 2014). Therefore the effect of urban density on PCE is ambiguous.

Industry structure denoted as *Sec_Share*): The industrial sectors have different energy consumption and CO_2 emissions. For example, secondary industry usually produces more CO_2 emissions than agriculture and tertiary industries. Therefore the output shares of secondary industries are included to capture possible variations in industry compositions across cities over time.

Capital intensity denoted as ln(*K/L*): This variable is measured as the natural logarithm of the capital to labor ratio. It represents another structural attribute in production composition. Capital intensive industries are always associated with high energy consumption and CO_2 emissions. Therefore the effects of capital intensity on CO_2 emissions are expected to be positive.

Trade openness denoted as (*Openness*): It is measured by the ratio of total value of foreign trade over GCP in a city. Although the impact of trade on CO_2 emissions is widely discussed in the literature (Jalil and Mahmud 2009; Halicioglu, 2009; Ren, et al., 2014), there is no consensus on the relationship between foreign trade and PCE. Foreign trade is an important channel for developing countries to obtain sophisticated technology from developed countries through technology spillover effects. However the export of energy intensive products may increase domestic CO_2 emissions. Furthermore the final results in a specific country depend on both factor endowment and pollution haven effect, which vary in terms of the level of development across the countries.

Foreign direct investment denoted as (*FDIY*): It is measured by the ratio of actually utilized FDI over GCP in a city. The effect of FDI on CO_2 emissions is related to the debate about "pollution haven" hypothesis. It is argued that foreign firms from developed countries which maintain stringent environmental regulations are attracted to developing countries with weak environment regulations (Kellenberg, 2009). However others studies, like Yang et al. (2012), argue that stringent environmental regulation may induce innovation rather than firm relocation. In fact the evidence for "pollution haven" effect is quite mixed. For example, Dean et al. (2009) found that firms funded by investors from Hong Kong, Macao, and Taiwan (HMT) are attracted by weak environmental standards; in contrast foreign investors outside the HMT regions are not significantly attracted by weak standards.

To test the regional differences we also included heat supply dummy variables and three regional dummies; namely central, west, and northeast, in the TFEEI regressions. In the literature, it is argued that environmental regulations and policies differ greatly between the 10^{th} FYP (2001-2005) and the 11^{th} FYP period (2006-2010) (Wei et al., 2009; Shi et al., 2010; Yeh et al., 2010; Zhang and Choi, 2013). In the 10^{th} FYP period, China experienced significant environment deterioration because of the development of heavy and chemical industries (Chen and Golley, 2014). However the Chinese government imposed stringent regulations in the 11^{th} FYP period and thereafter. Therefore we run regressions in two sub-periods, 2002-2005 and 2006-2011, respectively. Table 3 shows the estimation results. Hausman test shows that the FE estimators are preferred in all three models for the PCE regressions.

Table 3 Estimation results of TFEEI and PCE regressions

Dependent variables	TFEEI			PCE		
Sample	All	10^{th} FYP	11^{th} FYP	All	10^{th} FYP	11^{th} FYP
	(1)	(2)	(3)	(4)	(5)	(6)
Ln(*income*)	0.0324***	0.0653***	0.0024	0.5240***	0.3700***	0.6400***
	(0.0068)	(0.0095)	(0.0102)	(0.0209)	(0.0379)	(0.0355)
Ln(*income*)^2	0.0278***	0.0293***	0.0309***	-0.0141**	0.0067	-0.0347***
	(0.0029)	(0.0053)	(0.0040)	(0.0067)	(0.0145)	(0.0114)
$\ln(Energyintensity)$	-0.0022***	-0.0058***	-0.0025***	0.0618***	0.0752***	0.0667***
	(0.0008)	(0.0018)	(0.0009)	(0.0019)	(0.0049)	(0.0022)
Ln(*size*)	0.0256***	0.0247***	0.0250***	-0.214***	-0.312***	-0.371***
	(0.0038)	(0.0062)	(0.0046)	(0.0326)	(0.0499)	(0.0496)
Ln(*density*)	-0.0196***	-0.0239***	-0.0153***	0.0307*	-0.0003	0.0746***
	(0.0032)	(0.0052)	(0.0039)	(0.0183)	(0.0256)	(0.0281)
Ln(*K/L*)	0.0800***	0.0330***	0.1360***	0.0241**	0.1520***	-0.1040***
	(0.0046)	(0.0076)	(0.0072)	(0.0119)	(0.0216)	(0.0203)
Sec_Share	-0.0231	-0.0579	-0.0040	0.4410***	0.2280	-0.1480
	(0.0271)	(0.0468)	(0.0320)	(0.0882)	(0.141)	(0.120)
Ln(*Openness*)	-0.0070***	-0.0040*	-0.0105***	-0.0051	-0.0136***	0.0125**
	(0.0017)	(0.0024)	(0.0026)	(0.0033)	(0.0051)	(0.0061)
ln*FDIY*	0.0030***	-0.0009	0.0050***	0.0029*	0.0064***	0.0052**
	(0.0009)	(0.0016)	(0.0011)	(0.0017)	(0.0022)	(0.0023)
heatsupply	-0.0664***	-0.0882***	-0.0560***			
	(0.0059)	(0.0098)	(0.0072)			
central	-0.0309***	-0.0307**	-0.0420***			
	(0.0072)	(0.0122)	(0.0087)			
west	-0.0194**	-0.0112	-0.0375***			
	(0.0078)	(0.0132)	(0.0094)			
northeast	-0.0547***	-0.0626***	-0.0505***			
	(0.0096)	(0.0165)	(0.0114)			
Constat	0.1160***	0.3020***	-0.0886**	1.4200***	1.7670***	2.5390***
	(0.0294)	(0.0487)	(0.0391)	(0.2030)	(0.2980)	(0.2870)
Sigma/Constant	0.1290***	0.1370***	0.1180***			
	(0.0017)	(0.0029)	(0.0020)			
Log likelihood	1791.6	672.2	1232.2			
Hausman Test				147.57	131.57	92.66
Adj. R^2				0.7216	0.5115	0.6872
Estimation method	Tobit	Tobit	Tobit	FE	FE	FE
Observations	2860	1144	1716	2860	1144	1716

Notes: (1) Standard errors in parentheses; (2) ***, **, * denote that the variables are statistically significant at the 1, 5 and 10% levels, respectively.

The coefficients of the quadratic term of income in all three TFEEI regressions (columns 1-3) are significantly positive, implying that the U-shaped relationship between TFEEI and income exists. This suggests TFEEI first declines and then increases as the income rises. The result of the PCE regression for all samples (column 4) also supports the existence of the inverted U-shaped relationship between PCE and income. However in the two sub-sample regressions, the EKC hypothesis is only supported in the 11^{th} FYP regression (column 6). In view of the policy changes in the two sub-periods, this may suggest that the realization of EKC is not a spontaneous economic process, but depends upon exogenous policy interventions. However the estimated turning point level of income is far away from the highest income in our sample. This result is similar to the findings by Auffhammer and Carson (2008), and Jalil and Mahmud (2009).

The coefficients of energy intensity are significantly negative in the TFEEI regressions but positive in the PCE regressions. This implies that high energy intensity may reduce TFEEI but raise PCE. This result is intuitive and expected. We also found that city size is significantly positively associated with TFEEI but negatively associated with PCE suggesting that large cities not only have lower PCE, but also tend to be more efficient in CO_2 emissions than small cities. If this is the truth the migration restrictions in large cities may deteriorate CO_2 emission efficiency.

However population density is negatively correlated with TFEEI but positively correlated with PCE in columns 4 and 5, meaning that denser cities have high PCE and may be less efficient in CO_2 emissions. We find that denser cities tend be less green in terms of CO_2 emissions. Our results differ from those of Glaeser and Kahn (2010) and Zheng et al. (2011), which only take account of household CO_2 emissions.

The coefficients of capital intensity in all three TFEEI regressions are positive and significant at the 1% level, meaning that high capital intensity cities have high TFEEI. However the coefficients of capital intensity in two sub-period PCE regressions have different sign. One possible explanation is that the industry transformation and upgrading policy adopted at the beginning of the 11^{th} FYP has been effective and pollutions have since been reduced in many capital intensity cities. In fact it was reported in "*China's Energy Policy (2012)*" white paper that the national energy intensity was reduced by 20.7% during the 11^{th} FYP period. Our calculation indicates a 22.3％ reduction in energy intensity and a 20.6% reduction in CO_2 emission intensity in the cities in the same period.

The coefficient of the share of secondary industry is only positive and significant in PCE regressions (column 4) but insignificant in TFEEI regressions. These results may suggest that a relatively large secondary industry is associated with high PCE. TFEEI is negatively associated with trade openness. However the coefficients of trade openness in two sub-period PCE regressions have different sign, which may suggest that the trade structure has changed in the two periods. We also find strong positive impacts of FDI on both TFEEI and PCE. This may suggest that foreign investment may not only boost economic growth but also increase CO_2 emissions.

Cities with heat supply have significant low TFEEI values which are intuitive and expected. Cold winter does not contribute to income improvement but creates additional energy uses and CO_2 emissions. The coefficients of three regional dummy variables are all negative and most of them are significant at high levels. This confirms our concern that regional development program may deteriorate CO_2 emissions efficiency. With the execution of regional development program, the fixed investment share of the eastern cities declined from 57.5% in 2005 to 48.5% in 2011. Yet the output share of the eastern cities just slightly declined from 61.3% to 59.9% in the same period. Considering that the eastern cities have higher TFEEI than the central and the western cities, the Western Development Program and Rising of Central China Program seem to accelerate economic growth in low TFEEI areas. Therefore, the preferential development policy in the western and the central regions may deteriorate CO_2 emission efficiency as a whole. Moreover, the Northeast Revitalization Program is encouraging economic activities in high PCE and low TFEEI regions. These results show that regional development may have significant environmental consequences.

Some authors such as Auffhammer and Carson (2008) and Du et al. (2012) presented forecasts of China's CO_2 emissions by using provincial panel data. Our results show that their predictions should be treated with caution. China implemented very different environmental policies in different periods. This has resulted in significant structural change in CO_2 emissions. Neglecting these policy differences may lead to biased forecasting results. For robustness, we also use actual residential population to replace reregistered population in our regression. The results are quite the same because of the high correlation between the two indices.

6. Conclusion and policy implications

Rapid urbanization was one of the important drivers of China's economic growth during the past three decades. However China's urbanization may also have a significant influence on GHG emissions. Past research investigated the relationship between urban development and CO_2 emissions with time series data, provincial panel data and small samples of cities (such as Zheng et al. 2011). This article constructed a full panel data set of 286 cities over the period 2002-2011 to examine the relationship between urban development and CO_2 emissions in Chinese cities. As a developing country both economic growth and environmental protection are important objectives in China's urban development process. Therefore we construct a TFEEI index with a DEA approach, which can account for both objectives to measure urban CO_2 emissions efficiency. The key results and possible policy implications are summarized as follows.

Accompanied with rapid economic growth, PCE in all cities increased significantly from 2002 to 2011. However both TFEEI and PCE differ greatly across cities and have no tendency of convergence. We also find a U-shaped evolution trend of TFEEI in our sample period which may be the result of policy differences between the 10^{th} and the 11^{th} FYP.

In the four Chinese regions, the northwestern cities have the highest PCE but the lowest efficiency due to cold winters and presence of state-owned heavy industry. Yet the eastern cities have the highest TFEEI and second highest PCE. Currently China is pursuing strong regional development programs to reduce regional disparity. However, the Western Development Program and the Rising of Central China Program are likely to bolster economic activities in low TFEEI regions while the Northeast Revitalization Program is encouraging economic activity in both high PCE and TFEEI regions. Thus these regional development programs may have significant environmental consequences.

Our econometric results show that large cities have significantly higher TFEEI scores and lower PCE than small ones. China has implemented strict restrictions on rural-urban migration into large cities for decades through the household registration system. The positive news is that the Chinese government has moved to relax gradually these restrictions in recent years. Unlike their counterparts in developed economies China's large cities are more attractive to people than small ones. The development of more large cities will be helpful to China's CO_2 abatement.

Our findings support the hypothesis of the inverted U-shaped relationship between PCE and economic development. However this result may depend upon active governmental policy interventions according to our analysis of sub-period samples. Considering that the Chinese central government commits to cap aggregate CO_2 emissions before 2030, stringent intervention policies are necessary for the abatement of CO_2 emissions. This result also suggests that policy differences have to be considered in order to predict China's CO_2 emissions.

References

Auffhammer, M., and Carson, R.T., 2008. "Forecasting the path of China's CO_2 emissions using province level information." *Journal of Environmental Economics and Management*, 55 (3): 229–247.

Borck, R., and Pflüger, M. 2013. "Green cities? Urbanization, trade and the environment." Paper presented in Annual Conference 2013: Competition Policy and Regulation in a Global Economic Order (No. 79763). Duesseldorf,

Brandt, L., Tombe, T. and Zhu, X. 2013. "Factor market distortions across time, space and sectors in China." *Review of Economic Dynamics*, 16(1):39-58.

Chen, S., and Golley, J. 2014. "'Green' productivity growth in China's industrial economy." *Energy Economics*, 44:89-98.

Dean, J. M., Lovely, M. E. and Wang, H. 2009. "Are foreign investors attracted to weak environmental regulations? Evaluating the evidence from China." *Journal of Development Economics*, 90(1):1-13.

Dhakal S. 2009. "Urban energy use and carbon emissions from cities in China and policy implications." *Energy Policy*, 37(11): 4208-4219.

Du, L., Wei, C., and Cai, S. 2012. "Economic development and carbon dioxide emissions in China: Provincial panel data analysis." *China Economic Review*, 23(2): 371-384.Gaigné, C., Riou, S., and Thisse, J. F. 2012. "Are compact cities environmentally friendly?" *Journal of Urban Economics*, 72(2): 123-136.

General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China (AQSIQ) (2008) GB/T 15317-2009 Monitoring and testing for energy saving of coal fired industrial boilers.

Glaeser, E. L. and Kahn, M. E. 2010. "The greenness of cities: carbon dioxide emissions and urban development." *Journal of Urban Economics*, 67(3): 404-418.

Halicioglu, F. 2009. "An econometric study of CO_2 emissions, energy consumption, income and foreign trade in Turkey." *Energy Policy*, 37(3): 1156-1164.

Henderson, D. J., Tochkov, K. and Badunenko, O. 2007. "A drive up the capital coast? Contributions to post-reform growth across Chinese provinces." *Journal of Macroeconomics*, 29(3): 569-594.

Hu, J. L., and Wang, S. C. 2006. "Total-factor energy efficiency of regions in China." *Energy policy*, 34(17): 3206-3217.

Jalil, A., and Mahmud, S. F. 2009. "Environment Kuznets curve for CO 2 emissions: a cointegration analysis for China." *Energy Policy*, 37(12): 5167-5172.

Johnson, P. A. (2005). "A continuous state space approach to 'Convergence by Parts'." *Economics Letters*, 86(3): 317-321.

Juessen, F. (2008). "A distribution dynamics approach to regional GDP convergence in unified Germany." *Empirical Economics*, 37(3): 627-652.

Kahn, Matthew E., 2006 "*Green cities: urban growth and the environment*." Washington, DC: Brookings Institution Press.

Kellenberg, D. K. 2009. "An empirical investigation of the pollution haven effect with strategic environment and trade policy." *Journal of International Economics*, 78(2): 242-255.

Li, H., Lu, Y., Zhang, J., and Wang, T. 2013. "Trends in road freight transportation carbon dioxide emissions and policies in China." *Energy Policy*, 57(C): 99-106.

NBSC(National Bureau of Statistics of China), 2003-2012b. "*China Urban Construction Statistical Yearbook.*" Beijing: China Statistic Press.

NBSC, 2012a. "*China Energy Statistical Yearbook*," Beijing: China Statistic Press.

NBSC, 2012b. "*China Statistical Yearbook.*" Beijing: China Statistic Press.

NBSC, 2003-2012a. "*China City Statistical Yearbook*." Beijing: China Statistic Press.

Oliveira, E. A., Andrade Jr, J. S., and Makse, H. A. 2014. “Large cities are less green.” *Scientific reports*, *4*.

Qin B. and Wu J. 2015. “Does urban concentration mitigates CO_2 emissions? Evidence from China 1998–2008.” *China Economic Review*, 35: 220–231.

Ren, S., Yuan, B., Ma, X., and Chen, X. 2014. “International trade, FDI (foreign direct investment) and embodied CO_2 emissions: a case study of Chinas industrial sectors.” *China Economic Review*, 28(C):123-134.

Shi, G. M., Bi, J., and Wang, J. N. 2010. “Chinese regional industrial energy efficiency evaluation based on a DEA model of fixing non-energy inputs.” *Energy Policy*, 38(10): 6172-6179.

Stern, D. I. 2014. “The environmental Kuznets curve: A primer.” Centre for Climate Economics & Policy, Crawford School of Public Policy, the Australian National University working paper.

Wang, Z., and Feng, C. 2015. “Sources of production inefficiency and productivity growth in China: A global data envelopment analysis.” *Energy Economics*, 49: 380-389.

Wei, C., Ni, J., and Du, L. 2012. Regional allocation of carbon dioxide abatement in China. *China Economic Review*, 23(3): 552-565.

Wu, Y. 2009. “China's capital stock series by region and sector.” The University of Western Australia Discussion Paper 09.02.

Yang, C. H. Tseng, Y. H. and Chen, C. P. 2012. “Environmental regulations, induced R&D, and productivity: Evidence from Taiwan's manufacturing industries.” *Resource and Energy Economics*, 34(4): 514-532.

Yeh, T. L., Chen, T. Y., and Lai, P. Y. 2010. “A comparative study of energy utilization efficiency between Taiwan and China.” *Energy policy*, 38(5): 2386-2394.

Zhang, N., and Choi, Y. 2013. "Environmental energy efficiency of China's regional economies: A non-oriented slacks-based measure analysis." *The Social Science Journal*, 50(2): 225-234.

Zheng, S., Wang, R., Glaeser, E. L. and Kahn, M. E. 2011. "The greenness of China: household carbon dioxide emissions and urban development." *Journal of economic geography*, 11(5):761-792.

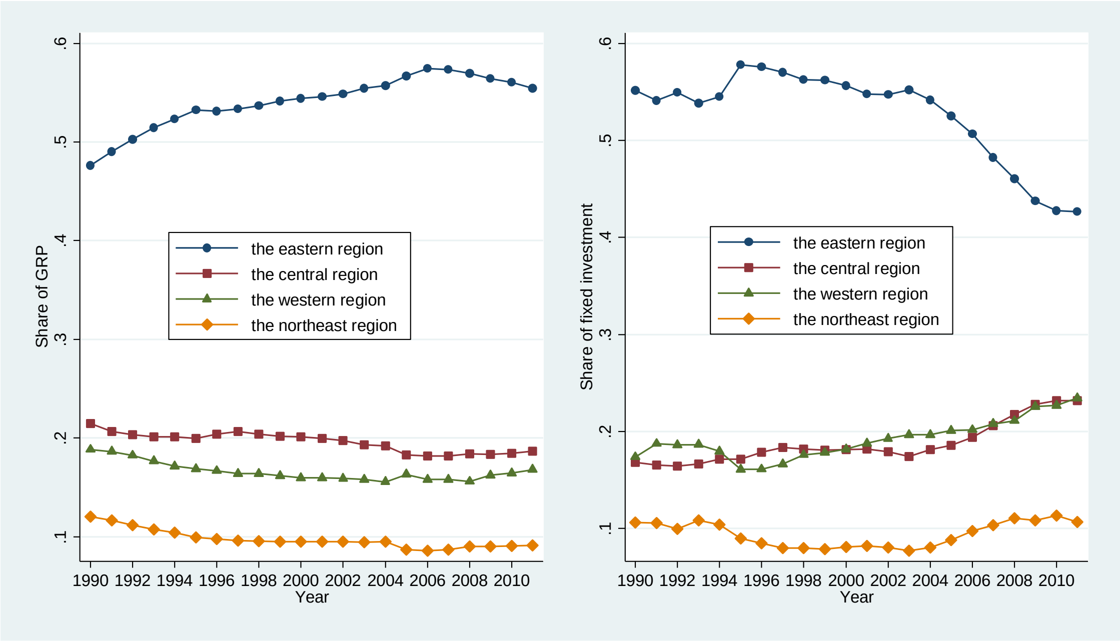

Figure 1 The evolution of GRP and fixed investment shares, 1990-2011
Source: Authors' calculation.

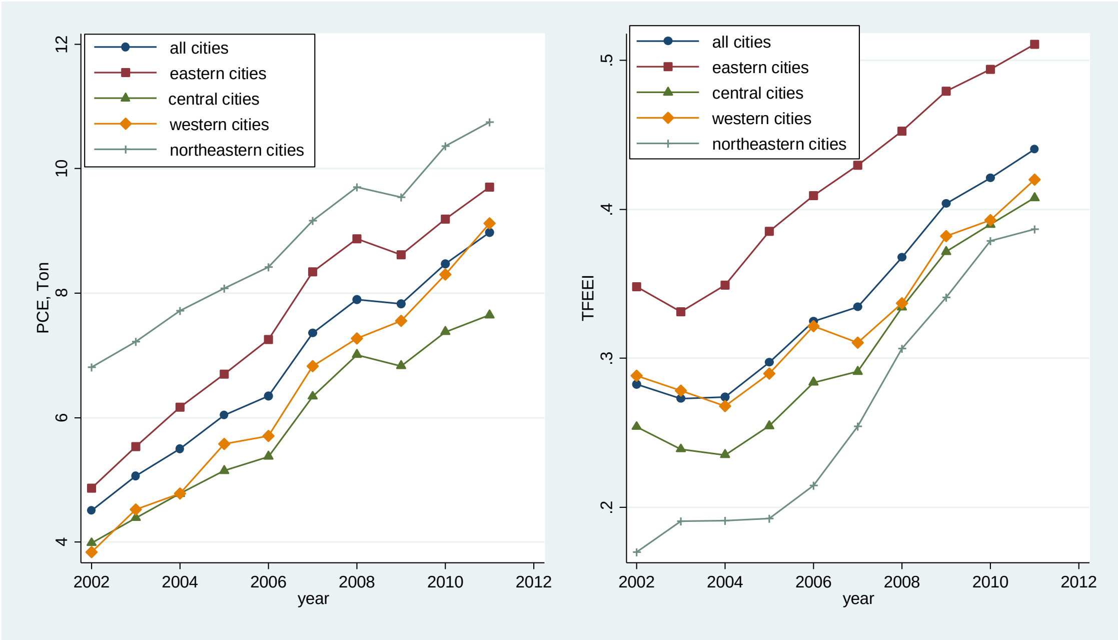

Figure 2 PCE and TFEEI by region, 2002-2011
Source: Authors' calculation.

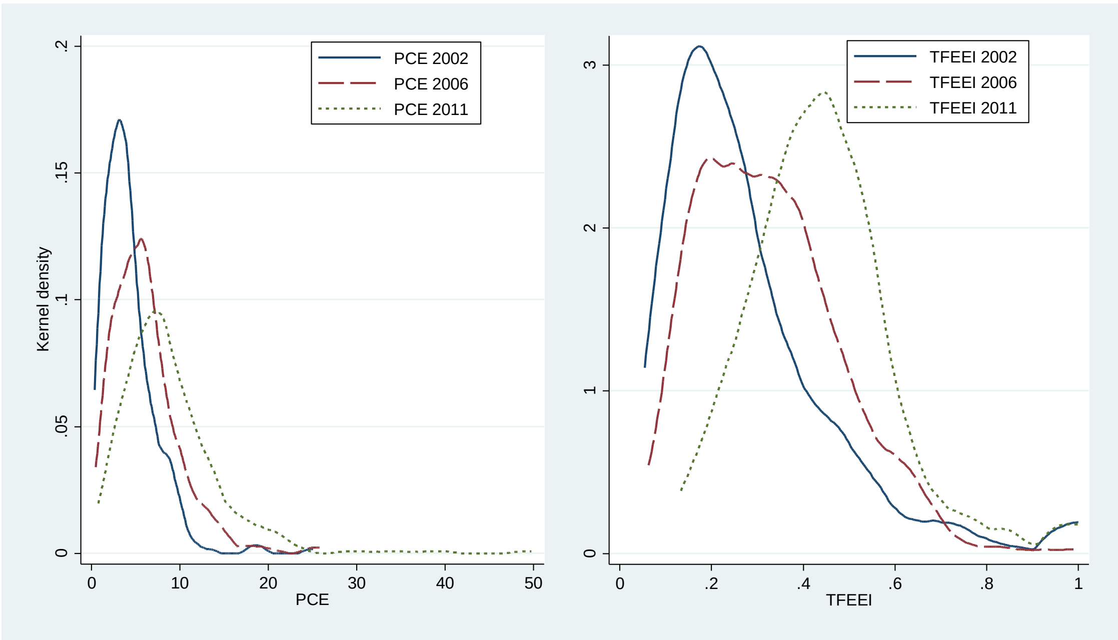

Figure 3 The kernel density of PCE and TFEEI
Source: Authors' calculation.

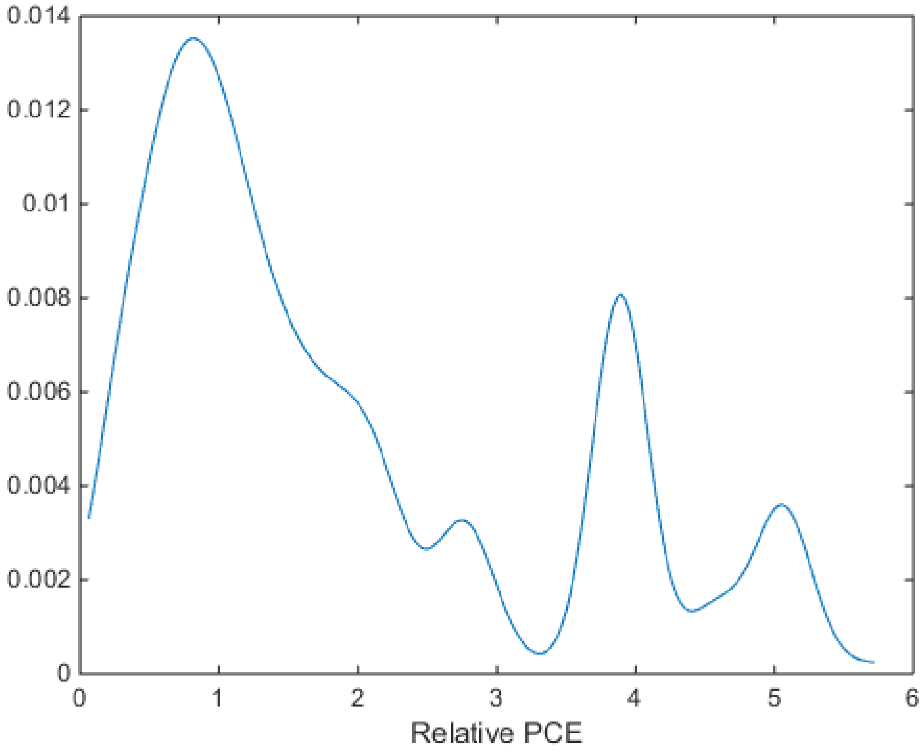

Figure 4 The ergodic distribution of relative PCE
Source: Authors' calculation.

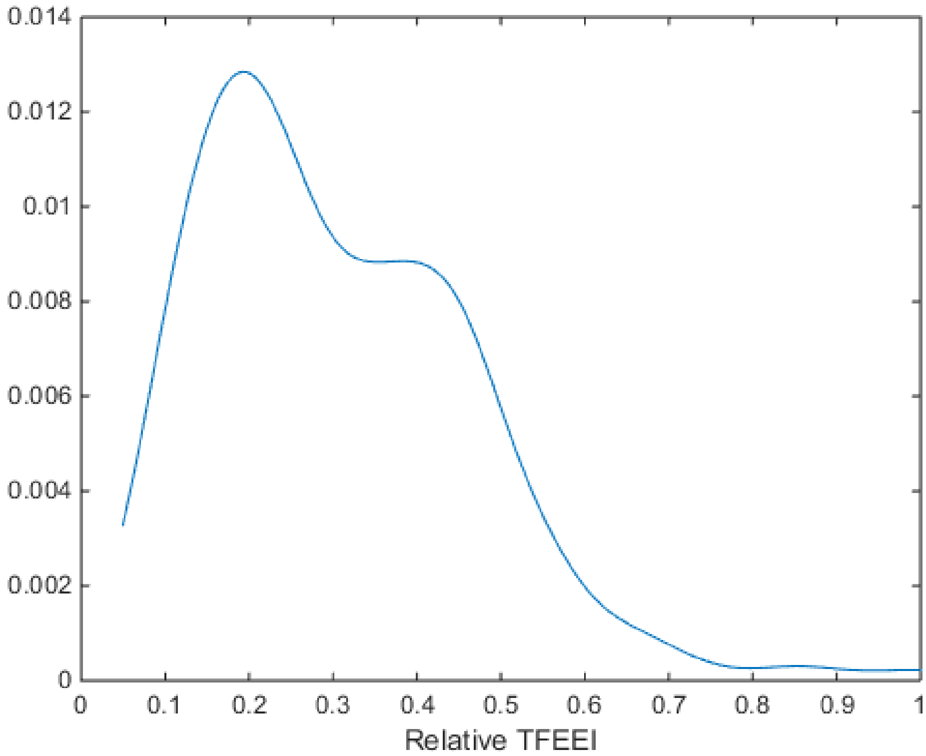

Figure 5 The ergodic distribution of relative TFEEI
Source: Authors' calculation.

Appendix:

Table 3 Estimation results of TFEEI and PCE regressions (actual residential population)

Dependent variables	TFEEI			PCE		
Sample	All	10th FYP	11th FYP	All	10th FYP	11th FYP
	(1)	(2)	(3)	(4)	(5)	(6)
Ln(*income*)	0.0313***	0.0642***	0.0022	0.5253***	0.4011***	0.6567***
	(0.00746)	(0.0113)	(0.0107)	(0.0207)	(0.0384)	(0.0348)
Ln(*income*)^2	0.0272***	0.0291***	0.0293***	-0.0410***	-0.0137	-0.0574***
	(0.0036)	(0.0081)	(0.0051)	(0.00650)	(0.0147)	(0.0111)
$\ln(Energyintensity)$	-0.0024**	-0.0061***	-0.0026*	0.0603***	0.0700***	0.0631***
	(0.0011)	(0.0020)	(0.0014)	(0.00189)	(0.0050)	(0.0022)
Ln(*size*)	0.0196***	0.0170**	0.0217***	0.0513	-0.0061	-0.1180**
	(0.0040)	(0.0073)	(0.0045)	(0.0324)	(0.0506)	(0.0485)
Ln(*density*)	-0.0177***	-0.0219***	-0.0140***	0.0387**	0.0747***	0.0269
	(0.0033)	(0.0060)	(0.0035)	(0.0181)	(0.0259)	(0.0275)
Ln(*K/L*)	0.0817***	0.0337***	0.1380***	0.0294**	0.1388***	-0.0873***
	(0.0065)	(0.0102)	(0.0078)	(0.0119)	(0.0219)	(0.0199)
Sec_Share	-0.0277	-0.0624	-0.0058	0.5844***	0.2299	-0.0054
	(0.0298)	(0.0559)	(0.0327)	(0.0875)	(0.1432)	(0.1174)
Ln(*Openness*)	-0.0071***	-0.0042	-0.0109***	-0.00359	-0.0080	0.0084
	(0.0021)	(0.0028)	(0.0029)	(0.00325)	(0.0052)	(0.0059)
ln*FDIY*	0.0031***	-0.0007	0.0050***	0.00168	0.0062***	0.0049**
	(0.0012)	(0.0018)	(0.0015)	(0.00165)	(0.0022)	(0.0020)
heatsupply	-0.0660***	-0.0876***	-0.0563***			
	(0.0060)	(0.0099)	(0.0073)			
central	-0.0315***	-0.0321***	-0.0425***			
	(0.0071)	(0.0120)	(0.0088)			
west	-0.0187**	-0.0114	-0.0371***			
	(0.0082)	(0.0139)	(0.0097)			
northeast	-0.0542***	-0.0629***	-0.0498***			
	(0.0085)	(0.0141)	(0.0102)			
Constat	0.130***	0.325***	-0.0846**	0.1296	-0.0086	1.5994***
	(0.0372)	(0.0638)	(0.0376)	(0.2013)	(0.3025)	(0.2812)
Sigma/Constant	0.130***	0.138***	0.118***			
	(0.0031)	(0.0056)	(0.0025)			
Log likelihood	1735.2	620.6	1210.6			
Hausman Test				162.48	129.18	83.88
Adj. R^2				0.6421	0.5698	0.7059
Estimation method	Tobit	Tobit	Tobit	FE	FE	FE
Observations	2860	1144	1716	2860	1144	1716

Notes: (1) Standard errors in parentheses; (2) ***, **, * denote that the variables are statistically significant at the 1, 5 and 10% levels, respectively.

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