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Energy consumption-economic growth relationship and carbon dioxide emissions in China

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ABSTRACT

This paper applies the panel unit root, heterogeneous panel cointegration and panel-based dynamic OLS to re-investigate the co-movement and relationship between energy consumption and economic growth for 30 provinces in mainland China from 1985 to 2007. The empirical results show that there is a positive long-run cointegrated relationship between real GDP per capita and energy consumption variables. Furthermore, we investigate two cross-regional groups, namely the east China and west China groups, and get more important results and implications. In the long-term, a 1% increase in real GDP per capita increases the consumption of energy by approximately 0.48–0.50% and accordingly increases the carbon dioxide emissions by about 0.41–0.43% in China. The economic growth in east China is energy-dependent to a great extent, and the income elasticity of energy consumption in east China is over 2 times that of the west China. At present, China is subject to tremendous pressures for mitigating climate change issues. It is possible that the GDP per capita elasticity of carbon dioxide emissions would be controlled in a range from 0.2 to 0.3 by the great effort.

1. Introduction

The using of fossil energy becomes the symbol of modern industrial civilization. Howerver, greenhouse gas emissions have increased constantly because of human activity and fossil fuel combustion, which could significantly influence the internal balance process of global natural ecosystem. Meanwhile, energy shortage problem is increasingly serious due to overexploitation and abuse of the fossil energy. The climate change and energy problem deeply threaten the sustainable existence and development of all humankind. It has become the common standpoint of countries worldwide to address climate change, reduce carbon dioxide emissions and implement sustainable development stratagem.

Since the introduction of reform and an open-door policy, China has experienced rapid economic growth. The consumption of primary energy has also been increasing continuously, even with an annual growth rate of 10.9% during the 2003–2007 periods. The total energy consumption amount has magnified by approximately 3.5 times from 7.67×10^8 tons of SCE in 1992 to 26.56×10^8 tons of SCE in 2007, accordingly one-off energy consumption including coal, crude oil and natural gas had a rising trend wholly. The coal consumption in China accounts for approximately 69.5% of the total primary energy consumption in 2007 and 70.7% in 1978, only decreased by about 1.2%, which is over 4 times more than the average level in developed countries. The development of hydroelectric power, nuclear power and wind power is slow, rose by only 3.9% from 3.4% of the total energy consumption in 1978 to 7.3% in 2007 (see Table 1). Now the coal consumption results in about 70% of the soot dust emissions and 90% of the carbon dioxide emissions. With the low efficiency of energy use, the pattern of extensive economic growth and the backward management mode, the energy consumption per unit of GRP is too high. China is confronted with double challenges—addressing climate change in the international society and environmental protection with domestic economic transition.

The relationship between energy consumption and economic growth, which is studied by many authors using various methodologies for different time periods since the pioneering work of Kraft and Kraft (1978), becomes key and hot topic in environmental science, climatology and other relative academic fields. To test for a long-run relationship, the cointegration technique developed by Engle and Granger (1987) has been used in many researches within the last two decades, which was firstly used to study power demand in America by Engle et al. (1989), thereafter has become the mainstream method for studying the relationship between the two variables in a large amount of empirical researches. This relationship has been the focus of numerous theoretical explorations as well as a large number of empirical investigations (see for example, Erol and Yu, 1987; Stern, 1993, 2000; Masih and Masih,

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Table 1
Total consumption of energy and its composition from 1985 to 2007.
Sources: China Statistical Yearbooks, various years.

Year	Total energy consumption (10 000 tons of SCE)	As percentage of total energy consumption (%)			
		Coal	Crude oil	Natural gas	Hydro-power, nuclear power and wind power
1985	76682	75.8	17.1	2.2	4.9
1986	80850	75.8	17.2	2.3	4.7
1987	86632	76.2	17.0	2.1	4.7
1988	92997	76.2	17.0	2.1	4.7
1989	96934	76.0	17.1	2.0	4.9
1990	98703	76.2	16.6	2.1	5.1
1991	103783	76.1	17.1	2.0	4.8
1992	109170	75.7	17.5	1.9	4.9
1993	115993	74.7	18.2	1.9	5.2
1994	122737	75.0	17.4	1.9	5.7
1995	131176	74.6	17.5	1.8	6.1
1996	138948	74.7	18.0	1.8	5.5
1997	137798	71.7	20.4	1.7	6.2
1998	132214	69.6	21.5	2.2	6.7
1999	133830.97	69.09	22.57	2.14	6.2
2000	138552.58	67.75	23.21	2.35	6.69
2001	143199.21	66.68	22.87	2.55	7.9
2002	151797.25	66.32	23.41	2.56	7.71
2003	174990.3	68.38	22.21	2.58	6.83
2004	203226.68	67.99	22.33	2.6	7.08
2005	224682	69.1	21.0	2.8	7.1
2006	246270	69.4	20.4	3.03	7.2
2007	265583	69.5	19.7	3.5	7.3

1998; Oh and Lee, 2004a, b; Ghali and El-Sakka, 2004; Beaudreau, 2005; for some recent studies on developing countries, e.g. Glasure, 2002; Lee, 2005; Chen et al., 2007; Mahadevan and Asafu-Adjaye, 2007; Squalli, 2007; Akinlo, 2008; Chontanawat et al., 2008; Lee and Chang, 2007,2008; Narayan and Smyth, 2009; Wolde-Rufael, 2009), which is researched mainly based on one of two perspectives: the time series econometric analysis and the dynamic panel data approach. The previous test results have mostly been based on individual city or country using time series data (See for example in China, Han et al., 2004; Wang et al., 2006; Zhong et al., 2007). However, non-stationarity in the time series was not taken into account in some researches, and the cointegration relationship should also be further tested for the limitations in the relatively small available time series sample. (See as Stern, 1993, 2000 and Oh and Lee, 2004a, b) Hence, studies that have tested the relationship between these two variables reveal conflicting results on the issue, mainly due to the fact that estimation results are very sensitive to the time period considered, the region and the methodology employed. Some recent studies have also employed the panel data approach to investigate the energy-economy nexus in both developed and developing countries (see for example, Huang et al., 2008; Narayan et al., 2007; Mahadevan and Asafu-Adjaye, 2007; Narayan and Smyth, 2007, 2008, 2009; Lee et al., 2008; Apergis and Payne, 2009; Sadorsky, 2009). In China, Yu and Meng (2008) and Wu et al. (2008) researched the relation using the provincial panel data, respectively. Xu and Pan (2009) investigated the six industrial sector data. Though employing the panel data approach, the cointegrated relationship among variables was neglected by some authors (See as Olatubi and Zhang, 2003), and the accuracy of OLS estimation and FMOLS estimation were also affected for small available dataset sample. In addition, elastic coefficients calculated were not in accordance with practice in some literatures.

The energy consumption-economic growth relation analysis, which is related to not only timing sequence dimensions, but also to cross-section dimensions, needs to be examined using econometrics strictly and carefully. Consideration of data properties is necessary because appropriate methods depend on whether data is stationary for time series. If there is no cointegration in a posited regression among non-stationary variables, the regression could be spurious, and interpreting the results in the classical way would be invalid. Furthermore, the panel data can provide much more information than either cross-sectional data or time series, and in light of the lack of power of individual unit root tests and traditional cointegration tests, the combined information from time series and cross-sectional data is needed. Harris and Tzavalis (1999) determined that these panel tests allow for both parameter and dynamic heterogeneity across groups, and that they are considerably more powerful than conventional tests. Instead of following a time series or traditional panel data approach to prevent further debate, we use a new heterogeneous panel cointegration technique to re-investigate the relationship between energy consumption and economic growth across 30 Chinese provincial economies from 1985 to 2007. Then we use the dynamic ordinary least squares (DOLS) technique to estimate the cointegration vector for heterogeneous cointegrated panels. This enables us to correct the standard OLS for bias induced by endogeneity and serial correlation of the regressors. When compared with the previous approach, it is a more powerful tool and allows us to increase the degrees of freedom. Finally, we explore different group issues that are of concern to the east China and the west China, and with the results of this study, we are able to examine the deeper characteristics that determine the most efficient policies with respect to energy consumption.

2. Data description and definition of the variables

We use the annual time series data from 30 provinces and municipalities (The data for Tibet are not available for most years) in mainland China. The sample includes Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia, Liaoning, Jilin, Heilongjiang, Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong, Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang, among them Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, Hainan are located in the east China and Inner Mongolia, Guangxi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang in the west china. Table 2 shows the indices of energy consumption and economic growth. All provincial data are available in the China Statistical Yearbooks and the China Energy Statistical Yearbooks. Chongqing was upgraded to a municipality (provincial level) in the late 1990s, and it is seen as a part of the Sichuan province in this paper. The empirical period depends on the availability of data, but overall, the data cover the 1985–2007 periods. All the variables are expressed in natural logarithms such that the elasticity can be interpreted. Since all the provincial data for the above variables reported in Chinese Statistical Yearbooks are calculated at current prices, we adjusted every provincial GDP per capita data by considering the official price index.

3. Theoretical structure and empirical results

The energy use is considered as an essential factor of production in the economic activities and economic growth is driven by increasing energy demands. In this section, we use the model of Oh and Lee (2004a,b) and Lee and Chang (2008) to investigate the relationship between energy consumption and economic growth. The econometric methods used and the resulting empirical findings will be introduced in this section. Firstly, unit roots properties of the panel data are properly examined. Secondly, the existence of a cointegrating relationship between energy consumption and GDP per capita is tested using the panel cointegration technology. Finally, the OLS and DOLS estimators are used to evaluate the long-run relationship among the variables considered.

Table 2
Indices of energy consumption and economic growth.

Index	Unit	Abbreviation of index
GDP per capita	RMB Yuan	GDP
Energy consumption	10 000 tons of SCE	EC

3.1. Panel unit root test

Before conducting the cointegration analysis of the panel data, we conduct a panel unit root test. We adopt two different methods, namely those of Levine et al. (2002) and Im et al. (2003), i.e. the LLC and IPS, respectively. In addition to these, we follow the procedures of Maddala and Wu (1999) and Choi (2001) that proposed a more straightforward, nonparametric unit root test and suggested using the Fisher-ADF and Fisher-PP statistics.

Table 3 shows the panel unit root test results, the statistics solidly confirm that the two series (GDP, EC) are the I(1) process.

3.2. Panel cointegration test

Secondly, we proceed to test GDP per capita and energy consumption respectively, for cointegration in the data using the heterogeneous panel cointegration test developed firstly by Pedroni (1997,1999). This test allows for cross-sectional interdependence with different individual effects. Pedroni (1999) suggests two types of residual-based tests. As for the first type, four tests are distributed as being standard normal asymptotically and are based on pooling the residuals of the regression for the within-group; they are the panel v-statistic, panel ρ-statistic, panel PP-statistic and panel ADF-statistic. With the second type, three tests are also distributed as being standard normal asymptotically but are based on pooling the residuals for the between-group; they are the group r-statistic, group PP-statistic and the group ADF-statistic. These statistics are based on estimators that simply average the individually estimated coefficients for each member, and each of these tests is able to accommodate individual specific short-run dynamics, individual specific fixed effects and deterministic trends, as well as individual specific slope coefficients (Pedroni, 2004). Our objective here is to test the variables for cointegration to determine whether there is a long-run relationship to control for in the econometric specification. With the findings in the Monte Carlo simulation experiments, Pedroni (1999, 2004) showed that the panel ADF-statistic and group ADF-statistic tests have better small-sample properties than the others, and hence, they are more reliable. In addition, Kao (1999) studied residual-based tests for

Table 3
Panel unit root test results.

	GDP Individual effects	GDP Individual effects and linear trends	D(GDP) Individual effects	D(GDP) Individual effects and linear trends	EC Individual effects	EC Individual effects and linear trends	D(EC) Individual effects	D(EC) Individual effects and linear trends
The whole China								
LLC	16.310	2.577	−5.831***	−7.97552***	6.940	−19.358***	−5.990***	−5.566***
IPS	22.808	4.072	−5.173***	−9.20025***	13.159	−1.940**	−8.054***	−5.396***
Fisher-ADF	0.217	50.897	144.716***	185.168***	1.918	59.093	163.642***	126.014***
Fisher-PP	0.142	36.143	146.754***	191.166***	1.269	9.693	164.915***	125.864***
The east China								
LLC	7.272	−1.018	−6.007***	−2.978***	3.339	−22.949***	−1.831**	−3.963***
IPS	10.047	−1.127	−5.379***	−4.059***	7.500	−6.538***	−4.258***	−3.999***
Fisher-ADF	0.175	26.010	64.686***	49.624***	0.713	39.756***	54.779***	41.981***
Fisher-PP	0.120	24.606	54.435***	43.154***	0.205	2.667	49.940***	35.325***
The west China								
LLC	11.773	4.560	−0.543	−4.552***	3.927	2.203	−6.397***	−2.114**
IPS	15.569	5.702	−1.082	−5.270***	7.928	2.372	−5.972***	−2.837***
Fisher-ADF	0.039	13.819	44.069***	65.270***	0.978	10.134	72.335***	55.636***
Fisher-PP	0.019	3.253	54.061***	92.477***	0.791	5.090	79.813***	64.036***

Note: D denotes first difference. LLC and IPS represent the panel unit root tests of Levine et al. (2002) and Im et al. (2003), respectively. Fisher-ADF and Fisher-PP represent the Maddala and Wu (1999) Fisher-ADF and Fisher-PP panel unit root tests, respectively. The LLC, IPS, Fisher-ADF and Fisher-PP examine the null hypothesis of non-stationarity, and ***, ** indicates statistical significance at the 1%, 5% and 10% level, respectively. Probabilities for Fisher-type tests were computed by using an asymptotic χ^2 distribution. All other tests assume asymptotic normality.

cointegration regression in panel data, we also use Kao residual cointegration test to investigate the null of no cointegration in dynamic panels.

Table 4 presents the panel cointegration test results. The Panel ADF-statistic and Group ADF-statistic mostly strongly reject the null of no cointegration significantly at less than 10% critical values, and Kao residual cointegration test also strongly reject the null of no cointegration significantly at 1% critical value. Hence we generally obtain strong evidence of cointegration among these series. Thus, it can be predicted that energy consumption and GDP per capita variables move together in the long-run. Thus, there is a steady-state relationship between GDP per capita and energy consumption. The next step is to estimate this relationship.

3.3. Panel cointegration estimation

The relatively small time series samples for each province necessitate using panel methods to improve the power of our tests. Recent development in the econometrics of panel datasets has sought to address the potential non-stationarity of the series entering the panel. The long-run energy economy relation can be further estimated by several methods for panel cointegration estimation, e. g. the fully modified ordinary least squares (FMOLS) estimator proposed firstly by McCoskey and Kao (1999), Pedroni (2004) and Phillips and Moon(1999), the dynamic ordinary least squares (DOLS) estimator proposed firstly by McCoskey and Kao (1999) and Mark and Sul (2001). The choice of the preferred methods has been discussed in McCoskey and Kao (1999) and Kao and Chiang (2000), they have demonstrated that the panel DOLS procedure exhibits less bias than the panel OLS and the panel fully modified OLS estimators in small samples using Monte Carlo simulations. Mark and Sul (2001) have emphasized the tractability of the DOLS estimator. Therefore, we use the dynamic ordinary least squares (DOLS) developed firstly by Kao and Chiang (2000) to estimate the long-run cointegrating vector between energy consumption and GDP per capita. This estimator is designed for non-stationary panels and corrects the standard pooled OLS for serial correlation and for endogeneity of regressors that are normally present in long-term economic relationships (See as Adedeji and Thornton, 2008).

The DOLS is an ordinary least squares estimation of an expanded equation including not only the explanatory variables but also leads and lags of their first difference terms to control for endogeneity and to calculate the standard deviations using a covariance matrix of errors that is robust to serial correlation. The leads and lags of the difference terms are included to ensure that the error term is orthogonalized. The DOLS estimators have a normal asymptotic distribution and their standard deviations provide a valid test for the statistical significance of the variables (See as Lopez-Pueyo et al., 2008). It has the following form:

$$y_{it} = \alpha + x_{it}\beta + \sum_{j=-q_1}^{q_2} c_{ij}\Delta x_{it+j} + v_{it}$$

where Δx_{it} asymptotically eliminates the effect of endogeniety of x_{it} on the distribution of OLS estimator of β, q_1 is the maximum lag length, q_2 is the maximum lead length, v_{it} is a Gaussian vector error process.

We proceed to estimate the relation. Two econometric techniques have been used that combine the traditional treatment of panel data with the technique of cointegration: ordinary least squares and the dynamic ordinary least squares. Table 5 provides the results of panel OLS and panel DOLS tests. A panel data model with fixed effects (including both individual specific and time specific effects) is adopted. The values of the DOLS estimator are determined under the assumption of one lead, one lag or two leads, two lags in the change of the regressors. Often the DOLS estimator has the drawback that its results are sensitive to the choice of number of lags and leads, but for our sample we find that most coefficient estimates vary only little when the leads and lags are changed. The parameters are quite significant mostly at a 1% level of significance. In the context of cointegration, the OLS estimations are "superconsistent", but their distribution is not usually standard, due to the presence of a finite samples bias, which may be caused either by the endogeneity of the explanatory variables or by the serial correlation of the error term (See as Lopez-Pueyo et al., 2008). The DOLS estimators outperform the OLS ones, and may have a higher performance of model fitting. Based on the results provided in Table 5, the panel estimator is 0.48–0.50 where the dependent variable is EC. Implicit here is that a 1% increase in GDP per capita leads to a 0.48–0.50% increase in energy consumption for the full sample of provinces. In this paper, we broaden the scope of our study by researching the two cross-regional groups in order to investigate the group effects the two blocs of provinces and to gain a better understanding of the energy-growth relationship. No matter if we consider the east China-panel or the west China-panel, EC has a positive sign and is statistically significant mostly at

Table 4
Panel cointegration test results.

		Panel v	Panel rho	Panel PP	Panel ADF	Group rho	Group PP	Group ADF	Kao Test
The whole China									
EC	No deterministic trend	3.273***	−0.511	−1.994**	−3.674***	1.696	1.005	−4.276***	−5.478***
	Deterministic intercept and trend	0.465	2.603	1.043	−1.845**	4.377	2.642	−3.798***	
GDP	No deterministic trend	1.080	0.179	−1.106	−2.996***	2.149	−0.288	−3.539***	−3.685***
	Deterministic intercept and trend	3.250***	2.795	−0.625	−2.295***	4.402***	0.547	−2.006**	
The east China									
EC	No deterministic trend	1.785**	−0.108	−0.913	−3.176***	1.316	−0.289	−3.162***	−2.856***
	Deterministic intercept and trend	0.511	1.910	1.289	−1.678**	3.009	2.427	−1.846**	
GDP	No deterministic trend	0.453	0.176	−0.622	−3.177***	1.573	0.043	−3.370***	−2.781***
	Deterministic intercept and trend	1.095	1.424	−1.448*	−2.732***	2.449	−0.643	−2.212***	
The west China									
EC	No deterministic trend	2.582***	−1.220	−2.187***	−2.726***	0.104	−1.675**	−2.739***	−4.736***
	Deterministic intercept and trend	0.894	0.575	−0.544	−1.857**	1.747	0.289	−1.328*	
GDP	No deterministic trend	2.546***	−0.846	−1.550*	−2.165**	0.327	−1.139	−2.129**	−4.011***
	Deterministic intercept and trend	2.370***	1.554	0.407	−0.569*	2.365	1.199	−0.463*	

Note: Statistics are asymptotically distributed as normal. The variance ratio test is right-sided, while the others are left-sided. ***, ** and * rejects the null of no cointegration at the 1%, 5% and 10% level, respectively. For the formulas used in the panel cointegration test statistics, it is described in details in Pedroni (1999, 2004) and Kao (1999).

Table 5
Panel cointegration estimation results by OLS and DOLS.

	EC			GDP		
	OLS	DOLS(1,1)	DOLS(2,2)	OLS	DOLS(1,1)	DOLS(2,2)
The whole China						
GDP	0.490*** (9.655)	0.483*** (7.961)	0.503*** (7.294)			
EC				0.280*** (9.655)	0.251*** (7.401)	0.236*** (6.040)
The east China						
GDP	0.896*** (10.033)	0.845*** (7.690)	0.781*** (6.429)			
EC				0.381*** (10.033)	0.311*** (7.085)	0.305*** (6.074)
The west China						
GDP	0.292*** (3.897)	0.354*** (3.879)	0.404*** (3.670)			
EC				0.246*** (3.897)	0.222*** (2.996)	0.180** (2.165)

Note: The *t*-Values are in parentheses. ***, ** denotes the estimator of a parameter is significant at 1%, 5% and 10% level, respectively.

Table 6
Carbon emission coefficient and oxidation percent of carbon for coal, crude oil and natural gas.

	Coal	Crude oil	Natural gas
Carbon emission coefficient	1.0052	0.753	0.6173
Oxidation percent of carbon	0.900	0.980	0.990
Carbon dioxide emission coefficient	0.905	0.738	0.611

Note: Data sourced from Zhu et al. (2009), Energy Research Institute of State NDRC (National Development and Reform Commission) (2003) and China Climate Change Country Study Group (2000).

the 1% level, which is indicative of an upward shock in GDP per capita, and vice versa. Based on the evidence from the DOLS tests, compared with the results for the full sample of provinces, although we only consider the 11 east China provinces and the 11 west China provinces, the panel estimators increase for the east China but does decrease with the west China sample. The income elasticity of energy consumption in east China is about 2 times that of the west China. The economy in east China is energy-dependent to a great extent, and relies on the consumption of the energy more than the west China, that is related to not only the fact that the West–East Gas Transmission Project, the West–East Power Transmission Project and the other support policies are carried out, but also the historical process of the reform and opening, and the industrialization situation.

The carbon dioxide emissions amount is calculated based on energy consumption data in the relative researches because of no direct monitoring data in China. Then, the estimating formula of carbon dioxide emissions amount is usually given by

$$CO_2 = EC \times \eta = EC \times C_{EC} \times C$$

where CO_2 denotes carbon dioxide emissions amount generated in energy consumption; η and C_{EC} represents carbon dioxide emission coefficient and carbon emission coefficient, respectively; and C is the oxidation percent of carbon.

Based on energy consumption structure in China, the carbon dioxide emission coefficient of energy consumption is calculated as 0.858 using data in Table 6. Implicit here is that a 1% increase in GDP per capita leads to a 0.48–0.50% increase in energy consumption and a 0.41–0.43% increase in carbon dioxide emissions in China. The energy consumption of China between the recent 4 years exceeds the total for 25 years before. The carbon dioxide emissions in China reached 59.6×10^8 tons in 2007, which ranked the first in the world, and only 58.2×10^8 tons in America in 2007. How to reduce carbon dioxide emissions has given rise to heated rhetoric in the world. China is subject to tremendous environmental pressures and will be confronted with a challenge for addressing climate change issues.

4. Conclusions and policy implications

In this paper, we argue that energy is indeed an essential factor in production and empirically re-examine the long-run co-movement between energy consumption and real GDP per capita on a panel dataset comprised of 30 provinces in China mainland from 1985 to 2007, employing panel unit root test, cointegration test and dynamic OLS developed recently, which have the advantage of higher power and more robust conclusion, since the time series data may yield unreliable and inconsistent results with the short time spans of typical datasets. Furthermore, we investigate not just the whole economy but rather the two groups of provinces, the east China and west China members.

The results obtained here are consistent with those of Yu and Meng (2008), Wu et al. (2008), who concluded that there is a long-run equilibrium relationship between economic growth and energy consumption in China, and provide solid support in favor of the past changes in energy consumption that have had a significant impact on economic growth in China. Therefore, one of the most urgent tasks for authorities in developing countries would be to establish well planned, long-term energy policy system, in order to avoid excessive shocks to economic growth. In addition, unquestionably, with the sustainable economic growth, greenhouse gas emissions increase continuously in China. Balanced against this increase in energy demand are energy security and climate change issues. It is suggested that a 1% increase in real GDP per capita increases carbon dioxide emissions by a value between 0.41% and 0.43% in China. In the future, we need to do our utmost to explore new and important ways to change the current economic growth pattern, to develop low-carbon economy and circular economy actively, and to combine construction of resources-saving societies and environmentally-friendly societies with construction of innovative countries. It is possible that the carbon dioxide emissions elasticity of GDP per capita would be controlled in a range from 0.2 to 0.3 by the great effort.

Furthermore, we proceed to investigate the group effects between two. Our results contradict the findings of Yu and Meng (2008) who concluded that there is no cointegration relationship between energy consumption and economic growth in west China. However, the results obtained here are consistent with Wu et al. (2008) who found evidence of long-run relationship in both the east China and west China. In east China, economic growth is based on extensive energy use mode, energy use efficiency is low, and the pollution emissions become more and more serious. Due to the need of mitigation of climate change in the international society, the nuclear energy and the renewable energy should be promoted rapidly. Renewable energy can play an important role in reducing a developing country's dependence on imported energy products, and can also play an important role in helping to address climate change issues. It is urgently demanded to stimulate the development of low-carbon economy and to implement a green development strategy in east China at first. In west China, the dematerializing cycle economy development policy should be carried out at the beginning of the developing stage, in order to improve energy use efficiency and reduce emissions.

At last, in contrast to the most previous studies, we employ the variable GDP per capita weighing economy growth, which can be better in reflecting the situation of behavioral preference and household energy consumption to some extent. The quantity of China residential energy consumption in urban region will increase rapidly in the future, hence the energy-saving and emissions-reducing policy should be carried out not only in the production field, but also in daily lives. Every person can use energy-saving devices and economize household energy to mitigate climate change. The energy-saving building can be developed and architectural planning should be improved in the future.

The history experiences indicate that, the new round of economic development, structural adjustment and technical innovation would begin possibly, after economic crisis and financial crisis. How to carry out energy-saving and emissions-reducing policies? How to integrate economic development and mitigation of climate change? These will be the key problems that need urgent research and solution in China.

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