Energy Policy 78 (2015) 113–124

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Energy and CO_2 emissions performance in China's regional economies: Do market-oriented reforms matter?

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HIGHLIGHTS

- A newly developed NDDF are applied to evaluate China's energy and carbon performance.
- Most of China's regions did not perform efficiently in energy use and CO_2 emissions.
- Market-oriented reforms contributed to improving China's energy and carbon efficiency.

ARTICLE INFO

Article history:
Received 20 September 2014
Received in revised form
11 November 2014
Accepted 19 December 2014
Available online 3 January 2015

Keywords:
Market-oriented reforms
Energy and carbon efficiency
Non-radial directional distance function

ABSTRACT

This paper employs a newly developed non-radial directional distance function to evaluate China's regional energy and CO_2 emission performance for the period 1997–2009. Moreover, we analyze the impact of China's market-oriented reform on China's regional energy and carbon efficiency. The main findings are as follows. First, most of China's regions did not perform efficiently in energy use and CO_2 emissions. Provinces in the east area generally performed better than those in the central and west areas. By contrast, provinces in the west area generally evidenced the lowest efficiency. Second, Market-oriented reforms, especially the promotion of factor market, were found to have positive effect on the efficiency of energy use and CO_2 emissions. Third, the share of coal in the total energy consumption and the expansion of the industrial sector were found to be negatively correlated with China's regional energy and CO_2 emissions performance. Based on the empirical findings, we provide policy suggestions for enhancing energy and carbon efficiency in China.

1. Introduction

The Chinese government instituted the policy of reform and opening-up in 1978. Since then, China adopted gradual market-oriented reforms and has been transitioning from a planned economy to a market economy. Benefiting from such polies, China's economy has obtained impressive achievement. According to NBSC, China's real GDP has increased by approximately 26-fold from 1978 to 2013. Along with such aggressive economic expansion, China's energy consumption has also risen substantially resulting in enormous growth of carbon dioxide (CO_2) emissions. As shown in Fig. 1, China consumed 2852 million tons of oil equivalent (Mtoe) of primary energy in 2013, increasing from 396 Mtoe in 1978. Meanwhile, the amount of China's CO_2 emissions reached 9524 million tons which increased from 1429 million tons in 1978. Since 2007, China has already surpassed the US as the largest energy consumer and the largest emitter of CO_2 in the world (Choi et al., 2012; K. Wang et al., 2013b).

The rapidly rising energy consumption and CO_2 emissions have raised concerns about China's sustainable development. Moreover, China is currently in the stage of industrialization which is inevitably inducing more energy consumption (Li and Lin, 2013), which makes the situation even more serious in the next decade. It is widely recognized that improving energy efficiency and CO_2 emissions efficiency is an important path for China to tackle energy challenges and environmental pollutions. As such, it is of great importance to evaluate China's efficiency performance in energy use and CO_2 emissions. This topic has attracted much attention. Many researchers have devoted to quantitatively measuring energy efficiency and CO_2 emissions efficiency in China's regions and industries. For example, based on the input-oriented DEA model, Hu and Wang (2006) proposed a

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http://dx.doi.org/10.1016/j.enpol.2014.12.025
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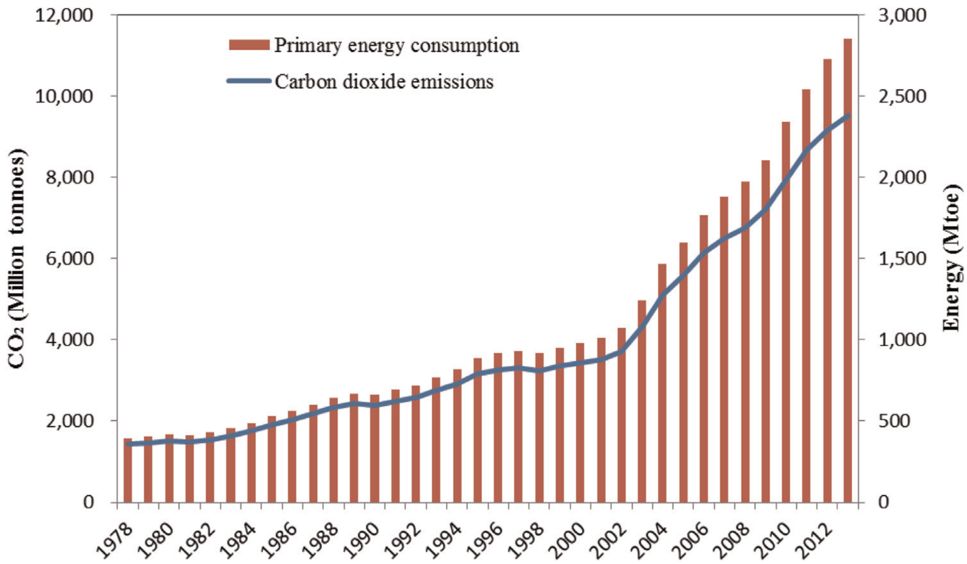

Fig. 1. hina's energy consumption and CO_2 emissions over years.
Source: BP Statistical Review of World Energy, 2014.

total factor energy efficiency index to assess China's 29 administrative regions for the period 1995–2002. Wu et al. (2012) constructed both static and dynamic efficiency indices which also take into account undesirable output to measure industrial energy efficiency in China's provinces for the period 1997–2008. Based on the non-radial directional distance function, H. Wang et al. (2013) investigated China's provincial energy efficiency and productivity under different production scenarios for the period 2006–2010. Lin and Du (2014) introduced a latent class stochastic frontier approach to measure energy efficiency at China's provincial level for the period 1997–2010.

In terms of CO_2 emission performance, Guo et al. (2011) employed an environmental DEA model to evaluate China's regional CO_2 emission efficiency for the period 2005–2007. Based on different efficiency orientations, Wang et al. (2012) proposed a group of efficiency models to assess China's regional economic efficiency and CO_2 emissions performance. Q. Wang et al. (2013b) used the directional distance function and combined with stochastic frontier analysis (SFA) techniques to estimate the total factor CO_2 emissions performance index at China's provincial level for the period from 1995 to 2009. Zhou et al. (2014) introduced several centralized DEA models to study the optimal allocation of CO_2 emissions in China from a perspective of efficiency analysis.

Unlike the aforementioned studies which separately analyzed China's energy efficiency and CO_2 emissions efficiency, there are also many studies simultaneously conducting both efficiency analysis in a single model. For instance, Zhang and Choi (2013b) developed two slack-based measure (SBM) efficiency indices to model China's regional energy and environmental (carbon dioxide, sulfur dioxide, and chemical oxygen demand) performance during the period 2001–2010. Choi et al. (2012) also employed SBM-DEA approach to estimate energy and carbon efficiency and the abatement cost of emissions in China's regions over the period 2001–2010. K. Wang et al. (2013a) used range-adjusted model (RAM) to evaluate China's provincial energy and carbon performances for the period 2006–2010. K. Wang et al. (2013b) employed multi-directional DEA model to estimate China's regional energy and carbon efficiency over the period 1997–2010.

It is worth pointing out that there are extensive literatures on this subject and the number of studies has been growing over years. More studies on China's energy efficiency and CO_2 emission efficiency are summarized in Table 1.

Thanks to the contribution of the pioneer studies, many insightful conclusions have been obtained. Although there are variations in the methods employed by previous studies, some common findings include (1) China's energy efficiency and CO_2 emission efficiency are

Table 1
Previous studies on China's energy and carbon efficiency.

Literature	Methodological approaches	Field of research	DMUs	Period
Hu and Wang (2006)	CCR-DEA model	Energy efficiency	China's 29 provinces	1995–2002
Wei et al. (2009)	CCR-DEA model	Energy efficiency	China's 29 provinces	1997–2006
Shi et al. (2010)	DEA model of fixing non-energy inputs	Industrial energy efficiency	China's 28 provinces	2000–2006
Wu et al. (2012)	Environmental DEA model	Industrial energy efficiency	China's 28 provinces	1997–2008
H. Wang et al. (2013)	NDDF	Energy efficiency and productivity	China's 28 provinces	2005–2010
Lin and Du (2013b)	Parametric metafrontier approach	Energy efficiency	China's 30 provinces	1997–2010
Q. Wang et al. (2013a)	Metafrontier DEA approach	Energy efficiency	China's 28 provinces	2000–2010
Lin and Du (2014)	Latent class stochastic frontier approach	Energy efficiency	China's 30 provinces	1997–2010
Guo et al. (2011)	Environmental DEA model	Carbon efficiency and potential reductions	China's 29 provinces	2005–2007
Du et al. (2014)	Non-parametric metafrontier approach	Carbon efficiency and potential reductions	China's 30 provinces	2006–2010
Q. Wang et al. (2013b)	DDF and SFA	Carbon efficiency	China's 28 provinces	1995–2009
Choi et al. (2012)	SBM-DEA model	Energy and carbon efficiency, abatement cost of emissions	China's 30 provinces	2001–2010
Zhang and Choi (2013b)	SBM-DEA model	Energy and environmental efficiency	China's 30 provinces	2001–2010
Wang et al. (2012)	Environmental DEA model	Economic and energy efficiency	China's 28 provinces	2001–2007
Wang et al. (2013b)	RAM-DEA model	Energy and carbon efficiency	China's 30 provinces	2006–2010
K. Wang et al. (2013b)	Multi-directional DEA model	Energy and carbon efficiency	China's 30 provinces	1997–2010

still at the low stage; (2) most of China's provinces are not energy-efficient or carbon-efficient; (3) the performances of China's provinces vary greatly. However, most existing literature only focused on the measurement of energy efficiency or/and CO_2 emission efficiency. Very few of them, so far as we know, have analyzed the influential factors of China's regional efficiency performance. Specially, the quantitative evidence on the impact of China's market-oriented reform on the energy and CO_2 emission performance of China's regions remains unexplored.

In theory, the development of the market can play a significant role in the improvement of the energy and CO_2 emission performance from three aspects. First, the reliance on market will optimize energy allocation which means that the priority of energy resource would be given to more efficient producers. Second, the market also provides economic agents with effective incentives to reduce waste and choose the most cost-reflective energy saving equipment and appliances. Third, the promotion of the market would enhance competition so that firms seek to be cost-effective and improve their productivity. In summary, market-oriented reforms will bring about efficiency gains for an economy due to optimized resource allocation instrument, improved incentive mechanism and increased competitive pressure.

Conducting empirical study on the relationship between market-oriented reforms and energy–carbon efficiency not only helps us to understand China's regional performance more in depth but also has significance in terms of policy guidance. It is therefore the purpose of this paper to fill the blank through empirically analyzing the role of market driven reforms in China's regional energy and CO_2 efficiency performance. Based on the empirical findings, we provide policy suggestions for enhancing energy and carbon efficiency in China. This paper also adds to the existing literature on the assessment of China's regional energy and CO_2 emission efficiency performance through applying a newly composite efficiency indicator which were recently developed by Zhou et al. (2012b) and Zhang et al. (2014a) based on the non-radial directional distance function.

The remainder of the paper is structured as follows. In Section 2, we give a brief introduction of China's market-oriented reforms. In Section 3, we describe the methods, variables and data in detail. In Section 4, we empirically measure energy and CO_2 emission performance in China's regional economies and present the results. In Section 5, we present the related discussion. In Section 6, we conclude the paper and provide the policy suggestions for enhancing energy and carbon efficiency in China.

2. China's market-oriented reforms

Prior to China's Comprehensive Economic Reform (CER) in 1978, China was a central planned economy which can be summarized in the following aspects. First, the macro economy was operated through commands of the government. In general, the Five Year Plan is set up to direct the operational aspect of the economy. Then the plan was passed on to the Planning Commission at various layers of government for execution and monitoring (Hou, 2011). People's communes (production teams) and state-owned enterprises (SOEs) were organized for production in the agricultural and industrial sectors, respectively. Second, a pure public ownership system was in place for the property right, which means that means of production (land, capital, mineral resources, and labor services) are all publically owned and allocated by the government according to the economic plan. Third, in the command economy, prices of resources, products and services are set by the government. To pursuit the heavy-industry-oriented development, raw materials, and living necessities were artificially undervalued. Fourth, the Chinese government established an egalitarian system of income distribution. Under the planned economy, people earned identically regardless of their contribution.

It can be seen that before CER, the economic policies of China run against the law of market which made its economy stagnated for decades. To revive the economy, the Chinese government began to carry out CER in 1978. Unlike the shock therapy in Eastern Europe, China's market-oriented reform have often been characterized as a gradual process. The first step of reforms took place in the rural agricultural production with the practice of the Household Responsibility System as the milestone. This system allocated the usage rights of land to farmers and allowed them to make their own production decisions and get most of their harvest. Due to the incentives from the Household Responsibility System (HRS), China's agricultural sector grew dramatically. With the success of the HRS, the reform was then expanded to urban industrial sector (Hou, 2011). Various “managerial responsibility” systems were introduced in the reform of SOEs. Moreover, private enterprises were also allowed to operate and develop (Hou, 2011).

Although the scope of the market for resource allocation were expanded, in the early stage of the reform the basic institutional framework of central planning remained intact (Qian and Wu, 2000). One important fact is the existence of the dual track system of prices. With the advancement of the reform, the dual track system was abolished in 1992. After that, the government decided to abolish the planning system and the establishment of a socialism market system had been regarded as the goal of the reform. Since then, the market has been being completed. Specially, in the product market most commodities' prices are determined via the interaction of supply and demand. According to Li (2006), the prices of more than 90% of products have been determined by free markets. In this sense, market reforms in the product market have been basically achieved.

Compared with the product market, the development of the factor market lags far behind the product market. Markets for production factors including land, capital, and energy remain distorted. Particularly in the energy market, the reforms are very slow. Over the past decades, energy (e.g., coal, oil, natural gas, and electricity) prices were artificially determined or regulated by the government. Until recent years, there have not been adequate reforms in the energy sector.

Taking electricity industry reforms as an example, historically, China's electricity industry was tightly controlled by the government. Specifically, prices and quantities for all final electricity users and for the coal input were determined by the central government (Gao, 2014). In addition, the Ministry of Electricity Power (MEP) was responsible for all electricity investments. Private investors, foreign investors, and even local governments were not allowed to invest in the electricity industry (Du et al., 2013). The first step of electricity reform took place in 1985. It allowed local governments, domestic enterprises and foreign enterprise to invest in electricity generation. But the MEP was still in charge of the transmission lines and the distribution grid. The next stage of electricity reform started in 1997 with the abolishment of the MEP as a mark. The State Power Company (SPC) was established for daily operation of electricity system and the State Economic and Trade Commission (SETC) were in charge of administrative functions. It is the first time to separate the electricity system between government and enterprises. The reform was further advanced in 2002, which aimed at introducing competition in electricity generation. The SPC was dismantled into two transmission and five generation companies. The generation companies were expected to bid into regional power pools for grid-accessing priority and a market-oriented pricing mechanism for the generation sector was expected to be set up. However, the reform does not really take effect until recently. Tariffs for generation and final users are still determined by the government. Moreover, the transmission and distribution sector was monopolized by the two power grid companies in their respective regions.

Another typical characteristic of China's reforms is that they often began with experiment in some specific regions and then gradually expanded to the whole country. Specifically, China's market-oriented reforms were first carried out in the provinces of the eastern area. After their successes, the reforms were promoted in provinces of the central area and then spread to the western area. For instance, the central government established several special economic zones (SEZs) in the coastal provinces and gradually applied their experiences to other zones. As a result, the step-wise development strategy makes China's regional marketization particularly uneven. Accordingly, China's regional economies are not evenly developed. As the pioneers of CER, provinces in the east area are economically well-developed. By contrast, provinces in the central area show less developed and those in the west area are generally the least developed (Du et al., 2014).

3. Method

3.1. Non-radial directional distance function

Data envelopment analysis (DEA) is a powerful tool in the evaluation of energy and environmental efficiency performance.[1] Methodologically, DEA is a nonparametric method which employs linear programming techniques to estimate the best-practice frontier. Consequently, the relative efficiency of the assessed decision-making unit (DMU) can be easily identified through its distance from the frontier (Chen and Golley, 2014). Conventional DEA models are generally built on the Sherphard distance function which expands desirable and undesirable outputs at the same proportion (Zhang and Choi, 2014). It means that reduction of undesirable output is not credited.[2] Thus, conventional DEA models are limited for the measurement of energy and environmental efficiency. To address this issue, Chung et al. (1997) proposed a directional distance function (DDF) method. DDF distinguishes strong disposability and weak disposability between desirable and undesirable outputs. Moreover, DDF allows for increment of desirable output and reduction of undesirable output and inputs simultaneously. As such, DDF has become popular in empirical application. Examples of such studies include Boyd and McClelland (1999), Färe et al. (2007), Oggioni et al. (2011), and Riccardi et al. (2012). Despite its merits, DDF has the limitation that the expansion of desirable output and the contraction of undesirable output/inputs are at the same rate (Du et al., 2014). In this sense, DDF is a radial efficiency measure which may underestimate the inefficiency of the assessed DMU. In view of the limitation of the conventional DDF, Zhou et al. (2012b) proposed a non-radial directional distance function (NDDF) method. Compared to DDF, NDDF allows for disproportional adjustments of inputs, desirable output and undesirable output (Zhou et al., 2012b). As a result, NDDF has higher discriminating power than DDF. The NDDF method was further developed by Zhang et al. (2013) and Zhang and Choi (2013a) to account for technology heterogeneity and to investigate the dynamic change in CO_2 emission performance, respectively.

Considering its distinct advantages, the NDDF method is applied in this paper. Suppose that there are N assessed regions and each region is regarded as a DMU. Each DMU uses capital (K), labor (L) and energy (E) to produce desirable goods (Y). Meanwhile, undesirable output CO_2 emissions (C) are generated as byproduct in the process of production. According to the joint production framework proposed by Färe et al. (1989), the production technology can be expressed as

$$P = \{(K, L, E, Y, C): (K, L, E) \text{ can produce } (Y, C)\}$$

Technically, the set P is usually assumed to possess the following properties.

(1) P is closed and bounded, which means that only finite amounts of output can be generated by finite amounts of input.
(2) If $C = 0$ and $(K, L, E, Y, C) \in P$, then $Y = 0$. It is termed as null-jointness of desirable output and undesirable output which means that desirable goods cannot be produced without generating undesirable output.
(3) If $(K, L, E, Y, C) \in P$ and $Y' < Y$, then $(K, L, E, Y', C) \in P$. This property is termed as strong disposability of input and desirable output, indicating that redundant input and desirable output can be disposed without any cost.
(4) If $(K, L, E, Y, C) \in P$ and $\alpha \in [0, 1]$, then $(K, L, E, \alpha Y, \alpha C) \in P$. This condition is termed as weak disposability of undesirable output, suggesting that undesirable output can be cleaned up at the cost of desirable output.

According to Zhou et al. (2012b), Zhang et al. (2013) and Zhang and Choi (2013a), the non-radial directional distance function is defined as

$$\vec{D}(K, L, E, Y, C; g) = \sup_{\beta \ge 0}\left\{w^T\beta: (K, L, E, Y, C) + diag(\beta)\cdot g \in P\right\} \tag{1}$$

where $\beta = (\beta_K, \beta_L, \beta_E, \beta_Y, \beta_C)^T$ is a vector of scaling factors which measures the departure of real production activity from the optimal state; $diag(\beta)$ represents a diagonal matrix with β; $g = (g_K, g_L, g_E, g_Y, g_C)^T$ is a directional vector determining the directions in which each input/output is scaled; $w = (w_K, w_L, w_E, w_Y, w_C)^T$ is a vector denoting the weights assigned to each inputs/outputs.

Note that the directional vector g and the weight vector w can be set in different ways to serve different policy goals. To evaluate energy and CO_2 emission performances in China's regional economies, we employ the energy–carbon performance index ($ECPI$) developed by Zhou et al. (2012b) and Zhang et al. (2014a). For $ECPI$, the directional vector g is set as $(0, 0, -E, Y, -C)$ and the weight vector w is set as $(0, 0, 1/3, 1/3, 1/3)$.[3] This setup emphasizes on the inefficiencies of energy input, desirable output and CO_2 emissions, and removes the diluting effect of other inputs (capital and labor). Suppose that $\beta^{**} = (\beta_E^{**}, \beta_Y^{**}, \beta_C^{**})$ is the solution to Eq. (1) under the scenario that $g = (0, 0, -E, Y, -C)$ and $w = (0, 0, 1/3, 1/3, 1/3)$.

According to Zhou et al. (2012b) and Zhang et al. (2014a), the energy–carbon performance index (ECPI) can be formulated as follows:

$$\text{ECPI} = \frac{1/2[(1 - \beta_E^{**}) + (1 - \beta_C^{**})]}{1 + \beta_Y^{**}} \tag{2}$$

[1] Here we just provide a brief review on the evolution of the methodology. There are already several excellent reviews of data envelopment analysis in energy and environmental studies. See, for example, Zhou et al. (2008), Song et al. (2012), and Zhang and Choi (2014).

[2] We also note that Zhou et al. (2010) proposed the Sherphard carbon distance function which allows the reduction of CO_2 emissions while keeping inputs and desirable output unchanged. In essence, the Shephard carbon distance function is a special case of non-radial directional distance function.

[3] This setup has also appeared in Wang et al. (2013a) for defining a scenario-based energy performance index. We thank a reviewer for pointing out this. The weight vector (0, 0, 1/3, 1/3, 1/3) means that energy reduction, desirable output expansion and carbon reduction are regarded as the same importance. This is a naive choice. But note that different choices of the weight vector might lead to different efficiency scores.

It can be easily derived that ECPI ranges from 0 to 1. The higher score of the index means the better energy–carbon performance. The assessed DMU is located in the production frontier and regarded as the best performance when ECPI is equal to 1.

Technically, ECPI can be estimated through DEA-type models.[4] For comparability of the evaluated results between different years, this paper employs the global environmental DEA method which is proposed by Oh (2010). The global DEA method uses the whole sample to construct a fixed benchmark technology frontier. This idea can date back to Berg et al. (1992). More recently, Zhang et al. (2014b) also used this idea to measure ecological total-factor energy efficiency. According to Oh (2010), the global production technology with constant returns to scale (CRS) can be formulated as[5]

$$
\begin{aligned}
P^g = \{(K, L, E, Y)\colon & \sum_{t=1}^{T}\sum_{n=1}^{N}\lambda_{n,t}K_{n,t} \le K \\
& \sum_{t=1}^{T}\sum_{n=1}^{N}\lambda_{n,t}L_{n,t} \le L \\
& \sum_{t=1}^{T}\sum_{n=1}^{N}\lambda_{n,t}E_{n,t} \le E \\
& \sum_{t=1}^{T}\sum_{n=1}^{N}\lambda_{n,t}Y_{n,t} \ge Y \\
& \sum_{t=1}^{T}\sum_{n=1}^{N}\lambda_{n,t}C_{n,t} = C \\
& \lambda_{n,t} \ge 0,\ n = 1, \ldots, N,\ t = 1, \ldots, T\}
\end{aligned}
\tag{3}
$$

Then, ECPI can be calculated after solving the following linear programmings (LPs).

$$
\begin{aligned}
\vec{D}(K, L, E, Y, C) = \ & \max \frac{1}{3}\beta_E + \frac{1}{3}\beta_Y + \frac{1}{3}\beta_C \\
s.\,t.\quad & \sum_{t=1}^{T}\sum_{n=1}^{N}\lambda_{n,t}K_{n,t} \le K \\
& \sum_{t=1}^{T}\sum_{n=1}^{N}\lambda_{n,t}L_{n,t} \le L \\
& \sum_{t=1}^{T}\sum_{n=1}^{N}\lambda_{n,t}E_{n,t} \le E - \beta_E E \\
& \sum_{t=1}^{T}\sum_{n=1}^{N}\lambda_{n,t}Y_{n,t} \ge Y + \beta_Y Y \\
& \sum_{t=1}^{T}\sum_{n=1}^{N}\lambda_{n,t}C_{n,t} = C - \beta_C C \\
& \lambda_{n,t} \ge 0,\ n = 1, \ldots, N,\ t = 1, \ldots, T\}
\end{aligned}
\tag{4}
$$

3.2. Econometric model, variables and data

For the empirical study, we collect a panel data set of 30 provinces in China from 1997 to 2009.[6] Regional gross domestic product (GDP) is chosen as the proxy of output variable. Raw data on regional GDP are obtained from China Premium Database and adjusted by the gross domestic product deflator so that they are measured by the constant prices in 1997. Since there are no official data of China's regional CO_2 emissions, we estimate the data according to the method described in Wu et al. (2012).

Data on energy consumption and labor force are directly collected from China Premium Database. Raw Data on capital stock for the period of 1997–2006 are directly obtained from Shan (2008) and then are extended to 2009 using the perpetual inventory method (PIM) as described in Shan (2008). Data on Capital stock are also converted into the constant prices in 1997 using the price index of investment in fixed assets.

To gain deeper insight into the role of market-oriented reform in China's regional energy and CO_2 emissions performances, we consider the following reduced form econometric model.

$$y_{it} = \beta_0 + \beta_1 Mak_{it} + Z_{it}'\gamma + \varepsilon_{it} \tag{5}$$

where the dependent variable $\boldsymbol{y}$ denotes the score of energy and CO_2 emissions performance (ECPI); *Mak* represents the marketization variable; *Z* represents a vector of control variables which are used to single out the influences from other specific characteristics of China's regional economies;ε is the stochastic error term.

We select three proxy variables to reflect the process of marketization in China's administrative regions. They are **Composite Index of Marketization (*CIM*)**, **Index of Product Marketization (*IPM*)**, and **Index of Factor Marketization (*IFM*)**. These indices are drawn from Fan et al. (2012), which captures the development of the entire market, product market and factor market in China's regional economies, respectively. A higher score of the index means a higher level of the market development. Fig. 2 plots the marketization in China's regional economies. It is can be seen that there are large variations in the development of the market in China's provinces. The provinces in the east area, which are the pioneers of the policy of reforming and opening-up, evidence the highest scores of marketization. On the contrary, the provinces in the west area generally show the lowest level of market development. Comparing the pictures in Panels (B) and (C), we can find there were less diverse across the provinces in the development of the product market than in the development of the factor market. Fig. 3 plots the dynamic change of the distribution of the three indices over years. From Fig. 3, we can observe the position of the distributions of marketization indices were shifting to the right side over years which indicates that the degree of China's marketization was gradually improving.

The control variables ($\boldsymbol{Z}$) in the regression model are selected and constructed as follows.

Energy price (denoted as ***Price*****)**. In theory, a raise in energy price increases the cost of energy use so that producers would response by improving energy efficiency (Wu, 2012), which helps to reduce CO_2 emissions. Thus, energy price is expected to be positively correlated with energy and CO_2 emissions performance. As data on China's regional energy price are unavailable, we follow Wu (2012) to use the fuel price index as the proxy of energy price.[7] Data on regional fuel price index are obtained from China Premium Database.

Energy consumption structure (denoted as ***ECS***). Physically, different types of energy vary in quality.[8] Electricity is more productive than oil which in turn is more productive than coal (Liddle,

[4] Regarding the assessment of energy performance, the applicability of parametric frontier approach has also been advocated by several earlier studies including Zhou et al. (2012a) and Lin and Du (2013b; 2014). But for the composite index of energy and carbon performance, it would be more difficult to conduct parametric specification and estimation.

[5] CRS technology provides bounds on the underlying true but unknown technology and captures the long run (Färe et al., 1997). Thus, CRS can be used as a benchmark in DEA analysis. Zhou and Ang (2008) also show that CRS technology satisfies all production technologies and has more discrimination ability than that of the corresponding VRS model. Moreover, the VRS model is more frequently to encounter infeasibility.

[6] Due to data unavailability, Tibet is not included in this study.

[7] It is need to note that the fuel price index only reflects the energy price change in each region. In other words, the difference of energy prices among regions cannot be measured by the fuel index. However, as data on China's regional energy price are unavailable, it may be hard to find a better proxy.

[8] It means that the one unit of different types of energy generates different amounts of work.

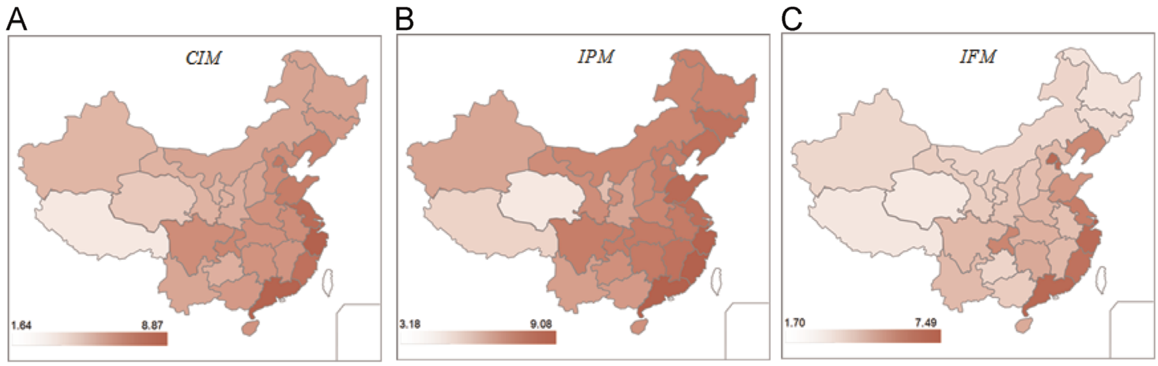

Fig. 2. Marketization in China's regions. *Note:* The data for plotting are average scores of the three indices of regional marketization. *Source:* Fan and Wu (2011).

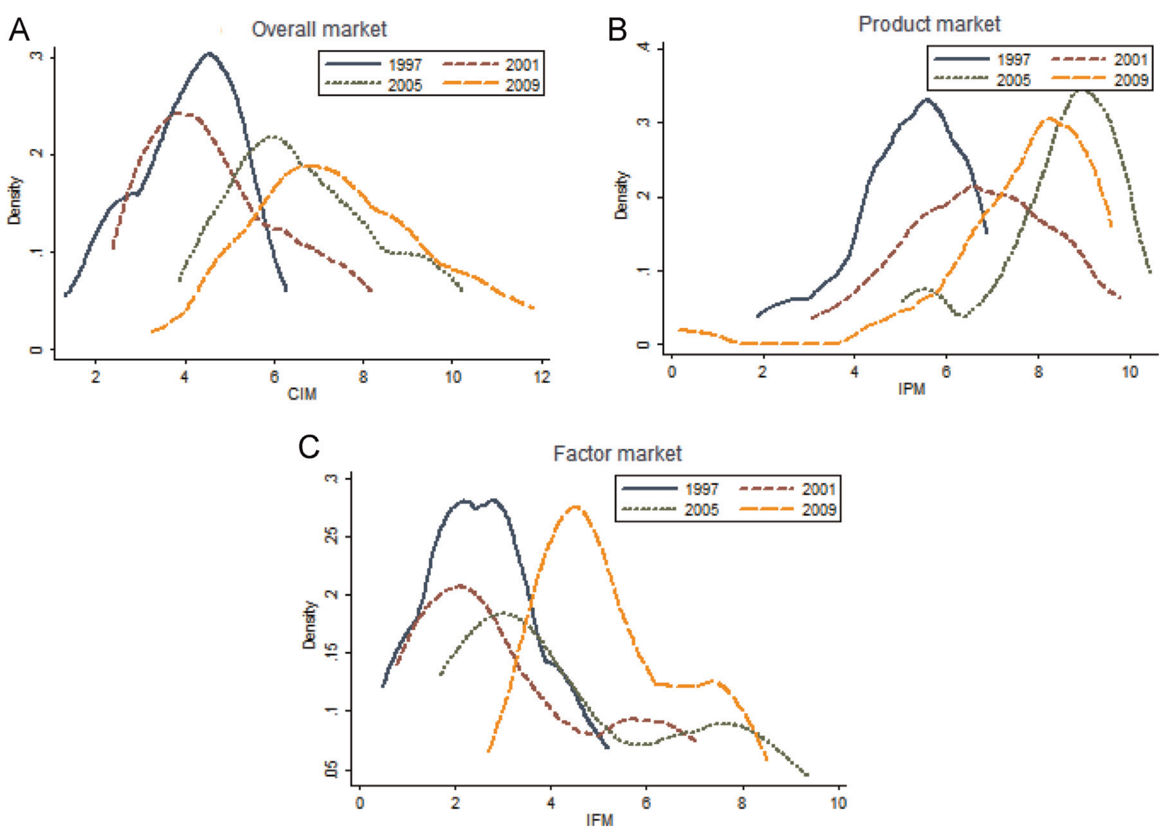

Fig. 3. Kernel density evolution of Marketization in China's regions.

2012). Some studies (Schurr, 1982; Wang, 2007) have found that the composition of energy consumption is correlated with energy efficiency. Specifically, increased consumption of high quality energy can significantly improve energy productivity. Additionally, different types of energy also have different CO_2 emission coefficients. For example, burning of coal would emit 1.2 and 1.6 times of CO_2 as the consumption of oil and natural gas, respectively (Du et al., 2012). Given this, the share of coal in total energy consumption is expected to be negatively correlated with the energy and CO_2 emissions performance. Thus, we include the variable of energy consumption structure to control provincial variations and use the share of coal in total energy consumption as the proxy. Raw data are obtained from China Energy Statistics Yearbook.

Industrial structure (denoted as ***IS***). Generally speaking, the secondary industry is more energy intensive than the first and tertiary industries. At present, most China's regions are still in the process of industrialization, which might be an unfavorable factor for improving their energy and CO_2 emissions performances. In this paper, industrial structure is measured by the share of the secondary industry accounting for regional GDP. Raw data are collected from China Premium Database.

Trade openness (denoted as ***Trade***). The existing studies (Ang, 2009; Jalil and Mahmud, 2009) have extensively explored the impact of international trade on environmental pollutions. On the one hand, local producers benefit from the diffusion of technology and managerial experience through international trade which promotes the growth of resource productivity. On the other hand, international trade generally allocates the production of energy and pollution intensive commodities toward China's regions. This phenomenon is usually termed “pollution refuge hypothesis”. It means that larger trade openness might lead to more energy consumption and CO_2 emissions. In summary, trade openness may influence the energy and CO_2 emissions performance in China's regional economies in two opposing sides and the net effect is unclear.[9] Following Du et al. (2012), we measure the trade openness by the share of the sum of import and export in GDP. The corresponding data are collected from China Premium Database.

Urbanization (denoted as ***Urban***). Similar to the impact of trade openness, Du et al. (2012) pointed out that urbanization also has two different effects. In the process of urbanization, the construction of infrastructure including road, railway, and airport consumes a lot of energy and results in more emissions of CO_2. Meanwhile, urbanization helps to bring production agglomeration which is widely regarded as an important contributor to economic growth. The change in production mode would affect the energy and CO_2 emissions performance at the economy-wide level through the scale effect and the spillover effect. In this paper, the share of non-agricultural population is employed as the proxy of urbanization level. Raw data are collected from China Employment Statistics Yearbook and China Population Statistics Yearbook China Population.

Policy dummy (denoted as ***Policy***). Considering that in the "Eleventh Five-Year (2006–2010) Plan" the Chinese government had laid more stress on the energy savings and environmental protection and issued various policies to achieve the target. Following Lin and Du (2013a), we set up a dummy variable to examine the impact of the polies. Specifically, ***Policy*** is set to one for the observations during the period from 2006 to 2009 and to 0 during other periods.

Provincial dummies. Except the aforementioned variables, there are also some other factors which also influence the energy and CO_2 emissions performances in China's regional economies, but might not be observed. In view of this fact, we also add provincial dummies in the econometric model which would help us to further control the regional heterogeneity.

The descriptive statistics of the variables are reported in Table 2. As the dependent variable in Eq. (5) is censored at 0 and 1, the tobit regression method is employed in this paper to get the consistent estimates.[10]

4. Results

We use Matlab 7.6 to solve the LPs presented in Eq. (4). The estimation results of the energy–carbon performance index (ECPI) in China's regional economies are reported in Table 3. It can be observed that only a few scores of the ECPI are equal to unity, indicating most of China's provinces did not perform efficiently in their production activities. The average score of ECPI in China during the sample period was only 0.489, which was still at a low stage. It implies that as a whole there is still a long way for China to develop an energy-efficiency and environmental-friendly economy. It can also be seen that as a whole China performed better during the 11th Five-Year Plan period. But this finding cannot be simply taken as evidence for the policy effect since there are many factors that would influence the carbon emission performance. We will examine this issue in more depth in the next section.

Table 3 also reveals that the scores of the ECPI vary significantly across China's provinces. Among the 30 provinces, Guangdong shows the best performance with an average score of 0.967, followed by Fujian (0.886) and Hainan (0.776). These three provinces are all from the east area of China. In general, the provinces in the east area were more efficient than those in the central and west areas. The provinces in the west area generally evidenced the lowest scores of ECPI. Taking Ningxia and Guizhou as examples, their average values only reached 0.169 and 0.197 respectively, which were at the bottom among China's provinces. Basically, these results are in line with the findings of previous studies such as Choi et al. (2012), K. Wang et al. (2013a), and K. Wang et al. (2013b).

Fig. 4 plots the trends of the average scores of the ECPI in the three grand areas. From Fig. 4, we can find that the score of the ECPI in east area was not only the highest but also grew fastest, which increased from 0.584 in 1997 to 0.775 in 2009, indicating an average growth rate of 2.4%. In contrast, the growth of the score in the west area which was backward in the energy–carbon performance index was very limited. Therefore, the ECPI gap between the leading and the backward regions was inclined to be widened.

5. Discussion

Fig. 5 plots the binary relationship between energy and CO_2 emissions performance and marketization in China's regional economies. It can be observed that ECPI is positively correlated with the marketization indices. It means that the regions with higher degree of marketization are inclined to perform more efficiently in energy use and CO_2 emissions.

The intuitive relationship shown in Fig. 6 is further examined by the multivariable regression model presented in Eq. (5). The corresponding estimation results are reported in Table 4. In Models I, the coefficients of CIM are estimated as 0.018 which is significant at 1% level. The result suggests that overall marketization had significantly positive effect on energy and CO_2 emissions performances of China's regions.

In Models II, the coefficients of IPM is negative but not significant even at 10% level, which means we do not find evidences to support that during the research period China's regions had benefited from the promotion of product market in terms of energy and CO_2 emissions performances. At the first sight, it is somehow out of our expectation. It is however important to recall that marketization of product has been largely achieved in the 1990s and the prices of most commodities are determined by the market. At the current stage the imperfection of the product market mainly lies in local protection which is originated from the interaction of local governments. It is understood that local protection benefits local economic growth in the short run but inhabits technological innovations in the long run (Lu and Chen, 2009). In the short run, the situation for efficiency performance in energy use and CO_2 emissions might be complicated. On the one hand, local protection hinders the diffusion of clean production technology. On the other hand, to some extent it can prevent the backward regions from specialized division with production of energy and pollution intensive commodities. In addition, as shown in Fig. 2 the disparities in the product market of China's regions are relatively small which means the variations of efficiency performances in energy use and CO_2 emissions might not be explained by the disparities in China's regional product markets. Therefore, it is not surprising to find that during the sample period the promotion of product market does not play a significant role in energy and CO_2 emissions performance. This result might be limited to the sample period of this study. In the early stage of China's market-oriented reforms, markets for products experienced great transformation from a planned system to a market system. For this period, it would be expected to show a different

[9] In growth literature, the openness is often used as an institution proxy. The marketization index proposed by Fan et al. (2012) also takes account of the openness. It means that for our regression model part of effect of marketization may be taken by the openness variables. In this sense, the effect of marketization would be underestimated. We thank a reviewer for pointing out this issue.

[10] It is also need to point out that recently tobit regression is also critical due to the possibility of serial correlation. The bootstrapped truncated model proposed by Simar and Wilson (2007) can be an alternative methodology which had been applied in Choi et al. (2012). We thank a reviewer for pointing out this issue.

Table 2
The descriptive statistics of the variables.

Variable	Symbol	Unit	Mean	Sd	Min	Max
GDP	***Y***	Billion RMB	561.654	554.394	20.279	3511.927
CO_2	***C***	10 thousand tons	19219.103	15340.377	705.049	91584.742
Capital	***K***	100 million RMB	10642.434	10191.351	459.409	62446.400
Energy	***E***	Mtoe	78.164	59.162	3.900	348.080
Labor	***L***	Million persons	22.460	14.866	2.304	60.416
CIM	***CIM***	–	5.788	2.120	1.290	11.800
IPM	***IPM***	–	7.111	1.886	0.160	10.610
IFM	***IFM***	–	4.015	2.231	0.400	11.930
Energy price	***Price***	%	148.460	47.583	89.600	288.339
Energy consumption structure	***ECS***	%	73.129	14.831	27.702	99.317
Industrial structure	***IS***	%	46.029	7.355	19.760	61.500
Trade openness	***Trade***	%	30.836	39.908	3.204	172.148
Urbanization	***Urban***	%	33.264	15.845	14.040	88.250

picture from our finding.

Contrary to the case of regressions against IPM, in Models III the coefficient IFM is estimated as 0.013 which is significant at 1% level. Unlike the development of the product market, the factor market is still heavily regulated by the government. Factor market distortions are found to result in productivity losses (Brandt et al., 2013; Hsieh and Klenow, 2009). Moreover, the under-developed factor market would induce inefficiency of resource allocation. It is also not in favor of industrial upgrade. Because that underpricing of resources makes the backward production survive. In this sense, to improve China's energy and CO_2 emissions performance the government should further promote reforms in the factor market. For instance, market-oriented pricing system should be created to replace government pricing. To accomplish this purpose, the government needs to establish a competitive electricity market. The market power of the two power grid companies should be weakened. And more players should be introduced into the transmission and distribution sector. It is known that such reforms do harm to vested interest groups. Thus, political constraints would be the barriers that block the future reforms.

As to the estimation results of the control variables, several results can be drawn from Table 4. First, the coefficients of energy price in all models are at least significant at 10% level, suggesting that increasing energy price helps to enhance energy and CO_2 emissions performance. This result is consistent with the common sense that an increase in energy price benefits energy conservation and emission reduction. Second, the share of coal in total energy consumption (referred to *ECS*) and the share of the secondary industry in GDP (referred to *IS*) have negative effects on energy and CO_2 emissions performance which is in line with our expectation. Third, the coefficients of trade openness are significantly positive. As we discussed above, trade openness has two opposing forces. This result suggests that its net effect contributes to the improvement of energy and CO_2 emissions performance.

Table 3
Estimation results of the energy–carbon performance index (ECPI) in China's regional economies.

Province	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	Average
(E)Beijing	0.417	0.453	0.486	0.529	0.553	0.604	0.640	0.689	0.734	0.784	0.845	0.932	1.000	0.667
(E)Fujian	1.000	1.000	0.980	0.901	1.000	0.869	0.835	0.809	0.757	0.795	0.821	0.869	0.885	0.886
(E)Guangdong	1.000	1.000	0.929	0.934	0.934	0.954	0.964	0.965	0.932	0.960	1.000	1.000	1.000	0.967
(E)Hainan	0.829	0.795	0.845	0.841	0.839	0.753	0.708	0.673	0.776	0.764	0.744	0.751	0.775	0.776
(E)Hebei	0.305	0.316	0.332	0.320	0.354	0.320	0.311	0.311	0.301	0.315	0.333	0.356	0.376	0.327
(E)Jiangsu	0.581	0.607	0.654	0.695	0.748	0.783	0.797	0.733	0.667	0.688	0.740	0.794	0.851	0.718
(E)Liaoning	0.261	0.283	0.296	0.287	0.314	0.346	0.361	0.351	0.377	0.399	0.415	0.451	0.469	0.355
(E)Shandong	0.522	0.566	0.608	0.614	0.648	0.555	0.539	0.520	0.456	0.470	0.499	0.533	0.577	0.547
(E)Shanghai	0.489	0.543	0.562	0.607	0.641	0.679	0.703	0.748	0.763	0.822	0.930	1.000	1.000	0.730
(E)Tianjin	0.354	0.393	0.421	0.425	0.456	0.496	0.547	0.543	0.570	0.603	0.647	0.706	0.754	0.532
(E)Zhejiang	0.667	0.691	0.722	0.697	0.744	0.714	0.729	0.706	0.700	0.723	0.746	0.801	0.840	0.729
(C)Anhui	0.424	0.433	0.454	0.465	0.480	0.506	0.517	0.543	0.548	0.570	0.590	0.608	0.633	0.521
(C)Heilongjiang	0.293	0.336	0.356	0.373	0.424	0.474	0.472	0.481	0.497	0.508	0.523	0.537	0.583	0.451
(C)Henan	0.450	0.437	0.452	0.457	0.463	0.461	0.444	0.401	0.397	0.407	0.424	0.458	0.480	0.441
(C)Hubei	0.327	0.354	0.382	0.402	0.450	0.450	0.434	0.424	0.435	0.439	0.460	0.509	0.543	0.431
(C)Hunan	0.441	0.465	0.598	0.663	0.629	0.609	0.578	0.522	0.439	0.459	0.482	0.521	0.561	0.536
(C)I-Mongolia	0.259	0.350	0.304	0.311	0.299	0.284	0.259	0.233	0.230	0.234	0.239	0.249	0.273	0.271
(C)Jiangxi	0.580	0.609	0.610	0.580	0.629	0.583	0.551	0.545	0.557	0.566	0.574	0.623	0.649	0.589
(C)Jilin	0.233	0.294	0.321	0.328	0.344	0.338	0.399	0.342	0.366	0.384	0.415	0.455	0.478	0.361
(C)Shanxi	0.167	0.187	0.204	0.213	0.193	0.178	0.183	0.191	0.196	0.199	0.215	0.225	0.227	0.198
(W)Chongqing	0.394	0.367	0.349	0.484	0.478	0.557	0.619	0.596	0.527	0.542	0.571	0.553	0.593	0.510
(W)Gansu	0.240	0.244	0.242	0.253	0.282	0.289	0.286	0.285	0.290	0.297	0.290	0.305	0.337	0.280
(W)Guangxi	0.696	0.709	0.694	0.671	0.698	0.715	0.678	0.575	0.563	0.577	0.592	0.641	0.661	0.652
(W)Guizhou	0.157	0.155	0.179	0.186	0.200	0.213	0.185	0.184	0.208	0.209	0.222	0.230	0.235	0.197
(W)Ningxia	0.201	0.224	0.225	0.184	0.174	0.170	0.135	0.142	0.144	0.145	0.150	0.150	0.159	0.169
(W)Qinghai	0.236	0.253	0.240	0.268	0.268	0.265	0.268	0.272	0.283	0.267	0.281	0.269	0.282	0.266
(W)Shananxi	0.289	0.330	0.404	0.443	0.414	0.403	0.396	0.373	0.371	0.391	0.412	0.435	0.458	0.394
(W)Sichuan	0.356	0.386	0.447	0.488	0.515	0.504	0.476	0.443	0.479	0.490	0.509	0.518	0.538	0.473
(W)Xinjiang	0.238	0.253	0.277	0.276	0.291	0.301	0.305	0.292	0.292	0.288	0.299	0.308	0.300	0.286
(W)Yunnan	0.392	0.402	0.443	0.471	0.473	0.443	0.419	0.533	0.361	0.363	0.375	0.396	0.409	0.422
Average	0.427	0.448	0.467	0.479	0.498	0.494	0.491	0.481	0.474	0.489	0.511	0.539	0.564	0.489

Note: E, C, and W in parentheses represent to the east, central, and west areas, respectively.

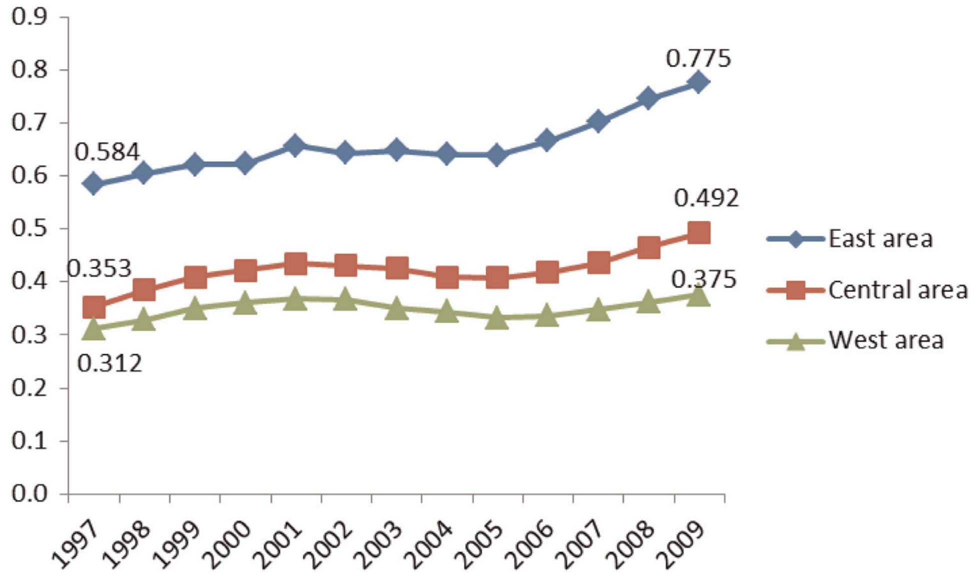

Fig. 4. The average scores of ECPI of different regions over years.

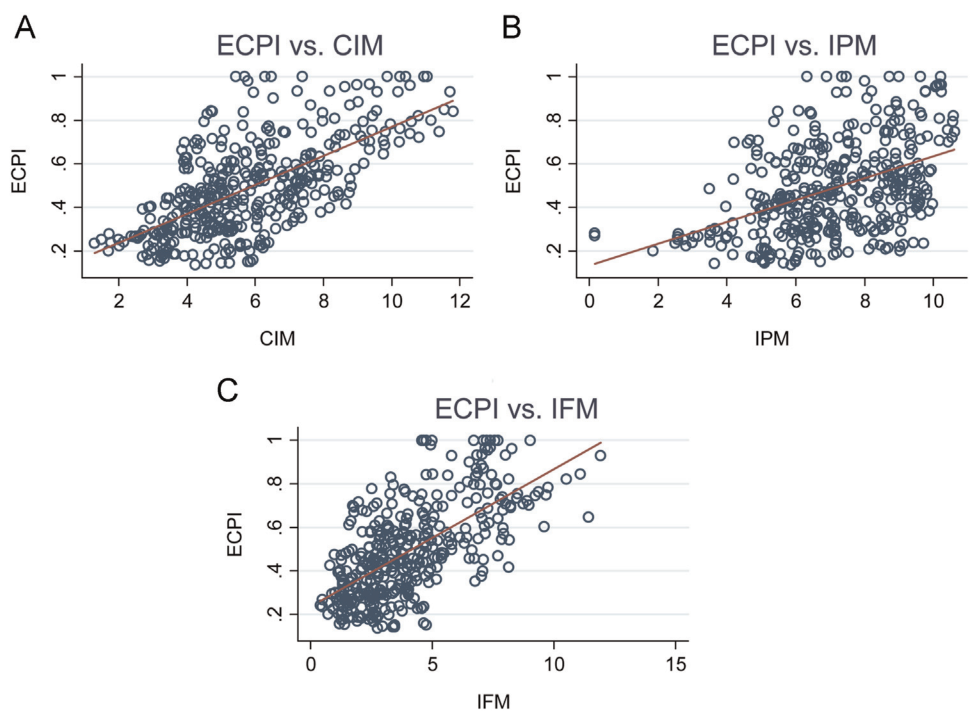

Fig. 5. Correlation between energy and CO_2 emissions performance and marketization.

Fourth, the coefficients of urbanization in most of the models are not significant. Thus, the two opposing effects of urbanization may offset each other. Fifth, although the Chinese government took more measures to promote energy conservation and emission reduction in the "Eleventh Five-Year" period, the effect of such policies are not found to be significant. This result is consistent with the finding of Lin and Du (2013a). One possible explanation is that most measures taken by the government were mainly command-and-control measures such as "blackout with force" which interrupted the normal production activities. Therefore, they are not effective policies and cannot contribute to the improvement of China's regional efficiency performances in terms of energy use and CO_2 emissions.

To examine the robustness of the results we discussed above, we further conduct the estimation of Eq. (5) using two alternative methods. First, we use random effect tobit model to estimate Eq. (5). Unlike the treatment of unobserved individual factors with dummy variables in the previous section, random effect tobit model does not introduce the dummy variables. It captures unobserved individual factors with a random variable which is often assumed to be a normal distribution. When unobserved individual factors are not correlated with the regressors, random effect model is not only consistent but also more efficient. The estimation results are reported in Table 6. Compared with Table 5, we can find that the results are very similar in terms of the sign and significance of the coefficients.

Another concern is the possibility of the bidirectional influencing relationship between marketization and energy and CO_2

Table 4
Estimation results of fixed effect tobit models.

Variable	Model I	Model II	Model III
CIM	1.784e−02[b]		
	(5.034e−03)		
IPM		−4.405e−05	
		(2.816e−03)	
IFM			1.273e−02[b]
			(3.381e−03)
Price	3.216e−06[a]	6.657e−06[b]	4.399e−06[b]
	(1.673e−06)	(1.455e−06)	(1.486e−06)
ECS	−5.568e−03[b]	−5.935e−03[b]	−5.783e−03[b]
	(7.620e−04)	(7.737e−04)	(7.540e−04)
IS	−7.701e−03[b]	−7.640e−03[b]	−7.726e−03[b]
	(9.517e−04)	(9.749e−04)	(9.490e−04)
Trade	5.706e−04[a]	1.042e−03[b]	5.437e−04[a]
	(3.113e−04)	(2.907e−04)	(3.102e−04)
Urban	−3.245e−03[b]	−1.807e−03	−1.531e−03
	(1.153e−03)	(1.112e−03)	(1.079e−03)
Policy	1.384e−02	1.517e−02	1.354e−02
	(1.148e−02)	(1.172e−02)	(1.146e−02)
Constant	1.276e+00[b]	1.330e+00[b]	1.312e+00[b]
	(7.639e−02)	(7.754e−02)	(7.481e−02)

Note: To converse space, estimation results of provincial dummies are not reported. Standard errors in parentheses.
[a] Denote coefficient significant at 10%.
[b] Denote coefficient significant at 1%.

Table 5
Estimation results of random-effects tobit models.

Variable	Model I	Model II	Model III
CIM	2.018e−02[c]		
	(5.020e−03)		
IPM		8.283e−04	
		(2.889e−03)	
IFM			1.381e−02[c]
			(3.511e−03)
Price	1.865e−06	5.965e−06[c]	3.662e−06[b]
	(1.757e−06)	(1.502e−06)	(1.521e−06)
ECS	−5.587e−03[c]	−5.884e−03[c]	−5.742e−03[c]
	(7.457e−04)	(7.631e−04)	(7.442e−04)
IS	−7.120e−03[c]	−7.158e−03[c]	−7.215e−03[c]
	(9.801e−04)	(1.001e−03)	(9.762e−04)
Trade	7.842e−04[b]	1.279e−03[c]	7.578e−04[b]
	(3.185e−04)	(3.002e−04)	(3.203e−04)
Urban	−3.088e−03[c]	−2.000e−03[a]	−1.655e−03
	(1.039e−03)	(1.041e−03)	(1.014e−03)
Policy	1.584e−02	1.767e−02	1.553e−02
	(1.198e−02)	(1.222e−02)	(1.194e−02)
Constant	1.155e+00[c]	1.177e+00[c]	1.381e−02[c]
	(7.243e−02)	(7.485e−02)	(3.511e−03)

Note: Standard errors in parentheses.
[a] Denote coefficient significant at 10%.
[b] Denote coefficient significant at 5%.
[c] Denote coefficient significant at 1%.

emissions performance, which would lead to endogeneity.[11] To address this issue, we use instrumental variable (IV) method. The instrumental variables we used are the lag variables of CIM, IPM and IFM. This strategy is similar to the idea of General Moment Method (GMM) for dynamic panel model. It is reasonable as the lag variables have been historical such that they would not be influenced and changed by the current energy and CO_2 performance. The estimation results are reported in Table 6. We can observe that for CIM, IPM, IFM, ECS, and IS, the previous results still hold while the coefficients of Price and Trade become insignificant in some models. In summary, our robust findings imply that for enhancing energy and CO_2 emission performance, the Chinese government should pay more attention to the improvement of market systems instead of taking command-and-control measures. Specially, deepening the reform of the factor market can significantly contribute to improving China's efficiency performance in energy use and CO_2 emissions.

Table 6
Estimation results of instrumental variable (IV) tobit models.

Variable	Model I	Model II	Model III
CIM	3.309e−02[b]		
	(7.324e−03)		
IPM		−3.472e−03	
		(4.920e−03)	
IFM			3.956e−02[b]
			(7.212e−03)
Price	−7.730e−07	5.874e−06[b]	−1.627e−06
	(1.956e−06)	(1.546e−06)	(1.956e−06)
ECS	−5.245e−03[b]	−5.914e−03[b]	−5.600e−03[b]
	(8.518e−04)	(8.575e−04)	(8.913e−04)
IS	−7.413e−03[b]	−7.249e−03[b]	−7.765e−03[b]
	(9.913e−04)	(1.006e−03)	(1.049e−03)
Trade	3.094e−05	9.858e−04[b]	−6.233e−04
	(3.508e−04)	(3.114e−04)	(4.160e−04)
Urban	−4.320e−03[b]	−1.586e−03	−2.619e−04
	(1.259e−03)	(1.151e−03)	(1.217e−03)
Policy	1.845e−02	2.150e−02[a]	1.605e−02
	(1.152e−02)	(1.153e−02)	(1.220e−02)
Constant	1.229e+00[b]	1.347e+00[b]	1.288e+00[b]
	(8.440e−02)	(8.677e−02)	(8.646e−02)

Note: To converse space, estimation results of provincial dummies are not reported. Standard errors in parentheses.
[a] Denote coefficient significant at 10%.
[b] Denote coefficient significant at 1%.

6. Conclusions and policy implications

This paper empirically explores whether market-oriented reforms can contribute to improving energy and CO_2 emissions performances in China's regional economies. To serve this purpose, we first employed a newly developed indicator proposed by Zhou et al. (2012b) and Zhang et al. (2014a) to evaluate China's regional efficiency performance in energy use and CO_2 emissions. Our main findings are as follows. First, most of China's region did not perform efficiently in energy use and CO_2 emissions. Second, provinces in the east area generally performed better than those in the central and west areas. Provinces in the west area generally evidenced the lowest efficiency. Third, during the research period the efficiency scores in most of provinces showed an increasing trend. Moreover, provinces in the east area grew faster than those in the other areas.

Multivariable regression model is then used to analyze the relationship between China's regional energy and CO_2 emissions performance and marketization. Several different estimation methods are also employed to examine the robustness of our findings. Taking together results from different estimation methods, we can draw some robust conclusions as follows.

(1) Market-oriented reform, especially the promotion of factor market was found to have positive effect on the efficiency of energy use and CO_2 emissions. In other words, the different performances in China's regions can be explained by the variation in their levels of marketization.

[11] It means that the improvement of efficiency may in turn promote marketization. Generally speaking, efficiency improvement would benefit economic growth. With increasing income, people may pay more attention to complete the market system. This logic is similar to the relationship between institutions and economic growth which is extensively discussed in economic literature.

(2) The share of coal in the total energy consumption and the expansion of industrial sector were found to have negative effects on China's regional energy and CO_2 emissions performances.

Based on the above findings, some important policy implications and suggestions can be proposed. First, the Chinese government should further promote the marketization in China's regions, especially for the provinces in the central and west areas. Second, as the factor market plays a basic role in resource allocation for production activity, the Chinese government should further implement market reforms in the factor market. Specifically, the government should slack control over factor price and enhance market system in resource pricing. Additionally, as all mineral resources in China belongs to the state, the government should further adopt a more open and transparent way to allocate the initial use right and strengthen the supervision and administration so that producers with higher efficiency are given priority to resource use. Third, the government is also suggested to optimize energy consumption structure through increasing the share of high quality and clean energy. More financial support should be given to the development of renewable energy. Fourth, the Chinese government should also take measures to adjust industrial structure and support the development of industries with low energy consumption and less environmental pollutions. Last but not the least, the disparity in China's regional efficiency performances implies variations in the abatement costs of CO_2 emissions. Thus, establishing carbon emission trade systems (ETS) can also play an important role in the development of a "low-carbon economy". This point has been also proposed by Zhou et al. (2013) which estimated China's provincial carbon abatement cost curves and found significant variation in the regional abatement costs of CO_2 emissions.

Finally, there are some limitations in this paper which should be duly noted. Restricted to data availability, our research period began in 1997. However, for the product market, great transformations had been accomplished since the 1990s. As such, in our sample period we do not find evidences of the general belief that product market reforms can contribute to energy and CO_2 emission performance. This result should be further investigated with a longer time span including the early stage of China's reforms. We leave this issue for the future study.

Acknowledgments

This paper is supported by the Research Fund of Newhuadu Business School, Ministry of Education Foundation (Funding no. 10JZD0018), Basic Research Universities Special Foundation (Funding no. 2010221051), Ministry of Education Foundation (Funding no. 10JBG013) and National Social Science Foundation (Funding no. 09&ZD050). Kerui Du thanks the financial support of Yinxing Economic Research Fund. We thank four anonymous reviewers for their helpful comments and suggestions which led to an improved version of this paper.

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