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Does energy and CO₂ emissions performance of China benefit from regional integration?

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A B S T R A C T

Low energy and carbon efficiency and widespread market segmentation are two stylized facts of China's regional economies. This paper evaluates energy and CO₂ emissions performance using a newly developed non-radial directional distance function, and China's regional integration is investigated using a price approach. The study points to evidence that: (1) most provinces do not perform efficiently in terms of energy use and CO₂ emissions with performance gaps among regions becoming larger, indicating regional segmentation; (2) magnitude of regional integration has increased dramatically, while China's eastern provinces are less integrated in domestic side due to their convenience to international openness; (3) regional integration has significant and robust positive effects on energy and CO₂ emissions performance with over 70% of effects coming from artificial barriers, rather than geographical distance; (4) international openness is also beneficial for promoting energy and CO₂ emissions performance, but cannot substitute for regional integration because of China's specialization in energy-intensive manufacturing in the global economy. Based on the empirical findings, we suggest that central government should continue to encourage regional integration given that local governments have incentives to fragment because it is a way of promoting energy and CO₂ emissions performance and stimulating economy at the same time.

1. Introduction

1.1. Background

There are two stylized facts in China's economic research. The first is the low energy and CO₂ emissions performance. China has overtaken US as the biggest energy consumer and CO₂ emitter in the world. The primary energy consumption of China was over 2800 million tonnes of oil equivalent (Mtoe) in 2013 while CO₂ emissions were over 9.5 billion tonnes. The corresponding figures for the US were 2266 Mtoe for primary energy and 5.9 billion tonnes for CO₂ emissions. Meanwhile, China’s gross domestic product (GDP) was only 55.8% of US in 2013. The over-consumption of energy and related CO₂ emissions due to low energy efficiency and carbon efficiency are big challenges for China’s sustainable development, especially in the process of industrialization and urbanization (Zhu et al., 2015a).

Fig. 1 displays the historical trends of China’s energy intensity and carbon intensity in comparison with European Union (EU), US, Japan, India and world average. Here, energy intensity and carbon intensity are defined as energy consumption and CO₂ emissions per unit of GDP (Lin and Li, 2014). Although China’s energy intensity and carbon intensity are both declined dramatically in near decades, they are still quite large according to international comparison, even about 60% larger than those in India. Previous studies, such as Fan et al. (2007), Lin and Ouyang (2014), Zhu et al. (2015b), also particularly pointed out China’s large energy and carbon intensity. It is therefore urgent for China to improve energy and CO₂ emissions performance for reducing energy consumption and mitigating CO₂ emissions.

The second stylized fact is the widespread market segmentation among China’s provinces. After implementing economic reform in 1978, China has gradually become an extroverted economy through international openness, but on the domestic side, market integration has been impeded. Similar to the prisoner’s dilemma in game theory, beggar-thy-neighbour policies are quite common in each province because local governments have a clear incentive to keep their production of scarce raw materials to themselves or to prevent the
inflow of goods produced in other provinces. It is worth noting that although there is widespread local protectionism, the magnitude of market segmentation is declining and China’s regional markets are becoming more and more integrated.

The objectives of this paper are: (1) to evaluate the energy and CO₂ emissions performance of each province in China and construct regional integration indices; and (2) to use the panel data constructed in step one to investigate whether energy and CO₂ emissions performance would benefit from regional integration.

1.2. Motivation and contribution

The large and rapidly increasing energy consumption and CO₂ emissions have made energy efficiency and CO₂ emissions efficiency in China become the subjects of intense discussion. Many studies have attempted to investigate energy efficiency and CO₂ emissions efficiency in China’s regions and industries (see, Hu and Wang (2006) and Lin and Yang (2014)). However, the literature usually measures energy efficiency and CO₂ emissions efficiency separately. One of the most recent contributions to the evaluation of energy and carbon efficiency is Zhang et al. (2014), which propose two non-radical directional distance functions (NDDF) for conducting both energy and CO₂ efficiency analysis simultaneously in a single model. Lin and Du (2015) apply this method for evaluating China’s regional energy and CO₂ emissions performance. They find that China’s efficiencies in energy use and CO₂ emissions are still at the low stage in most regions.

Another strand of literature focuses on analyzing how economic factors affect energy efficiency or carbon efficiency, such as Chen and Golley (2014) and Lin and Yang (2014). However, to the best of our knowledge, the question of whether energy and CO₂ emissions performance could benefit from regional integration is still unanswered empirically.

Regional integration has positive effects on energy and CO₂ emissions performance for at least four mechanisms. First, economic unification encourages the competition among provinces, and thus enterprises have more incentives to invest in research and development (R & D) on energy efficiency. Melitz and Ottaviano (2008) develop a monopolistically competitive model to show that market size affects the toughness of competition. Grossman and Helpman (2015) also stress the importance of competition in a large scale. Second, regional integration could achieve scale economy which has been stressed by previous literature as a source of productivity growth (Tybout and Westbrook, 1995; Tybout, 2000; Biesbroeck, 2005). Third, the diffusion of technological progress and managerial experience is limited by regional barriers (Córdova and Moreira, 2003; Peluffo, 2013), while regional integration could promote performance by eliminating the barriers. Lastly, regional integration encourages specialization according to comparative advantage (Grossman and Helpman, 2015), which has been regarded as the main source of productivity growth since Adams Smith. Due to the severe of resource depletion and global warming, the productivity incorporating energy input and CO₂ emissions has become more and more important (Chen and Golley, 2014). To the best of our knowledge, there is no literature on the effect of regional integration on energy and CO₂ emissions performance.

Given the previous literatures, there are three issues to be addressed. First, most studies have conducted energy efficiency and CO₂ emissions efficiency analysis separately, but the evaluation of energy and CO₂ emissions performance in a single framework is still limited. Second, increasing regional integration is a significant trend of China’s regional economies and there is no literature studying its potential impact on China’s energy and CO₂ emissions performance. Third, the literature has shown that international openness is good for improving energy/carbon efficiencies (Taskin and Zaim, 2001; Lin and Du, 2015), but the question of whether international market could substitute domestic markets in promoting energy and CO₂ emissions performance is still unanswered.

To address the first issue, the recently developed NDDF proposed by Zhang et al. (2014) is adopted in this paper to measure China’s provincial energy and CO₂ emissions performance simultaneously. Unlike Lin and Du (2015), both the unified efficiency and energy-environmental performance of each province in China are evaluated2 in our paper. The two are applied to estimate the effects of regional integration on energy and CO₂ emissions performance to check the robustness of our results.3

To investigate the second issue, two works have been conducted: (1) we use the price approach proposed by Parsley and Wei (2001a) to construct the panel data of regional integration of provinces because price convergence is the most common indicator of market integration (Xu, 2002). (2) Local protectionism has been particularly identified by filtering the underlying effects of geography. In a country as large as

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2 The definition of the unified efficiency and energy-environmental performance are shown in Section 3.

3 The weight vector used in calculating the energy and CO₂ emissions performance might influence the results even conclusions. Thus, a sensitivity analysis using different weights is desirable to show that the weights of contraction ratios may not significantly change the efficiency scores and their relationship with regional integration.
China, geographical distance might be a reason for regional segmentation (indicated by price differences) rather than local protectionism. While at the policy level, the latter is the one that matters, after all local protectionism caused by political barriers can be eliminated but we cannot change the spatial location of each province.

In addition, to answer the final question of whether domestic market can be substituted by international market in improving energy and CO₂ emissions performance, the cross term of openness and regional integration has been included into the baseline econometric model.

The rest of the paper is organized as follows. In Section 2, we give a brief introduction to the stories of China's domestic regional integration. Section 3 describes the model specification, econometric variables and data used in this paper. In Section 4, we empirically evaluate energy and CO₂ emissions performance and regional integration and report the results. Section 5 presents further discussions on the impact of regional integration on energy and CO₂ emissions performance, and whether it could be substituted by international openness. Section 6 is conclusions and policy implications.

2. Stories of Chinese domestic regional integration

Before economic reforms in the late 1970s, China's economy has the characteristics of "cellular" structure because of its horizontal management principles. Chinese provinces are natural entities due to geographic reason and they are also social and political entities in that one geographic territory is most governed by its local authority. Notably, Maoist introverted development strategy stresses the importance of regional self-sufficiency, that is, the ability for each province or region to support itself with its own resources and productions. Therefore, the borders of the 31 Chinese (mainland) provinces segment China into so many fragmented markets (Young, 2000; Poncet, 2005).

Regional segmentation limits the potentials of scale economy, technological diffusion and regional competition, regional division is also restricted due to self-reliance. Thus, in China's incremental reforms starting in 1978, the pursuit of rapid economic development not only creates production and factor markets, but also promotes spatial integration. In after-reform China, spatial domestic market integration has been promoted alongside state withdrawal, economic transformation, and international openness.

It was widely recognized that China's international integration was a success, however, there are much concern about the degree of domestic integration among Chinese provinces. In the striking analysis by Young (2000), he argues that the process of devolution has made China's central government plan being taken up by many local government plans, and China has evolved into "a fragmented internal market with fiefdoms controlled by local officials" (Young, 2000). Contrarily, studies by Poncet (2003) and Gui et al. (2006) conclude that domestic regional integration has been increasing even though Chinese provinces are still less integrated from each other.

There are many reasons for explaining the widespread domestic regional segmentation in China. Local protectionism might be the first reason because under the stress of mutual GDP championship, local governments tend to prevent local employment and revenue goals might not be sustainable. But a typical characteristic in after-reform China is that market segmentation among provinces is a longstanding problem. As Zhang et al. (2010) reveal, most of Chinese provinces prefer to implement market segmentation. Although market segmentation leads to local enterprises unable to take advantage of domestic market, it can be achieved through stimulating export expansion of local enterprises, relying on international markets to obtain scale economies and technological spillover (Grossman and Helpman, 2015). This also explains why provinces with larger international openness are more likely to exacerbate market segmentation (Zhang et al., 2010).

3. Model specification

3.1. Non-radical directional distance function for measuring energy and CO₂ emissions performance

Data envelopment analysis (DEA) has been widely applied to evaluate energy and environmental efficiency performance (Zhou et al., 2012a, 2012b). The efficiency performance of a given decision-making unit (DMU) can be defined as its distance to the frontier (Chen and Golley, 2014). In comparison to traditional DEA types, distance function could specify desirable and undesirable outputs simultaneously, and therefore has drawn much attention.

The conventional distance function is usually based on Shephard distance function which requires that the desirable and undesirable outputs expand proportionally, and thus is limited for the measurement of energy and environmental performance, especially in considering reduction of undesirable outputs. In order to address this issue, Chung et al. (1997) propose a directional distance function (DDF) which is defined such that it is able to measure efficiency by increasing desirable outputs and reducing undesirable output simultaneously. Thus, DDF could credit reduction of undesirable outputs in particular.

Essentially, DDF is a generalized form of the Shephard distance function and is more flexible than it. As such, many studies have assessed energy and environmental performance employing DDF method. See, for example, Färe et al. (2007). Despite the aforementioned advantages, DDF is limited because it contracts undesirable outputs (inputs) and expands desirable outputs at the same rate, and thus overestimates efficiency of the assessed DMU if there are some slack resources. By incorporating slacks into the efficiency measurement, recent studies, such as Fukuyama and Weber (2010) and Barros et al. (2012), have developed the conventional DDF to non-radical DDF (NDDF) in order to eliminate the slack-bias of conventional DDF. Zhou et al. (2012a, 2012b) provide a formal definition of NDDF with desirable mathematical properties. Compared to conventional DDF, NDDF does not require the proportional adjustments of inputs, desirable and undesirable outputs, and thus has higher discriminating power than DDF.

Given the substantial advantages of NDDF, this paper employs two NDDFs proposed by Zhang et al. (2014) to measure the unified efficiency and energy-environmental performance of regions in China. Both are regarded as indicators for energy and CO₂ emissions performance. Assume that there are \( n = 1, \ldots, N \) regions to be assessed in China and each region uses input vector \( x \in \mathbb{R}^k \) to produce the desirable outputs \( y \in \mathbb{R}^l \); meanwhile, undesirable outputs \( b \in \mathbb{R}^m \) are generated as byproducts in the production process. In the present paper, the input vector contains capital (\( K \)), labor (\( L \)) and energy (\( E \)), the desirable outputs are regional GDP (\( Y \)), and CO₂ (\( C \)) is the undesirable output as the byproduct.

The production technology can be expressed as:
$T = \{(K, L, E, Y, C): (K, L, E) \text{ can produce } (Y, C)\}$

(1)

The set $T$ is often assumed to satisfy the standard axioms of production theory: (1) inactivity is always possible; (2) finite amounts of inputs can only produce finite amounts of outputs; and (3) inputs and desirable outputs are often assumed to be strongly or freely disposable. In addition, according to the joint framework proposed by Färe et al. (1989), weak disposability and null-jointness assumptions should be imposed on production technology that produces both desirable and undesirable outputs. Specifically, the two assumptions indicate that:

1. If $(K, L, E, Y, C) \in T$ and $\theta = [0, 1]$, then $(K, L, E, \theta Y, \theta C) \in T$.
2. If $C = 0$ and $(K, L, E, Y, C) \in T$, then $Y = 0$. This null-jointness condition states that desirable outputs cannot be produced without generating undesirable outputs.

As proposed by Zhou et al. (2012a, 2012b) and Zhang and Choi (2013), the NDDF can be expressed as:

$$D^*(K, L, E, Y, C; g) = \sup \{w^T \beta^* : (K, L, E, Y, C) + \text{diag}(\beta^* g) \in T\}$$

(2)

where $\beta = (\beta_K, \beta_L, \beta_E, \beta_Y, \beta_C)^T \geq 0$ is a vector of scaling factors which measures individual inefficiency for each input/output; the symbol $\text{diag}$ refers to diagonal matrices; $g = (g_K, g_L, g_E, g_Y, g_C)^T$ denotes the directional vector determining the direction of each input/output to be scaled; $w = (w_K, w_L, w_E, w_Y, w_C)^T$ is the vector of weights assigned to each input/output.

It should be pointed out that the directional vector $g$ and weight vector $w$ can be set according to the specific policy goals. In order to assess the energy and CO$_2$ emissions performance of China’s regional economies, both unified efficiency index (UEI) and energy-carbon performance index (ECPI) are employed. The former specifies the directional vector of $g$ and weight vector $w$ to be $(-K, -L, -E, Y, -C)$ and $(1/9, 1/9, 1/9, 1/3, 1/3)$, respectively. The reasons are intuitive: We first assign equal weights to inputs and desirable/undesirable outputs, i.e., $1/3$. Then, there are three inputs (capital, labor, energy), the averaged weights for the three inputs are thus set as $1/9$ (a third of $1/3$). Given no prior information, it seems more appropriate to set equal weights. Suppose that $\beta^* = (\beta_K^*, \beta_L^*, \beta_E^*, \beta_Y^*, \beta_C^*)^T$ is the solution to Eq. (2), then the UEI can be expressed as (Zhang et al., 2014):

$$\text{UEI} = \frac{1}{4} \left[ \frac{(1 - \beta_K^* + (1 - \beta_L^*) + (1 - \beta_E^*) + (1 - \beta_Y^*)}{1 + \beta_C^*} \right]$$

(3)

According to the definition in Eq. (3), the UEI is termed as the average efficiency performance of each factor. In order to evaluate pure energy and CO$_2$ performance, we do not consider the potential slacks of non-energy inputs (capital and labor), because in order to measure the performance of energy usage and CO$_2$ emission, it might be more preferred to keep other factor inputs constant. Similar specification is also employed in Zhang and Choi (2013). In this sense, the elements of non-energy inputs in the directional vector $g$ and weight vector $w$ can be set as $0$. Therefore, the directional vector $g$ is specified to be $(0, 0, -E, Y, -C)$ and the normalized equal weight vector $w$ is specified to be $(0, 0, 1/3, 1/3, 1/3)$ in the calculation of ECPI. Let $\beta^{**} = (\beta_K^{**}, \beta_L^{**}, \beta_E^{**}, \beta_Y^{**})^T$ be the solution to Eq. (2), following Zhang and Choi (2013), the ECPI can be expressed as:

$$\text{ECPI} = \frac{1}{4} \left[ \frac{(1 - \beta_K^{**} + (1 - \beta_L^{**}) + (1 - \beta_E^{**})}{1 + \beta_Y^{**}} \right]$$

(4)

Obviously, the ranges of UEI and ECPI are $[0, 1]$ by definition, and larger UEI and ECPI both indicate better efficiency performance. UEI=1 (ECPI=1) implies that all the slacks are 0 and the assessed DMU can be regarded to have the best efficiency performance. The reasons for using both the two indicators are: (1) the efficiency performance under different setup can be compared; (2) both indicators are used as dependent variable in econometric regression in Section 4 to check whether the impact of regional integration on efficiency performance is dependent on the indicators we chose.

In order to improve the comparability between different years, the global technology has been incorporated into the proposed model. In a recent study, Zhang et al. (2015) also apply global technology in evaluating ecological efficiency. According to Oh (2010), the global NDDF could be obtained by solving the following DEA-type models, and UEI and ECPI could be calculated using the solution of Eqs. (5) and (6), respectively.

For UEI:

$$D_G(K, L, E, Y, C) = \max \left\{\frac{1}{9} \beta_K + \frac{1}{9} \beta_L + \frac{1}{9} \beta_E + \frac{1}{3} \beta_Y + \frac{1}{3} \beta_C\right\} \text{ s.t.}$$

$$\begin{align*}
\sum_{n=1}^{N} \zeta_n K_n &\leq K - \beta_K S_K \sum_{n=1}^{N} \zeta_n L_n \leq L - \beta_L S_K \sum_{n=1}^{N} \zeta_n E_n \leq E - \beta_E S_K \sum_{n=1}^{N} \zeta_n Y_n \geq Y + \beta_Y S_E \sum_{n=1}^{N} \zeta_n C_n = C - \beta_E S_C \zeta_n \geq 0, \quad n = 1, 2, 3, \ldots, N \beta_K, \beta_L, \beta_E, \\
\beta_Y, \beta_C &\geq 0
\end{align*}$$

(5)

For ECPI:

$$D_G(K, L, E, Y, C) = \max \left\{\frac{1}{3} \beta_K + \frac{1}{3} \beta_L + \frac{1}{3} \beta_E + \frac{1}{9} \beta_Y + \frac{1}{9} \beta_C\right\} \text{ s.t.}$$

$$\begin{align*}
\sum_{n=1}^{N} \zeta_n K_n &\leq K \sum_{n=1}^{N} \zeta_n L_n \leq L \sum_{n=1}^{N} \zeta_n E_n \leq E \sum_{n=1}^{N} \zeta_n Y_n \geq Y + \beta_Y S_E \sum_{n=1}^{N} \zeta_n C_n = C - \beta_E S_C \zeta_n \geq 0, \quad n = 1, 2, 3, \ldots, N \beta_K, \beta_L, \\
\beta_Y, \beta_C &\geq 0
\end{align*}$$

(6)

It needs to be clarified that the DEA model used in this paper is not a cross section DEA model. The global technology contains production information from both cross section and time series dimensions (Oh, 2010). The global technology is defined as $P^G = P^1 \cup P^2 \cup \ldots \cup P^T$, and thus envelops all benchmark technologies in time dimension. Fig. 2 shows concept of global technology including both cross section and time series dimensions. The two interior sets depict the contemporaneous technologies for period $t$ and $t+1$, respectively. The exterior set is the global technology. The remaining (T-2) contemporaneous technologies are not depicted for simplicity. Here, $al$ and $a2$ are observations for a province in two periods $t$ and $t+1$, respectively. Suppose that the coordinates of $a1$ is $(C_{al}, Y_{al})$, of $a2$ is $(C_{a2}, Y_{a2})$. Similarly, the
coordinates of other points can be obtained in Fig. 2. The energy and CO₂ performance for this province in period t is \( \frac{G_i}{K_i} \) and in period t +1 is \( \frac{G_i}{K_i} \). Because global technology encompasses all benchmark technologies from t=1 to t=T, inter-temporal linkages have been incorporated in global technology used in this paper.

3.2. Measuring China’s regional integration

Another key variable of this paper is regional integration. The law of one price (PPP) or purchasing power parity (PPP) suggests that prices in each region would converge because factors, goods and services could flow across regions, and the process of arbitrage would eliminate the price differentials (Parsley and Wei, 2001b). Even considering transportation cost due to geographical distance, the price differentials should fall within a range depending on the cost of arbitrage, and thus the dispersion of price differentials should be stable.

In the real world, however, dispersions of regional price differences are usually substantial in China. Parsley and Wei (2001a) propose a useful model to investigate regional integration by studying the cross regional dispersion of price differences for each region-pair and time period. The intuition underlying Parsley and Wei (2001a) is that the small dispersion of price differentials between a region and other regions indicates that the region is more integrated with others, and vice versa. In addition, this method allows for incorporating the price information of various goods and obtaining a comprehensive indicator for regional integration. In the entire process of measuring Chinese regional integration depicted by Eqs. (7)–(11), there is no regression, but obtaining panel dataset by calculation. This method for measuring regional integration is first proposed by Parsley and Wei, (2001a, 2001b) and has been widely adopted and referenced, including Poncelet and Wei (2004), Cosar et al. (2015), Ke (2015), Elberg (2016), etc.

Suppose that \( p_{ijt}^k \) is the price of good k in region i at time t. For a given region pair \( (i, j) \) and a given good k at time t, the price difference between regions i and j could be defined as:

\[
Q_{ijt}^k = \ln(p_{ijt}^k) - \ln(p_{jkt}^k) = \ln\left(\frac{p_{ijt}^k}{p_{jkt}^k}\right)
\]

(7)

The change of price differentials can be expressed as:

\[
\Delta Q_{ijt}^k = \ln(p_{ijt}^k/p_{jkt}^k) - \ln(p_{i(t-1)}^k/p_{j(t-1)}^k) = \ln(p_{ijt}^k/p_{jkt}^k) - \ln(p_{ij(t-1)}^k/p_{j(t-1)}^k)
\]

(8)

According to Parsley and Wei (2001a), we employ the absolute value \( \Delta Q_{ijt}^k \) to measure the price dispersion. It can be easily derived from Eq. (8) that \( \Delta Q_{ijt}^k = -\Delta Q_{ijt}^k \), while bilateral price differentials measured by \( \Delta Q_{ijt}^k \) and \( \Delta Q_{ijt}^k \) should be equivalent. Hence, the strategy adopted here is to study the price dispersion using absolute value of \( \Delta Q_{ijt}^k \).

It is necessary to note that the price dispersion measured by \( \Delta Q_{ijt}^k \) is not entirely induced by regional segmentation. The price dispersion is composed of two parts: \( \Delta Q_{ijt}^k = \alpha^k + \epsilon^k \). The first part is good-specific heterogeneity. For example, the price of grain is much more easily shocked by the weather situation of particular region, which usually cause large price dispersion of grain prices. The second part \( \epsilon^k \) is the price dispersion caused by region segmentation. Without filtering the good-specific effects, it might underestimate the magnitude of regional integration. Hence, according to Parsley and Wei (2001a), prior to measuring variability, we remove the time t average price differentials \( \Delta Q_{ijt}^k \) across each region pair, for each good separately:

\[
q_{it}^k = |\Delta Q_{ijt}^k| - \bar{Q}^k_t = (\alpha^k - \bar{\alpha}^k) + (\epsilon^k - \bar{\epsilon}^k)
\]

(9)

Eq. (9) filters the good-specific effects \( \alpha^k \) from the calculation of cross regional variance. The standard deviation of \( q_{it}^k \) across goods k is the measurement of variability, that is, \( \text{Var}(q_{it}^k) \). Next, we merge the price variability in each region and then obtain the indicator for regional segmentation:

\[
\text{Var}(q_{it}^k) = \sum_{k=1}^{K} \text{Var}(q_{it}^k)/N
\]

(10)

where N is the number of province to be merged.

On the reverse side of segmentation, we define the indicator for domestic regional integration (dmainteg) as:

\[
dmainteg = \{1/\text{Var}(q_{it}^k)\}^{1/2}
\]

(11)

3.3. Econometric model, variables and data

We collect panel data set across 28 provinces in China over the period 1995–2012. In addition, data of Tibet, Chongqing and Hainan provinces are excluded due to serious data missing. For constructing the indicator of regional integration, the price indexes of 9 goods⁵ are used corresponding to available data published by the National Bureau of Statistics of China. These data are detailed three-dimensional panel data on price across each province, over 18 years, for each good.

The data on provincial desirable output (GDP), labor input, energy input are obtained from China Premium Database. Capital input data before 2007 are directly obtained from Shan (2008) and then extended to 2012 using the perpetual inventory method as described in Shan (2008). Data on GDP and capital stock have been deflated to constant price in 1995. Provincial CO₂ emissions are constructed according to Chen and Golley (2014).

The following econometric model is the basis of our empirical work for investigating the effects of regional integration on energy and CO₂ emissions performance:

\[
y_i = \beta_0 + \beta_1 \text{dmainteg} + \gamma_i + \delta_i + \epsilon_i
\]

(12)

where \( y_i \) could be either UEI or ECPI of province i in period t; the main variable of interest is \( \text{dmainteg} \), the indicator measuring regional integration; all other potential control variables are included in vector \( \gamma_i \); moreover, the \( \delta_i \)’s represent the set of province dummies and the \( \mu_i \)’s represent the set of time effects capturing common trends in (or common shocks on) the energy and CO₂ emissions performance. \( \epsilon_i \) is error term that capture all other omitted factors.

In order to control for the characteristics of each province, six control variables are included in the econometric estimation (vector \( \gamma_i \) in Eq. (12)): (1) international openness (OPEN); (2) ownership (OWN); (3) environmental regulation (REGU); (4) energy price (PRICE); (5) human capital (HMCA); (6) fiscal expenditure (FISCAL).

The reasons for controlling for these variables and their measure-

⁵The goods include: (1) grain, (2) dish, (3) beverages and tobacco, (4) clothing, (5) cultural and sports goods, (6) articles for daily use, (7) medicine, (8) newspaper and magazine, (9) fuels.
ment are as follow. Unless otherwise noted, the raw data for constructing the control variables are collected from China Premium Database.

(1) International openness (OPEN). On the one hand, international openness is beneficial for energy and/or environmental performance for several reasons, such as spillover effect, scale economy for research and development (R & D), diffusion of technology and managerial experience, see Taskin and Zaim (2001) and Lin and Du (2015). On the other hand, international openness might promote China’s energy consumption and CO₂ emissions because of China’s exporting for energy and carbon-intensive products (Wang and Watson, 2008). Foreign investments also usually focus on energy and carbon-intensive industries, such as chemical industry (Al-mulali and Tang, 2013; Lin and Sun, 2016). In this sense, international openness might also have adverse effect, which is usually termed as “pollution haven” or “pollution refuge”.

In general, there are two measures for international openness. The first measure is trade openness, and the second is foreign direct investment (FDI). Either of them might only include one aspect of international openness (Mao and Sheng, 2011). We conduct a principle components analysis (PCA) to summarize the information underlying foreign trade and FDI into a single indicator for international openness. Following Du et al. (2012), we use the sum of import and export as a share of nominal GDP to present trade openness, and the share of FDI in GDP as proxy of FDI.

(2) Ownership (OWN). According to the existing studies on privatization, the extent of ownership reform might affect efficiency (Song et al., 2011). We use the share of state-owned enterprise output in the gross output to measure the ownership in each province.

(3) Environmental regulation (REGU). On one hand, according to the Porter hypothesis proposed by Porter and Van der Linde (1995), environmental regulation could encourage innovations and thus help improve efficiency. On the other hand, several studies suggest that the diversion of resources to the required abatement of environmental regulation would increase the cost of production and lesser resources could be used for R & D. From this point, it might be harmful for energy and CO₂ emissions performance improvement. Hence, environmental regulation affects energy and CO₂ emissions performance in two opposing sides and the net effect is ambiguous. Similar to Lanoie et al. (2008), we use the ratio of investment in pollution-control to the GDP to measure the magnitude of environmental regulation.

(4) Energy price (PRICE). Generally speaking, higher energy price would induce energy consumers to decrease energy consumption and thus reduce CO₂ emissions. Due to the diversified energy resource endowments of each region and the administrative control of the Chinese government, there is substantial difference in energy price across provinces. It is thus necessary to capture the provincial heterogeneity of energy price. Data on provincial energy price for each year are not available, following Lin and Du (2015), we use the fuel price index converted to 2000 constant price as the proxy of energy price.

(5) Human capital (HMCA). Numerous studies have shown that human capital plays a key role in productivity improvement (see such as, Hall and Jones, 1999; Bowls and Robinson, 2012). Similarly, the innovation and adoption of new technology for enhancing energy and CO₂ emissions performance also depends on human capital. Referring to Hall and Jones (1999), human capital is given by \( \phi(S, t, i) \), where \( S_{ti} \) is the average years of schooling (education) of province \( i \) in year \( t \), and \( \phi(S) \) reflects the efficiency of a worker with 5 years of schooling relative to the one with no schooling (\( \phi(0) = 0 \)). The derivative \( \phi'(S) \) is the return to schooling which is obtained from the estimation in Psacharopoulos and Patrinos (2004).

(6) Fiscal expenditure (FISCAL). Government is an important partici-
According to the translation properties in Eq. (18), quadratic form is more appropriate for DDF’s parametric specification, as following:

\[ D(u_o, K_o, E_o, Y_o) \]

\[ C_0 = \beta_0 + \beta_1K_o + \beta_2E_o + \beta_3Y_o + \beta_4C_o + \beta_5[K_o \times L_o] \]

\[ + \beta_6[K_o \times E_o] + \beta_7[K_o \times Y_o] + \beta_8[K_o \times C_o] + \beta_9[L_o \times E_o] \]

\[ + \beta_{10}[L_o \times Y_o] + \beta_{11}[L_o \times C_o] + \beta_{12}[E_o \times Y_o] + \beta_{13}[E_o \times C_o] \]

\[ + \beta_{14}[Y_o \times C_o] + \beta_{15}[E_o \times Y_o] + \beta_{16}[E_o \times C_o] + \beta_{17}[Y_o \times C_o] \]

\[ + \beta_{18}[L_o \times E_o] + \beta_{19}[L_o \times Y_o] + \beta_{20}[E_o \times Y_o] + \beta_{21}[E_o \times C_o] \]

\[ + \beta_{22}[Y_o \times C_o] + \nu_2 \]

(19)

where \( \nu_2 \) is random error and \( \nu_2 \) is distributed as \( N(0, \sigma_2^2) \).

Combining properties in Eq. (18), distance function in Eq. (19) can be derived as:

\[ -C_0 = \alpha_0 + \alpha_1K_o + \alpha_2L_o + \alpha_3E_o + \alpha_4Y_o + \alpha_5C_o + \alpha_6[K_o \times L_o] \]

\[ + \alpha_7[K_o \times E_o] + \alpha_8[K_o \times Y_o] + \alpha_9[K_o \times C_o] \]

\[ + \alpha_{10}[L_o \times Y_o] + \alpha_{11}[L_o \times C_o] + \alpha_{12}[E_o \times Y_o] + \alpha_{13}[E_o \times C_o] \]

\[ + \alpha_{14}[Y_o \times C_o] + \alpha_{15}[E_o \times Y_o] + \alpha_{16}[E_o \times C_o] + \alpha_{17}[Y_o \times C_o] \]

\[ + \alpha_{18}[L_o \times E_o] + \alpha_{19}[L_o \times Y_o] + \alpha_{20}[E_o \times Y_o] + \alpha_{21}[E_o \times C_o] \]

\[ + \alpha_{22}[Y_o \times C_o] + \alpha_{23}[E_o \times Y_o] + \alpha_{24}[E_o \times C_o] + \alpha_{25}[Y_o \times C_o] \]

\[ + \alpha_{26}[L_o \times E_o] + \alpha_{27}[L_o \times Y_o] + \alpha_{28}[E_o \times Y_o] + \alpha_{29}[E_o \times C_o] \]

\[ + \alpha_{30}[Y_o \times C_o] + \nu_1 \]

(20)

where \( \nu_1 \) is distributed as \( \nu_1 \) is, therefore inefficiency is defined as \( (1 - D(u_o, K_o, E_o, Y_o, C_o)) \times C_0 \). The minimum CO2 emission in the evaluated region theoretically is \( \min CO2 = 0 \). Therefore efficiency can be defined as \( (1 - D(u_o, K_o, E_o, Y_o, C_o)) \).

The distance function is parametric. Table 2 is the ordering of each province using UEI and ECPI by time average. The results show that the orderings are quite insensitive to the change of weight specification. The correlation between orderings in UEI and that in ECPI is as large as 0.957.

4.2. Measuring regional integration

As noted above, we construct two measures of regional integration. In the first measure which is denoted as \( \text{dmininteg} \), all bilateral price comparisons are studied. There are 378 (=28 x 27/2) province-pairs, each with 18 annual time periods. Hence, for each of the 9 prices, the vector of price deviations contains 61236 observations. Merging the price deviation by province according to Eqs. (10) and (11), we could obtain a panel dataset for regional integration including 504 (=28 x 18) observations, and we denote it as \( \text{dmininteg} \).

It is worth noting that, in a country as large as China, geographical distance might be an important impediment for regional integration. For example, even facing the same artificial barriers, it is highly likely that the magnitude of regional integration between Fujian and Jiangxi (they are adjacent) is larger than that between Fujian and Xining which are thousands of miles apart. In order to filter the effects of geographical distance and particularly identify local protectionism, we pair the bilateral provinces depending on whether the two provinces are adjacent. According to this criterion, there are 59 adjacent province-pairs in our sample. We also merge the price deviation by province using Eqs. (10) and (11), and then the second measure for regional integration identifying local protectionism is constructed, which also contains 504 (=28 x 18) observations, and we denote it as \( \text{dmininteg} \).

4.3. Measuring energy and CO2 emissions performance

Taking capital, labor and energy as inputs, real GDP as desirable output and CO2 emissions as undesirable output, both UEI and ECPI are calculated across each province in China and for each year. To save space, we report the results for selected years in Table 1. Table 1 suggests that both UEI and ECPI for most of east and central provinces have improved substantially, while the performances for western provinces are ambiguous. This is consistent with the stylized fact that high energy consuming and high emitting industries in China has gradually transferred from east and central to the western region. Fig. 3 depicts the historical trends of UEI and ECPI of the national average and the three regions (east, central and west) grouped by geographical distance. Beside the dramatic improvement in both UEI and ECPI which is similar to Table 1, we also note that the performance gaps among the three regions are becoming larger. A possible interpretation for the divergence might be the effects of regional segmentation on energy and CO2 emissions performance, because intuitively the performance across regions with sufficient market integration should be convergent due to the diffusion of technology and managerial experience. To better examine the effects of regional integration on UEI and ECPI, we first construct the panel dataset of regional integration, and then formally investigate its effects on UEI and ECPI in the following sections.
Respiratory Syndrome (SARS) (2003–2004), and global financial crisis (2008). During the financial crisis of 1997 and 2008, local governments usually tend to protect local markets using artificial barriers, and in the period of the SARS, Chinese government sharply limited the flow of people and used quarantine measures to control the contagion of disease, thus regions are fragmented. Third, compared to central and western provinces, provinces in the east are less integrated. The reason for this phenomenon is that provinces located in eastern areas usually place more emphasis on international trade; while on the domestic side, interprovincial trade is only considered as residual. For province located in the interior, i.e., central and west, more emphasis is placed on interprovincial trade due to their geographical restriction to international trade or policy restriction to FDI.\(^7\) Thus, the domestic regional integration in the central and western regions is more sufficient.

![Fig. 3](image-url)  
Fig. 3. The averaged trends of energy and CO\(_2\) emissions performance.

### Table 1
Estimation of UEI and ECPI across China’s provinces.

|     | UEI       | ECPI      |
|-----|-----------|-----------|
|     | 1995      | 2000      | 2006      | 2012      | average   | 1995      | 2000      | 2006      | 2012      | average   |
| Anhui(C) | 0.548 | 0.660 | 0.786 | 1.000 | 0.749 | 0.400 | 0.553 | 0.634 | 0.851 | 0.610 |
| Beijing(E) | 0.328 | 0.466 | 0.630 | 1.000 | 0.606 | 0.294 | 0.421 | 0.618 | 1.000 | 0.583 |
| Fujian(E) | 0.955 | 0.946 | 0.990 | 1.000 | 0.973 | 0.958 | 0.898 | 0.977 | 1.000 | 0.958 |
| Gansu(W) | 0.195 | 0.224 | 0.240 | 0.310 | 0.242 | 0.229 | 0.204 | 0.237 | 0.283 | 0.238 |
| Guangdong(E) | 0.628 | 0.714 | 0.847 | 1.000 | 0.797 | 0.612 | 0.771 | 0.845 | 1.000 | 0.807 |
| Guangxi(W) | 0.576 | 0.635 | 0.659 | 0.676 | 0.636 | 0.496 | 0.655 | 0.623 | 0.652 | 0.606 |
| Guizhou(W) | 0.259 | 0.287 | 0.306 | 0.354 | 0.301 | 0.208 | 0.225 | 0.192 | 0.255 | 0.220 |
| Hebei(E) | 0.371 | 0.386 | 0.425 | 0.538 | 0.430 | 0.229 | 0.304 | 0.296 | 0.365 | 0.298 |
| Henan(C) | 0.377 | 0.435 | 0.424 | 0.524 | 0.440 | 0.316 | 0.434 | 0.394 | 0.512 | 0.414 |
| Heilongjiang(C) | 0.434 | 0.522 | 0.647 | 0.741 | 0.586 | 0.242 | 0.337 | 0.433 | 0.566 | 0.394 |
| Hubei(C) | 0.426 | 0.470 | 0.508 | 0.641 | 0.511 | 0.289 | 0.400 | 0.429 | 0.554 | 0.418 |
| Hunan(C) | 0.433 | 0.611 | 0.561 | 0.689 | 0.573 | 0.289 | 0.621 | 0.464 | 0.638 | 0.503 |
| Jilin(C) | 0.366 | 0.482 | 0.489 | 0.638 | 0.494 | 0.216 | 0.327 | 0.390 | 0.503 | 0.359 |
| Jiangsu(E) | 0.483 | 0.606 | 0.701 | 1.000 | 0.697 | 0.446 | 0.659 | 0.627 | 1.000 | 0.683 |
| Jiangxi(C) | 0.295 | 0.421 | 0.425 | 0.548 | 0.422 | 0.325 | 0.482 | 0.497 | 0.669 | 0.493 |
| Liaoning(E) | 0.585 | 0.730 | 0.962 | 1.000 | 0.819 | 0.329 | 0.487 | 0.923 | 1.000 | 0.685 |
| Inner-Mongolia(W) | 0.307 | 0.338 | 0.344 | 0.431 | 0.355 | 0.206 | 0.243 | 0.209 | 0.249 | 0.227 |
| Ningxia(W) | 0.289 | 0.318 | 0.282 | 0.307 | 0.299 | 0.166 | 0.187 | 0.149 | 0.149 | 0.163 |
| Qinghai(W) | 0.323 | 0.334 | 0.346 | 0.406 | 0.352 | 0.235 | 0.268 | 0.245 | 0.262 | 0.252 |
| Shaanxi(E) | 0.429 | 0.526 | 0.504 | 0.682 | 0.535 | 0.387 | 0.531 | 0.421 | 0.554 | 0.473 |
| Shanxi(C) | 0.244 | 0.321 | 0.344 | 0.391 | 0.325 | 0.197 | 0.141 | 0.162 | 0.195 | 0.174 |
| Shaanxi(W) | 0.278 | 0.360 | 0.340 | 0.458 | 0.359 | 0.241 | 0.378 | 0.311 | 0.386 | 0.329 |
| Shanghai(E) | 0.420 | 0.556 | 0.757 | 1.000 | 0.683 | 0.355 | 0.497 | 0.681 | 1.000 | 0.633 |
| Sichuan(W) | 0.388 | 0.526 | 0.581 | 0.830 | 0.581 | 0.226 | 0.469 | 0.460 | 0.673 | 0.457 |
| Tianjin(E) | 0.422 | 0.516 | 0.766 | 1.000 | 0.676 | 0.256 | 0.390 | 0.531 | 1.000 | 0.544 |
| Xinjiang(W) | 0.315 | 0.339 | 0.345 | 0.382 | 0.345 | 0.202 | 0.244 | 0.241 | 0.204 | 0.223 |
| Yunnan(W) | 1.000 | 1.000 | 0.917 | 1.000 | 0.979 | 1.000 | 1.000 | 0.834 | 1.000 | 0.958 |
| Zhejiang(E) | 0.612 | 0.649 | 0.714 | 0.944 | 0.730 | 0.537 | 0.651 | 0.660 | 0.893 | 0.690 |
| east | 0.523 | 0.609 | 0.730 | 0.916 | 0.695 | 0.442 | 0.561 | 0.658 | 0.881 | 0.636 |
| central | 0.390 | 0.490 | 0.523 | 0.647 | 0.513 | 0.284 | 0.412 | 0.425 | 0.561 | 0.421 |
| west | 0.393 | 0.436 | 0.436 | 0.515 | 0.445 | 0.321 | 0.387 | 0.350 | 0.411 | 0.367 |
| average | 0.439 | 0.513 | 0.566 | 0.696 | 0.554 | 0.354 | 0.456 | 0.481 | 0.622 | 0.478 |

Note: E, C and W in parentheses denote the east, central and west, respectively.

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\(^7\) An interesting characteristic of China’s reform, which is usually named as incrementalism, is that they often start reform with experimentation at the local level, and gradually introduced to the entire nation if the local experiment is succeed. Special economic zones (SEZs) located in the east are the main areas that experiment for international openness, which have authorized less restrictions on international trade and attracting FDI. An interesting and detailed discussion on China’s gradual transition could be seen in Brandt and Rawski (2008).
Table 2
Ordering of each province.

| Province  | Rank in UEI | Rank in ECPI | Province  | Rank in UEI | Rank in ECPI |
|-----------|-------------|--------------|-----------|-------------|--------------|
| Anhui(C)  | 5           | 9            | Jiangxi(C)| 19          | 12           |
| Beijing(E)| 11          | 10           | Liaoning(E)| 3           | 4            |
| Fujian(E) | 1           | 1            | Inner-Mongolia(W)| 22 | 25 |
| Gansu(W)  | 28          | 24           | Ningxia(W)| 27          | 28           |
| Guangdong(E)| 4          | 3            | Qinghai(W)| 23          | 22           |
| Guangxi(W)| 10          | 7            | Shandong(E)| 15          | 14           |
| Guizhou(W)| 26          | 26           | Shanxi(C) | 25          | 27           |
| Hebei(E)  | 19          | 21           | Shaanxi(W)| 21          | 20           |
| Henan(C)  | 18          | 17           | Shanghai(E)| 8           | 8            |
| Heilongjiang(C)| 12          | 18           | Sichuan(W)| 14          | 15           |
| Hubei(C)  | 16          | 16           | Tianjin(E)| 9           | 11           |
| Hunan(C)  | 13          | 13           | Xinjiang(W)| 24          | 23           |
| Jilin(C)  | 17          | 19           | Yunnan(W) | 2           | 2            |
| Jiangsu(E)| 7           | 6            | Zhejiang(E)| 6           | 5            |

Note: The scores of UEI and ECPI are both averaged by time.

dminteg_inter and dminteg_intra. Two features stand out. First, the distributions have shifted to the right side which indicates the provincial markets are becoming more integrated. This is consistent with Fig. 4. Second, there are several outliers in the left side of the distributions as the fat tailed density. For example, due to its special political status as China’s capital, Beijing is more politically segmented.

The results of this study are quite robust whether using UEI or ECPI. Moreover, filtering geographical distance would not change our conclusion that regional integration significantly contributes to the improvement of energy and CO2 emissions performance, as the coefficients only decrease by less than 30%. This indicates that more than 70% of the effects are caused by artificial barriers (such as local protectionism), rather than geographical distance.

For the control variables, several results can be drawn from Table 4. (i) In all models, the coefficients of fiscal expenditure are negative which imply that government spending would lead to the distortions of resource allocation and thus reduce energy and CO2 emissions performance. (ii) The share of SOE has positive effects on energy and CO2 emissions performance. Usually, privatization is considered to enhance efficiency improvement because private sector has more incentives to improve efficiency due to competition. But for energy and CO2 emissions performance, it might not be the case. Facing the government’s requirement of energy conservation and CO2 mitigation, political pressure makes state-owned enterprise to have more incentive to achieve the requirement. (iii) The effects of fuel price on energy and CO2 emissions performance are ambiguous and statistically insignificant. This might be indicative of the administrative control on energy prices (Lin and Li, 2014). This is because compared with the product markets, factor markets in China are still distorted and the prices of energy are controlled even decided by the Chinese government. (iv) The coefficients of environmental regulation are significantly negative. As discussed above, environmental regulation has two opposing effects. The results imply that its net effect contributes to more energy use and CO2 emissions because the diversion of resources to the required abatement might reduce the resources that could be used for R & D. (v) Human capital promotes energy and CO2 emissions performance which is consistent with our expectations.

In particular, Table 4 suggests that international openness helps to
enhance energy and CO₂ emissions performance. We would further discuss it and its interaction with regional integration in Section 5.2.

In order to evaluate the robustness of our results in Table 4, three alternative estimations are adopted. The first one is alternative method proposed by Simar and Wilson (2007). Recently, Tobit regression in DEA related two-stage studies has been critical due to the possibility of

![Empirical density functions of market integration.](image1)

![Regional integration and energy and CO₂ emissions performance.](image2)
The effect of regional integration on energy and CO2 emissions performance.

|                | UEI     | ECPI    | UEI     | ECPI    |
|----------------|---------|---------|---------|---------|
| (1) dminteg_inter | 0.0339*** | 0.0424*** | (2.42) | (2.13) |
| (2) dminteg_intra | 0.0234*** | 0.0386*** | (2.56) | (2.82) |
| FISCAL | -0.264*** | -0.457*** | -0.253*** | -0.434*** |
| OWN | 0.236*** | 0.199*** | 0.226*** | 0.185*** |
| REGU | -0.0173*** | -0.0218*** | -0.0172*** | -0.0215*** |
| PRICE | 0.0490 | -0.0559 | 0.0413 | -0.0675 |
| OPEN | 0.0411*** | 0.0244*** | 0.0403*** | 0.0233*** |
| HMCA | 0.0035*** | 0.00420*** | 0.0035*** | 0.0041*** |
| _cons | -0.223 | 0.0120 | -0.157 | 0.0835 |
| province FE | Yes | Yes | Yes | Yes |
| year FE | Yes | Yes | Yes | Yes |
| N | 504 | 504 | 504 | 504 |

Note: * t statistics in parentheses, ** p < 0.1, *** p < 0.01.

Serial correlation. To solve this problem, Simar and Wilson (2007) propose a bootstrapped truncated model. Many studies have applied this approach, such as Choi et al. (2012), Barth et al. (2013). The results using method proposed by Simar and Wilson (2007) are shown in Table 5. It further supports our results that China’s energy and CO2 emissions performance benefits from regional integration.

Second, we exclude the outliers in regional integration in the sample by excluding all provinces above the 95th percentile and below the 5th percentile. The results in Table 6 are robust to this trimming methodology, which also suggest that regional integration enhance energy and CO2 emissions performance.

Third, another issue which needs to be addressed is the possibility of reverse causality which might lead to endogeneity and thus estimation bias. Reverse causality means that the improvement in efficiency might in turn encourage regional integration. In general, energy and environment efficiency is also a kind of competitiveness, provinces that perform more efficiently in energy use and CO2 emissions might have fewer incentives to implement regional segmentation because they might be more competitive than other provinces and thus domestic openness would not substantially threaten their internal markets. We propose the instrumental variable method to address the issue of reverse causality. Similar to Lin and Du (2015), the lag terms of regional integration are employed as the instrumental variables. The intuition underlying this strategy is similar to the idea of General Moment Method (GMM) for dynamic panel model. The results as shown in Table 7 using instrumental variable method are also similar to those in Table 4 which further support the robustness.

5.2. The substitutability of regional integration and international integration

The results in Table 4 and the robustness check in Tables 5–7, all suggest that international openness enhances energy and CO2 emissions performance. Recall that, the positive effects of regional integration on energy and CO2 emissions performance are based on four reasons, i.e., (i) the increased competition encourages enterprises to invest in energy efficiency R & D; (ii) the expanded markets achieve scale economy; (iii) lowered barriers lead to technological diffusion; and (iv) comparative advantage through specialization. Provinces with more international openness might have achieved the four mechanisms through international markets, which means that international integration could substitute domestic integration in terms of energy and CO2 emissions performance. We formally examine this hypothesis in
between regional integration and international openness has been unanswered by previous literature relates to whether the expansion of domestic markets by regional integration can be substituted by international openness. We show that domestic markets are unsubstitutable in terms of energy and CO2 emissions performance.

6. Conclusion and policy implication

Does regional integration have a positive causal effect on energy and CO2 emissions performance? This paper shows that the answer to this important policy question is yes and the results are quite robust. Particularly, we filter the underlying contamination of geographical distance in measuring artificial barriers. Another issue that was unanswered by previous literature relates to whether the expansion of domestic markets by regional integration can be substituted by international openness. We show that domestic markets are unsubstitutable in terms of energy and CO2 emissions performance.

The main findings of this paper can be summarized in the following points:

- Most provinces did not perform efficiently in terms of energy use and CO2 emissions, although the performance has improved substantially. The performance gaps among regions have become larger indicating that the performance is divergent across provinces. This is indicative of regional segmentation because in a sufficiently integrated market, the performance should be convergent due to technological diffusion.
- In general, the magnitude of regional integration has increased dramatically which might be the result of the central government’s strive for prohibiting local protectionism. At the local level, provinces located in the eastern areas are less integrated on the domestic side, which might be explained by their convenience to international openness due to geographic location and preferential policies.
- Regional integration has significant and quantitatively substantial positive effects on energy and CO2 emissions performance, and the results are quite robust to alternative indicators, samples and methods. In addition, over 70% of the effects are attributed to artificial barriers, rather than geographical distance.
- International openness (or named as international integration) is also beneficial for promoting energy and CO2 emissions performance. However, this cannot substitute domestic regional integration because of China’s specialization in energy-intensive manufacturing in the global economy (by exporting energy-intensive commodities in trade openness or becoming "pollution refuge" in FDI openness).

The theory of trade implies that free trade would increase the economic welfare for both sides of trade, especially in a unified nation like China (Yin, 2004). Our results suggest that regional integration is also beneficial for energy and CO2 emissions performance. Other measure such as political requirement for energy-saving and pollution mitigating is usually achieved at the cost of growth, while regional integration might be a way for promoting energy and CO2 emissions performance and stimulating the economy at the same time. Given that local governments have incentives to fragment, as for policy implication,

### Table 8
The substitution between international and domestic markets.

|                | (1) | (2) | (3) | (4) |
|----------------|-----|-----|-----|-----|
|                | UEI | ECPI| UEI | ECPI|
| dminteg_inter  | 0.0350** | 0.0434** | (2.50) | (2.19) |
| cross_inter    | -0.00881* | -0.00863* | (-1.72) | (-1.19) |
| dminteg_intra  | 0.0248*** | 0.0374*** | (2.71) | (2.90) |
| cross_intra    | -0.00778* | -0.00633* | (-1.93) | (-1.11) |
| OPEN           | 0.0799*** | 0.0614* | (3.52) | (1.93) |
| province FE    | Yes | Yes | Yes | Yes |
| year FE        | Yes | Yes | Yes | Yes |
| N              | 504 | 504 | 504 | 504 |

Note: t statistics in parentheses.
* $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

this section.

Consider the following econometric model:

$$y_t = \beta_0 + \beta_1 \text{dminteg}_{it} + \text{dminteg}_{it} \times \text{Open}_{it} + Z_{it}' \beta_4 + \mu_i + \delta_t + \epsilon_{it} \tag{21}$$

Compared with Eq. (12) in Section 3.3, the interaction term between regional integration and international openness has been included. Thus,

$$\partial y_t / \partial \text{dminteg}_{it} = \beta_1 + r \times \text{Open}_{it} \tag{22}$$

Given that $\beta_1 > 0$, if $r$ is significantly negative, provinces that are more extroverted would be less affected by regional integration. Table 8 reports the estimation results for the substitutability between international and domestic sides. What we are particularly interested in are the coefficients of the interaction terms, cross_inter and cross_intra. Columns (1)–(4) in Table 8 suggests that the coefficients of the interaction terms are quantitatively small (from $-0.0063$ to $-0.0088$) and statistically insignificant or only significant at the 10% level. The results imply that regional integration on the domestic side cannot be substituted by international integration in improving energy and CO2 emissions performance.

Furthermore, if the effects of regional integration on energy and CO2 emissions performance could be substituted by international openness, the regression results of the baseline model as described in Eq. (12) should be substantially decreased if we only use the subsample of provinces above the 50th percentile on international openness. The results of the estimation using the subsample above the 50th percentile are shown in Table 9. The coefficients of regional integration are quite similar to those in Tables 4–6. Thus, the results in Table 9 further reject the hypothesis of substitutability between regional integration and international integration.

### Table 9
The results using subsample of provinces above 50th percentile on international openness.

|                | (1) | (2) | (3) | (4) |
|----------------|-----|-----|-----|-----|
|                | UEI | ECPI| UEI | ECPI|
| dminteg_inter  | 0.0446  | 0.0437  | (2.06) | (1.32) |
| dminteg_intra  | 0.0336*  | 0.0446**  | (2.35) | (2.05) |
| OPEN           | 0.0258**  | 0.00441  | (4.37) | (0.49) |
| province FE    | Yes | Yes | Yes | Yes |
| year FE        | Yes | Yes | Yes | Yes |
| N              | 252 | 252 | 252 | 252 |

Note: t statistics in parentheses. * $p < 0.1$.
** $p < 0.05$.
*** $p < 0.01$.

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tion, the central government needs to continuously encourage regional integration. As noted above, the eastern provinces have even more incentives for regional segmentation on the domestic side because they can turn to international markets to export their products and attract FDI. However, domestic regional integration cannot be substituted for international openness in terms of energy and CO2 emissions performance. Thus more attention should be paid to eastern provinces to promote regional integration.

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