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Will regional economic integration influence carbon dioxide marginal abatement costs? Evidence from Chinese panel data

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With frequent trade and technology diffusion, the barriers between regions are gradually weakening, and regions have become more integrated over recent years. Regional economic integration not only stimulates labour mobility, but also achieve scale economy, both of which may also influence carbon dioxide (CO\textsubscript{2}) marginal abatement costs through affecting energy consumption, CO\textsubscript{2} emissions, productivity growth, and technical progress. Nevertheless, to the best of our knowledge, none of the studies has currently concerned the influence of regional economic integration on CO\textsubscript{2} marginal abatement costs. To fill this research gap, this study first theoretically clarifies the influence mechanism of regional economic integration on CO\textsubscript{2} marginal abatement cost, and then empirically attempts to investigate their relationship in the context of China, with panel data models. To serve this purpose, the provincial CO\textsubscript{2} marginal abatement cost and regional economic integration are estimated by parametric directional distance function and price-based approach, respectively. The results show that China’s regional economic integration level indeed gradually improved over 2002–2011 except in 2003–04 and 2006–09 due to the spread of Severe Acute Respiratory Syndrome (SARS) and the sub-prime loan crisis. Moreover, evolution of regional economic integration indeed contributes to the increase of CO\textsubscript{2} marginal abatement cost at 5% significance level. Using robust tests, it can be found that the results are also reliable and robust to sub-samples.

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1. Introduction

Regional economic integration (REI) has been an inevitable trend within the context of the rapid economic development and frequent economic trade over recent years, leading to the integration of several economies, such as the formation of the North America Free Trade Area, the European Union, and Asia-Pacific Economic Cooperation Organisation. Nevertheless, there is no unified definition of REI in academia thus far, even though some studies have attempted to investigate this issue (Auer, 2005; Hans et al., 2003). For instance, Hans et al. (2003) defines REI as a procedure by which states within a given region increase their level of collaboration with respect to political, economic, security, and socio-cultural issues. Auer (2005) notes that REI implies a removal of barriers to free trade in the region, growing the free movement of people, labour, goods, and capital across states. In general, there are five levels, beginning from a free trade area, to customs union, common market, economic union, and finally political union in the evolution of REI (Ester, 2013).

The evolution of REI in 31 provinces in Mainland China also experiences a similar process from relatively low to high similar to other countries in recent years. Being an agricultural country, given China’s economic reform before 1978, provinces could always be self-sufficient, i.e., a province always supports itself with its own resource and products (Li and Lin, 2017). The level of REI was relatively low as each province is a relatively complete industrial system (Ke, 2015). After 1978, the new market economy encouraged economic cooperation among provinces and flow of goods, and therefore regional barriers were gradually weakening, which led to an increase of regional economic integration levels, such as that seen in the Beijing-Tianjin-Hebei area, and Yangtze River Delta. The integration of regions not only accelerates the flow of production factors, management, and technology but also stimulates the mobility of labour and capital, according to the
career construction theory (Corse and Rehfluss, 2011). For example, 8.2 million people flow into Beijing in 2015, accounting for about 37.9% of her permanent population (BSY, 2016), and 9.8 million did likewise, a share of 40.6% in Shanghai (SSY, 2016).

Currently, several studies have attempted to investigate REI and its corresponding influences on labour and capital mobility (Berkowitz and Dejong, 2003; Xu and Voon, 2003). Berkowitz and Dejong (2003) assess the evolution of REI within Russia during 1995–1999 and explore potential determinants of this evolution. The study finds a strong negative correspondence between openness to international trade and internal economic integration. Similarly, Xu and Voon (2003) gauge the degree of China’s regional integration using a statistical model, and the results show that China is relatively integrated across provinces and the level of integration has increased over time. Meanwhile, several studies explore the impact of REI on the mobility of labour and capital, investment, and trade (Behrens et al., 2007; Ester, 2013; Kumar et al., 2014; Schöb and Wildasin, 2007). Ester (2013) investigates the relationship between REI and professional labour mobility within the context of the African community. Kumar et al. (2014) analyses the capital mobility caused by regional economic integration within four regional economic communities in Africa. Behrens et al. (2007) investigates the impact of regional economic integration on trade and finds that the benefits of integration come as trade barriers fall; however, to the best of current knowledge, no study has investigated the influence of REI on CO2 marginal abatement cost (MAC). With increasingly serious climate change, MAC of CO2 emissions, measuring the economic loss of reducing an additional unit of CO2 emissions, are intensively discussed over the past decades with a bottom-up approach (Vaillancourt et al., 2008), macroeconomic approach (Minihan and Wu, 2012; Zhang and Polener, 1998), and an efficiency analysis approach (Choi et al., 2012; Du and Mao, 2015; Färe et al., 2006; Lee and Zhang, 2012; Lee and Zhou, 2015; Leleu, 2012; Tang et al., 2016; Wang and He, 2017a, 2017b). Among these studies, some prefer to evaluate the value of MAC of CO2 emissions at national, regional, and industrial levels (Lee and Zhou, 2015; Wei et al., 2013), while some focus on the dynamic relationship between MAC and CO2 abatement to provide wider application to energy and environmental policy-making (Müller and Tol, 2013; Gao et al., 2016; Du et al., 2015b).

Meanwhile, some are interested in investigating the determinants of MAC, which includes industrial structure, energy consumption structure, and urbanisation level (Du et al., 2015b). For a firm, the age, scale, and location are the determinants of MAC (Wei et al., 2013) however, the influence of REI on MAC has been ignored to investigate. In fact, REI has a significant effect on the key parameters used in MAC estimation. On the one hand, the mobility of labour and capital caused by REI will not only contribute to gross domestic product (GDP) growth from the perspective of the production side, according to the Cobb-Douglas production function, but also increase the local energy consumption, and therefore CO2 emissions and environmental pressure, which may influence the MAC of CO2 emissions. On the other hand, technological progress benefitting from REI will also have an impact on local production and carbon emissions technology, which is conducive to the improvement of productivity and carbon emissions efficiency, both of which will affect CO2 marginal abatement costs (Wang and He, 2017b).

Based on these important recognition, this study will first investigate the impact of REI on MAC of CO2 emissions in the context of China with panel data models. To serve this purpose, the provincial CO2 marginal abatement costs incurred during 2002–2011 are firstly evaluated with a parametric directional distance function (PDDF) model. Secondly, following the approach of Parsley and Wei (2001), a regional economic integration index is constructed using a price-based approach considering the stylised fact that the dispersion of price differentials will be gradually weakening by the evolution of regional economic integration (Li and Lin, 2017; Parsley and Wei, 2001; Xu, 2002). Finally, a panel data model with 30 cross-sections and 10 periods is established. In addition to empirical results, robustness tests are conducted through the use of a resampling, and different regional economic integration indexes. The study could provide important insights about the determinants of CO2 marginal abatement cost change.

The remainder of the study is organised as follows: Section 2 includes the theoretical directional distance models for marginal abatement cost estimation and construction of REI index with a price-based approach; Section 3 summarises the data sources; the empirical results, and their robustness testing, are shown in Section 4, and Section 5 concludes the study.

2. Theoretical framework

In this Section, the theoretical framework and specific models are established. Before deriving the measures of REI and MAC, Section 2.1 first elaborates the mechanism of influence of REI on MAC from several important perspectives, which is the theoretical basis of this study. Then Sections 2.2 and 2.3 introduce the measures of MAC, and REI, respectively.

2.1. Mechanism of influence of REI on MAC

There is no doubt that the evolution of REI has considerable effects on labour and capital mobility, investment, as well as the CO2 marginal abatement cost. Based on previous studies, REI could influence the MAC of CO2 emissions via the following mechanisms (see Fig. 1). Firstly, the evolution of REI stimulates the mobility of labour and capital across different regions (Ester, 2013; Kumar et al., 2014), which may influence the MAC of CO2 emissions from both production, and consumption sides. On the one hand, the mobility of labour will influence the amount of energy consumption, and therefore CO2 emissions. On the other hand, labour mobility will also influence local labour input. Proper labour input increases are conducive to regional GDP growth; however, labour mobility may also result in congestion of labour input considering the unbalanced level of economic development, which may worsen productivity and GDP growth (Sueyoshi and Goto, 2016). Therefore, labour mobility may lead to both positive and negative influences on input-output indicators. If the positive influence is greater than the negative influence, then labour mobility may lead to an increase of MAC and vice versa. Secondly, the evolution of REI is conducive to achieving a certain scale economy, which is regarded as an important source of productivity growth in many studies (Wang and Feng, 2015; Li and Lin, 2017). The achievement of scale in an economy contributes to productivity growth, which would influence the MAC of CO2 emissions. Thirdly, the evolution of REI encourages competition among regions, which accelerates technological progress and the improvement of management as enterprises have more incentive to invest in R&D aimed at improving technology and management (Ke, 2015; Li and Lin, 2017). Finally, regional economic integration encourages specialisation according to comparative advantage theory (Grossman and Helpman, 2015; Li and Lin, 2017). In the process of REI, the firms tend to have more opportunities to choose collaborative partners with relatively low opportunity cost, which urges firms to promote their technology and management to achieve specialisation to decrease their opportunity cost. Specialisation, a source of productivity growth, could also influence the MAC of CO2 emissions.

Nevertheless, regional economic integration is just a small part of the sources of CO2 marginal abatement cost change, and the main components are technological progress and adjustment of economic structure. With the progress of production and CO2 technology, the potential of CO2 emissions reduction would gradually decrease, directly resulting in higher marginal abatement cost, vice versa and regional economic integration merely accelerates this process. Another main component is the adjustment of economic structure. In general, heavy industries are always typified as high energy consumption and CO2 emissions, low efficiency (Wang and Feng, 2015; Wang et al., 2017). High emission with low efficiency always results in great potential of
CO₂ abatement, and therefore the marginal abatement cost is relatively low. With the adjustment of economic structure, the share of heavy industries is falling, and that of the tertiary industry is increasing. As a consequence, the marginal abatement cost of CO₂ emissions also changes accordingly. In empirical study, we also take technology progress and adjustment of economic structure into consideration.

2.2. Derivation of pollutant marginal abatement costs

As discussed above, a PDDF model is established to derive the MAC of CO₂ emissions. Assume that there are \( K \) decision making units (DMU) and \( T \) periods and each DMU employs \( N \) identical inputs \( \{(x_t, y_t, u_t, g_t, -g_t)\} \) to produce \( M \) desirable outputs \( \{(y_t, y_t, u_t, g_t, -g_t)\} \) as well as \( L \) by-products \( \{(u_t, g_t, -g_t)\} \). Accordingly, environmental production technology, considering various such environmental factors, can generally be defined as:

\[
P(x) = \{ (y, u) | x \in \mathbb{R}^{N \times 1}, y \in \mathbb{R}^{L \times 1} \}
\]

In general, the generalised environmental production technology (1) is assumed to be convex, conical, and weakly disposable (Leleu, 2012; Wang and He, 2017a; Xie et al., 2017). Based on environmental production technology (1), the input-oriented Shephard distance function, \( S^i = \inf \{ \alpha | (y, u) \in P(\alpha x) \} \), serves to minimise inputs with fixed outputs under that environmental production technology, and was widely used to derive the MAC of pollutants. However, as the Shephard distance function could only optimise one of the inputs and outputs, failing to optimise multiple items, the directional distance function was accordingly proposed by Chung et al. (1997), explicitly expressed as:

\[
D^f(x, y, u, g, -g) = \sup \{ \beta : (y + \beta g, u - \beta g) \in P(x) \}
\]

where, \( g = (g, -g) \) is a direction vector associated with outputs and by-products and \( \beta \) is an adjustment coefficient. As shown in (2), direction distance function serves to maximise outputs and minimise by-products at the same time with fixed inputs under environmental production technology \( P(x) \). In other words, the directional distance function (2) measures the distance between a DMU and its projection on a frontier along direction vector \( g \). A smaller \( \beta \) implies a better production performance of the evaluated DMU, or vice versa. In particular, \( \beta = 0 \) implies that the DMU is on the frontier. According to Färe et al. (2006) and Wei et al. (2013), the directional distance has following properties: i) convexity; ii) non-negativity, i.e., for all \( (x, y, u) > 0, D^f(x, y, u, g, -g) \geq 0 \), equivalently, \( D^f(x, y, 0; g, -g) < 0 \); iii) monotonicity, specifically, the \( D^f(x, y, u, g, -g) \) monotonically decreases with respect to inputs and by-products and monotonically increase with respect to outputs; iv) translation property, i.e., for any \( \alpha \in \mathbb{R}, D^f(x, y + \alpha g, u - \alpha g; g, -g) = D^f(x, y; g, -g) - \alpha \) holds.

Suppose that the observed marker price of the ith desirable output equals its absolute marginal cost \( p_i \) according to directional distance function (2), then the MAC of the jth undesirable output could be derived as:

\[
q_j = -p_i \frac{\partial D^f(x, y, u, g, -g)}{\partial y_j} \quad j = 1, 2, ..., I;
\]

To estimate the MAC of CO₂ emissions empirically, we should first estimate the directional distance function (2). Currently, several approaches have been widely used to characterise the directional distance function such as the non-parametric approach with no specific function form (Leleu, 2012), and a parametric approach with trans-log function or quadratic forms (Färe et al., 2006; Wei et al., 2013). This study used the following quadratic function to characterise the directional distance function (Färe et al., 2006):

\[
\bar{D}^f(x, y, u, g, -g) = \alpha_0 + \sum_{n=1}^{N} \alpha_n^x x_n + \sum_{m=1}^{M} \beta_m y_m + \sum_{l=1}^{L} \gamma_l u_l + \frac{1}{2} \sum_{n=1}^{N} \sum_{m=1}^{M} \alpha_{nm} x_n x_m + \frac{1}{2} \sum_{m=1}^{M} \beta_{mn} y_m y_m + \sum_{n=1}^{N} \sum_{m=1}^{M} \alpha_{nm} x_n y_m + \sum_{n=1}^{N} \sum_{l=1}^{L} \gamma_{nl} x_n u_l + \sum_{m=1}^{M} \sum_{l=1}^{L} \beta_{ml} y_m u_l
\]

(4)

In model (4), the directional vector is chosen as \( g = (1, -1) \) to expand outputs and contract by-products spontaneously. Currently, an optimisation method, similar to the idea of ordinary least squares in econometrics, is widely used to estimate the parameters in (4). Following the manner in Färe et al. (2006); Wei et al. (2013); and Du et al. (2015b), the optimisation model used to estimate the coefficients in (4) could be expressed as:

\[
\min \left[ \sum_{n=1}^{N} \sum_{m=1}^{M} \sum_{l=1}^{L} \bar{D}^f(x, y, u; g, -g) \right]
\]

(5)

s.t. \( D^f(x, y, u; g, -g) \geq 0, k = 1, 2, ..., N; T = 1, 2, ..., T \);
\[
\frac{\partial D}{\partial \theta_{k}}(x_i, y_i, u_i; I, 1, -1) \geq 0, k = 1, 2, ..., K, t = 1, 2, ..., T; l = 1, 2, ..., L;
\] (5.4)

\[
\sum_{m=1}^{M} \beta_{m} - \sum_{l=1}^{L} \gamma_l = -1; \sum_{l=1}^{L} \gamma_l = \sum_{m=1}^{M} \varphi_{mi}, l = 1, 2, ..., L;
\] (5.5)

\[
\sum_{m=1}^{M} \beta_{mm} = \sum_{m=1}^{M} \varphi_{mi}, m = 1, 2, ..., M; \sum_{m=1}^{M} \delta_{mn} = \sum_{l=1}^{L} \eta_n, n = 1, 2, ..., N;
\] (5.6)

\[
\alpha_{mi} = \alpha_{mi} \cdot n \cdot \eta_n / \beta_{mm} \cdot n \cdot m \cdot m^2 / \gamma_l.
\] (5.7)

As shown above, the objective function of the model (5.1–5.7) serves to maximise the sum of the directional distance functions of each DMU in each period. The constraints (5.1) mean that all directional distance functions should be non-negative; constraints (5.2–5.4) capture the monotonicity assumption of the directional distance function, which is assumed to be monotonically decreasing for inputs and by-products and monotonically increasing with respect to desirable outputs, while the constraints (5.5–5.7) are a translation property. Once model (5) has been solved, the marginal abatement cost of the \( j \)th product could be estimated by:

\[
q_j = -p_i \frac{\gamma_j + \sum_{l=1}^{L} \gamma_l y_{il} + \sum_{n=1}^{N} \eta_n y_{in} + \sum_{m=1}^{M} \varphi_{mi} y_{im}}{\beta_j + \sum_{m=1}^{M} \beta_{mm} y_{im} + \sum_{n=1}^{N} \delta_{mn} y_{in} + \sum_{l=1}^{L} \varphi_{li} y_{il}}.
\] (6)

2.3. Measure of regional integration

The previous studies have documented several fundamentally different approaches, such as the traditional gravity model, econometric models, and price approaches to measuring economic regional integration, (Li and Lin, 2017; McCallum, 1995; Xu, 2002); however, as the gravity model ignores region-specific characteristics that affect trade, it also attracts some criticism from studies (Baldwin, 2003; Ke, 2015). Considering data availability, this study chose a price-based approach to construct REI index. In general, as suggested by the law of one price (POP), the dispersion of the price differentials of the goods across the regions will tend to be stable with the evolution of regional economic integration. In other words, the prices of goods in different regions will converge with the evolution of regional economic integration level as the production factors, goods, technology, and management flow across the regions. Based on this important fact, Ke (2015) and Parsley and Wei (2001) constructed a comprehensive index incorporating price information about various goods, to measure the level of REI with a price approach. Similarly, this study will also construct a regional economic integration index by incorporating price information about eight diversified goods items, covering several categories to reduce the error of estimation.

Firstly, let the price of goods be \( k \) in region \( i \) at time \( t \) and denote this by \( P(i, t, k) \). Then for a given region pair \( (i, j) \) and a given item of goods \( k \) at time \( t \), according to Parsley and Wei (2001), the common currency percentage price difference \( Q_{ij}^{pk} \) could be defined as:

\[
Q_{ij}^{pk} = \ln P(i, t, k) - \ln P(j, t, k)
\] (7)

As we are only concerned about the dispersion of price differentials in this study, Eq. (8) uses the absolute value to measure the dispersion following the method proposed by Li and Lin (2017). A stylised fact is that the dispersion of price differentials with respect to the goods \( k \) defined in (8) is not completely caused by regional segmentation but also goods-specific characteristics. Therefore, as suggested in Li and Lin (2017), filtering these additional factors could better estimate the regional economic integration. By Li and Lin (2017), the dispersion of price differentials is divided into two parts: \( \Delta Q_{ij}^{pk} = \Delta r + \Delta \bar{Q}_{ij}^{pk} \). The first part is a goods-specific heterogeneity, while the second part is caused by regional segmentation. To remove the goods-specific heterogeneity, a new dispersion index is defined by minus the average dispersion of price differentials across all province-pairs \((i, j)\) at time \( t \) on the basis of Eq. (8):

\[
R_{Sij} = |\Delta Q_{ij}^{pk} - \frac{1}{S} \sum_{j(i) \neq i} |\Delta Q_{ij}^{pk} - \bar{Q}_{ij}^{pk} | | - \bar{Q}_{ij}^{pk}
\] (9)

where, \( \bar{Q}_{ij}^{pk} \) is the mean of \( \Delta Q_{ij}^{pk} \) with respect to province pair \((i, j)\), and \( S \) represents the total of province-pair. After removing the goods-specific heterogeneity, we use the standard deviation of dispersion index \( R_{Sij} \) across item of goods \( k \), \( \text{Var}(R_{Sij}) \) to measure the fluctuation of price differentials of goods \( k \). Next, the regional segmentation based on variable variability in each region could be expressed as \( \text{Var}(R_{Sij}) = \sum_{j(i) \neq i} \text{Var}(R_{Sij}^{pk}) \), where \( N \) is the number of regions to be merged. Based on Li and Lin (2017), the regional economic integration index in region \( i \) at time \( t \) can be defined as:

\[
\text{REI}_i = \frac{1}{\sqrt{\text{Var}(R_{Sij})}}
\] (10)

A larger REI implies a narrow dispersion of price differentials, and a high level of regional economic integration of region \( i \) with the other \( N - 1 \) regions, and vice versa.

3. Variables and data

This study chose the 30 provinces in Mainland China within the period of 2002–2011 as study samples, excluding Tibet due to the availability of data. According to their location and level of economic development, 30 provinces are divided into eastern, central, and western areas, where the eastern area consists of Beijing, Tianjin, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Fujian, Shandong, Guangdong, and Hainan, and the central area includes Shanxi, Jilin, Heilongjiang, Anhui, Jiangxi, Hunan, Hebei, and Henan. The other 11 provinces (Inner Mongolia, Guizhi, Chongqing, Sichuan, Guizhou, Yunnan, Shaanxi, Gansu, Qinghai, Ningxia, and Xinjiang) form the western area.

When estimating the CO2 marginal abatement cost, according to Leleu (2012) and Wei et al. (2013), we assume every province employs fossil energy \( x_1 \), capital stock \( x_2 \), and labour \( x_3 \), to generate GDP \( y \) and by-product CO2 emissions \( u \). The data pertaining to fossil fuel-based energy consumption (measured as a coal equivalent), are extracted from the China Energy Statistical Yearbook (NBSC, 2012b), while the data for labour and GDP are derived from the China Statistical Yearbook (NBSC, 2012a, 2012c). The capital of each province was calculated by \[ x_2^t = x_2^{t-1} + I^t \], where \[ x_2^{t-1} \] and \[ x_2^{t-1} \] are the capital stock of region \( i \) in period \( t \) at time \( t - 1 \), respectively (Choi et al., 2012; Wang and He, 2017b); \[ I^t \] is the investment of region \( i \) at time \( t \) and \( I^t \) represents the rate of depreciation thereof. The data of investment are from China Statistical Yearbook (NBSC, 2012a) and were converted to 2000 constant price. As CO2 emissions account for a large share of greenhouse gas, this study only covers CO2 emissions and excludes other greenhouse gas. Since no official data are issued, the data for CO2 emissions were
estimated thus (IPCC, 2006): 
\[ C_h = \sum_l E_{l,h} \times CF_h \times CC_h \times COF_h \times 3.67, \]
where \( C_h \) are the CO2 emissions of the \( h \)th type of energy consumption of the \( h \)th DMU, and \( E_{l,h} \) represents the \( l \)th type of energy consumption of the \( h \)th DMU. In addition, \( CF_h \), \( CC_h \), and \( COF_h \) are the average net caloric value, the carbon content, and the carbon oxidation factor, respectively. 3.67 is the mass ratio of CO2 to C. It is worth mentioning that this study only covers the energy-related CO2 emissions following the manner in Du et al. (2015a) and Wei et al. (2013), considering its very large share and difficulty in evaluating non-energy CO2 emissions. The descriptive statistics pertaining to the aforementioned data are summarised in Table 1.

Currently, China Statistical Yearbook only issues the price index of 16 kinds of goods, covering foods, cigarettes and wine, clothing, textiles, office supplies, fuel, magazines and publications etc. To estimate the REI index accurately, considering the data availability, consistency and diversity of goods, eight kinds of goods covering several categories are considered: grains, cigarettes and wine, commodities, medicines, domestic appliances, fuels, newspapers and magazines, and cosmetics. All of the prices of these goods are extracted from the China Statistical Yearbook (NBSC, 2003a, 2003b, 2003c).

4. Empirical study

Based on these theoretical models, the provincial CO2 emissions marginal abatement cost, regional economic integration and their correlation will be empirically investigated in this Section within the context of China. The marginal abatement costs are run in Lingo11 software, while the relationship between marginal abatement cost and regional integration is investigated by panel data model in Eviews8.

4.1. Estimation of provincial marginal abatement costs

In empirical study, to expand GDP and contract CO2 emissions as far as possible, the directional vector of directional distance function in this Section is chosen as \( g = (1, -1) \). To overcome the convergence problem when solving model (5), all the inputs and outputs are normalised by dividing them by their mean value, respectively, (Färe et al., 2006).

The parameter estimation of the directional distance function is summarised in Table 2. Using estimated coefficients and Eq. (6), we estimate the provincial CO2 marginal abatement costs during 2002–2011, where the actual price of GDP is assumed to be 1 (\( p_i = 1 \)) following the approach of Du et al. (2015a).

Fig. 1 shows the average CO2 marginal abatement cost of each province during 2002–2011 with the colour of each province on a map of China. A deeper colour represents a higher marginal abatement cost, while a lighter colour implies a lower cost. As shown in Fig. 2, Beijing, Jiangsu, Zhejiang, Guangdong, and Shanghai, with relatively high economic levels of development, have higher marginal abatement cost, and specifically, a cost of more than RMB 300 will be incurred per additional unit of CO2 emissions abatement. Similarly, other eastern provinces, for instance, Tianjin, Jilin, Fujian, and Shandong, have a relatively high marginal abatement cost. While turning attention to the Central and Western provinces with relatively less developed economies, it could be found that their marginal abatement costs are significantly lower than those of the eastern provinces, especially for some western provinces, such as Gansu, Qinghai, Ningxia, Inner Mongolia, etc., with less than RMB 100 marginal abatement cost. With higher production technology and more developed economies, scholars agree that China’s eastern provinces would suffer more cost per additional unit of CO2 emissions reduction relative to less developed provinces in the west and in central China (Choi et al., 2012; Du et al., 2015b).

To capture further the cost difference among three areas, Fig. 3 illustrates the average CO2 marginal abatement costs of these areas in each period. Firstly, with the passage of time, the average marginal abatement cost of three areas all consecutively rises from 2002 to 2011. In accordance with macroeconomic theory, technological progress inevitably occurs over time, which certainly leads to higher CO2 marginal abatement costs. Secondly, CO2 marginal abatement costs in eastern areas are higher than those in central and western areas: differing from many previous studies which conclude that western provinces had the lowest marginal abatement costs, this study finds that the average abatement cost of central provinces is first slightly lower than that of western provinces before 2009, and then higher thereafter. Although this finding was unexpected, it is, nonetheless, explicable. Du et al. (2015a) found that a significant U-shaped relationship exists between carbon intensity and CO2 marginal abatement cost. It specifically concluded that when the carbon intensity is relatively low (less than 6 ton/RMB 10,000), the marginal abatement cost will decrease with increasing carbon intensity; however, after exceeding 6 ton/RMB 10,000, the marginal abatement cost will also increase with increasing carbon intensity. Here, it is well known that western provinces have the largest

| Variables | Coefficients | Values | Variables | Coefficients | Values |
|-----------|--------------|-------|-----------|--------------|-------|
| \( \alpha_i \) | -0.02348 | \( x_1^2 \) | \( \alpha_{13} \) | -0.09682 |
| \( x_1 \) | 0.03202 | \( y^2 \) | \( \gamma_{11} \) | -0.20222 |
| \( x_2 \) | 0.77695 | \( \gamma_{12} \) | \( \eta_{11} \) | 0.03123 |
| \( y \) | -0.86261 | \( x_{22} \) | \( \delta_{21} \) | 0.40619 |
| \( u \) | 0.13739 | \( u^2 \) | \( \gamma_{21} \) | 0.01000 |
| \( x_1^2 \) | -0.05989 | \( x_{31} \) | \( \delta_{31} \) | 0.03123 |
| \( x_1x_2 \) | 0.00285 | \( x_{32} \) | \( \delta_{32} \) | 0.40619 |
| \( x_1x_3 \) | -0.01053 | \( x_{33} \) | \( \gamma_{31} \) | 0.01000 |
| \( x_2^2 \) | -0.82196 | \( yu \) | \( \theta \) | -0.20222 |
| \( x_2x_3 \) | 0.00102 |

Table 1

| Variables | Unit | Statistics |
|-----------|------|------------|
|           |      | Maximum    | Minimum  | Mean   | Std. Dev | a |
| Energy    | Mtec | -1001.6    | 371.4   | 99.1   | 68.7     | |
| Capital   | Billion RMB | -1001.6    | 7914.0  | 1621.0 | 1408.0   | |
| Labor     | Million people | -1001.6    | 60.4    | 22.2   | 14.9     | |
| GDP       | Billion RMB | -1001.6    | 3470.8  | 722.1  | 648.8    | |
| CO2       | Million ton | -1001.6    | 988.8   | 221.7  | 163.0    | |

\( a \) Std.Dev = standard deviation.

\( b \) Mtec = million ton of equivalent coal.

Fig. 2. Average CO2 marginal abatement cost of each province in 2002–2011 (unit: Yuan/ton).
carbon intensity among all provinces, followed by central provinces, and eastern provinces, resulting in the highest CO2 marginal abatement cost falling of the eastern provinces, followed by that on the central provinces. If the carbon intensity of western provinces was too high, its marginal abatement cost may also be higher than that of central provinces according to their U-shaped relationship.

Recently, there have been many studies concerning on China’s CO2 marginal abatement cost at provincial-, industrial-, city-, and firm-level. Fig. 4 summarises these results in comparison with the results of this study. The results are significantly related to the estimation approaches. The results of Du et al. (2015a) range from RMB 100/ton to about RMB 5800/ton, while those of Choi et al. (2012) range from RMB 3/ton to about RMB 100/ton. The marginal abatement costs estimated by this study lie in the middle of these results, ranging from RMB 40–1200/ton, and most of the costs were between RMB 100–300/ton. Therefore, the results of this study are more reliable and could reflect the real cost of CO2 abatement.

4.2. Estimation of regional economic integration

As discussed in Section 2, this study measures regional economic integration by the dispersion of price differentials of eight goods among different provinces. In Eq. (8), \( P(i,t,k)/P(i,t−1,k) \) actually represents the price index of goods \( k \) in province \( i \) between period \( t \) and \( t−1 \). Therefore, 2400 original data points were collected from consideration of eight types of goods in 30 provinces from 2002 to 2011. With frequent trade, the flow of goods actually happens between any two provinces today. Therefore, 423 \((30 \times 29/2)\) province-pairs with eight types of goods over 10 years generate 33,840 observations. By means of Eqs. (9) and (10), the panel data of regional economic integration with 30 provinces and 10 periods are generated. It should be noted that, while constructing this REI index, the other factors influencing the dispersion of price differentials, such as good-specific heterogeneity, have been filtered out.

Fig. 5 shows the average regional integration of eastern, central, western, and the whole country during 2002–2011. Generally, regardless of sub-area, or the whole country, their level of REI has gradually improved with the passage of time. This phenomenon is explained as follows: with the development of China’s economy and transportation systems, trade activities have become more frequent. For instance, people in Beijing could buy bananas produced in Hainan, and raisins produced in Xinjiang could be traded to Shanghai, Guangdong, etc. The frequent flow of various goods among different provinces prevents the dispersion of price differentials, resulting in the evolution of regional economic integration.

Nevertheless, the average scores of regional integrations present a rapid decline during two periods (2003–04 and 2006–09). Combining this with the social and economic environment prevailing at those times, the decline of regional integration in these two periods could also be interpreted: in 2003, the Severe Acute Respiratory Syndrome (SARS) spread throughout the country, while the sub-prime loan crisis began in the USA, also affecting China, in 2008. In these two periods, many relevant trading activities had to be canceled, and the flow of goods was not as frequent as before, resulting in a decline in REI. The results of this study are similar to those of Li and Lin (2017), regarding the trends therein, even though the absolute regional integration in this study differs from that of Li and Lin (2017), due to the different selection of types of goods.

4.3. The influence of regional economic integration on marginal abatement cost

As discussed in Section 2.1, the regional integration could affect CO2 marginal abatement cost in several ways. Here, the impact of regional integration on CO2 marginal abatement cost will be investigated by panel data models, as it is appropriate to capture individual heterogeneity. Mathematically, the panel data model can be expressed by:

\[
MAC_i = \alpha_0 + \beta_1 \text{REI}_i + \beta_2 Z_{it} + \mu_i + \lambda_t + \xi_{it} \tag{11}
\]

where \( MAC_i \) and \( \text{REI}_i \) represent the CO2 marginal abatement cost and regional economic integration of region \( i \) in period \( t \), respectively. \( Z_{it} \) represents several control variables, \( \mu_i \) and \( \lambda_t \) represent time, and individual, effects, respectively, while \( \xi_{it} \) are error terms.

4.3.1. Selection of control variables

In Section 2.1, the influence mechanisms of regional economic integration on CO2 marginal abatement cost have been discussed. In addition to regional economic integration, other control variables that may potentially influence marginal abatement cost, were also selected as follows:

(i) CO2 emission intensity (CAR_INT).

As discussed in Section 2.1, technological progress is actually the main sources of CO2 marginal abatement cost change. In empirical study, CO2 emissions intensity (CO2 emissions per unit of GDP), is chosen to measure the technology according to the following reasons. In general, with the progress of production, and carbon emissions...
4.2.1. Input factors

(ii) Environmental regulation (EN_REGU)

Environmental regulation refers to a series of policies aimed at controlling environmental pollution. Severe environmental regulation urges firms to increase environmental governance investment and optimise their production technology as far as possible to obtain more revenue. Environmental regulation thus encourages innovation and improves productivity (Porter et al., 1995), both of which will influence the CO₂ marginal abatement cost. Meanwhile, increased environmental regulation may lead to the dispersion of resources and reduce investment in R&D, and thus represent an opponent of technical progress (Li and Lin, 2017). Environmental regulation was measured by the ratio of environmental-control investment to GDP, extracting the data from China Environmental Statistical Yearbook, by Li and Lin (2017).

(iii) Economic structure (ECO_STR)

Economic structure of emitters is another main source of CO₂ marginal abatement cost change. Heavy industries, always typified as high energy consumers, pollutant emitters, and being of low emissions efficiency, always tend to have higher CO₂ emissions intensity and obsolete CO₂ emissions technology, relative to primary and service industries, and therefore the share of heavy industry certainly have a significant effect on the marginal abatement cost. Here the share of heavy industry in the total output for each province is used to quantify the level of economic structure in each province (Du et al., 2015a).

(iv) Level of urbanisation (URBAN)

With the rapid development of the economy, urbanisation has increased over last decade, resulting in increased energy consumption and CO₂ emissions (Karathodorou et al., 2010), which may also affect marginal abatement costs by changing carbon emissions levels. This study uses the proportion of urban population to total population as a proxy for the level of urbanisation. Relevant data are extracted from China Population and Employment Statistics Yearbook (NBSC, 2003a, 2003b, 2003c).

(v) Energy mix (EN_MIX)

Different energy types are always different in terms of their net calorific value, carbon content, and carbon oxidation factor (Du and Mao, 2015), which results in different CO₂ emissions when burning a unit of coal, oil, and gas. Furthermore, the relevant study showed that the marginal abatement cost of CO₂ from coal burning also differ from that of CO₂ emissions from the burning of oil and gas. Consequently, the energy mix may be another factor influencing marginal abatement costs. In accordance with Du et al. (2015a), the share of coal consumption to total energy consumption is used to proxy for the energy mix. Relevant data are extracted from the China Energy Statistical Yearbook.

4.3.2. Regression results

Fig. 6 depicts the scatter diagram between regional economic integration and CO₂ marginal abatements costs across provinces. The
left one presents the original relationship between regional economic integration and MAC of CO2 emissions, in which it can be easily found the existence of heteroscedasticity. In the theory of econometrics, the logarithmic form of variables could effectively overcome the defect of heteroscedasticity, and therefore the relationship between the logarithmic REI and MAC is shown in the right diagram in Fig. 6. As shown in the two scatter diagrams, a province with a higher regional integration level always tends to have a higher CO2 marginal abatement cost. Furthermore, the relationships tend to be different in different provinces, i.e., individual heterogeneity prevails.

Next, an econometric approach, panel data models is applied to investigating the specific quantitative correlation between regional economic integration and CO2 marginal abatement cost as it provides a more convenient way to examine the individual and time individual effects (Wooldridge, 2015). The better to search for an optimal model, the method of adding control variables one-by-one is followed (Du et al., 2015a) (Table 3).

In general, Hausman test should be applied to determining whether the effects of individuals and time are fixed or random. Nevertheless, this study directly employs the fixed effects models of individual and time to estimate the regression Eq. (11). The reasons are two-fold. On the one hand, as the sample periods in this study are not enough long, random effect model is easy to ensure the effectiveness of estimation, but difficult to guarantee the consistency of estimation. On the contrary, the fixed effect model could better guarantee the consistency. On the other hand, in the theory of econometrics, consistency of estimation is a more important principle in relative to effectiveness of estimation, particularly in the relatively small sample estimation. In addition, as regional economic integration is actually correlated to the position, economic level of the provinces, fixed effect model is indeed a more appreciate approach. A similar manner could also be found in Du et al. (2015a, 2015b) and Hao and Peng (2017).

Following the estimation approach of fixed effect models, the regression results, as well as the values of the Akaike Information Criterion (AIC) and adjusted $R^2$, are summarised in Table 4. The AIC index is a widely used model section criterion as the best control variables cannot be pre-determined before regression. Smaller values for AIC are preferred since their calculation is based on the in-sample fitness of the regression (Du et al., 2015a, 2015b). Adjusted $R^2$ measures the goodness of data fitting.

Without including any control variables in model 1, we find that the coefficient of ln(ln(REI)) is not significant, which implies that regional economic integration cannot totally interpret the increase of marginal abatement cost of CO2 emissions. By controlling variables CO2 emissions intensity, urban level, composition of industry, environmental regulation and energy consumption structure in Models 2 to 6, the regression coefficients of ln(ln(REI)) is significantly positive at 5% significance level, which imply that the evolution of regional economic integration partially contributes to the increase of MAC of CO2 emissions. In addition, these models also show a relatively stable relationship between regional economic integration and marginal abatement cost as the coefficients of ln(ln(REI)) in Models 2 to 6 ranged from 0.203 to 0.224. Therefore, we can conclude that the evolution of REI indeed contributes the increase of CO2 marginal abatement cost. In the process of regional economic integration, goods, labour, capital, advanced technology, and management philosophy flow among provinces. Meanwhile, the evolution of REI stimulates the reallocation of resource and energy, which is conducive to the improvement of carbon emissions efficiency. Consequently, the evolution of REI contributes to the improvement of carbon emissions efficiency and technological progress, resulting in the increase of MAC of CO2 emissions. Earlier studies have shown a positive relationship exists between CO2 emissions performance and marginal abatement cost, while Li and Lin (2017) also conclude that CO2 emissions performance benefits from the evolution of regional economic integration. These two important conclusions could also provide indirect evidence for the results of this study.

In addition to regional economic integration, the impact of other control variables on marginal abatement cost could also be found in

| Table 3 | Specific control variables setting of every model. |
| --- | --- |
| Dependent variable | Independent variable | Control variables |
| **Ln(MAC)** | **Ln(Ln(REI))** | **CAR_INT** | **URBAN** | **EN_REGU** | **ECO_STR** | **EN_MIX** |
| **Model 1** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Model 2** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Model 3** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Model 4** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Model 5** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Model 6** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |

Note: **EN_REGU**$^2$ = **EN_REGU**$^*$ **EN_REGU**.

* ✓ refers to the included variables.

| Table 4 | Regression results of Model 1-Model 6. |
| --- | --- |
| Dependent variable: **LN (MAC)** | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 |
| **CONST** | 5.208*** (0.06) | 5.748*** (0.11) | 5.171*** (0.29) | 5.155*** (0.29) | 5.808*** (0.38) | 5.736*** (0.41) |
| **LN(LN(REI))** | −0.068 (0.09)* | 0.224** (0.10) | −1.869*** (0.34) | −1.829*** (0.34) | −1.631*** (0.73) | −1.572*** (0.35) |
| **CAR_INT** | 1.608*** (0.74) | 1.528*** (0.74) | 2.176*** (0.77) | 2.095*** (0.78) | 2.176*** (0.77) | 2.095*** (0.78) |
| **URBAN** | 0.137 (0.11) | 0.132 (0.11) | 0.135 (0.11) | 0.132 (0.11) | 0.135 (0.11) | 0.132 (0.11) |
| **EN_REGU**$^2$ | 0.057*** (0.03) | 0.059*** (0.03) | 0.059*** (0.03) | 0.059*** (0.03) | 0.059*** (0.03) | 0.059*** (0.03) |
| **EN_MIX** | −0.173 (0.34) | −1.180*** (0.47) | −1.220*** (0.45) | −1.523*** (0.36) | −1.572*** (0.35) | −1.523*** (0.36) |
| **ECO_STR** | −0.04 | −0.15 | −0.16 | −0.18 | −0.20 | −0.20 |
| **AIC** | 0.89 | 0.90 | 0.90 | 0.91 | 0.91 | 0.91 |

| **EN_REGU**$^2$ = **EN_REGU**$^*$ **EN_REGU**. |

* Significant at 10% level.
** Significant at 5% level.
*** Significant at 1% level.

Standard errors shown in brackets.
in Section 2.1 and 4.3.1, technological progress is one of the main sources of MAC increase. The significant positive coefficient indicates that the positive influence is greater than the negative influence. Therefore, the increase in environmental regulation may affect MAC positively or negatively. The significantly positive coefficient indicates that the positive influence is greater than the negative influence. The increase in environmental regulation will induce an increase in MAC. It is worth mentioning that the square of environmental regulation significantly contributes to MAC of CO2 emissions, which indicates that the influence of environmental regulation on MAC will be larger and larger with the increase of share of environment control investment.

On the contrary, the coefficients of the carbon intensity, and industrial structure are negative at the 1% or 5% significance level, ranging from $-1.869$ to $-1.523$, and $-1.220$ to $1.180$ respectively. As discussed in Section 2.1 and 4.3.1, technological progress is one of the main sources of marginal abatement cost change, and CO2 emissions intensity reflects the technology level to some extent. Negative coefficient of CO2 emissions intensity at 1% significant level provides the strong evidence that technological progress is one of the main sources of MAC increase. As another main source of marginal abatement cost change, economic structure also negatively influences the marginal abatement cost of CO2 emissions according to the regression results. With the increase of share of heavy industry, typified as high emissions and low efficiency, CO2 abatement potential increases and therefore the marginal abatement cost of CO2 emissions falls. Note that in our results, energy consumption structure doesn’t significantly influence the MAC of CO2 emissions. The main reason is that the dependent variable is the logarithm of MAC to overcome the heteroscedasticity. According to the last two rows of Table 6, Model 6 is the best model regarding choice of control variable and data fitting.

It is worth noting that regional economic integration presents a downturn over the two periods, while the MAC of CO2 emissions increases steadily over the sampled periods. The phenomenon is easy to understand: in our opinion, regional economic integration is not the only reason for the increasing MAC. The main reason for the increasing MAC is technical progress, including the application of energy conservation and carbon abatement technology, which improve the carbon emissions efficiency and reduce the potential for carbon abatement. Regional economic integration just accelerates technical progress. Overall, these key findings suggest that regional economic integration should be further encouraged, as it actually stimulates the decrease of potential for CO2 abatement, and technological progress.

### 4.3.3. The robustness check

Considering the fact that different choices of goods in Section 4.2, may generate different regional economic integration level, this Section will conduct the robustness check of the results, which involves the measure of regional economic integration and their impact on marginal abatement cost of CO2 emissions.

#### 4.3.3.1. The robustness of REI measure

In Section 4.2, we have employed the price index of eight goods to measure the regional economic integration level. Considering the fact that different choices of the goods may potentially influence the regional economic level, in this Section, we construct another eight kinds of regional economic integration indexes (REI1, REI2, ..., REI8) by employing the price information of different goods combinations to confirm the robustness of the measure.1

### Table 5

| Dependent variable: LN (MAC) | Models | Subsamples |
|-----------------------------|--------|------------|
| | Model 6.1 | Model 6.2 | Model 6.3 | Model 6.4 | Model 6.5 | Model 6.6 | Model 6.7 | Model 6.8 |
| CONST | 5.744*** (0.41) | 5.757*** (0.11) | 5.790*** (0.41) | 5.761*** (0.29) | 5.738*** (0.41) | 5.746*** (0.41) | 5.743*** (0.41) | 5.759*** (0.41) |
| LN(LN(REI)) | 0.193* (0.10) | 0.188* (0.10) | 0.204* (0.10) | 0.190* (0.09) | 0.193* (0.11) | 0.193* (0.11) | 0.188* (0.11) | 0.199* (0.11) |
| CAR_INT | -1.494*** (0.36) | -1.483*** (0.36) | -1.526*** (0.36) | -1.497*** (0.36) | -1.471*** (0.36) | -1.470*** (0.36) | -1.456*** (0.36) | -1.484*** (0.36) |
| URBAN | 2.102*** (0.78) | 2.090*** (0.79) | 2.075*** (0.78) | 2.089*** (0.78) | 2.124*** (0.78) | 2.095*** (0.79) | 2.126*** (0.79) | 2.093*** (0.79) |
| EN_REGU | 0.059** (0.03) | 0.060** (0.03) | 0.059** (0.03) | 0.060** (0.03) | 0.059** (0.03) | 0.059** (0.03) | 0.059** (0.03) | 0.059** (0.03) |
| EN_REGU | -0.132 (0.11) | -0.137 (0.11) | -0.133 (0.11) | -0.134 (0.11) | -0.133 (0.11) | -0.136 (0.11) | -0.133 (0.11) | -0.134 (0.11) |
| ECO_STR | -1.193** (0.47) | -1.203** (0.47) | -1.183** (0.47) | -1.204** (0.47) | -1.211** (0.47) | -1.207** (0.47) | -1.218** (0.47) | -1.205** (0.47) |
| EN_MIX | -0.170 (0.34) | -0.169 (0.34) | -0.168 (0.34) | -0.171 (0.34) | -0.172 (0.34) | -0.168 (0.34) | -0.171 (0.34) | -0.168 (0.34) |

Note: The definition of variables and significance level are same as Table 4.

### Table 6

| Dependent variable: LN (MAC) | Models | Subsamples |
|-----------------------------|--------|------------|
| | Subsample 1 | Subsample 2 | Subsample 3 | Subsample 4 |
| CONST | 5.736*** (0.41) | 5.724*** (0.39) | 5.418*** (0.39) | 5.724*** (0.41) |
| LN(LN(REI)) | 0.205* (0.10) | 0.209* (0.10) | 0.209* (0.09) | 0.202* (0.10) |
| CAR_INT | -1.523*** (0.36) | -1.514*** (0.35) | -1.484*** (0.34) | -1.460*** (0.37) |
| URBAN | 2.095*** (0.78) | 1.504*** (0.78) | 1.964*** (0.76) | 1.748*** (0.82) |
| EN_REGU | 0.059** (0.03) | 0.057** (0.03) | 0.056** (0.03) | 0.058** (0.03) |
| EN_REGU | -0.132 (0.11) | -0.171 (0.11) | -0.168 (0.11) | -0.163 (0.12) |
| IND_STR | -1.180* (0.47) | -0.633 (0.46) | -1.040** (0.46) | -0.633 (0.46) |
| MIX | -0.173 (0.34) | -0.248 (0.34) | -0.184 (0.33) | -0.169 (0.36) |

Note: The definition of variables and significance level are same as Table 4.

---

1 REI is measured by the price index of grains, cigarettes and wine, medicines, domestic appliances, fuels, newspapers and magazines, and office supplies; REI2 includes grains, cigarettes and wine, cosmetics, medicine, clothing and shoes, domestic appliances, fuels, newspapers and magazines, and office supplies; REI3 includes grains, cigarettes and wine, cosmetics, medicine, clothing and shoes, commodities, domestic appliances, fuels, and office supplies; REI4 includes grains, cigarettes and wine, cosmetics, medicines, clothing and shoes, domestic appliances, fuels, and office supplies; REI5 includes grains, cigarettes and wine, cosmetics, clothing and shoes, commodities, domestic appliances, fuels, and newspaper supplies; REI6 includes grains, cigarettes and wine, cosmetics, clothing and shoes, commodities, domestic appliances, fuels, and newspaper supplies; REI7 includes grains, cigarettes and wine, medicines, clothing and shoes, commodities, domestic appliances, fuels, and newspaper supplies; REI8 includes grains, cigarettes and wine, cosmetics, medicines, clothing and shoes, commodities, domestic appliances, fuels, and office supplies.
Fig. 7 depicts the kernel density curves of eight new regional economic integration indexes and original one in Section 4.2. According to Fig. 7, it can be easily found that nine kinds of regional economic integration indexes almost follow the same kernel density distribution, from which we could conclude that the measure of regional economic integration is robust.

Furthermore, to more specifically capture the differences of eight kinds of regional economic integration, Fig. 8 also shows the boxplots of these indicators in 2002, 2005, 2008, 2011, respectively. Taking 2002 as an example, even though their maximum, minimum, 25 percentage quantiles and 75 percentage quantiles are not totally same, but their differences are slight. For instance, the maximum of REI8, the largest one among these indicators, is just 0.2 greater than that of REI 2, the smallest maximum of these indicators. Moreover, these indexes in other years also follow this phenomenon. Therefore, we could conclude that the measure of regional economic integration is robust to the choice of goods, even though slight differences exist among them.

4.3.3.2. The robustness of regression results. Currently, many approaches are used to test the robustness of such results including using an alternative approach to estimate the results, resampling and so on (Lin and Du, 2015). In this Section, we firstly would like to employ the eight new regional integration indexes replace the original index in Section 4.3 to check whether the new indexes would also influence marginal abatement cost of CO2 emissions. And then we will check whether the results are also robust to the subsamples.

We firstly use eight new indexes constructed in Section 4.3.3.1 to check the influence of regional economic integration on marginal abatement cost of CO2 emissions, and regression results are summarised in Table 5. Model 6.1–6.8 use eight new regional economic integration indexes (REI1, REI2, ..., REI8) to replace REI index in model 6, respectively. As shown in Table 5, it can be easily found that all of the regional economic integrations in model 6.1–6.8 positively influence the marginal abatement cost of CO2 emissions at 5% or 10% significance level, even though the price index of several different goods are used to construct the regional economic integration index. Consequently, these results reveal that the influence of regional economic integration on marginal abatement cost is robust to the choice of goods. Next, we will also check whether the results are robust to the subsamples. Here, we construct four subsamples by excluding some years and some outliers.
Specifically, subsample 1 and 2 excludes year 2011 and 2010, while subsample 3 and subsample 4 exclude the outliers above 95th percentile and below the 5th percentile in terms of average regional economic integration across provinces. The regression results are presented in Table 6. It can be easily found that the coefficients of regional integration are positive at the 5% significance level, and they are also close to those of the full sample. There is no doubt that these results reveal the robust positive influence of regional economic integration on marginal abatement cost of CO2.

5. Conclusions and policy implications

5.1. Conclusions

Under the background of frequent trade and blurring of barriers among regions, this study empirically investigates whether regional economic integration affects the CO2 marginal abatement cost or not, in the context of China. To serve this purpose, a parametric distance function model was used to estimate the CO2 marginal abatement costs in 30 provinces between 2002 and 2011. Then the level of regional integration was estimated by a price-based approach. Finally, a series of panel data models were constructed to investigate the impact of regional integration on marginal abatement cost. The main results may be summarised as follows:

i) CO2 marginal abatement costs vary by region. On average, these of eastern areas with higher-level-economies, are the highest, at approximately RMB 300–400/ton, followed by those in central areas. Some western areas have the lowest CO2 marginal abatement cost at less than RMB 100/ton. Although varying greatly, the CO2 marginal abatement costs of most provinces present an upward trend from 2002 to 2011, which implied a certain technical progress in these provinces in the sample periods.

ii) As expected, the regional integration of China shows an upward trend in 2002–2011 with the exception of 2003–2004 and 2006–2009 due to the spread of the SARS virus in 2003 and the effects of the American sub-prime loan crisis in 2008. Moreover, regional integration also exhibits regional differences.

iii) The evolution of regional economic integration indeed contributes to the increase of CO2 marginal abatement cost at the 5% significance level, as regional economic integration accelerates the labour mitigation, technological progress. Furthermore, the results are robust to the choice of sub-sample and several new regional economic integration measured by the price index of different goods.

5.2. Policy implications

CO2 marginal abatement cost is key to policy-making with regards carbon abatement, such as in the setting of CO2 reduction targets, implementation of a nationwide carbon trading system, etc. Based on this study, some important policy implications arise. Firstly, implementation of a CO2 trading system is beneficial for the improvement of the cost-effectiveness of CO2 abatement in China. According to the study, CO2 marginal abatement costs range from 40 to 1200 RMB/ton among 30 provinces, therefore a nationwide carbon trading system is conducive to reducing the total abatement cost considering regional differences in MAC. Nowadays, a nationwide CO2 trading system is conducive to the flow of technology.

The results of the study could provide a more detailed reference for formulating specific provincial carbon price regimes, considering the reliability of the results compared to these of earlier studies. Thirdly, although regional economic integration contributes to the increase in CO2 marginal abatement cost, Local Government should also encourage, and accelerate, the evolution of regional economic integration. The main reason is that an increase in CO2 marginal abatement cost implies an increase in CO2 emissions efficiency, more reasonable resource allocation, and technical progress, therefore regional economic integration actually accelerates technological progress and increases the potential reduction in CO2 emissions. In particular, western, and central, provinces should accelerate the evolution of regional economic integration through more cooperation with other regions, trade, and the flow of technology.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2018.06.010.

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