Spatial Differentiation of Carbon Emission Efficiency of "Silk Road Economic Belt" based on Environmental Regulation

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Abstract. The construction of the “Silk Road Economic Belt” may bring about a new round of carbon emission growth, and the dual control of total energy consumption and intensity should be strengthened. In this study, the SE-SBM model considering undesirable output was adopted to measure the carbon emission effects of 9 core provinces and regions in the economic belt from 2006 to 2016, and the panel threshold model was adopted to estimate the carbon emission effect under environmental regulation. The results showed that the overall carbon emission efficiency in the economic belt showed a U-shaped trend, with provinces such as Sichuan and Chongqing showing higher efficiency, Gansu and Guangxi showing a larger decline. When the per capita GDP was <10700.01, environmental regulation showed a significant negative effect; when per capita GDP was >47192.96, environmental regulation showed a significant positive effect; energy structure and foreign direct investment had a significant negative effect; technological innovation had a significant positive effect; urbanization, industrialization and opening-up had not passed the significance test. China should adhere to green and low-carbon development, formulate appropriate environmental regulation intensity, select reasonable environmental policy tools, develop and utilize clean energy, guide FDI to low-carbon environmental friendly industries, and strengthen technological innovation and application transformation.

1. Introduction
According to the latest World Energy Data Yearbook, the total energy-related carbon emissions in 2017 increased by 1.6% compared with 2016, breaking the basically steady zero growth in 2013-2016, while China alone increased its total carbon emissions in 2017 by 119 million tons. Under the background of the overall economic downturn in the world and the slowdown of China's economic growth, the “Silk Road Economic Belt” initiative can create a new engine for China's economic growth and boost China's industrial transformation and upgrading. However, most of its routes are emerging economies and developing countries, and the construction of core provinces in the economic belt is also faced with the historical task of development and opening-up, which will inevitably lead to a new round of growth in carbon emissions and aggravate energy shortage and environmental pollution caused by industrialization and industrial transfer. The “13th Five-Year Plan “has clearly proposed the implementation of dual-control actions such as energy and water resources consumption, construction land, etc. If the path...
chosen and the policies implemented are appropriate, it will instead promote the transformation of China's economic development mode towards green and low-carbon (He, 2014) [1]. Therefore, scientific definition and measurement of the carbon emission efficiency of the "Silk Road Economic Belt" and exploration of the action direction and intensity of environmental regulation on carbon emission efficiency are of great practical value for building a green "Silk Road Economic Belt" and building a low-carbon economic community.

2. Literature References
The existing research on carbon emissions mainly focuses on environmental Kuznets curve test, international trade implied carbon emissions, and carbon emission reduction policy tools, etc. (Wang Wenju, 2011; Chen, 2015) [2-3], and the measurement of carbon emission efficiency involves super-efficiency DEA model, stochastic frontier model, LMDI-PDA decomposition method, etc. (Zhang Jincan, 2015; Moutinho V, 2018) [4-5], whose research field also extends to the carbon emission efficiency in the fields of tourism, land use, transportation logistics, agricultural production, etc., and also involves comparison in various provinces and cities in China, metropolitan circles, economic belt and overseas (Wang Kai et al., 2018; Shuai CY, 2019) [6-7]. In the research on the driving factors of carbon emission efficiency, many scholars also conduct empirical tests on the impact of market segmentation, urbanization, foreign direct investment, technological progress, industrial structure and environmental regulations on carbon emission efficiency at the regional level (Zhang Degang, 2018; Zhang Y, 2018) [8-9], which is also the basis for formulating carbon emission reduction policies.

In addition, regional carbon emission transfer issues has become increasingly prominent, such as transfer from developed industrial countries to developing countries (Peng Shuijun, 2018; Lopez LA, 2013) [10-11], or transfer from developed coastal areas to less developed inland areas (Guo JE, 2012; Shi Minjun, 2012) [12-13], scholars also concluded some driving factors into the pollution heaven hypothesis (Cai X, 2018) [14]. The impact of environmental regulations on carbon emissions is not simply a positive emission reduction or negative green paradox (Zhang Hua, 2014; Van der Ploeg, 2012) [15-16], and stricter environmental regulations will significantly curb the growth of industries with high emissions and high pollution, but will also lead to the transfer to areas with less environmental regulations (Zhong ZQ, 2018) [17]. Some scholars believe that stricter environmental regulations can stimulate the innovation compensation effect (Zhang Cheng, 2011) [18], but the existence of cost compliance also makes the discussion on its action direction unclear (Zhang K, 2017) [19].

3. Research Method
3.1. SE-SBM model
The SE-SBM model considering undesirable output is adopted. The SBM model is a DEA model considering slack improvement, which can solve the problem that the radial model does not contain slack variables for inefficiency measurement, and SE-SBM also solves the problem of effective DMU. And SE-SBM also solve the problem of efficient DMU efficiency high and low to distinguish, while the Undesirable Output Model also incorporates “bad” output into the measurement system, which can more accurately reflect the regional carbon emission efficiency. Supposing there are n decision making units, each decision unit can be divided into m type of input (x), s, expectation output (ys), s, unexpected output(yb), the input, expected output and non-expected output x, ys, yb were >0. Under the constant scale remuneration, the production set can be expressed as P={(x,ys,yb)λ ≥ Xλ, y ≥ Yλ, y ≥ Yλ, s ≥ 0}. The objective function ρ takes between 0 and 1, xij is the i item input of the item j DMU, and yrij is the r item output of the item j DMU [20].
\[
\min \rho = \frac{1 + \frac{1}{m} \sum_{i=1}^{m} S_i}{1 - \frac{1}{q_1 + q_2} \left( \sum_{i=1}^{m} S_i^2 + \sum_{i=1}^{m} y_i^2 \right)}
\] (1)

\[
s.t. \sum_{j=1,j \neq k}^{n} x_{ij} \lambda_j - s_i \leq x_{ik}, \quad \sum_{j=1,j \neq k}^{n} y_{ij} \lambda_j + s_i^* \geq y_{ik}^*, \quad \sum_{j=1,j \neq k}^{n} y_{ij}^n - s_i^b \leq y_{ik}^b, \quad 1 - \frac{1}{q_1 + q_2} (\sum_{i=1}^{n} S_i + \sum_{i=1}^{n} y_i^2) > 0,
\]

\[s > 0, \quad s^b > 0, \quad s^* > 0, \quad \lambda > 0, \quad i = 1, 2, \ldots, m; r = 1, 2, \ldots, n (j = k)
\]

### 3.2. Threshold regression model

As for the panel data, Hansen (1999) proposed a threshold regression model considering the fixed effect and simplified it by using the indicator function, which could be transformed into the form of deviation and estimated with the two-step method to avoid the arbitrary threshold value set by the researcher [21]. In formula (2), \(q_0\) is the threshold variable, which can also be understood as part of the independent variable, \(\gamma\) is the threshold value to be estimated, and \(\epsilon_i\) is the random disturbance term. Similarly, a panel regression model with two or more threshold values can be constructed (formula 3), where the threshold value \(\gamma_i < \gamma_j\), which \((\gamma_1, \gamma_2)\) can be given under the two-step method, use OLS model to estimate its deviation model, and select \((\gamma_1, \gamma_2)\) to minimize the estimated residual sum of squares \(SSR(\gamma_1, \gamma_2)\).

\[
y_i = \mu_i + \beta_1 x_{i\gamma} I(q_i \leq \gamma) + \beta_2 x_{i\gamma} I(q_i > \gamma) + \epsilon_i
\] (2)

\[
y_i = \mu_i + \beta_1 x_{i\gamma} I(q_i \leq \gamma_1) + \beta_2 x_{i\gamma} I(\gamma_1 < q_i \leq \gamma_2) + \beta_3 x_{i\gamma} I(q_i > \gamma_2) + \epsilon_i
\] (3)

### 4. Empirical Test

The five northwestern provinces (Shanxi, Gansu, Qinghai, Ningxia, Xinjiang) and the four southwestern provinces (Chongqing, Sichuan, Yunnan, and Guangxi) will be selected, and the SE-SBM model considering undesirable output will be adopted for its 2006-2016 carbon efficiency measure, and on this basis, threshold panel model is adopted to estimate the influence of the efficiency of environmental regulation on carbon emissions.

### 4.1. Carbon emission efficiency measure

The study uses the SE-SBM model for carbon emission efficiency measurement. Taking into account the specific situation of carbon emissions among regions, capital, labor and energy are used as input indicators, and GDP and CO2 emissions are used as indicators of desirable output and undesirable output, respectively. ①Capital investment, considering the “permanent inventory method” of depreciation of capital stock, depreciation is obtained by accounting for capital stock and capital services, and the study sets the depreciation rate to 0.96; ②Labor input is expressed by the total number of employees at the end of year of each province and municipality; ③Energy input, using the total energy consumption expressed in standard coal; ④Expected output index is real GDP. In order to eliminate the impact of price changes, the nominal GDP of each province and city is converted into real GDP; ⑤The undesired output indicator is carbon dioxide emissions. Since the official data on carbon dioxide emissions has not been published, it is calculated here with reference to the standard formula published by the Climate Change Committee (IPCC).
Table 1. Measurement results of carbon emission efficiency: 2006-2016

|         | 2006  | 2007  | 2008  | 2009  | 2010  | 2011  | 2012  | 2013  | 2014  | 2015  | 2016  |
|---------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Chongqing | 0.739 | 0.726 | 0.726 | 0.793 | 0.809 | 0.744 | 0.874 | 0.919 | 0.945 | 1.061 | 1.387 |
| Gansu    | 1.001 | 0.855 | 0.707 | 0.714 | 0.723 | 0.668 | 0.725 | 0.719 | 0.719 | 0.703 | 0.700 |
| Guangxi  | 1.011 | 0.829 | 0.836 | 0.760 | 0.780 | 0.733 | 0.822 | 0.839 | 0.889 | 1.032 | 0.891 |
| Ningxia  | 0.594 | 0.606 | 0.592 | 0.587 | 0.632 | 0.611 | 0.674 | 0.680 | 0.694 | 0.708 | 0.559 |
| Qinghai  | 0.658 | 0.667 | 0.683 | 0.651 | 0.645 | 0.599 | 0.689 | 0.702 | 0.731 | 0.759 | 0.712 |
| Sichuan  | 0.883 | 0.803 | 0.790 | 0.787 | 0.817 | 0.768 | 0.869 | 0.900 | 0.935 | 1.018 | 1.036 |
| Shanxi   | 0.700 | 0.713 | 0.696 | 0.712 | 0.709 | 0.671 | 0.761 | 0.752 | 0.768 | 0.777 | 0.677 |
| Xinjiang | 0.685 | 0.699 | 0.721 | 0.691 | 0.699 | 0.640 | 0.654 | 0.649 | 0.666 | 0.662 | 0.658 |
| Yunnan   | 0.718 | 0.722 | 0.789 | 0.727 | 0.768 | 0.686 | 0.618 | 0.704 | 0.736 | 0.771 | 0.810 | 0.764 |
| Mean     | 0.777 | 0.735 | 0.727 | 0.714 | 0.722 | 0.673 | 0.752 | 0.766 | 0.791 | 0.837 | 0.820 |
| SD       | 0.151 | 0.080 | 0.072 | 0.066 | 0.067 | 0.062 | 0.084 | 0.097 | 0.105 | 0.157 | 0.254 |
| CV       | 0.195 | 0.109 | 0.099 | 0.092 | 0.093 | 0.112 | 0.126 | 0.133 | 0.187 | 0.310 | 0.310 |

It can be seen from table 1 that most of the provinces and regions show a u-shaped trend on the whole, and the average carbon emission efficiency of each province also declined first and then increased. In 2011, the carbon emission efficiency of the five provinces in the northwest and the four provinces in the southwest all declined to an inflection point, followed by a slow or rapid rise. From 2006 to 2016, the carbon emission efficiency of Chongqing and Sichuan provinces increased significantly. In 2016, the carbon emission efficiency of the two provinces exceeded 1, which was an effective decision-making unit. Yunnan province also increased slightly. The most significant downward trend was in Gansu province, from 1.001 in 2006 to 0.700 in 2016. Guangxi, Shanxi, Xinjiang and Ningxia also declined slightly, and a certain degree of decline in carbon emissions was also a necessary stage of its industrialization and urbanization development. From the perspective of variation coefficient, its value rose from 0.195 in 2006 to 0.093 in 2011 and then to 0.310 in 2016. The regional difference of carbon emission efficiency shows a trend of divergence before convergence. In the construction of "Silk Road Economic Belt", different industrial structures and development roads are selected in different provinces and municipalities, and the inter-regional difference in carbon emission efficiency is increasingly larger.

4.2. Environmental regulation threshold estimation

The carbon emission efficiency of each province is selected as the explanatory variable, the environmental regulation is selected as the core explanatory variable, and the per capita GDP is selected as the threshold variable to investigate the effect of environmental regulation on carbon emission efficiency along with regional economic growth, and the direction and intensity of environmental regulation in different stages of economic development. The energy structure, urbanization, industrialization, technological innovation, opening-up and FDI are selected as control variables, supposing there exist double threshold values. The proportion of the cost of industrial pollution treatment in the added value of industrial production is selected as the index of environmental regulation. The degree of industrial water pollution control also represents the intensity of regional water environment treatment. The index of energy consumption structure is expressed as the proportion of coal consumption in the total amount. The technological innovation index is the number of three kinds of patent authorization for every ten thousand people in each province and province. Foreign direct investment and per capita GDP are treated on a logarithmic basis, the proportion of total import and export to GDP is taken as a measure of opening-up.
Table 2. Environmental Regulation and Threshold Estimation of Carbon Emission Efficiency

| Variable          | Coefficient | Standard deviation | t     | P-value |
|-------------------|-------------|--------------------|-------|---------|
| Energy structure  | -0.2125     | 0.0748             | -2.8405 | 0.0057  |
| Urbanization      | 0.0863      | 0.4258             | 0.2026 | 0.8400  |
| LNFDI             | -0.0313     | 0.0147             | -2.1358 | 0.0356  |
| Industrialization| -0.0458     | 0.1613             | -0.2843 | 0.7769  |
| Opening-up        | 0.0673      | 0.1739             | 0.3873 | 0.6996  |
| Technological innovation | 0.0275 | 0.0144 | 1.9118 | 0.0594 |
| Lnpergdp>10.7620  | 18.0082     | 2.5171             | 7.1545 | 0.0000  |
| [9.2780, 10.7620] | 2.4715      | 1.6333             | 1.5132 | 0.1341  |
| Lnpergdp<9.2780   | -5.7551     | 1.7143             | -3.3572 | 0.0012  |

In the double threshold estimation result, the F value is 7.3090, and its corresponding P value is 0.0210, which can pass the 5% significance level test. As can be seen from Table 2, the threshold values are 9.2780 and 10.7620, respectively, and the corresponding GDP per capita is 10700.01 and 47192.96 respectively. When per capita GDP is lower than 10700.01, environmental regulation has a significant negative effect on carbon emission efficiency. On the one hand, local governments pursue extensive economic growth, environmental regulation has not been effectively implemented, and on the other hand, this also leads to the carbon consumption path moving forward, and the carbon emission efficiency has decreased. In addition, the growth of per capita GDP at this stage is accompanied by the advancement of industrialization and urbanization. When per capita GDP is greater than 47192.96, provinces with higher levels of economic development have begun to pay attention to ecological and environmental issues. The formulation and implementation of environmental regulations are stricter, and the industrial structure has been optimized and upgraded to make concessions in economic growth, therefore carbon emission efficiency has increased. While the per capita GDP is between 10700.01 and 47192.96, it has not passed the significance test, but it is also known by the P value of 0.1341 that environmental regulation has a positive effect on carbon emissions.

In terms of energy structure, the higher the proportion of coal consumption, the smaller the proportion of clean energy, such as Ningxia, Shanxi and other provinces, where the proportion of coal consumption is significantly higher than other provinces, the lower the carbon emission efficiency, but also it should be noted that as the proportion of clean energy increases, carbon emission efficiency will also increase. In terms of foreign direct investment, FDI has a significant negative effect on carbon emission efficiency. The FDI investment introduced in the northwest and southwest regions is more high-energy and high-emission industries. Foreign direct investment is more concerned with the more relaxed environmental regulation policies and cheap labor in these areas, and the pollution heaven effect is far greater than the pollution halo effect. In terms of technological innovation, it has a significant positive effect on carbon emission effects. In places like Sichuan and Chongqing, where the per capita ownership of three patents is higher, carbon emissions are more efficient, and technological innovation can drive industrial transformation and upgrading, as well as energy conservation and emission reduction. However, urbanization, industrialization and opening-up do not play a significant role in carbon emission efficiency. For example, industrial structure is also undergoing the transformation from primary industry to secondary industry and then to tertiary industry. The improvement of carbon emission efficiency should be more related to the degree of industrial upgrading rather than the proportion of secondary industry.
5. Conclusion
With the promotion of the “Silk Road Economic Belt” initiative, China should carry out dual control actions of total energy consumption and intensity, and shoulder more responsibilities of emission reduction in the economic belt. The study takes capital, labor and energy as input indicators, and GDP and carbon emissions as desirable and undesirable outputs respectively. The carbon emission efficiency of the core provinces of the “Silk Road Economic Belt” from 2006 to 2016 was measured by using the SE-SBM model that considers undesirable output, and the relation between environmental regulation and carbon emission efficiency is estimated by using panel threshold model. The results showed that from 2006 to 2016, all provinces and regions in the economic belt showed a U-shaped trend on the whole, with higher carbon emission efficiency in Chongqing, Sichuan, Ningxia, Shanxi, Xinjiang and other places, lower carbon emission efficiency in Gansu, Guangxi and other places. In the threshold of environmental regulation and carbon emission efficiency, when per capita GDP was <10700.01, environmental regulation showed a significant negative effect; when per capita GDP was >47192.96, environmental regulation showed a significant positive effect; energy structure and foreign direct investment had a significant negative effect; technological innovation had a significant positive effect; urbanization, industrialization and opening-up had not passed the significance test.

In view of the above research conclusions, this paper believes that measures should be taken from the following aspects: ① Adhere to green and low-carbon development, establish the conviction of lucid waters and lush mountains are invaluable assets, transform the extensive growth model into high-quality growth, and avoid a new round of carbon emissions growth with economic belt construction; ② We should formulate appropriate environmental regulation intensity and select reasonable environmental policy tools to strengthen coordinated governance of economic belt carbon emission regions, and avoid pollution heaven, beggar-thy-neighbor or sluggish economic development caused by too high or too low intensity of environmental policies. ③ Develop and utilize clean energy to achieve “decarbonization” development, increase the proportion of clean energy used in wind energy and solar energy, improve the utilization efficiency of coal resources, and accelerate the promotion of technologies such as clean coal and underground coal gasification; ④ Provide reasonable guidance to FDI, restrict high-carbon enterprises, overcapacity enterprises and other foreign investment, guide FDI to high-tech industries, low-carbon environmental protection industries, and make full use of advanced technologies brought by FDI to improve energy efficiency; ⑤ Strengthen technological innovation and transformation of achievements, implement the innovation-driven development strategy, provide financial support or tax incentives for technological transformation of enterprises' energy conservation and emission reduction, and strengthen the transformation and application of existing energy-saving and emission reduction technologies.

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