Emission reduction tournament would postpone carbon peaking in China

Ming Chen [a, b], Dan Yu [c], Xunpeng Shi [d] and Ke Wang [a, b, e, f, *]

[a] Center for Energy and Environmental Policy Research, Beijing Institute of Technology, Beijing, P. R. China; [b] School of Management and Economics, Beijing Institute of Technology, Beijing, P. R. China; [c] Zhejiang Huayun Electric Power Engineering Design and Consultation Company, Hangzhou, Zhejiang, China; [d] Australia-China Relations Institute, University of Technology Sydney, Ultimo, NSW, Australia; [e] Sustainable Development Research Institute for Economy and Society of Beijing, Beijing, P. R. China; [f] Beijing Key Lab of Energy Economics and Environmental Management, Beijing, P. R. China

Abstract

Climate change is a serious issue of global public governance. To addressing the climate crisis, Chinese government has proposed clear target of carbon peaking and carbon neutrality. Regional efforts are expected to play a key role in delivering China's pledge to peak CO_2 emissions before 2030. However, emission reduction tournament would result in rapid increases in emission transfers among provinces in China. If the current trend of provincial economic development and associated emission transfer mode remains unchanged, we forecast that, 24 progressive provinces in China would peak their CO_2 emissions before 2030, while 6 lagged provinces would peak later than 2030. However, if the emission transfers were not existed, the nationwide carbon peaking time would be one year earlier, and the corresponding carbon peaking level would be 13% lower. This indicates that the current emission transfers in China are actually "robbing the poor to help the rich". Furthermore, compared with the situation in 2012, the emission transfer mode in 2017 would lead to higher carbon peaking level, indicating the switch of emission transfer mode from 2012 to 2017 had increased the difficulty of carbon peaking in China. We suggest that the principle of common but differentiated responsibilities should be applied when decomposing the national carbon peaking targets into provinces, and China need to avoid a tournament among local governments on carbon peaking.

Keywords

Carbon peaking, climate governance, counterfactual analysis, emission reduction, emission transfer, forecast, input-output analysis

1 Introduction

China has pledged to peak CO_2 emissions before 2030 and achieve carbon neutrality before 2060. To achieve the carbon peaking target as early as possible, the Chinese government has introduced a series of policies for reducing CO_2 emissions. However, some existed phenomena may be harmful to the achievement of the carbon peaking target nationwide, and one of which is the emission reduction tournament among China's provinces. Although the central government of China has released a nationwide schedule for carbon peaking, the implementation depends on the regional governments of China. China has 34 provincial regions, and each of which has its own regional CO_2 emission governance. Since China pledged to strive to peak CO_2 emissions before 2030, emission reduction becomes an important performance index for regional governments. Recently, an emission reduction tournament among provinces in China as some regional governments have proposed advanced schedules of carbon peaking, leading to over ambitious energy transition[1]. For example, among the 16 provinces that have announced carbon peaking targets, 14, with Fujian and Ningxia as exceptions, promised to achieve carbon peaking target by 2030 or to peak their CO_2 emissions earlier than other provinces.

Table 1. The carbon peaking targets of some provinces

Province	**Release time**	**Emission reduction target**
Beijing	Oct. 2021	To be the "bellwether" of nationwide peaking carbon.
Hebei	Jan. 2022	Ensuring peaking carbon by 2030.
Jilin	Nov. 2021	By 2030, CO_2 emissions will have reached a peak and decreased steadily.
Shanghai	Sep. 2021	Taking the lead in reaching carbon peak in 2025
Jiangsu	May 2021	The carbon peaking time will be earlier than 2030 proposed by the nation.
Zhejiang	Dec. 2021	Peaking carbon with high quality by 2030.
Fujian	Apr. 2022	By 2035, CO_2 emissions will decline steadily after reaching the peak.
Jiangxi	Apr. 2022	By 2030, CO_2 emissions will have reached a peak and decreased steadily.
Henan	Feb. 2022	CO_2 emissions have reached a peak by 2030, and decreased steadily by 2035.
Hunan	Mar. 2022	By 2030, CO_2 emissions will have reached a peak and decreased steadily.
Guangdong	Feb. 2021	Taking the lead to peak carbon.
Hainan	Feb. 2021	Striving to achieve "carbon peak" by 2025.
Chongqing	Apr. 2022	Taking effective measures to promote the realization of the goal of peaking CO_2 emissions by 2030.
Sichuan	Dec. 2021	By 2030, CO2 emissions will have reached a peak and decreased steadily.
Shaanxi	Oct. 2021	Ensuring that the carbon peak target by 2030 is achieved on schedule.
Ningxia	Jan. 2022	By 2030, CO_2 emissions will reach a peak smoothly

Radical carbon reduction goals may defeat long-term environmental goals[2]. Recently, National Development and Reform Commission (NDRC) in China has pointed out that there are some inefficient carbon reduction policies in some provinces, which could be called "campaign-style" carbon reduction[3]. Some provinces have set overly ambitious and unrealistic goals without making solid energy-saving efforts, which are not beneficial for nationwide carbon peaking. If all current policies could be implemented effectively, China is likely to peak CO_2 emissions before 2030[4]. However, this does not mean all provinces and regions will peak before 2030. Because of the remarkable differences in characteristics of energy consumption[5] and the difficulty to balance the target of emissions reduction and economic development[6], each province in China may not reach carbon peak value at the same time[7]. For some provinces, peaking carbon as early as possible may not be the best opinion[8]. In order to propose a reasonable carbon peaking schedule, each province needs to consider many factors, such as the potential energy intensity and carbon factor effects[9], industrial structure[10], and the population structure and income level[11]. Emission reduction tournament would promote unreasonable carbon peaking schedules in provinces.

Environmental integrity is a key principle to achieving climate mitigation all over the world[14]. On the one hand, global time flexibility in GHG emission reduction is justifiable. On the other hand, international trade may cause adverse effects on emission reductions in developing countries[15]. The globalization of supply chains has resulted in rapid increases in emission transfers. Developed countries have been able to decarbonize domestically, at the expense of increased emissions in developing countries[16].

In order to achieve a common emission reduction target, there are two types of reduction regimes, which are universal regime and fragmented regime. The universal regime involves a single comprehensive climate regime in which all countries participate, and the fragmented regime involves either multiple treaties or a single treaty in which not all countries participate[17]. Although global time flexibility is justifiable to some extent, this equity-oriented argument may be robust against time and spatial efficiency consideration[18]. However, establishing a universal regime will be challenging due to cost differences among regions[17]. It is necessary to consider the environmental integrity and the regional differences while setting the carbon peaking targets.

Moreover, emissions transfers have been suggested to integrate climate policy[19]. Accompanied by foreign direct investment, CO_2 emissions decreased in high-income countries, and increased in middle-income countries in the short-run[20]. Therefore, the developed regions should implement stricter emissions regulations under nearly all scenarios based on current researches[21].

Currently, almost all provinces in China have been deeply involved in domestic supply chains by economic flows[22], and the economic flows are always accompanied by CO_2 emissions flows[23-24]. In order to reduce their own CO_2 emissions and peak carbon earlier, some regional governments had been transferring CO_2 emissions to other provinces through supply chains for years. These emission transfers exist both within well-developed and less-developed regions and among them[25]. In specific, 64% and 35% of China's emissions are transferred among provinces driven by final demands and primary inputs, respectively[26]. Some economically underdeveloped provinces always receive CO_2 emissions from economically developed provinces[27-28]; and some developed provinces with enough self-sufficiency abilities still transfer more CO_2 to other provinces to promote their own development[29]. Based on the multi-regional input-output (MRIO) table, we could estimate the effect of emission transfers among provinces by input-output analysis, which is a common method in many similar studies[22,30-32].

Given the likelihood of heterogeneous carbon peak timelines, it is important to set fair targets for different provinces. It is an important but difficult task for the Chinese government which need to balance the CO_2 emissions in provinces reasonably[12-13]. This target setting will incur all the debates on the common but differential responsibility (CBDR) that has been popular in the international carbon negotiations. Additionally, the heterogeneity would allow industry transfer (or relocation) among provinces and thus create domestic carbon leakage similar to that between countries. Therefore, this circumstance creates two research questions. First, what is the consequence of the emission reduction tournament? Second, how industry transfer will impact the national emission peak targets?

The emission transfers caused by emission reduction tournament play important roles in China's CO_2 emissions, and may be beneficial or detrimental to the achievement of the carbon peaking target. Nevertheless, very few studies have attempted to examine the effects of the inter-provincial trade on the carbon peaking target of China.

Here, we try to reveal the role of emission reduction tournament in the carbon peaking target, and estimate the consequence by counterfactual analysis. In this study, we estimate three groups of carbon peaking times and levels for each province. Firstly, we use an econometric model to forecast the future CO_2 emissions of each province and, based on this, we could find out each province's carbon peaking time and carbon peaking level under the benchmark scenario. Then, supposing there were no emission transfers, we establish two counterfactual scenarios based on MRIO table in 2017 and 2012, respectively. Under the counterfactual scenario (2017), we adjust the CO_2 emissions of each province by MRIO table in 2017, and find out a new group of carbon peaking times and carbon peaking levels. The difference between the benchmark scenario and the counterfactual scenario (2017) can be used to evaluate whether emission transfer mode in China would affect nationwide carbon peaking time or carbon peaking level. Then, we replace the MRIO table in 2017 with the MRIO table in 2012, and get the counterfactual scenario (2012). The differences between the two counterfactual scenarios would release the effects of the change in emission transfer modes on carbon peaking.

Our contributions are three folds. Firstly, we estimate the impact of emission transfer mode on the achievement of carbon peaking target. Secondly, we discuss the effect of the change in the emission transfer code. Lastly, we derive some purposeful policy implications to avoid the emission reduction tournament and peak CO_2 emissions efficiently.

By our research, we find out that China have the ability to achieve the nationwide carbon peaking target before 2030, but not all provinces would peak CO_2 emissions by 2030. Current carbon peaking proposals at provincial level show that there is an emission reduction tournament among provinces in China. The emission reduction tournament would postpone the nationwide carbon peaking and increase the nationwide carbon peaking level. Therefore, we suggest that the principle of common but differentiated responsibilities should be applied when decomposing the national carbon peaking targets into provinces. Decreasing emission intensities is the main measure to reduce CO_2 emissions, and the progressive provinces have responsibilities and obligations to help achieve emission reduction targets in lagged provinces.

The remainder of this article is organized as follows. Section 2 review the existing studies. Section 3 describes the econometric model to forecast the CO_2 emissions, the input-output method to adjust the prediction results, and the data used in this paper. Section 4 explains and compares estimation results under the benchmark and the counterfactual scenarios. Based on discussing the estimating results, section 5 presents some policy implications. Section 6 conclude this paper.

2 Method

2.1 Forecast of carbon peaking

We establish an econometric model to forecast the CO_2 emissions. Firstly, the CO_2 emissions could be decomposed into two variables, which are the outputs and the emission factors[33]. In this paper, we choose GDP as the variable output, and the emission intensity (*EI*) as the variable emission factor. While the GDP and emission intensity have been forecast, it will be easy to forecast the CO_2 emissions for each province:

$$emission_{i,t} = GDP_{i,t} \times EI_{i,t} \quad (1)$$

In equation (1), *i* denotes the province and *t* denotes the year. In order to simplify the calculation, this research defines *t*=1 when the variable is for 1997, *t*=2 when the variable is for 1998, etc.

To forecast GDP, we establish ARIMA model[1] for each province, which is one of the most

[1] Autoregressive Integrated Moving Average model

popular models for time series forecasting analysis[34]. The ARIMA(p, d, q) model is

$$y_{i,t} = Q_0 + \sum_{j=1}^{p} \varphi_j y_{i,t-j} + \sum_{k=1}^{q} \theta_k e_{i,t-k} + e_{i,t}$$

in which, $y_{i,t}$ is the data series after *d*th-order difference, $e_{i,t}$ denotes the random error term, and Q_0 denotes the constant term. The parameters *p*, *d*, and *q* of ARIMA are determined by Unit Root Test and Akaike Information Criterion (AIC). The parameters and AIC for each province are shown in Appendix Table 1.

In recent years, the emission intensity in China declined steadily. We suppose that the emission intensity would reduce by a fixed proportion in coming years, and the index *EI* could be forecast by the regression equation (2):

$$EI_{i,t} = \propto_i e^{-\beta_i t} \quad (2)$$

in which, $\propto_i$ and β_i are the regression coefficient for province *i*. Taking logarithms on both sides of the equation, it could be easily obtained by OLS method. The regression results are shown in Appendix Table 2.

While the GDP and emission intensity have been forecast, the product of these two indexes are the predictive value of CO2 emissions. Then, we could find out the carbon peaking time and carbon peaking level of each province.

2.2 Input-output analysis for measuring emission transfers

In this section, we aim to get the avoid emission coefficient ($AEC_{i1,i2}$) between provinces. Along with the economic flow from province $i1$ to province $i2$, province $i2$ could avoid their own CO_2 emissions by increase CO_2 emissions in province $i1$. The ratio that the avoided CO_2 emissions in province $i2$ to the CO_2 emissions in province $i1$ will be defined as $AEC_{i1,i2}$. In other words, $AEC_{i1,i2}$ can be considered as how much CO_2 emissions in province $i2$ will be reduced when province $i1$ adds a unit of CO_2 emissions under the current emission transfer mode.

In this section, all the data are for the same year (2017 or 2012). For simplicity, the subscript of year is omitted. Firstly, the direct consumption coefficient matrix (*A*) and Leontief inverse matrix (*L*) could be calculated by MRIO table as follows:

$$A = \begin{bmatrix} A_{1,1,1,1} & A_{1,1,1,2} & \cdots & A_{1,1,1,29} & A_{1,1,2,1} & A_{1,1,2,2} & \cdots & \cdots & A_{1,1,30,29} \\ A_{1,2,1,1} & A_{1,2,1,2} & \cdots & A_{1,2,1,29} & A_{1,2,2,1} & A_{1,2,2,2} & \cdots & \cdots & A_{1,2,30,29} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & & \ddots & \vdots \\ A_{1,29,1,1} & A_{1,29,1,2} & \cdots & A_{1,29,1,29} & A_{1,29,2,1} & A_{1,29,2,2} & \cdots & \cdots & A_{1,29,30,29} \\ A_{2,1,1,1} & A_{2,1,1,2} & \cdots & A_{2,1,1,29} & A_{2,1,2,1} & A_{2,1,2,2} & \cdots & \cdots & A_{2,1,30,29} \\ A_{2,2,1,1} & A_{2,2,1,2} & \cdots & A_{2,2,1,29} & A_{2,2,2,1} & A_{2,2,2,2} & \cdots & \cdots & A_{2,2,30,29} \\ \vdots & \vdots & \ddots & \vdots & \vdots & \vdots & & \ddots & \vdots \\ \vdots & \vdots & & \vdots & \vdots & \vdots & & & \vdots \\ A_{30,29,1,1} & A_{30,29,1,2} & \cdots & A_{30,29,1,29} & A_{30,29,2,1} & A_{30,29,2,2} & \cdots & \cdots & A_{30,29,30,29} \end{bmatrix} \quad (3)$$

$$A_{i1,j1,i2,j2} = \begin{cases} \frac{a_{i1,j1,i2,j2}}{total_{i2,j2}}, & total_{i2,j2} \neq 0 \\ 0, & total_{i2,j2} = 0 \end{cases} \quad (4)$$

$$L = (I - A)^{-1} \quad (5)$$

In equations (3) to (5), $a_{i1,j1,i2,j2}$ denotes the economic flow from province $i1$ sector $j1$ to province $i2$ sector $j2$; $total_{i2,j2}$ denotes the total input (which is equal to total output in input-output table) of province $i2$ sector $j2$; I is an identity matrix.

Then, the complete economic flow (*CEF*) from province $i1$ sector $j1$ to province $i2$ sector $j2$ is calculated as in equation (6):

$$CEF_{i1,j1,i2,j2} = L_{i1,j1,i2,j2} * F_{i2,j2} \quad (6)$$

in which, F denotes the final use in MRIO table.

The production technology and production environment are obviously different among provinces. For this reason, the CO_2 emissions may be not same when the same amount of the same products are produced in different provinces. For province i sector j, we define the emission intensity ($EI_{i,j}$) as the ratio of CO_2 emissions to economic value added (*EVA*). The variable economic value added for each province and sector, which is equal to the GDP in macroeconomics, could be obtained from the input-output table. Some sectors do not exist in all provinces. The $EI_{i,j}$ could not be directly calculated if province i does not have any economic activity in sector j. For this reason, if $EVA_{i,j} = 0$, we assume that the $EI_{i,j}$ is equal to the weighted average of all provinces' emission intensity for sector j. The math is shown in equation (7):

$$EI_{i,j} = \begin{cases} \dfrac{emission_{i,j}}{EVA_{i,j}} & , EVA_{i,j} > 0 \\ \dfrac{\sum_i emission_{i,j}}{\sum_i EVA_{i,j}} & , EVA_{i,j} = 0 \end{cases} \quad (7)$$

Because of the economic flow from province $i1$ sector $j1$ to province $i2$ sector $j2$, province $i2$ could avoid some CO_2 emissions. The CO_2 emissions avoided in province $i2$ are defined as the emissions avoided by import ($EAI_{i1,j1,i2,j2}$). The definition is similar to the studies in López et al.[35] and Feng et al. [22]. If the products in province $i1$ sector $j1$ are demanded by provinces $i2$ sector $j2$, we suppose that province $i2$ sector $j1$ would produces them. To produce these products, the additional CO_2 emissions in province *i2* are the $EAI_{i1,j1,i2,j2}$ which calculated in equation (8).

$$EAI_{i1,j1,i2,j2} = CEF_{i1,j1,i2,j2} * EI_{i2,j1} \quad (8)$$

Lastly, the above mentioned avoid emission coefficient (*AEC*) can be calculated as:

$$AEC_{i1,i2} = \frac{\sum_{j1,j2} EAI_{i1,j1,i2,j2}}{emission_{i1}} \quad (9)$$

By using the avoid emission coefficient, we could adjust each province's CO_2 emissions into the counterfactual scenario, under which we could suppose there were no emission transfers among provinces in China.

2.3 Adjustment of carbon peaking forecast

After forecasting the CO_2 emissions and calculating the *AEC*s, we could establish a counterfactual scenario. For this scenario, we assume that all the production demanded by a province would be produced in this province, and there are no economic flows among provinces. Under this scenario, all the CO_2 emissions in a province can be entirely blamed for the demand of this own province.

To calculate the CO_2 emissions of each province in each year under the counterfactual scenario, the estimation results under the benchmark scenario should be adjusted by *AEC*s as follows:

$$emission_{i2,t}^{after} = \sum_{i1} AEC_{i1,i2} emission_{i1} \quad (10)$$

In equation (10), $emission_{i2,t}^{after}$ represents the CO_2 emissions of province *i*2 in year *t* under the counterfactual scenario. After the adjustment, we could find out the counterfactual estimation results of carbon peaking time and carbon peaking level for each province and the entire country.

2.4 Data Sources

The GDP data of from 1997 to 2017 is published by China National Bureau of Statistics. The CO_2 emissions data from 1997 to 2017 is obtained from the table "Emission Inventories for 30 Provinces" in Carbon Emission Accounts & Datasets (CEADs)[36-38], which covers 47 socioeconomic sectors (45 production sectors and 2 consumption sectors). And the MRIO tables of China are obtained from the tables "China multi-regional input-output table for 2012" and "China multi-regional input-output table for 2017" in CEADs[39], which cover 42 socioeconomic sectors. All of the data cover 30 provinces in China. Other Chinese provincial regions of Tibet, Hong Kong, Macao, and Taiwan are not estimated because of the lack of data. There are 45 sectors in the data CO_2 emissions and 42 sectors in MRIO tables, and the sectors in MRIO tables for 2012 and 2017 are not the same as well. Therefore, we combine the data into 29 sectors by Appendix Table 3.

3 Results

3.1 Most provinces could achieve carbon peaking before 2030 under current trend of emission transfer mode

As described above in Section 3.1, working with the econometric model, we are able to forecast the CO_2 emissions of each province. Then, we can find out each province's carbon peaking time and carbon peaking level. The carbon peaking times and carbon peaking levels are shown in Figure 1, and the estimation results are shown in Appendix Table 4 in detail.

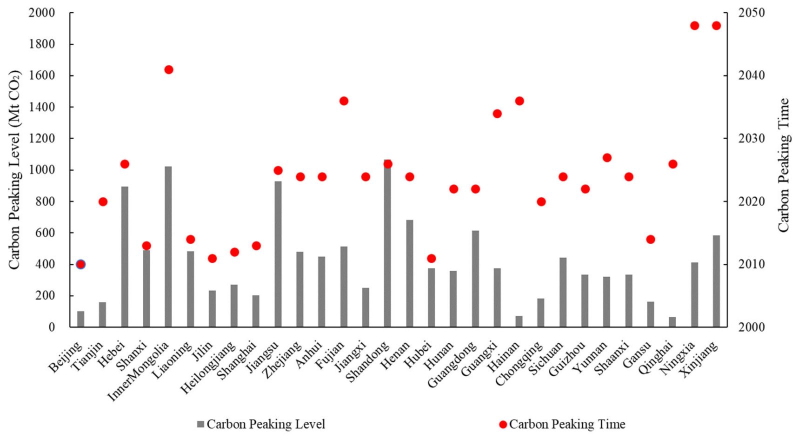

Figure 1. The times and levels of carbon peaking

Based on the prediction results, the 30 provinces are divided into 3 groups. As shown in Figure 1, 8 provinces have been carbon peaking during the data collection period, which are Beijing, Jilin, Hubei, Heilongjiang, Shanghai, Shanxi, Gansu, and Liaoning; 16 other provinces would peak their CO_2 emissions between 2020 to 2030, which are Tianjin, Chongqing, Guizhou, Hunan, Guangdong, Jiangxi, Shaanxi, Sichuan, Anhui, Zhejiang, Henan, Jiangsu, Qinghai, Hebei, Shandong, and Yunnan; and 6 provinces would peak their CO_2 emissions after 2030, which are Guangxi, Hainan, Fujian, Inner Mongolia, Ningxia, and Xinjiang.

During the past decades, China has made significant efforts on carbon reduction. From our prediction results, 24 of the 30 provinces are able to peak their CO_2 emissions before 2030, which could be considered as the progressive provinces. Moreover, to obtain the prediction results, we suppose that the current trend of provincial economic development and associated emission transfer mode remains unchanged, and the provincial emission reduction policies could be implemented effectively. Therefore, it is important for these progressive provinces to ensure that all the current provincial economic development and associated emission transfer mode remains unchanged, and the provincial emission reduction policies would be implemented effectively.

But for the other 6 provinces in China, it is difficult to peak carbon before 2030 by our prediction results, which could be considered as the lagged provinces. These provinces are all in the northwest (Inner Mongolia, Ningxia, and Xinjiang) or south (Fujian, Guangxi, and Hainan) of China. To peak carbon earlier than 2030, these lagged provinces need to take more addition policies or measures to reduce CO_2 emissions.

By our estimation, China will get nationwide CO_2 emissions peak in 2025. In this year, the total CO_2 emissions in China may be 12.02Bt. If all provinces could keep economic development and technological development stably, China is possibly to achieve the nationwide carbon peaking target before 2030. But for some provinces, the carbon peaking time may be later.

3.2 Nationwide carbon peaking time would be advanced supposing no emissions transfers

In this section, we calculate all the AECs among 30 provinces in 2017 by input-output analysis. Figure 2 show the avoid emission coefficient matrix. In Figure 2, each row represents a province which cause emission transfer by export, and each column represents a province which cause emission transfer by import. The colour of each square denotes the number of AEC.

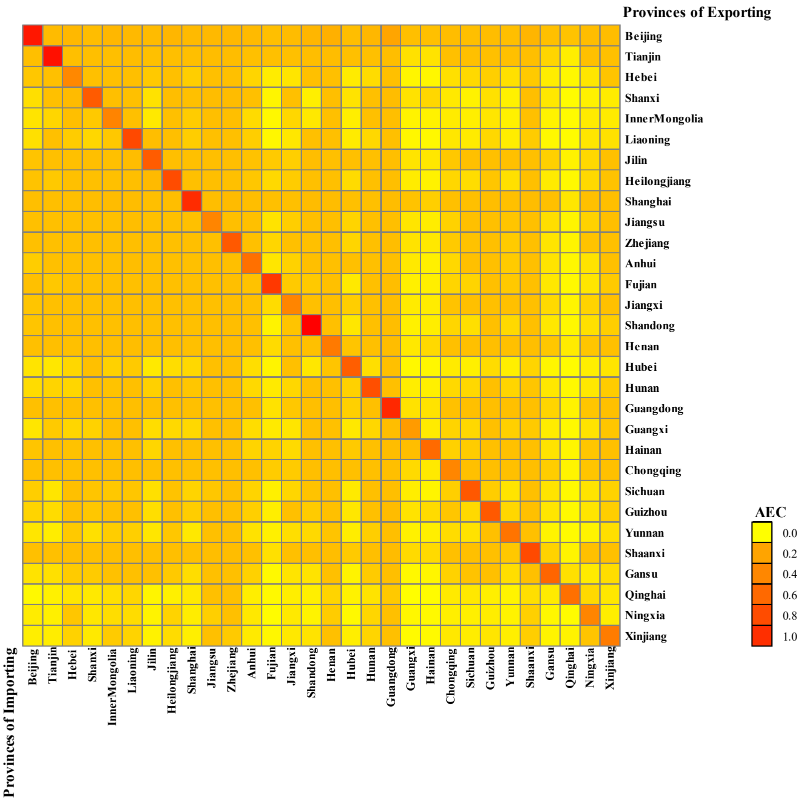

Figure 2. The avoid emission coefficient matrix

There is obvious difference in AECs among provinces, which could be explained by the differences of trade structure and emission intensity. Summing the avoid emission coefficient matrix by row, we could obtain the sum of AECs induced by export for each province. The results are shown in Table 2.

Table 2. The sum of AECs induced by export

Province	Sum of AECs	Province	Sum of AECs
Beijing	2.5346	Henan	0.7825
Tianjin	1.5902	Hubei	0.7579
Hebei	0.5205	Hunan	0.9017
Shanxi	0.9685	Guangdong	1.2696
Inner Mongolia	0.5486	Guangxi	0.3783
Liaoning	0.9388	Hainan	0.8015
Jilin	0.9395	Chongqing	0.6585

Province	Sum of AECs	Province	Sum of AECs
Heilongjiang	1.0038	Sichuan	0.8371
Shanghai	1.5293	Guizhou	0.8821
Jiangsu	0.6337	Yunnan	0.6242
Zhejiang	0.9413	Shaanxi	1.1140
Anhui	0.7317	Gansu	0.7330
Fujian	1.1047	Qinghai	0.6046
Jiangxi	0.6398	Ningxia	0.4835
Shandong	1.5105	Xinjiang	0.5332

For each province, if the sum of AECs induced by export is larger than 1, the emission transfers from other provinces would reduce total CO_2 emissions in China; otherwise, if the sum of AECs induced by export is less than 1, the emission transfers from other provinces would add total CO_2 emissions in China.

For example, under the emission transfer mode in 2017, in order to reduce an additional unit of CO_2 emissions in Beijing through emission transferring, other provinces have to increase 2.5346 unit of CO_2 emissions. Therefore, the nationwide CO_2 emissions will increase by 1.5346 unit, indicating the inefficiency of transferring CO_2 emissions from Beijing to other provinces.

Therefore, the emission transfers in China would affect the achievement of carbon peaking target in China. For this reason, we establish a counterfactual scenario, under which we suppose that there are no emission transfers among provinces in China. Based on the estimating results under the benchmark scenario and the emission transfer mode in 2017, we establish the counterfactual scenario (2017).

Under the benchmark scenario, we forecast that the carbon peaking time and carbon peaking level would be 2025 and 12.02Bt. But after adjusted by AECs, the carbon peaking time under the counterfactual scenario (2017) would be one year earlier; and the carbon peaking level in this scenario is 10.46Bt, about 13% lower than the benchmark scenario.

Because of the vast territory and the notable disparities in socioeconomic development and energy system, provinces in China are unlikely to keep pace in peaking carbon[1]. However, since the carbon peaking target has been proposed, some developed provinces urged to transfer the high-emission industries to underdeveloped provinces in order to peak CO_2 emissions locally earlier. Therefore, the underdeveloped provinces achieve economic growth, and the developed provinces achieve emission reduction. However, the emission intensities in underdeveloped provinces usually higher than those in developed provinces. For this reason, the emissions transfers may increase the total CO_2 emissions in China.

Compared with the estimating results under benchmark scenario, we estimate that the emission transfer mode in 2017 would postpone the carbon peaking time and increase carbon peaking level nationwide. Therefore, China should avoid a tournament among local governments on carbon peaking. Reducing CO_2 emissions by emission transfers is not an effective and efficient measure in China.

3.3 Current emission transfers in China are actually "robbing the poor to help the rich"

For each province, the estimating results could be adjusted by AECs as well. Then, we find out another group of carbon peaking times and carbon peaking levels of provinces. The detail results under the counterfactual scenario (2017) are shown in Appendix Table 5. Under the benchmark scenario and the counterfactual scenario (2017), the carbon peaking times may be different in some provinces. We compare the carbon peaking time under the two scenarios in Figure 3.

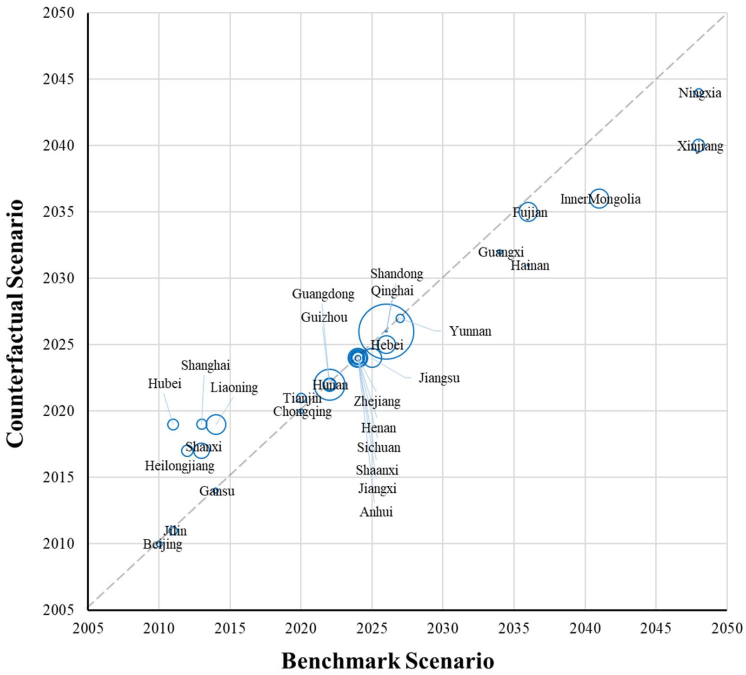

Figure 3. Comparison of carbon peaking time under the two scenarios

The horizontal axis represents the carbon peaking time under the benchmark scenario which discussed in Section 3.1. And the longitudinal axis represents the carbon peaking time under the counterfactual scenario (2017), which could be also considered as the carbon peaking time without any emission transfers among provinces in China. The area of each dot represents the carbon peaking level under the counterfactual scenario (2017).

In Figure 3, most of the progressive provinces are above the diagonal line, especially Heilongjiang, Hubei, Liaoning, Shanghai, and Shanxi. Without any emission transfers, these progressive provinces could peak CO_2 emissions earlier than 2030 as well. The emission transfer mode makes these progressive provinces' carbon peaking time even earlier, at the expense of transferring emissions to other provinces.

Moreover, the lagged provinces which may peak CO_2 emissions after 2030, such as Fujian, Guangxi, Hainan, Inner Mongolia, Ningxia, and Xinjiang, are all below the diagonal line. The emission transfer mode in China is not beneficial for the achievement of carbon peaking target in these provinces.

By our estimation above, these provinces would peak their CO_2 emissions later than 2030. It could be partly attributed to the emission transfers from other provinces. Without any emission transfers, these lagged provinces could be peaking carbon earlier.

The current emission transfers caused by carbon reduction tournament among provinces are actually “robbing the poor to help the rich”. Some of the progressive provinces which have enough abilities to peak their CO_2 emissions before 2030, could achieve carbon peaking target even earlier by emission transfers. But for the lagged provinces which have difficulty to peak their CO_2 emissions before 2030, the emission transfer mode is not beneficial for the achievement of carbon peaking targets in these provinces. Without any emission transfers, some of the progressive provinces would peak CO_2 emissions 1-8 years later, but the carbon peaking times of these provinces may not later than 2030 under the counterfactual scenario (2017). For some lagged provinces, the carbon peaking time would advance 1-8 years without any emission transfers, but not earlier than 2030.

Radical carbon reduction targets are harmful[2,40], and thus, a gradual and regional-specific roadmap is required. Therefore, the Chinese government should take measures in the incoming national emission reduction roadmaps to account for the regional heterogeneity.

In addition, the developed provinces have responsibilities and obligations to provide funds and technology for the emission reduction in the underdeveloped provinces. It is beneficial to the achievement of nationwide carbon peaking target.

3.4 Change in emission transfer mode is detrimental to achievement of carbon peaking target

The emission transfer mode in China plays an important role on China’s CO_2 emissions. However, there are obvious difference between emission transfer modes in 2017 and 2012. Therefore, we establish the counterfactual scenario (2012) based on the MRIO table in 2012 in this section. We replace the MRIO table for 2017 with the MRIO table for 2012, then repeat the steps mentioned above. Comparing the results under the two counterfactual scenarios, we could reveal the effect of the change in emission transfer mode on carbon peaking target in China.

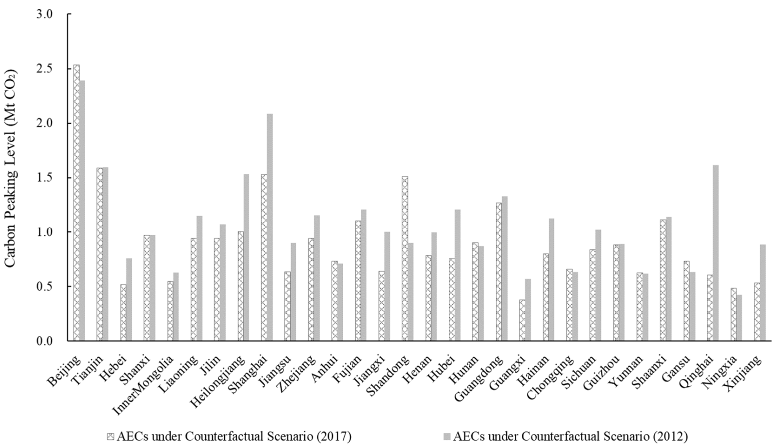

Figure 4. Comparison of AECs in 2012 and 2017

Figure 4 compares the AECs calculated by the MRIO table in 2012 and 2017. The sum of AECs induced by exported of each province is shown above the horizontal axis. For each province, the length of the left bar represents the sum of AECs in 2017, and the length of the right bar represents the sum of AECs in 2012.

For most provinces, the sums of AECs induced by exported are close between 2012 and 2017. However, it is more valuable to pay attention to the provinces whose AECs are greatly different in 2012 and in 2017. The differences reveal the effect of the change in emission transfer mode on the change in CO_2 emissions. During the 30 provinces, the AECs of 8 provinces are increase from 2012 to 2017, which are Shaanxi, Guangdong, Qinghai, Beijing, Fujian, Jilin, Anhui, and Zhejiang. Other 22 provinces' AECs is lower in 2017 than in 2012.

Based on the AECs in 2012, the carbon peaking time and carbon peaking level of each province could be adjusted into the counterfactual scenario (2012). The estimating results after adjustment are shown in Appendix Table 6.

Under the counterfactual scenario (2012), the nationwide carbon peaking time would be same as the counterfactual scenario (2017). However, the nationwide carbon peaking level is 11.55Bt under this scenario, a little larger than the counterfactual scenario (2017). For these two counterfactual scenarios, we both suppose that there are no emission transfers among provinces in China. Hence the carbon peaking levels in these two scenarios could be considered as the carbon peaking levels which have excluded the effect of emission transfer mode. Therefore, we can explain the carbon peaking levels as follows: the emission transfer mode in 2017 may increase 1.56Bt CO_2 emissions on nationwide carbon peaking level; and the emission transfer mode in 2012 may increase just 0.47Bt CO_2 emissions on nationwide carbon peaking level. The emission transfer mode in 2017 is more detrimental for peaking carbon level than the emission transfer mode in 2012.

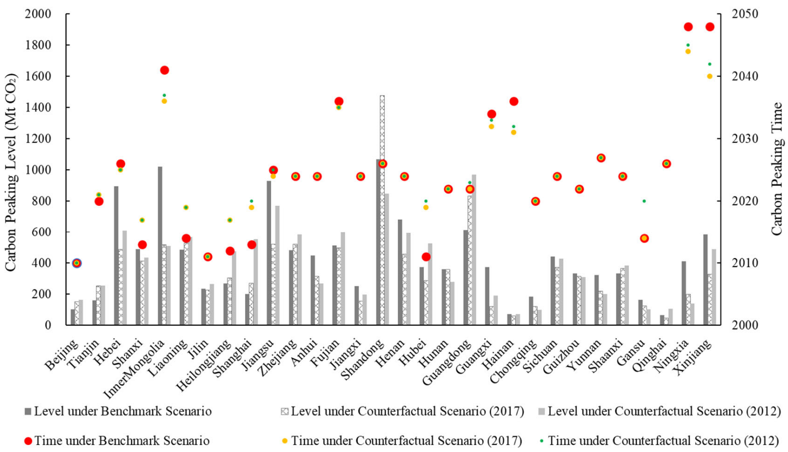

Figure 5. Comparison of carbon peaking level and carbon peaking level

We compare the carbon peaking level and carbon peaking time of each province under the three scenarios (one benchmark scenario and two counterfactual scenarios) in Figure 5. Compared with the benchmark scenario, if the emission transfer mode is more beneficial or less detrimental to the achievement of carbon peaking target in China, the carbon peaking time would be later, and the carbon peaking level would be larger under the counterfactual scenarios.

Among all the 30 provinces, the carbon peaking time of 14 provinces are totally same under the three scenarios. However, for the other provinces, most of the carbon peaking times under the counterfactual scenario (2012) are later than the carbon peaking times under the counterfactual scenario (2017). Moreover, the carbon peaking levels under the counterfactual scenario (2012) are mostly larger than the carbon peaking levels under the counterfactual scenario (2017) as well. For most provinces, it is more difficult to achieve the carbon peaking targets under the emission transfer mode in 2017 than under the emission transfer mode in 2012.

As a result of the emission reduction tournament among provinces, local governments may be urged to transfer CO_2 emissions to other provinces. The additional emission transfers could be reflected in the change in emission transfer modes. By the comparison of estimation results between two counterfactual scenarios, the “campaign-style” carbon reduction may be more detrimental in 2017 than 2012. To peak CO2 emissions more efficient, the Chinese government should transform the trend of emission transfer mode.

4 Discussions and policy implications

As we forecast, most of provinces have enough abilities to peak CO_2 emissions before 2030. Nevertheless, if there were not any emission transfer among provinces, the nationwide carbon peaking time would be one year earlier, and the nationwide carbon peaking level would be a little lower. Both the emission transfer modes in 2017 and 2012 are not beneficial to the achievement of carbon peaking target in China. The emission transfer mode in 2017 is more detrimental than the emission transfer mode in 2012.

Without any emission transfers, most of the progressive provinces would peak CO_2 emissions later, and most of the lagged provinces would peak CO_2 emissions earlier. The emission transfer mode in China is beneficial for the progressive provinces, and detrimental for the lagged provinces.

To achieve the carbon peaking target, China need make more effects on it. We suggest some policy implications to ensure that China could peak CO_2 emissions before 2030 effectively and efficiently.

(1) The principle of common but differentiated responsibilities should be applied when decomposing the national carbon peaking targets into provinces when setting the initial targets for each province. In order to coordinate the nationwide carbon peaking target and local carbon peaking schedule, it is an important issue that how to reasonably allocate carbon emission rights among provinces and industries. ~~To balance the targets of economic growth and emissions reduction is crucial since ~~O~~o~~ur estimation shows that some economically effective emission transfers are, however, not environmentally effective. This initial allocation of targets should allow those less-developed provinces to continuously increase their emissions after 2030. As mentioned before, most of the provinces in China could be divided into two groups. Progressive provinces are mostly economically developed, and lagged provinces are mostly economically backward. In the recent future, the

progressive provinces could make more contributions to the national emission reduction targets, and provide services to lagged provinces. And the lagged provinces need pay more attention to economic targets, while introduce the financial transfers and technology transfers to reduce CO_2 emissions. Promoting the construction of the national carbon emission trading market would be helpful to transfer carbon emission rights to more efficient places and industries. Other ~~M~~market instruments, such as energy consumption permit trading, can be applied at the regional level to minimize emission reduction costs. Enterprises should pay more attention to adapt the carbon market. Considering the changes in carbon prices while making business strategies would be effective to lower production costs and reduce CO_2 emissions.

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(2) The central government~~China~~ should avoid a tournament among local governments on carbon peaking. The central government and the public should not commend those who have peaked and condemn those who have not. The assessment should instead focus on the progress toward their individual goals. ~~(5)~~ For the lagged provinces, peaking CO_2 emissions may not be the most important policy objectives currently. As shown above, most of the provinces which have abilities to peak CO_2 emissions before 2030 are progressive. The achievement of peaking carbon target mainly depends on the decrease of emission intensity, not the decrease of economic outputs. Emission reduction tournament is not beneficial in long-run, especially for lagged provinces. These provinces need take more efficient measures to reduce CO_2 emissions in long-run, but not strive to peak CO_2 emissions as early as possible.

(3) The central government should facilitate cooperation among regional governments. The progressive provinces whose carbon peaking time is early, such as Beijing, Jilin, Heilongjiang, and Shanghai, might have also transferred emissions to other provinces. These provinces have responsibilities and obligations to provide funds and technology for the emission reduction in the provinces which would peak carbon later than 2030. ~~(6) It is necessary for the lagged provinces to introduce the low-carbon technologies from progressive provinces.~~ For the reason that the emission intensities in lagged provinces are significantly higher than that in progressive provinces, there must be some existing low-carbon technologies in progressive provinces. These low-carbon technologies could be helpful to decrease the emission intensities in lagged provinces. The lagged provinces could introduce these low-carbon technologies. As current studies, financial transfers from developed countries to developing countries would enhance pro-poor growth and help the effectiveness of poor countries in reducing emissions[41]. No financial transfers would lead to great efficiency losses[42]. ~~We believe t~~The transfers between progressive provinces and lagged provinces will likely ~~would~~ have the same effects.

(4) ~~Reducing~~ CO_2 emission reduction strategies ~~s~~ need ~~decrease~~ reduce emission intensity and increase energy efficient, but not transfer high-emission enterprises to other provinces. Although emission transfers could reduce a province's CO_2 emissions quickly, it may not beneficial to the nationwide emission reduction. Because of the difference on emission intensity between provinces before and after transferring, these enterprises may increase their CO_2 emissions after relocating. Therefore, the emission transfers would increase CO_2 emissions in the provinces to which enterprises

have been relocated, and the increased CO_2 emissions may be more than the reduced CO_2 emissions in the provinces of enterprises moving out.

~~(5) For the lagged provinces, peaking CO_2 emissions may not be the most important policy objectives currently. As shown above, most of the provinces which have abilities to peak CO_2 emissions before 2030 are progressive. The achievement of peaking carbon target mainly depends on the decrease of emission intensity, not the decrease of economic outputs. Emission reduction tournament is not beneficial in long-run, especially for lagged provinces. These provinces need take more efficient measures to reduce CO_2 emissions in long-run, but not strive to peak CO_2 emissions as early as possible.~~

~~(6) It is necessary for the lagged provinces to introduce the low-carbon technologies from progressive provinces. For the reason that the emission intensities in lagged provinces are significantly higher than that in progressive provinces, there must be some existing low-carbon technologies in progressive provinces. These low-carbon technologies could be helpful to decrease the emission intensities in lagged provinces. The lagged provinces could introduce these low-carbon technologies.~~

(7) To improve the energy consumption structure, China should promote the use of clean energy as a whole. It is also a key measure to decrease the emission intensities while keeping economic growing. Replacing high-emission energy with clean energy, which could reduce CO_2 emissions while ensure economic production. However, improving the energy consumption structure often requires large initial investment, which is used to develop clean energy production and use technologies and establish a clean energy market. The initial investment is huge and has ~~obvious~~ significant externalities for local governments. Therefore, it is beneficial to promote the use of clean energy at the national level. Progressive provinces could invest more on the clean energy use technologies, and lagged provinces should actively introduce these technologies. ~~(9)~~ Consumers could also play an important role by changing~~e~~ their consumption structure to avoid the products with much embodied carbon. In China, most of the economic productions are demand driven. While consumers tend to purchase cleaner products, the producers would reduce the products with much embodied carbon. It could effectively reduce CO_2 emissions by the "invisible hand" of the market.

(8) ~~China needs to continually promote the construction of the national carbon emission trading market. In order to coordinate the nationwide carbon peaking target and local carbon peaking schedule, it is an important issue that how to reasonably allocate carbon emission rights among provinces and industries. At present, the construction of China's carbon market is still in its infancy and has not played a full role. Promoting the construction of the national carbon emission trading market would be helpful to transfer carbon emission rights to more efficient places and industries. Enterprises should pay more attention to adapt the carbon market. Considering the changes in carbon prices while making business strategies would be effective to lower production costs and reduce CO_2 emissions.~~

~~(9) Consumers could change the consumption structure to avoid the products with much embodied carbon. In China, most of the economic productions are demand driven. While consumers tend to purchase cleaner products, the producers would reduce the products with much embodied carbon. It could effectively reduce CO_2 emissions by the "invisible hand" of the market.~~

(10) ~~To balance the targets of economic growth and emissions reduction is crucial since our estimation shows that some economically effective emission transfers are, however, not~~

~~environmentally effective. As mentioned before, most of the provinces in China could be divided into two groups. Progressive provinces are mostly economically developed, and lagged provinces are mostly economically backward. In the recent future, the progressive provinces could make more contributions to the national emission reduction targets, and provide services to lagged provinces. And the lagged provinces need pay more attention to economic targets, while introduce the financial transfers and technology transfers to reduce CO_2 emissions.~~

5 Conclusions

In this paper, we forecast the future CO_2 emissions and estimate the carbon peaking time and carbon peaking level for China's each province. Then, we adjust the estimation results by AECs which calculated based on two MRIO tables. Comparing the estimation results under the benchmark scenario and two counterfactual scenarios, we discuss the possible effect of the emission reduction tournament among provinces on the achievement of carbon peaking target in China. Firstly, if the current trend of provincial economic development and associated emission transfer mode remains unchanged, and the provincial emission reduction policies could be implemented effectively, most provinces could peak carbon earlier than 2030. Secondly, supposing there were no emission transfers among provinces in China, the nationwide carbon peaking time would be one year earlier than the benchmark scenario, and the corresponding carbon peaking level would reduce 13%. Thirdly, the current emission transfers in China are actually "robbing the poor to help the rich". Fourthly, compared with 2012, the emission transfer mode in 2017 may be more detrimental to the achievement of carbon peaking target in China.

Based on the analysis, we first suggest that the principle of common but differentiated responsibilities should be applied when decomposing the national carbon peaking targets into provinces. Less developed provinces should be given less responsibility of emission control. In addition, China needs to avoid a tournament among local governments on carbon peaking. Each province should be assessed against their goals, which should be different among provinces. Lastly, the Chinese central government should facilitate cooperation among regional governments to achieve just and cost-effective emission reduction nationwide. Once the goals are set up, the cap in emissions or energy consumption can be traded among provinces so that the national total compliance costs can be minimized.

There are some limitations of this study. Firstly, due to the lack of more samples and data, the forecast of CO_2 emissions is not accurate enough. Based on the research on impact factors of CO_2 emissions, a detailed forecast of each sector and each province may be more convincing. Secondly, we do not consider the possible effect of COVID-2019, which may change the economic development trend in China. Thirdly, due to the limitation of data, we could not analyze the uncertainties of the results.

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Notes

1. Shi et al., "China's ambitious energy transition plans."

2. Liu et al., "Don't cheat Chinese environment laws."
3. Zheng, "China to rectify ‘campaign-style’ carbon reduction: NDRC. "
4. Gallagher et al., "Assessing the Policy gaps for achieving China's climate targets in the Paris Agreement."
5. Zhang et al., "Does one path fit all? An empirical study on the relationship between energy consumption and economic development for individual Chinese provinces."
6. Ning et al., "Energy conservation and emission reduction path selection in China: A simulation based on Bi-Level multi-objective optimization model."
7. Zhang et al., "China's energy-related carbon emissions projections for the shared socioeconomic pathways."
8. Fang et al., "Will China peak its energy-related carbon emissions by 2030? Lessons from 30 Chinese provinces."
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10. Nie et al., "A Study of the Stability of China's Carbon Dioxide Emissions."
11. Deng et al., "Ecological compensation of grain trade within urban, rural areas and provinces in China: a prospect of a carbon transfer mechanism."
12. Li et al., "Managing the mitigation: Analysis of the effectiveness of target-based policies on China's provincial carbon emission and transfer."
13. Wang et al., "Regional carbon imbalance within China: An application of the Kaya-Zenga index."
14. Schneider, et al. "Environmental integrity of international carbon market mechanisms under the Paris Agreement."
15. Babiker, et al. "The Kyoto Protocol and developing countries."
16. Wood et al. "Beyond peak emission transfers: historical impacts of globalization and future impacts of climate policies on international emission transfers."
17. Hof, et al. "Environmental effectiveness and economic consequences of fragmented versus universal regimes: what can we learn from model studies?"
18. Sugiyama et al. "Must developing countries commit quantified targets? Time flexibility and equity in climate change mitigation."
19. Scott et al. "An integration of net imported emissions into climate change targets."
20. Marques et al. "The impact of foreign direct investment on emission reduction targets: Evidence from high- and middle-income countries."
21. Tamaki et al. "Controlling CO2 emissions for each area in a region: the case of Japan."
22. Feng et al., "Carbon transfer within China: Insights from production fragmentation."
23. Steininger et al., "Multiple carbon accounting to support just and effective climate policies."
24. Yang et al., "Mapping global carbon footprint in China."
25. Pan et al., "Structural Changes in Provincial Emission Transfers within China."
26. Chen et al., "Provincial emission accounting for CO2 mitigation in China: Insights from production, consumption and income perspectives."
27. Wang et al., "Carbon footprints and embodied CO2 transfers among provinces in China."
28. Han et al., "China's intra- and inter-national carbon emission transfers by province: A nested network perspective."

29. Zhai et al., "Inter-regional carbon flows embodied in electricity transmission: network simulation for energy-carbon nexus."
30. Ji et al., "The mutual benefits from Sino-Africa trade: Evidence on emission transfer along the global supply chain."
31. Long et al., "Comparison of city-level carbon footprint evaluation by applying single- and multi-regional input-output tables."
32. Mi et al., "Economic development and converging household carbon footprints in China."
33. Du et al., "China's carbon dioxide emissions from cement production toward 2030 and multivariate statistical analysis of cement consumption and peaking time at provincial levels."
34. Ediger et al., "ARIMA forecasting of primary energy demand by fuel in Turkey."
35. López et al., "Parcelling virtual carbon in the pollution haven hypothesis."
36. Shan et al., "Data Descriptor: China CO2 emission accounts 1997-2015."
37. Shan et al., "China CO2 emission accounts 2016-2017."
38. Zheng et al., "Regional determinants of China's consumption-based emissions in the economic transition."
39. Zheng et al., "Regional determinants of China's consumption-based emissions in the economic transition."
40. Lu et al., "China's ineffective plastic solution to haze."
41. Cantore et al. "How Can Low-income Countries Gain from a Framework Agreement on Climate Change? An Analysis with Integrated Assessment Modelling."
42. Bauer, N., et al. (2020). "Quantification of an efficiency-sovereignty trade-off in climate policy." Nature 588(7837): 261.

Acknowledgements

This work was supported by the National Natural Science Foundation of China [grant number 71871022, 72174056], the National Program for Support of Top-notch Young Professionals, the Fok Ying Tung Education Foundation [grant number 161076], the Joint Development Program of Beijing Municipal Commission of Education.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributors

Ming Chen is a PhD candidate at School of Management and Economics, Beijing Institute of Technology. His research interest includes energy economics, environmental policy, and quantitative economics.
Dan Yu is an engineer at Zhejiang Huayun Electric Power Engineering Design and Consultation Company. His research area includes electricity economics and policy.
Xunpeng Shi is a professor at Australia-China Relations Institute, University of Technology Sydney. His research interest includes energy and environmental policy, sustainability and energy transition.

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Ke Wang is a professor at School of Management and Economics, Beijing Institute of Technology. His research interest includes energy economy system modeling, energy management and climate policy.

ORCID

Ming Chen https://orcid.org/0000-0001-5693-7853
Dan Yu N/A
Xunpeng Shi https://orcid.org/0000-0001-9653-7395
Ke Wang https://orcid.org/0000-0002-4808-2637

References

Babiker, M., Reilly, J. M., Jacoby, H. D. (2000). "The Kyoto Protocol and developing countries." Energy Policy 28(8): 525-536.

Bauer, N., Bertram, C., Schultes, A., Klein, D., Luderer, G., Kriegler, E., Popp, A., Edenhofer, O. (2020). "Quantification of an efficiency-sovereignty trade-off in climate policy." Nature 588(7837): 261.

Cantore, N., te Velde, D. W., Peskett, L. (2014). "How Can Low-income Countries Gain from a Framework Agreement on Climate Change? An Analysis with Integrated Assessment Modelling." Development Policy Review 32(3): 313-326.

Chen, J. D., Xu, C., Cui, L. B., Huang, S., Song, M. L. (2019). "Driving factors of CO2 emissions and inequality characteristics in China: A combined decomposition approach." Energy Economics 78: 589-597.

Chen, W. M., Lei, Y. L., Feng, K. S., Wu, S. M., Li, L. (2019). "Provincial emission accounting for CO2 mitigation in China: Insights from production, consumption and income perspectives." Applied Energy 255.

Deng, Y., Sarkar, A., Yu, C., Lu, Q., Zhao, M., Das, J. C. (2021). "Ecological compensation of grain trade within urban, rural areas and provinces in China: a prospect of a carbon transfer mechanism." Environment Development and Sustainability.

Du, Z. W., Wei, J. X., Cen, K. (2019). "China's carbon dioxide emissions from cement production toward 2030 and multivariate statistical analysis of cement consumption and peaking time at provincial levels." Environmental Science and Pollution Research 26(27): 28372-28383.

Ediger, V. S., Akar S. (2007). "ARIMA forecasting of primary energy demand by fuel in Turkey." Energy Policy 35(3): 1701-1708.

Fang, K., Tang, Y. Q., Zhang, Q. F., Song, J. N., Wen, Q., Sun, H. P., Ji, C. Y., Xu, A. Q. (2019). "Will China peak its energy-related carbon emissions by 2030? Lessons from 30 Chinese provinces." Applied Energy 255.

Feng, T., Du, H. B., Zhang, Z. K., Mi, Z. F., Guan, D. B., Zuo, J. (2020). "Carbon transfer within China: Insights from production fragmentation." Energy Economics 86.

Gallagher, K. S., Zhang, F., Orvis, R., Rissman, J., Liu, Q. (2019). "Assessing the Policy gaps for achieving China's climate targets in the Paris Agreement." Nature Communications 10(1): 1256.

Han, M. Y., Yao, Q. H., Lao, J. M., Tang, Z. P., Liu, W. D. (2020). "China's intra- and inter-national carbon emission transfers by province: A nested network perspective." Science China-Earth Sciences 63(6): 852-864.

Hof, A. F., den Elzen, M. G. J., van Vuuren, D. P. (2009). "Environmental effectiveness and economic consequences of fragmented versus universal regimes: what can we learn from model studies?" International Environmental Agreements-Politics Law and Economics 9(1): 39-62.

Ji, X., Liu, Y. F., Han, M. Y., Meng, J. (2020). "The mutual benefits from Sino-Africa trade: Evidence on emission transfer along the global supply chain." Journal of Environmental Management 263: 110332.

Li, M., Gao, Y. N., Meng, B., Yang, Z. S. (2021). "Managing the mitigation: Analysis of the effectiveness of target-based policies on China's provincial carbon emission and transfer." Energy Policy 151.

Liu, D., Wang, R., Thompson, J. (2020). "Don't cheat Chinese environment laws." Nature 578(7793): 37-37.

Long, Y., Yoshida, Y., Liu, Q. L., Zhang, H. R., Wang, S. Q., Fang, K. (2020). "Comparison of city-level carbon footprint evaluation by applying single- and multi-regional input-output tables." Journal of Environmental Management 260: 110108.

López, L. A., Arce, G., Zafrilla, J. E. (2013). "Parcelling virtual carbon in the pollution haven hypothesis." Energy Economics 39: 177-186.

Lu, X. Q., Vogt, R. D., Li, H., Han, S. Q., Mo, X. Q., Zhang, Y. F., Ullah, S., Chen, C., Han, X. X., Li, H. Y., Seip, H. M. (2019). "China's ineffective plastic solution to haze." Science 364(6446): 1145-1145.

Marques, A. C., Caetano R. (2020). "The impact of foreign direct investment on emission reduction targets: Evidence from high- and middle-income countries." Structural Change and Economic Dynamics 55: 107-118.

Mi, Z. F., Zheng, J. L., Meng, J., Ou, J. M., Hubacek, K., Liu, Z., Coffman, D., Stern, N., Liang, S., Wei, Y. M. (2020). "Economic development and converging household carbon footprints in China." Nature Sustainability 3(7): 529-537.

Nie, Y. Y., Tian, H., Zhang, P., Wang, E. C., Zhang, T. Y., Guo, Q. X. (2020). "A Study of the Stability of China's Carbon Dioxide Emissions." Emerging Markets Finance and Trade 56(13): 3193-3204.

Ning, Y. D., Chen, K. K., Zhang, B. Y., Ding, T., Guo, F., Zhang, M. (2020). "Energy conservation and emission reduction path selection in China: A simulation based on Bi-Level multi-objective optimization model." Energy Policy 137.

Pan, C., Peters, G. P., Andrew, R. M., Korsbakken, J. I., Li, S. T., Zhou, P., Zhou, D. Q. (2018). "Structural Changes in Provincial Emission Transfers within China." Environmental Science & Technology 52(22): 12958-12967.

Schneider, L., Theuer, S. L. (2019). "Environmental integrity of international carbon market mechanisms under the Paris Agreement." Climate Policy 19(3): 386-400.

Scott, K., Barrett J. (2015). "An integration of net imported emissions into climate change targets." Environmental Science & Policy 52: 150-157.

Shan, Y. L., Liu, J. H., Liu, Z., Xu, X., Wang, H., Shao, S., Wang, P., Guan, D. B. (2016). "New provincial CO2 emission inventories in China based on apparent energy consumption data and

updated emission factors." Applied Energy 184: 742-750.
Shan, Y. L., Guan, D. B., Zheng, H. R., Ou, J. M., Li, Y., Meng, J., Mi, Z. F., Liu, Z., Zhang, Q. (2018). "Data Descriptor: China CO2 emission accounts 1997-2015." Scientific Data 5: 170201.
Shan, Y. L., Huang, Q., Guan, D. B., Hubacek, K. (2020). "China CO2 emission accounts 2016-2017." Scientific Data 7(1): 54.
Shi, X., Sun, Y., Shen, Y. (2021). "China's ambitious energy transition plans." Science 373(6551): 170-170.
Steininger, K., Lininger, C., Meyer, L., Munoz, P., Schinko, T. (2016). "Multiple carbon accounting to support just and effective climate policies." Nature Climate Change 6(1): 35-41.
Sugiyama, T., Liu, D. S., (2004). "Must developing countries commit quantified targets? Time flexibility and equity in climate change mitigation." Energy Policy 32(5): 697-704.
Tamaki, T., Nozawa, W., Managi, S. (2019). "Controlling CO2 emissions for each area in a region: the case of Japan." Carbon Balance and Management 14(1): 19.
Wang, Z. H., Yang, Y. T., Wang, B. (2018). "Carbon footprints and embodied CO2 transfers among provinces in China." Renewable & Sustainable Energy Reviews 82: 1068-1078.
Wang, C., Guo, Y., Shao, S., Fan, M. T., Chen, S. Y. (2020). "Regional carbon imbalance within China: An application of the Kaya-Zenga index." Journal of Environmental Management 262: 110378.
Wood, R., Grubb, M., Anger-Kraavi, A., Pollitt, H., Rizzo, B., Alexandri, E., Stadler, K., Moran, D., Hertwich, E., Tukker, A. (2020). "Beyond peak emission transfers: historical impacts of globalization and future impacts of climate policies on international emission transfers." Climate Policy 20(sup1): S14-S27.
Yang, Y. T., Qu, S., Cai, B. F., Liang, S., Wang, Z. H., Wang, J. N., Xu, M., (2020). "Mapping global carbon footprint in China." Nature Communications 11(1): 2237.
Zhai, M. Y., Huang, G. H., Liu, L. R., Zheng, B. Y., Guan, Y. R. (2020). "Inter-regional carbon flows embodied in electricity transmission: network simulation for energy-carbon nexus." Renewable & Sustainable Energy Reviews 118.
Zhang, F., Deng, X. Z., Xie, L., Xu, N. (2021). "China's energy-related carbon emissions projections for the shared socioeconomic pathways." Resources Conservation and Recycling 168.
Zhang, Q. X., Liao, H., Hao, Y. (2018). "Does one path fit all? An empirical study on the relationship between energy consumption and economic development for individual Chinese provinces." Energy 150: 527-543.
Zheng, H. R., Zhang, Z. K., Wei, W. D., Song, M. L., Dietzenbacher, E., Wang, X. Y., Meng, J., Shan, Y. L., Ou, J. M., Guan, D. B. (2020). "Regional determinants of China's consumption-based emissions in the economic transition." Environmental Research Letters 15(7).
Zheng Z. (2021) "China to rectify 'campaign-style' carbon reduction: NDRC." Xinhua News Agency.

Appendix

Appendix Table 1

Appendix Table 1. The parameters and AIC for each province

Beijing	**Tianjin**	**Hebei**	**Shanxi**
ARIMA(2,2,2): 237.7834 ARIMA(0,2,0): 230.0679 ARIMA(1,2,0): 232.0501 ARIMA(0,2,1): 232.0476 ARIMA(1,2,1): 234.8691 Best model: ARIMA(0,2,0)	ARIMA(2,2,2): Inf ARIMA(0,2,0): 248.1177 ARIMA(1,2,0): 250.2729 ARIMA(0,2,1): Inf ARIMA(1,2,1): 252.6152 Best model: ARIMA(0,2,0)	ARIMA(2,2,2): Inf ARIMA(0,2,0): 242.9575 ARIMA(1,2,0): 242.7886 ARIMA(0,2,1): 240.7958 ARIMA(1,2,1): 242.6464 ARIMA(0,2,2): 242.7950 ARIMA(1,2,2): 245.8933 Best model: ARIMA(0,2,1)	ARIMA(2,2,2): Inf ARIMA(0,2,0): 247.3299 ARIMA(1,2,0): 249.7479 ARIMA(0,2,1): Inf ARIMA(1,2,1): Inf Best model: ARIMA(0,2,0)
Inner Mongolia	**Liaoning**	**Jilin**	**Heilongjiang**
ARIMA(2,2,2): Inf ARIMA(0,2,0): 237.8057 ARIMA(1,2,0): 238.0363 ARIMA(0,2,1): 238.7339 ARIMA(1,2,1): 240.4667 Best model: ARIMA(0,2,0)	ARIMA(2,1,2): Inf ARIMA(0,1,0): 317.5271 ARIMA(1,1,0): 307.8521 ARIMA(0,1,1): 311.0926 ARIMA(0,1,0): 339.4543 ARIMA(2,1,0): 311.0181 ARIMA(1,1,1): 311.0184 ARIMA(2,1,1): Inf ARIMA(1,1,0): 308.3855 Best model: ARIMA(1,1,0)	ARIMA(2,2,2): Inf ARIMA(0,2,0): 222.4157 ARIMA(1,2,0): 221.8090 ARIMA(0,2,1): 221.2419 ARIMA(1,2,1): 223.8388 ARIMA(0,2,2): Inf ARIMA(1,2,2): Inf Best model: ARIMA(0,2,1)	ARIMA(2,2,2): Inf ARIMA(0,2,0): 227.1688 ARIMA(1,2,0): 223.1002 ARIMA(0,2,1): 223.7028 ARIMA(2,2,0): 224.8558 ARIMA(1,2,1): 225.3829 ARIMA(2,2,1): 227.7266 Best model: ARIMA(1,2,0)
Shanghai	**Jiangsu**	**Zhejiang**	**Anhui**
ARIMA(2,2,2): 253.3838 ARIMA(0,2,0): 250.0955 ARIMA(1,2,0): 252.0739 ARIMA(0,2,1): 251.7710 ARIMA(1,2,1): 254.6176 Best model: ARIMA(0,2,0)	ARIMA(2,2,2): Inf ARIMA(0,2,0): 262.6673 ARIMA(1,2,0): 260.1996 ARIMA(0,2,1): 260.3230 ARIMA(2,2,0): 262.1263 ARIMA(1,2,1): 262.5790 ARIMA(2,2,1): 264.9575 Best model: ARIMA(1,2,0)	ARIMA(2,2,2): 273.6264 ARIMA(0,2,0): 266.3017 ARIMA(1,2,0): 268.6577 ARIMA(0,2,1): 268.5837 ARIMA(1,2,1): 271.4178 Best model: ARIMA(0,2,0)	ARIMA(2,2,2): Inf ARIMA(0,2,0): 231.8909 ARIMA(1,2,0): 228.8699 ARIMA(0,2,1): 230.3330 ARIMA(2,2,0): 231.0889 ARIMA(1,2,1): Inf ARIMA(2,2,1): Inf Best model: ARIMA(1,2,0)
Fujian	**Jiangxi**	**Shandong**	**Henan**
ARIMA(2,2,2): Inf	ARIMA(2,2,2): Inf	ARIMA(2,2,2): 258.7286	ARIMA(2,2,2): Inf

ARIMA(0,2,0): 236.9505 ARIMA(1,2,0): 235.2459 ARIMA(0,2,1): 234.8543 ARIMA(1,2,1): 237.7040 ARIMA(0,2,2): 237.7041 ARIMA(1,2,2): Inf Best model: ARIMA(0,2,1)	ARIMA(0,2,0): 210.4173 ARIMA(1,2,0): 197.4867 ARIMA(0,2,1): 202.0680 ARIMA(2,2,0): 200.3064 ARIMA(1,2,1): Inf ARIMA(2,2,1): Inf Best model: ARIMA(1,2,0)	ARIMA(0,2,0): 259.1599 ARIMA(1,2,0): 253.0570 ARIMA(0,2,1): 253.9658 ARIMA(2,2,0): 255.5260 ARIMA(1,2,1): 253.6007 ARIMA(2,2,1): Inf Best model: ARIMA(1,2,0)	ARIMA(0,2,0): 245.7682 ARIMA(1,2,0): 243.8675 ARIMA(0,2,1): 242.3129 ARIMA(1,2,1): 245.1626 ARIMA(0,2,2): 245.1626 ARIMA(1,2,2): Inf Best model: ARIMA(0,2,1)
Hubei	**Hunan**	**Guangdong**	**Guangxi**
ARIMA(2,2,2): Inf ARIMA(0,2,0): 233.6551 ARIMA(1,2,0): 226.5905 ARIMA(0,2,1): Inf ARIMA(2,2,0): 229.1289 ARIMA(1,2,1): Inf ARIMA(2,2,1): Inf Best model: ARIMA(1,2,0)	ARIMA(2,2,2): Inf ARIMA(0,2,0): 233.4328 ARIMA(1,2,0): 230.8494 ARIMA(0,2,1): Inf ARIMA(2,2,0): 232.9109 ARIMA(1,2,1): 231.1715 ARIMA(2,2,1): Inf Best model: ARIMA(1,2,0)	ARIMA(2,2,2): Inf ARIMA(0,2,0): 286.4972 ARIMA(1,2,0): 289.0100 ARIMA(0,2,1): 289.0077 ARIMA(1,2,1): Inf Best model: ARIMA(0,2,0)	ARIMA(2,2,2): 217.6841 ARIMA(0,2,0): 213.6292 ARIMA(1,2,0): 212.9985 ARIMA(0,2,1): 214.2546 ARIMA(2,2,0): 212.8916 ARIMA(3,2,0): 213.7768 ARIMA(2,2,1): 215.1232 ARIMA(1,2,1): 212.9180 ARIMA(3,2,1): 216.6917 Best model: ARIMA(2,2,0)
Hainan	**Chongqing**	**Sichuan**	**Guizhou**
ARIMA(2,2,2): Inf ARIMA(0,2,0): 179.8303 ARIMA(1,2,0): 182.2507 ARIMA(0,2,1): 182.0869 ARIMA(1,2,1): 184.8079 Best model: ARIMA(0,2,0)	ARIMA(2,2,2): 227.5303 ARIMA(0,2,0): 224.4398 ARIMA(1,2,0): 220.4253 ARIMA(0,2,1): 220.2983 ARIMA(1,2,1): 222.9241 ARIMA(0,2,2): 223.0037 ARIMA(1,2,2): Inf Best model: ARIMA(0,2,1)	ARIMA(2,2,2): 266.2091 ARIMA(0,2,0): 255.8373 ARIMA(1,2,0): 257.6613 ARIMA(0,2,1): 257.8419 ARIMA(1,2,1): 260.3397 Best model: ARIMA(0,2,0)	ARIMA(2,2,2): 202.9688 ARIMA(0,2,0): 197.9360 ARIMA(1,2,0): 196.1244 ARIMA(0,2,1): 197.9899 ARIMA(2,2,0): 197.5228 ARIMA(1,2,1): Inf ARIMA(2,2,1): 199.3491 Best model: ARIMA(1,2,0)
Yunnan	**Shaanxi**	**Gansu**	**Qinghai**
ARIMA(2,2,2): Inf ARIMA(0,2,0): 227.2157 ARIMA(1,2,0): 229.4815 ARIMA(0,2,1): 229.5703 ARIMA(1,2,1): Inf Best model: ARIMA(0,2,0)	ARIMA(2,2,2): Inf ARIMA(0,2,0): 216.1266 ARIMA(1,2,0): 212.8080 ARIMA(0,2,1): 214.8371 ARIMA(2,2,0): 215.2872 ARIMA(1,2,1): 215.2725 ARIMA(2,2,1): Inf	ARIMA(2,2,2): Inf ARIMA(0,2,0): 206.1899 ARIMA(1,2,0): 207.1689 ARIMA(0,2,1): 207.0816 ARIMA(1,2,1): 209.9021 Best model: ARIMA(0,2,0)	ARIMA(2,2,2): 159.5478 ARIMA(0,2,0): 149.3025 ARIMA(1,2,0): 151.8165 ARIMA(0,2,1): 151.8167 ARIMA(1,2,1): 154.4945 Best model: ARIMA(0,2,0)

	Best model: ARIMA(1,2,0)		
Ningxia	**Xinjiang**		
ARIMA(2,2,2): Inf ARIMA(0,2,0): 138.9798 ARIMA(1,2,0): 138.0686 ARIMA(0,2,1): 138.6844 ARIMA(2,2,0): 140.7058 ARIMA(1,2,1): Inf ARIMA(2,2,1): Inf Best model: ARIMA(1,2,0)	ARIMA(2,2,2): Inf ARIMA(0,2,0): 199.0304 ARIMA(1,2,0): 199.1597 ARIMA(0,2,1): 198.4839 ARIMA(1,2,1): Inf ARIMA(0,2,2): 201.2544 ARIMA(1,2,2): Inf Best model: ARIMA(0,2,1)		

Appendix Table 2

Appendix Table 2. The regression results of emission intensities

	Beijing	Tianjin	Hebei	Shanxi	Inner Mongolia	Liaoning
lnt	-0.0791*** (-37.38)	-0.0645*** (-23.80)	-0.0250*** (-7.49)	-0.0319*** (-11.53)	-0.0221*** (-6.01)	-0.0452*** (-27.73)
Cons.	-3.4959*** (-131.50)	-3.0349*** (-89.24)	-2.7740*** (-66.30)	-22305*** (-64.20)	-2.5019*** (-54.24)	-2.9344*** (-163.33)
	Jilin	**Heilongjiang**	**Shanghai**	**Jiangsu**	**Zhejiang**	**Anhui**
lnt	-0.0533*** (-12.24)	-0.0473*** (-21.71)	-0.0629*** (-57.12)	-0.0285*** (-8.78)	-0.0341*** (-8.87)	-0.0361*** (-14.96)
Cons.	-2.6694*** (-48.79)	-2.9535*** (-107.99)	-3.4477*** (-249.20)	-3.5756*** (-87.81)	-3.6198*** (-74.92)	-3.1118*** (-102.67)
	Fujian	**Jiangxi**	**Shandong**	**Henan**	**Hubei**	**Hunan**
lnt	-0.0162* (-2.55)	-0.0238*** (-9.01)	-0.0264*** (-4.23)	-0.0326*** (-6.03)	-0.0518*** (-12.34)	-0.0302*** (-4.72)
Cons.	-4.0000*** (-50.13)	-3.4337*** (-103.60)	-3.3675*** (-43.00)	-3.1475*** (-46.38)	-2.9635*** (-56.23)	-3.4412*** (-42.82)
	Guangdong	**Guangxi**	**Hainan**	**Chongqing**	**Sichuan**	**Guizhou**
lnt	-0.0441*** (-16.14)	-0.0165*** (-4.37)	-0.0060 (-1.32)	-0.0576*** (-14.33)	-0.0431*** (-10.88)	-0.0371*** (-7.90)
Cons.	-3.7728*** (-109.97)	-3.5025*** (-73.93)	-3.9118*** (-67.33)	-3.0781*** (-61.00)	-3.2766*** (-65.91)	-2.2842*** (-38.74)
	Yunnan	**Shaanxi**	**Gansu**	**Qinghai**	**Ningxia**	**Xinjiang**
lnt	-0.0211* (-2.30)	-0.0243*** (-5.76)	-0.0324*** (-12.87)	-0.0215*** (-9.97)	0.0140 (1.73)	0.0096* (2.27)
Cons.	-3.2923*** (-28.58)	-3.1114*** (-58.76)	-2.7889*** (-88.30)	-2.8899*** (-106.54)	-2.4416*** (-22.63)	-3.1111*** (-58.55)

Appendix Table 3

Appendix Table 3. Sector classification for the CO_2 emissions and the MRIO table

Sector code	CO_2 emissions	MRIO for 2012	MRIO for 2017
1	Farming, forestry, animal husbandry, fishery and water conservancy	Agriculture, forestry, animal husbandry and fishery	Agriculture, forestry, animal husbandry and fishery
2	Coal mining and dressing	Mining and washing of coal	Mining and washing of coal
3	Petroleum and natural gas extraction	Extraction of petroleum and natural gas	Extraction of petroleum and natural gas
4	Ferrous metals mining and dressing	Mining and processing of metal ores	Mining and processing of metal ores
	Nonferrous metals mining and dressing		
5	Nonmetal minerals mining and dressing	Mining and processing of nonmetal and other ores	Mining and processing of nonmetal and other ores
	Other minerals mining and dressing		
6	Food processing	Food and tobacco processing	Food and tobacco processing
	Food production		
	Beverage production		
	Tobacco processing		
7	Textile industry	Textile industry	Textile industry
8	Garments and other fiber products	Manufacture of leather, fur, feather and related products	Manufacture of leather, fur, feather and related products
	Leather, furs, down and related products		
9	Logging and transport of wood and bamboo	Processing of timber and furniture	Processing of timber and furniture
	Timber processing, bamboo, cane, palm fiber & straw products		
	Furniture manufacturing		
10	Papermaking and paper products	Manufacture of paper, printing and articles for culture, education and sport activity	Manufacture of paper, printing and articles for culture, education and sport activity
	Printing and record medium reproduction		
	Cultural, educational and sports articles		
11	Petroleum processing and coking	Processing of petroleum, coking, processing of nuclear	Processing of petroleum, coking, processing of nuclear

Sector code	CO_2 emissions	MRIO for 2012	MRIO for 2017
		fuel	fuel
12	Raw chemical materials and chemical products	Manufacture of chemical products	Manufacture of chemical products
	Medical and pharmaceutical products		
	Chemical fiber		
	Rubber products		
	Plastic products		
13	Nonmetal mineral products	Manuf. Of non -metallic mineral products	Manuf. Of non -metallic mineral products
14	Smelting and pressing of ferrous metals	Smelting and processing of metals	Smelting and processing of metals
	Smelting and pressing of nonferrous metals		
15	Metal products	Manufacture of metal products	Manufacture of metal products
16	Ordinary machinery	Manufacture of general purpose machinery	Manufacture of general purpose machinery
17	Equipment for special purposes	Manufacture of special purpose machinery	Manufacture of special purpose machinery
18	Transportation equipment	Manufacture of transport equipment	Manufacture of transport equipment
19	Electric equipment and machinery	Manufacture of electrical machinery and equipment	Manufacture of electrical machinery and equipment
20	Electronic and telecommunications equipment	Manufacture of communication equipment, computers and other electronic equipment	Manufacture of communication equipment, computers and other electronic equipment
21	Instruments, meters, cultural and office machinery	Manufacture of measuring instruments	Manufacture of measuring instruments
22	Other manufacturing industry	Other manufacturing	Other manufacturing and waste resources
	Scrap and waste	Comprehensive use of waste resources	
		Repair of metal products, machinery and equipment	Repair of metal products, machinery and equipment
23	Production and supply of electric power, steam and hot water	Production and distribution of electric power and heat power	Production and distribution of electric power and heat power
24	Production and supply of gas	Production and distribution of gas	Production and distribution of gas
25	Production and supply of tap	Production and distribution of	Production and distribution of

Sector code	CO_2 emissions	MRIO for 2012	MRIO for 2017
	water	tap water	tap water
26	Construction	Construction	Construction
27	Wholesale, retail trade and catering services	Wholesale and retail trades	Wholesale and retail trades
		Accommodation and catering	Accommodation and catering
28	Transportation, storage, post and telecommunication services	Transport, storage, and postal services	Transport, storage, and postal services
		Information transfer, software and information technology services	Information transfer, software and information technology services
29	Others	Finance	Finance
		Real estate	Real estate
		Leasing and commercial services	Leasing and commercial services
		Scientific research and polytechnic services	Scientific research
			Polytechnic services
		Administration of water, environment, and public facilities	Administration of water, environment, and public facilities
		Resident, repair and other services	Resident, repair and other services
		Education	Education
		Health care and social work	Health care and social work
		Culture, sports, and entertainment	Culture, sports, and entertainment
		Public administration, social insurance, and social organizations	Public administration, social insurance, and social organizations

Appendix Table 4

Appendix Table 4. The forecast of carbon peaking (Unit: CO_2)

Year	**Carbon peaking provinces**
2010	Beijing (103.00 Mt)
2011	Jilin (233.90 Mt), Hubei (373.60 Mt)
2012	Heilongjiang (269.20 Mt)
2013	Shanghai (201.20 Mt), Shanxi (488.20 Mt)
2014	Gansu (163.50 Mt), Liaoning (484.5 Mt)
2020	Tianjin (158.21 Mt), Chongqing (184.03 Mt)
2022	Guizhou (334.32 Mt), Hunan (359.41 Mt), Guangdong (614.54 Mt)
2024	Jiangxi (249.78 Mt), Shaanxi (333.35 Mt), Sichuan (441.91Mt), Anhui (447.75 Mt), Zhejiang (481.06 Mt), Henan (681.68 Mt)
2025	Jiangsu (928.25 Mt)
2026	Qinghai (63.75 Mt), Hebei (893.99 Mt), Shandong (1067.32 Mt)
2027	Yunnan (322.25 Mt)
2034	Guangxi (374.19 Mt)
2036	Hainan (71.64 Mt), Fujian (511.83 Mt)
2041	Inner Mongolia (1021.40 Mt)
2048	Ningxia (411.41 Mt), Xinjiang (583.15 Mt)

There are peaking carbon levels in parentheses.

The CO_2 emissions for 1997-2017 are obtained from CEADs, and the CO_2 emissions for 2018-2050 are the forecast results of this research.

Appendix Table 5

Appendix Table 5. The carbon peaking under the counterfactual scenario (2017) (Unit: CO_2)

Year	Carbon peaking provinces
2010	Beijing (151.93 Mt)
2011	Jilin (224.96 Mt)
2014	Gansu (124.67 Mt)
2017	Heilongjiang (302.99 Mt), Shanxi (413.90 Mt)
2019	Shanghai (268.90 Mt), Hubei (287.40 Mt), Liaoning (529.14 Mt)
2020	Chongqing (120.31 Mt)
2021	Tianjin (252.75 Mt)
2022	Guizhou (315.24 Mt), Hunan (358.50 Mt), Guangdong (831.94 Mt)
2024	Jiangxi (153.90 Mt), Anhui (314.61 Mt), Shaanxi (364.93 Mt), Sichuan (372.06 Mt), Henan (457.45 Mt), Zhejiang (520.30 Mt), Jiangsu (521.84 Mt)
2025	Hebei (485.35 Mt)
2026	Qinghai (44.99 Mt), Shandong (1478.42 Mt)
2027	Yunnan (219.35 Mt)
2031	Hainan (59.25 Mt)
2032	Guangxi (121.22 Mt)
2035	Fujian (498.11 Mt)
2036	Inner Mongolia (517.11 Mt)
2040	Xinjiang (328.92 Mt)
2048	Ningxia (199.33 Mt)

There are peaking carbon levels in parentheses.

Appendix Table 6

Appendix Table 6. The carbon peaking under the counterfactual scenario (2012) (Unit: CO_2)

Year	Carbon peaking provinces
2010	Beijing (163.04 Mt)
2011	Jilin (264.59 Mt)
2017	Heilongjiang (475.96 Mt), Shanxi (433.84 Mt)
2019	Liaoning (565.91 Mt)
2020	Chongqing (97.74 Mt), Gansu (103.63 Mt), Hubei (524.44 Mt), Shanghai (554.21 Mt)
2021	Tianjin (254.97 Mt)
2022	Hunan (279.96 Mt), Guizhou (308.09 Mt)
2023	Guangdong (969.16 Mt)
2024	Jiangxi (198.33 Mt), Anhui (266.87 Mt), Shaanxi (384.33 Mt), Sichuan (426.50 Mt), Zhejiang (585.07 Mt), Henan (594.97 Mt)
2025	Hebei (609.92 Mt), Jiangsu (769.40 Mt)
2026	Qinghai (107.04 Mt), Shandong (847.32 Mt)
2027	Yunnan (199.59 Mt)
2032	Hainan (70.15 Mt)
2033	Guangxi (188.89 Mt)
2035	Fujian (599.96 Mt)
2037	Inner Mongolia (509.05 Mt)
2042	Xinjiang (489.49 Mt)
2045	Ningxia (137.93 Mt)

There are peaking carbon levels in parentheses.