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著者	Gao Yuning, Li Meng, Bo Meng, Xue Jinjun
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Yuning GAO[1], Meng LI[1], Bo MENG[2*], Jinjun XUE

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Keywords: Carbon Emission; Carbon Transfer; Mandatory Mitigation Target; Input-Output Analysis; Chinese economy

JEL classification: Q54, Q58, C67, C54

1: School of Public Policy and Management, Tsinghua University, China; 2: Institute of Developing Economies – JETRO, Japan (bo_meng@ide.go.jp); 3: School of Economics, Nagoya University, Japan

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INSTITUTE OF DEVELOPING ECONOMIES (IDE), JETRO
3-2-2, WAKABA, MIHAMA-KU, CHIBA-SHI
CHIBA 261-8545, JAPAN

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Yuning GAO[1], Meng LI[1], Bo MENG[2], Jinjun XUE[3]

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The complexity of shared emissions responsibility for carbon transfers in various regions of China has further raised additional challenges for energy savings and carbon mitigation efforts. This paper establishes an extended provincial input-output (IO) model for each province to calculate carbon emissions based on production, consumption, and transfers from 2005 through 2015, and examines whether carbon mitigation policies can effectively promote energy conservation and emissions reduction in the various provinces. The empirical analysis established that: (1) an increase in the implementation strength of mitigation policy can effectively reduce production-based carbon emissions amongst the different provinces; (2) stricter mitigation policy increases the possibility that a province will transfer more of their emissions to other areas, thus causing a net emissions outflow; and (3) subsequent policy enforcement will weaken once mitigation goals are accomplished. Therefore, this paper repudiates the accepted belief that mitigation policy effectively controls carbon emissions, especially for production-based emissions. More refined policy design and supplementation is needed when considering consumption-based emissions and related carbon transfers.

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1. Introduction

As of 2005, China surpassed the United States (US) as the world's largest carbon emitter and its annual carbon emissions have been growing rapidly along with its economic development ever since (Minx, 2011). Its emissions declined for the first time in 2014 but quickly rebounded thereafter. China faces arduous mitigation challenges (Lin & Liu, 2010) and is making tangible efforts. In 2009 at the Copenhagen Conference, China announced the goal of reducing 40-45% of its carbon dioxide (CO2) emissions per unit of gross domestic product (GDP) by 2020. In the US-China Joint Announcement on Climate Change in 2014, China also claimed to expect an emissions peak in the year 2030, when non-fossil fuel energy would comprise 20% of all energy consumption. China further set its goal for reducing CO2 emissions by 60% to 65%—lower than that of 2005—per unit of GDP by 2030. It is important to note that with global economic integration, a considerable amount of China's carbon emissions is generated by the consumers at the end of the global value chain (GVC) of China's exports (Meng *et al.*, 2018). A similar phenomenon also occurs in China's domestic value chain, which is composed of its various provinces. Therefore, current mitigation policies need to clarify emissions responsibility first, both on the international and domestic levels.

On the other hand, China has formulated corresponding mitigation policies based on administrative and market means. The Five-Year Program (FYP) policy is an important administrative tool for management of China's energy conservation and emissions reduction. Contents related to those subjects in FYPs have been increasing continuously in terms of quantity and policy details (Yuan & Zuo, 2011). According to the FYPs, China's energy policy can be divided into two stages. The first phase is to expand energy production and consumption increase rapidly. From the first to the tenth FYP, there were clear goals for coal production. Targets of total energy production existed from the sixth to the ninth FYP. The tenth FYP become a turning point for not setting such targets anymore, indicating that the government will no longer simply encourage the expansion of energy production. The second phase starts from the eleventh FYP until now. During this period, targets for energy conservation and emissions reductions have increased in quantity as well as quality. In the eleventh FYP, China proposed mandatory targets to reduce 10% of its total pollutant emissions and 20% of its energy consumption per unit GDP. It decomposed these targets into governments and enterprises at all levels and set energy-savings targets under the "One Thousand Enterprises Energy Saving and Emission Reduction Action Plan." Completion of those targets has been incorporated into performance appraisals of governments and state-owned enterprises (SOEs) (State Council, 2011). On carbon emissions, the eleventh FYP proposed a general and broad mitigation target, addressed as "effectively controlling greenhouse gas (GHG) emissions" (State Council, 2006). In the twelfth FYP, however, China proposes a 16% reduction in energy consumption and a 17% reduction in CO2 emissions per unit of GDP. It would reduce 8% of total COD and 10% of ammonia nitrogen and nitrogen oxide emissions, respectively. China also plans to level its forest coverage up to 21.66% and increase 600 million cubic meters of forest stock. In January 2012, Plans for GHG Emission Control in the twelfth FYP was issued (State Council, 2011). Apparently, the twelfth FYP has more detailed targets for carbon emissions. It has a chapter focusing solely on carbon emissions and climate change issues. This chapter lays out many mitigation measures to ease energy consumption intensity and carbon intensity, such as adjusting industrial and energy structures, promoting energy conservation and efficiency, and increasing forest carbon absorption. From the eleventh FYP to the twelfth FYP, the numbers of indices related to resources and the environment increase from eight to 12. Mandatory indices increase to 11 from six, suggesting that the government is making a stronger effort with mitigation policies.

According to calculations of carbon emissions based on production, consumption, and net carbon transfers of China's provinces between 2005 and 2015, this paper clarifies the direct and indirect carbon emissions responsibilities of each province. By including policy variables into an empirical analysis framework, this paper tries to answer the following questions: Do these policies effectively promote mitigation? What kind and which part of mitigation are promoted? Do policies promote or undermine carbon balances in provinces that have different characteristics? Do the FYP's mitigation policies have a sustainable impact?

This paper is organized as follows. Section 2 reviews the relevant literature on extended input-output analysis and policy impact on energy conservation and emissions reduction. Section 3 establishes and describes various methods for carbon emissions accounting, and expands the traditional method to include an extended provincial input-output model to calculate carbon emissions based on production, consumption, and other criteria. Section 4 outlines data sources, provides the results of emissions accounting calculations, and builds a carbon emissions database for 30 provinces for the years between 2005 and 2015. Sections 5 and 6 carry out empirical calculations and present results; Section 5 analyzes the impact of mitigation policies of different emissions calibers and components and Section 6 examines the implementation stringency of mitigation policies in the remaining years after the realization of mitigation targets. Section 7 provides concluding remarks and discusses policy implications.

2. Literature Review

Due to its importance, a large number of scholars have conducted many research studies on the subject of carbon emissions estimation, inter-regional carbon transfer and spillover effects, and the policy impacts on drivers of growing emissions. This paper is concerned with two elements of that research, including the measurement of "real" carbon emissions and the factors driving emissions based on those calculations.

The literature on measuring "real" carbon emissions primarily consists of the production-based and consumption-based approaches, namely, "give credit where credit is due" (Koopman, 2010). Calculations of carbon emissions have two major principles, producer-based and consumer-based (Atkinson *et al.*, 2011; Peters, 2008; Steininger *et al.*, 2014). The producer-based principle allocates emissions to producers. The carbon emissions from the production of all goods and services in a certain region are used to either meet consumption demands locally or are exported elsewhere. The consumer-based principle, on the other hand, attributes emissions to the final consumer. Emissions of the goods and services consumed by local residents, businesses, and governments in a certain region are either directly generated from the local market or are purchased from other regions (Davis and Caldeira, 2010; Feng *et al.*, 2014; Takahashi *et al.*, 2014; Tian *et al.*, 2014; Wang *et al.*, 2018; Wiedmann *et al.*, 2011). To clarify the emissions responsibilities of producers and consumers (Guan *et al.*, 2014; Lenzen *et al.*, 2007), the accurate calculation of consumption-based emissions must trace the carbon emissions embedded in inter-regional trade (Jakob *et al.*, 2014; Peters and Hertwich, 2008a, 2008b; Steininger *et al.*, 2014). Scholars first apply input-output analysis (IOA) to environmental areas (Hertwich *et al.*, 2009; Leontief, 1970; Su *et al.*, 2010; Su and Ang, 2014; Wiedmann *et al.*, 2007; Wiedmann, 2009), and confirm the accuracy and superiority of the multi-regional input-output model (MRIO) (Liu *et al.*, 2017). They then began using the MRIO for the calculation of international carbon transfers (Liu and Fan, 2017; Meng *et al.*, 2018) and inter-regional emissions levels within nations. On such a basis, scholars used the extended input-output model (EIO) to calculate China's "real" carbon emissions and discuss carbon transfers within China. Some research examined China's inter-regional carbon spills in 2002, 2007, and 2012. They estimated the consumption-based carbon emissions inventory on the basis of production-based emissions (Wang *et al.*, 2016; Zhao *et al.*, 2015). Some scholars believed that the carbon spillovers and transfers embedded in inter-regional trade were very common in China due to the domestic disparity between the economy and technology (Duan *et al.*, 2018; Feng *et al.*, 2012; Feng *et al.*, 2013; Meng *et al.*, 2013; Liang *et al.*, 2007; Liu *et al.*, 2015; Zhang *et al.*, 2018a). Some studies embedded China's inter-regional input-output table into the global table in order to analyze China's inter-regional carbon transfers from the perspective of their participation in GVCs (Guo *et al.*, 2012; Pei *et al.*, 2018; Yu, 2014; Zhang *et al.*, 2018b).

The literature on driving factors mainly conducts studies through empirical analysis, such as regression analyses based on models such as the IPAT, STRIPAT, and Kaya (Dietz and Rosa, 1994; Ehrlich and Holdren, 1971, 1972; Yoichi Kaya, 1989), as well as structural decomposition analysis. Recent literature focuses on the impact of mitigation policy on carbon emissions and economic development, in particular, the FYPs (Tang *et al.*, 2016; Yuan and Zuo, 2011), carbon trade (Cong and Wei, 2010; Li *et al.*, 2018; Dai *et al.*, 2018), and energy or carbon taxes (Chen and Guo, 2017; Fan *et al.*, 2018; Zheng *et al.*, 2016; Zou *et al.*, 2018). They further divided emission responsibilities for each province in China (Wang *et al.*, 2018), proposed policy recommendations (Lin and Liu, 2010), and concluded that China should alter its energy structure and promote energy conservation to achieve mitigation targets.

In summary, with the support of a larger database and expanded IOA methods, the existing literature re-calculated production- and consumption-based carbon emissions at the international and domestic levels, respectively. They also evaluated or simulated the impacts of various types of policies. However, most conducted research at a larger regional level rather than at a provincial level, for a given year, or created case studies of specific provinces. This paper extends the current MRIO model to establish provincial-level panel data for production-based, consumption-based, and transferred emissions. This method has several advantages. Firstly, it can trace the "real" carbon emissions for different industries and individual provinces by expanding the existing MRIO. In addition, this paper offers a more consistent and continuous time span that covers several FYPs and makes evaluations more systematic. Moreover, this paper establishes better research reliability by taking each province's economy, population, natural resources, and policy differences into consideration when conducting empirical analyses at the provincial level.

3. Methods for Carbon Emissions Accounting

There are two causes of carbon emissions. Carbon can be emitted from the direct combustion of fuels, such as cooking and heating, which is referred to as direct emissions. The other cause is consumption-based. Although no direct emissions are created during consumption, products consumed by residents, businesses, and governments cause emissions during their production process. This type is called indirect emissions.

Therefore, under a complete carbon calculation framework, carbon emissions consist of two major components, direct and indirect emissions. Indirect emissions contain three distinct branches: emissions that are embedded in products that are produced and consumed locally, those that are embedded in imported products, and those that exist in exported products. Based on different calculation principles, these three components can add up to a variety of results. Combining carbon emissions embedded in local production and consumption with emissions embedded in import transfers yields the total for consumption-based emissions. One can calculate production-based emissions by adding the emissions embedded in local production to those in export transfers. One can also calculate net carbon imports, namely, the carbon surplus, by subtracting the emissions embedded in export transfers from those in import transfers. Furthermore, we are able to obtain carbon emissions based on the regional geographical boundaries by adding direct emissions and production-based emissions together. The framework for carbon emissions calculations is shown in Figure 1.

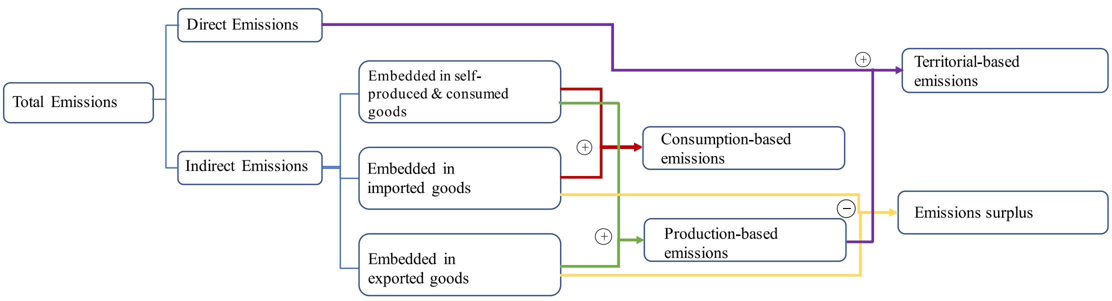


Figure 1. Accounting Framework for Carbon Emissions.

The most widely used method for carbon emissions calculations is the MRIO. Researchers calculate China's inter-regional carbon transfers based on this model (Feng *et al.*, 2013; Liu *et al.*, 2015; Wang *et al.*, 2017). The MRIO shows its superiority by accurately include flows of carbon emission in different industries and regions (Liu *et al.*, 2017). Since the inter-regional input-output table of China is only available for the years of 2007 and 2012, and it is aggregated at the regional or industry level, the MRIO is more suitable for reflecting carbon transfers and responsibility commitments amongst major regions, rather than calculating provincial indirect emissions.

In calculations, direct emissions can be measured by energy consumptions. Indirect emissions, by expanding the MRIO into an environmentally EIO, can be calculated by tracing all final consumption back to its production. The EIO serves as a bridge that connects final consumption to carbon emissions. Through the "Final Use-Total Output-Carbon Emissions" process, the EIO tracks all indirect emissions. On the other hand, the EIO also connects consumption-based emissions at the input end to production-based emissions at the output end. It unifies two emissions calculation calibers into one unified model.

Therefore, this study expands the IOA to an extended provincial IO model, which is a derivative of, or an exception to, the MRIO. An extended provincial input-output (IO) table distinguishes between "local" and the "rest of China" for each province. This table enables accurate emissions calculations across all provinces for consecutive years. Instead of emphasizing the detailed distribution of carbon transfers between regions, it focuses on the measurement of total production-based and consumption-based emissions in different industries across various provinces in different years. For a given province *i*, the extended provincial IO table can be obtained by combining the regional and national IO tables, as shown in Table 1.

Table 1. Structure of the Extended Provincial IO Table.

		Intermediate Use				Final Use						Total Output
						Consumption			Capital Formation	Export		
						Household		Government				
		Industry 1	…	Industry n	Total	Rural	Urban					
Province i	Industry 1											
	…											
	Industry n											
	Total											
Rest of China & Import	Industry 1											
	…											
	Industry n											
	Total											
Value Added												
Total Input												

The extended provincial IO model still satisfies the basic equation:

$$X = (I - A^*)^{-1} Y^* \tag{1}$$

$$C^* = F^*(I - A^*)^{-1} Y^* \tag{2}$$

$$C^M = \overline{F}\left(I - \overline{A}\right)^{-1} Y^M \tag{3}$$

$$Y = Y^* + Y^M \tag{4}$$

$$C = C^* + C^M \tag{5}$$

In which:

X: Total Output for Province i

A^*, $\overline{A}$: Direct consumption coefficient matrix for Province i and the *Rest of China*

$(I - A^*)^{-1}$, $\left(I - \overline{A}\right)^{-1}$: Leontief Inverse Matrix for Province i and the *Rest of China*

Y, Y^*, Y^M: Sum of Final Use, Final Use from Province i, Final Use Imported from the *Rest of China* and foreign countries

F^*, $\overline{F}$: Carbon emission coefficient for Province i and the *Rest of China*

C, C^*, C^M: Carbon emissions caused by final use of Province i, that produced in Province i, produced in the *Rest of China*,

We continue to sub-divide the final use of local products and the final use of imported products. According to their specific flows, we can sub-divide these into five sectors: urban consumption, rural consumption, government consumption, capital formation, and exports.

$$Y^* = Y_U^{CON*} + Y_R^{CON*} + Y_G^{CON*} + Y^{CAP*} + E^* \tag{6}$$

$$Y^M = Y_U^{CON\_M} + Y_R^{CON\_M} + Y_G^{CON\_M} + Y^{CAP\_M} + E^M \tag{7}$$

We expand Y^* and Y^M[1]:

$$C^* = F^*(I - A^*)^{-1}(Y_U^{CON*} + Y_R^{CON*} + Y_G^{CON*} + Y^{CAP*} + E^*)$$
$$= C_U^{CON*} + C_R^{CON*} + C_G^{CON*} + C^{CAP*} + C^E \tag{8}$$

$$C^M = \overline{F}\left(I - \overline{A}\right)^{-1}\left(Y_U^{CON_M} + Y_R^{CON_M} + Y_G^{CON_M} + Y^{CAP_M}\right)$$
$$= C_U^{CON_M} + C_R^{CON_M} + C_G^{CON_M} + C^{CAP_M} \tag{9}$$

1 E^{IM} refers to re-export Trade which is not consumed. It should be excluded when calculating total carbon emissions.

Therefore, we can calculate total carbon emissions C:

$$
\begin{aligned}
C &= C^{*} + C^{M} \\
&= (C_U^{CON*} + C_R^{CON*} + C_G^{CON*} + C^{CAP*} + C^{E}) + \left(C_U^{CON_M} + C_R^{CON_M} + C_G^{CON_M} + C^{CAP_M}\right) \\
&= (C_U^{CON*} + C_U^{CON_M}) + (C_R^{CON*} + C_R^{CON_M}) + (C_G^{CON*} + C_G^{CON_M}) + (C^{CAP*} + C^{CAP_M}) + C^{E} \\
&= C_U^{CON} + C_R^{CON} + C_G^{CON} + C^{CAP} + C^{E} \qquad (10)
\end{aligned}
$$

Similarly, we can also aggregate those sub-divided carbon emissions categories to obtain total emissions for household consumption, total emissions from household and government, and emissions generated by local products and services that include consumption and fixed capital.[2] These three categories are listed below.

$$C^{H} = C_U^{CON} + C_R^{CON} \qquad (11)$$

$$C^{CON} = C^{H} + C_G^{CON} \qquad (12)$$

$$C^{CON\&CAP} = C^{CON} + C^{CAP} \qquad (13)$$

Net carbon transfers can be shown as follows.

$$C^{B} = C^{M} - C^{E} \qquad (14)$$

Production-based carbon emissions, consumption-based emissions, and their relationship, are shown as follows.

$$C^{P} = C^{CON} + C^{CAP} + C^{E} \qquad (15)$$

$$C^{C} = C^{CON} + C^{CAP} + C^{M} \qquad (16)$$

$$C^{C} = (C^{CON} + C^{CAP} + C^{E}) + (C^{M} - C^{E}) = C^{P} + C^{B} \qquad (17)$$

The Carbon Emissions Matrix, measured by the extended provincial IO table, can be seen in Table 2.

Table 2. The Carbon Emissions Transfer Matrix, Under an Extended Provincial IO Table.

		Emissions induced by local				Emissions induced by exports
		Consumption			Capital Formation	
		Household		Government		
		Rural	Urban			
Province i	Industry 1	A. Emissions in Province i induced by final consumption of Province i				B. Emissions in Province i induced by exports of Province i
	Industry 2					
	…					
	Industry n					
Rest of China & Import	Industry 1	C. Emissions outside Province i induced by final consumption of Province i				D. Re-export Trade (excluded from emission calculations)
	Industry 2					
	…					
	Industry n					

From Table 2, we can now calculate production-based carbon emissions, consumption-based carbon emissions, and transferred emissions, respectively. We arrive at the production-based carbon emissions of province i by adding A, carbon emissions in province i caused by final consumption in province i, with B, carbon emissions in province i caused by exports of province i, horizontally. This yields consumption-based carbon emissions by combining A, carbon emissions in province i caused by final consumption of province i with C, carbon emissions for the *Rest of China* that are caused by final consumption in province i, vertically. Furthermore, we can measure the net carbon transfer (carbon surplus) of province i by subtracting B, carbon

[2] Carbon emissions used by local goods and services that are consumed locally equal the sum of household consumption, government consumption, and capital formation. Corresponding to the local end in final use, it can be sub-divided into rural consumption, urban consumption, government consumption, and capital formation.

emissions in province i caused by exports of province i from C, carbon emissions in the $Rest\ of\ China$ caused by final consumption in province i.

The extended provincial IO model has three major advantages. The first is that the IO data comes directly from the National Bureau of Statistics with less artificial processing and estimation. The data source is more authoritative, accurate, and easier to access. Secondly, as a transformation of the MRIO, it retains the accuracy of the MRIO. Moreover, it enables us to measure carbon emissions for each individual province and provides provincial penal data that is feasible for use in further empirical analysis.

4. Data Sources and the Results of Accounting

The extended provincial IO model requires three categories of data, which are carbon intensity, Leontief inverse matrix, and final consumption.

Constructing carbon intensity data includes two steps. One is the collection of carbon emissions from various industries across different regions. The other is to collect the total output for each region and industry. Industry-level emissions data in this paper is from the CEADS database (Shan *et al.*, 2017), which covers direct emissions from 45 industries, urban and rural households, 47 sections in total. The total output data in this paper is directly from the regional input-output table in certain feasible years. In other years, data of 36 industrial sectors, except for architecture, is from China Industry Economy Statistical Yearbook, China Industry Statistical Yearbook, or China Economic Census Yearbook. Data on agriculture, forestry, animal husbandry, fishery, and architecture come from the National Bureau of Statistics website. Data of service industry is calculated based on added value and its growth rate.

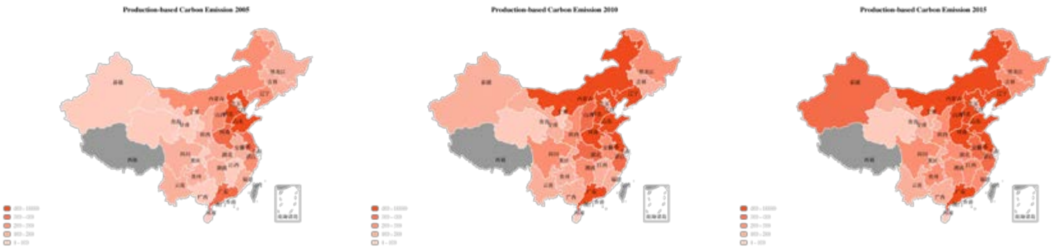
The Leontief inverse matrix comes from the national and provincial level IO tables released by the National Bureau of Statistics for the years 2007 and 2012 (NBS, 2011; NBS, 2016), covering 42 departments in 30 provinces, with the exception of Tibet. In this paper, we first calculate the direct input coefficient matrix through the intermediate input matrix and total output. On that basis, we obtain the Leontief inverse matrix.

Data regarding final use is derived from sub-divisions of the National Bureau of Statistics' provincial-level gross regional products (by expenditure approach) for the years of 2005 through 2016. It consists of rural consumption, urban consumption, capital formation, and the net outflow of goods and services. This paper, combines the structure of final use for each province in the IO table, and then splits the total for final use of each type to obtain the data for final use in each year, province, and industry.

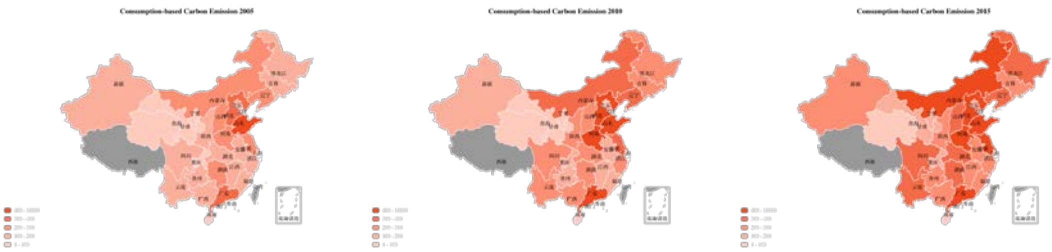
This paper combines the IO tables, CEADS emissions data, and total output data for different years in 28 business sectors, including general agriculture, forestry, animal husbandry, and fisheries, 24 industries, and three service sectors. Appendix A shows these specific correspondences.

Based on the models above, this paper uses the direct consumption coefficient matrix and carbon emissions coefficient matrix for each province to estimate the local carbon emissions embedded in self-consumed and outflowed products. It uses the direct consumption coefficient matrix and carbon emissions coefficient matrix in ROC to estimate carbon emissions in ROC that are embedded in imported goods and services to the local market. The panel database for carbon emissions in 30 provinces between 2005 and 2015 is then established.

Figure 2 shows production-based carbon emissions, consumption-based carbon emissions, and net carbon transfers for each province in the years 2005, 2010, and 2015. The deeper the red color, the higher the level of carbon emitted or transferred. From 2005 to 2015, production-based carbon emissions have significantly increased, mainly in the Beijing Circle, which includes Hebei, Shandong, Henan, and the Shanghai circle, which includes Anhui, Jiangsu, Zhejiang, the economically developed Guangdong, and coal-producers such as Shanxi and Inner Mongolia. In general, Shandong, Hebei, Jiangsu, and Inner Mongolia are the provinces with the highest production-based carbon emissions. Beijing, Tianjin, Shanghai, Yunnan, Sichuan, Qinghai, and Ningxia are the regions with the lowest emissions. From 2005 to 2015, consumption-based carbon emissions also increased significantly, mainly in the Beijing Circle, east coast line, and in heavily populated provinces. Shandong, Heibei, Jiangsu, Henan, and Guangdong are the largest consumption-based emitters. Beijing, Tianjing, Shanghang, Jiangxi, Hainan, Chongqing, Gansu, Qinghai, and Ningxia have relatively small consumption-based emissions scales. Crimson areas refer to a net outflow carbon transfer while the blue areas represent the opposite. Heibei, Shanxi, Inner Mongolia, Gansu, Liaoning, Shanghai, Jiangsu, and Zhejiang constantly keep a carbon transfer deficit. Yunnan, Hunan, Tianjing, Guangdong, Guangxi, Qinghai, Sichuan, Beijing, Fujian, and Hainan hold a stable surplus. Shandong, Hubei, Heilongjiang, and Henan's performances vary between those years.



(a) Production-Based Carbon Emissions.



(b) Consumption-Based Carbon Emissions.

(c) Net Carbon Transfers.

Figure 2. Distribution of Carbon Emissions and Transfers in the Provinces.

5. Empirical Analysis and Results

In this sector, we examine the impact of mandatory targets. Specifically, this study investigates whether the implementation of mandatory targets has effectively reduced emissions and how it changes net emissions transference for a province. This study uses panel data for carbon emissions in 30 provinces from 2005 to 2015 to conduct regression analysis on production-based carbon emissions, consumption-based carbon emissions, and net carbon transfers.

5.1 Construction of Policy Variables

To analyze the impact of mitigation policy, this paper quantitatively measures the implementation of mandatory targets in the following ways. This paper uses the reduction rate of energy consumption per unit of GDP and completions of mandatory mitigation targets in the FYPs as proxy variables for policy implementation intensity. The reduction rate of energy consumption per unit of GDP is the indicator that superior government concerns most often use to evaluate the performance of subordinate governments. The provincial governments tend to strengthen policy implementation intensity to reduce their energy consumption per unit of GDP if they want better assessment results[3]. In the same way, the earlier that provincial governments want to complete their tasks, the faster and the higher the proportion of completion of mandatory targets. In this paper, we use three variables to reflect the stringency of mitigation policy, including $energy\ \ rate_t$, the reduction rate of energy consumption per unit of GDP in year *t*; $completeness\_\%_t$, the progress of mandatory target accomplished in year *t*; and $completeness\_d_t$, whether the yearly mandatory target is achieved in year *t*. The policy implementation variables are calculated as follows:

$$energy\ \ rate_t = E_t = (1 - \frac{erergy\ \ consumption_t / GDP_t}{erergy\ \ consumption_{t-1} / GDP_{t-1}}) \times 100\% \qquad (18)$$

$$COMPLETE\_year_t = \frac{log[(1+E_1)(1+E_2)\cdots(1+E_t)]}{log(1+E_0)} \qquad (19)$$

$$COMPLETE\_\%_t = \frac{COMPLETE\_year_{11/12}}{5} \times 100\% \qquad (20)$$

$$completeness\_\%_t = COMPLETE\_\%_t - COMPLETE\_\%_{t-1} \qquad (21)$$

$$completeness\_d_t = \begin{cases} 0, & E_t < E_0 \\ 1, & E_t \geq E_0 \end{cases} \qquad (22)$$

Where t represents the ordinal of that year for the corresponding FYPs. $erergy\ \ consumption_t$ refers to local energy consumption in terms of standard coal in year *t*. GDP_t is the local GDP in 2000 constant price in year *t*. E_t is the local reduction rate of energy consumption per 10000 Yuan of GDP in year *t*. E_0 is the expected annual reduction rate of energy consumption per unit of GDP, according to the FYP. $COMPLETE\_year_t$ is the number of years that meet the expected targets from the FYPs in year *t*. $COMPLETE\_\%_t$ is the completion rate(in %) of

[3] The superior government will conduct evaluations according to the reduction rate in energy consumption per unit of GDP of lower-level governments. It divides completion into four levels: excessively completed, completed, generally completed, and uncompleted. At the same time, data on the completion progress of each province will be calculated and released.

the targets by the end of year t. $completeness\_\%_t$ is the progress of mandatory targets accomplished in year t, which is the difference between the general progress of year t and year t-1. $completeness\_d_t$ is a dummy variable representing whether or not 20% progress of the mandatory target will be met in year t. It is equivalent to the dummy variable of whether or not the progress in the reduction rate of energy consumption per unit of GDP in year t can reach the annual average to achieve mandatory targets. The statistical descriptions of the policy variables used in the empirical model are shown in Table 3.

Table 3. Statistical Descriptions of Major Policy Variables.

Variables	Definition	Obs	Mean	Sd.	Min	Max
energy rate	reduction rate of energy/GDP	330	1.690	3.910	-20.80	22.75
completeness_%	Annual progress of FYP in that year	300	26.68	23.17	-85.37	148.03
completeness_d	If complete 20% or more of FYP target	300	0.670	0.470	0	1

5.2 The Emission Reduction Effect of Mandatory Mitigation Policies

Firstly, we examine whether the implementation of mandatory targets has effectively reduced emissions. Mandatory targets reduce emissions not only by lowering the energy intensity, but also through other channels, such as encouraging carbon sequestration technology, encouraging research and development, and enhancing productivity as well as sending emissions reduction signals. Here the dependent variables are production-based and consumption-based emissions. The independent variables are the different measures for the completion of mitigation targets. With reference to the IPAT, the STRIPAT, and the Kaya models, this paper also introduces other control variables. We run the following model to test the effectiveness of mandatory targets.

$$y_{it} = \alpha + \beta X_{it} + \theta Z_{it} + \gamma_i + \delta_t + \varepsilon_{it} \qquad (23)$$

where y_{it} is production-based emissions or consumption-based emissions of region i in year t. X_{it} is the policy variable with which we are concerned. The policy variable measures the completion of mitigation targets in the given year. We consider *energy rate*, $completeness_{\%}$, and c*ompleteness_d* as policy variables. Z_{it} is a series of control variables, including the logarithm of per capita GDP, *lnGDP*, population, *lnPopulation*, urbanization rate, *urbanrate*, share of children, and elderly in population, *old&young*, GDP ratio of third industry *industry_3rd*, GDP ratio of imports, *IM_%* and exports, *EX_%*, and the proportion of coal in total energy consumption *coalrate*, which is often considered and controlled for in the previous literature. These variables are calculated from the China Statistical Yearbook and the National Bureau of Statistics website. γ_i and δ_t are the fixed effects of the province and time, respectively. ε_{it} is the random error term. Since key independent variables are all expressed in percentages, we calculate the logarithms of two dependent variables, consumption-based and production-based carbon emissions, respectively. We then discuss the elasticity between policy intensity and emissions. The main regression results of the total effect are shown in Table 4.

Table 4 indicates that the implementation of mandatory targets significantly reduces production-based emissions. It also has a negative, but insignificant, impact on consumption-based emissions. Regressions (1), (2) and (3) demonstrate the interrelationship between consumption-based emissions and policy implementation intensity. The results suggest that mandatory targets can reduce consumption-based emissions as a vane policy. But policy implementation intensity does not result in significant reductions in consumption-based emissions. Regressions (4), (5) and (6) show the interrelationship between production-based emissions and policy implementation intensity. Since mitigation policies mainly target local enterprises and residents, we expect that the implementation of mandatory targets would reduce production-based emissions. The regressions show that: (1) for every 1% increase in the reduction rate of energy consumption per unit of GDP, production-based emissions drop by 0.551%; (2) for each 1% increase in overall completion of the mandatory target during the relevant FYP, production-based emissions decrease by 0.118%; (3) if the yearly mandatory target is completed, production-based emissions also decrease, notwithstanding insignificantly. It is worth noting that control variables like *coalrate* might also be influenced by mitigation policy, for instance, the policy might lower the share of coal in total energy use. However, this does not affect the basic results of our study since we might have underestimated the policy effect. As long as the mandatory target is effective under current our estimation, it shall still be effective when we further take into consideration the mediating effect of changes in industry and energy structures.

Table 4. Emission Reduction Effect of Mandatory Mitigation Policies.

	Consumption-based Emissions			Production-based Emissions		
	(1)	(2)	(3)	(4)	(5)	(6)
lnGDP	1.405***	1.378***	1.327***	0.827***	0.908***	0.812***
	(6.72)	(5.87)	(5.74)	(6.80)	(6.68)	(5.90)
lnPopulation	0.981***	0.962***	0.977***	0.810***	0.670***	0.599***
	(2.98)	(2.67)	(2.69)	(4.24)	(3.22)	(2.77)
urbanrate	0.0140**	0.0164**	0.0176**	0.0189***	0.0145***	0.0163***
	(2.17)	(2.33)	(2.50)	(5.06)	(3.56)	(3.90)
old&young	-0.00266	-0.00169	-0.00202	-0.00538**	-0.00359	-0.00393
	(-0.65)	(-0.38)	(-0.45)	(-2.26)	(-1.39)	(-1.48)
industry_3rd	0.00875**	0.0101**	0.00962**	-0.00292	-0.000972	-0.00169
	(2.25)	(2.40)	(2.30)	(-1.29)	(-0.40)	(-0.68)
IM_%	0.0107***	0.00617*	0.00648**	0.0105***	0.00806***	0.00883***
	(3.65)	(1.89)	(1.99)	(6.12)	(4.25)	(4.55)
EX_%	-0.00944***	-0.00685**	-0.00711**	-0.00787***	-0.00654***	-0.00761***
	(-3.38)	(-2.31)	(-2.41)	(-4.86)	(-3.81)	(-4.34)
coalrate	0.0127***	0.0122***	0.0126***	0.0170***	0.0168***	0.0175***
	(5.29)	(4.80)	(5.00)	(12.20)	(11.39)	(11.64)
energy rate	-0.00292			-0.00551***		
	(-1.14)			(-3.71)		
completeness_%		-0.000494			-0.00118***	
		(-0.96)			(-3.98)	
completeness_d			0.0165			-0.0118
			(0.68)			(-0.82)
Constant	-17.96***	-17.78***	-17.47***	-10.99***	-10.51***	-9.105***
	(-4.43)	(-4.04)	(-3.98)	(-4.67)	(-4.12)	(-3.49)
Year	Y	Y	Y	Y	Y	Y
Province	Y	Y	Y	Y	Y	Y
Observations	330	300	300	330	300	300
Adjusted R^2	0.788	0.756	0.755	0.894	0.864	0.856

t statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

5.3 The Impact Of Mitigation Policies on Emissions Transfers

This paper then examines how mitigation policies would change the provinces' net emissions transfers. That is, for this sector, we try to test whether more emissions would outflow from the provinces with more stringent mandatory target implementation. We run the following model to test the impact of mandatory targets.

$$y_{it} = \alpha + \beta X_{it} + \theta Z_{it} + \gamma_i + \delta_t + \varepsilon_{it} \qquad (24)$$

Here the dependent variable, y_{it}, is variable $d.balance_{it}$, which indicate net emissions transfer changes in province i in year t as compared to last year.

$$d.balance_{it} = balance_{it} - balance_{it-1} \qquad (25)$$

The independent variable X_{it} still measures the implementation of mitigation targets. We consider *energy rate*, $completeness_{\%}$, and c*ompleteness_d* as the policy variables. The lag terms of these policy variables are also considered to include the time-lag effect of mitigation policy. Similar to previous models, we also include other controlled variables in this model as Z_{it}. γ_i, and δ_t which are the fixed effects of the province and time, respectively. ε_{it} is the random error term. The results are presented in Table 6.

Table 5. Impact on Net Emissions Transfers.

	(1)	(2)	(3)	(4)	(5)	(6)
GDP	5.269	4.688	5.459	1.982	8.706	8.259
	(0.29)	(0.26)	(0.30)	(0.09)	(0.49)	(0.37)
sqGDP	-1.068	-1.121	-1.041	-0.882	-1.162	-1.063
	(-0.71)	(-0.75)	(-0.69)	(-0.49)	(-0.78)	(-0.59)
population	0.016	0.014	0.017	0.013	0.020	0.017
	(0.87)	(0.73)	(0.93)	(0.59)	(1.06)	(0.75)
urbanrate	1.083	0.934	1.092	1.065	0.985	0.931
	(0.73)	(0.62)	(0.73)	(0.60)	(0.66)	(0.52)
old&young	0.111	0.042	0.106	-0.279	0.004	-0.298
	(0.11)	(0.04)	(0.11)	(-0.25)	(0.00)	(-0.26)
industry_3rd	0.965	0.989	0.931	0.529	0.947	0.561
	(1.12)	(1.15)	(1.08)	(0.52)	(1.10)	(0.55)
IM_%	-0.220	-0.186	-0.192	0.018	-0.286	-0.138
	(-0.30)	(-0.25)	(-0.26)	(0.02)	(-0.39)	(-0.16)
EX_%	-0.257	-0.375	-0.259	-0.608	-0.016	-0.141
	(-0.37)	(-0.52)	(-0.37)	(-0.74)	(-0.02)	(-0.18)
coalrate	-0.286	-0.251	-0.332	-0.241	-0.419	-0.402
	(-0.50)	(-0.43)	(-0.58)	(-0.37)	(-0.74)	(-0.62)
energy rate	1.389*	1.443*				
	(1.78)	(1.84)				
L.energy rate		0.433				
		(0.75)				
completeness_%			0.185*	0.199*		
			(1.67)	(1.67)		
L.completeness_%				0.145		
				(1.15)		
completeness_d					8.919*	9.646*
					(1.70)	(1.69)
L.completeness_d						3.960
						(0.65)
Constant	-153.986	-134.131	-155.014	-107.818	-158.400	-124.991
	(-1.18)	(-1.01)	(-1.19)	(-0.69)	(-1.21)	(-0.80)
Observations	300	300	300	270	300	270
Adjusted R^2	0.114	0.112	0.112	0.082	0.113	0.078
F	4.543	4.336	4.517	3.784	4.525	3.732

z statistics in parentheses

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The results reveal that the implementation of mandatory targets has a significant impact on a province's net emissions transfer. Under stricter mitigation policies, a province will transfer more of their emissions to other areas. Specifically, the higher the energy intensity reduction rate, the higher the completion share of the mandatory target, as well as the completeness of the target as measured by a dummy variable, which all contribute to the overall increase in net emissions transfers. This implies that stringent mitigation policy encourages a net emissions outflow and induces the carbon leakage embodied in inter-provincial trade.

6. The Effectiveness of Implementation Intensity of Mitigation Targets

Establishing mandatory mitigation targets can efficiently obtain expected goals in the short term. One flaw of such short-term targets is that once the goal is achieved, governments may no longer have the incentive to continue policy implementation. For example, in the FYP, before mitigation targets are realized, provincial governments tend to strengthen policy implementation to accomplish mandatory targets on time and avoid administrative accountability. However, if the government completes the FYP target in advance, it has no further incentive to maintain stringent mitigation policies during the remaining years of the relevant FYP. By doing this, the local government can ease the negative pressure of mitigation on the economy and living standards. Meanwhile, it leaves enough room for the successful completion of the next FYP's targets. This leads to a weaker implementation of mitigation policies in the remaining years of the FYP.

To test this hypothesis, this study examines the implementation patterns of mitigation policies, that is, we investigate how stringency changes over time. We use three indicators for policy implementation intensity: $energy\ rate$, $completeness\_d$, and $completeness\_\%$ as independent variables. We use two models to test for changes in policy stringency. First, we use a dummy variable $l.completeness\_d$ to test whether achievement of the mandatory target in a previous year would weaken stringency in the following year. Second, we also use the ordinal of that year in the corresponding FYPs, t and its quadratic terms sqt to test for the stringency change in mitigation policy. Other controlled variables are also included in the model. The regression model is as follows.

$$y_{it} = \alpha + \beta X_{it} + \beta_2 t_{it} + \beta_3 sqt_{it} + \gamma_i + \varepsilon_{it} \quad (26)$$

$$y_{it} = \alpha + \beta X_{it} + \beta_1 l.completeness\_d_{it} + \gamma_i + \varepsilon_{it} \quad (27)$$

Regressions (1) and (2) test energy rate reductions. Regressions (3) and (4) concern the completeness progress for each year. And regressions (5) and (6) test whether 20% or more of the total target is completed (or not) as the dependent variable, using the random effect model and Probit regression. Results are shown in Table 6.

Table 6. The Effectiveness of Mitigation Policy after the Achievement of FYP Targets.

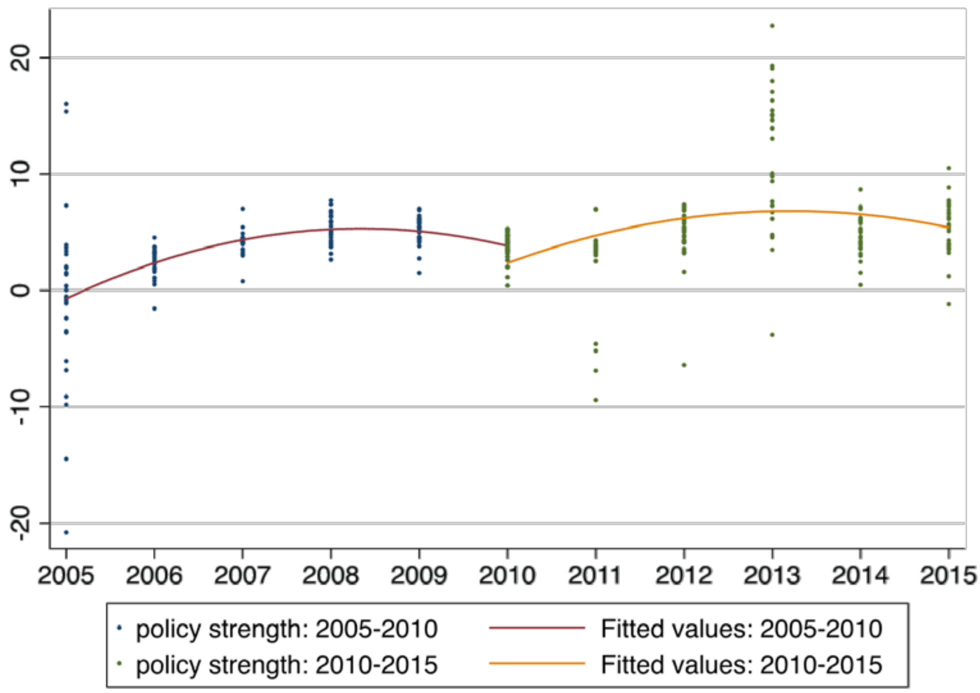
	energy rate		completeness_%		completeness_d	
	(1)	(2)	(3)	(4)	(5)	(6)
lnGDP	5.071***	9.726***	38.80***	66.11***	4.065***	8.576***
	(2.59)	(4.80)	(2.87)	(4.85)	(4.90)	(4.99)
lnPopulation	-7.336	-8.193	-49.69	-55.06	-0.296	-3.542
	(-1.33)	(-1.43)	(-1.30)	(-1.42)	(-1.10)	(-0.82)
urbanrate	-0.197	-0.321**	-1.099	-1.766*	-0.121***	-0.358***
	(-1.34)	(-2.11)	(-1.08)	(-1.72)	(-3.03)	(-2.98)

old&young	0.0256	0.262^{***}	0.278	1.802^{***}	0.0378	0.151^{***}
	(0.30)	(2.88)	(0.48)	(2.94)	(1.09)	(2.69)
industry_3rd	0.0873	0.220^{***}	0.811^{*}	1.610^{***}	0.0636^{**}	0.0664
	(1.24)	(2.95)	(1.67)	(3.20)	(2.23)	(1.37)
coalrate	-0.129^{**}	-0.196^{***}	-0.667^{*}	-1.093^{***}	0.0239^{*}	-0.0349
	(-2.38)	(-3.39)	(-1.78)	(-2.81)	(1.71)	(-0.90)
t	5.085^{***}		29.44^{***}		2.892^{***}	
	(8.70)		(7.28)		(7.11)	
sqt	-0.830^{***}		-4.930^{***}		-0.478^{***}	
	(-8.74)		(-7.50)		(-7.08)	
L. completeness_d		-4.546^{***}		-29.94^{***}		-1.502^{***}
		(-7.01)		(-6.86)		(-3.45)
Constant	20.78	-15.85	60.35	-159.7	-39.94^{***}	-40.79
	(0.47)	(-0.35)	(0.20)	(-0.52)	(-5.70)	(-1.33)
lnsig2u						
Constant					-0.390	-16.80
					(-0.79)	(-0.49)
Observations	300	300	300	300	300	300
Adjusted R^2	0.242	0.176	0.231	0.211		

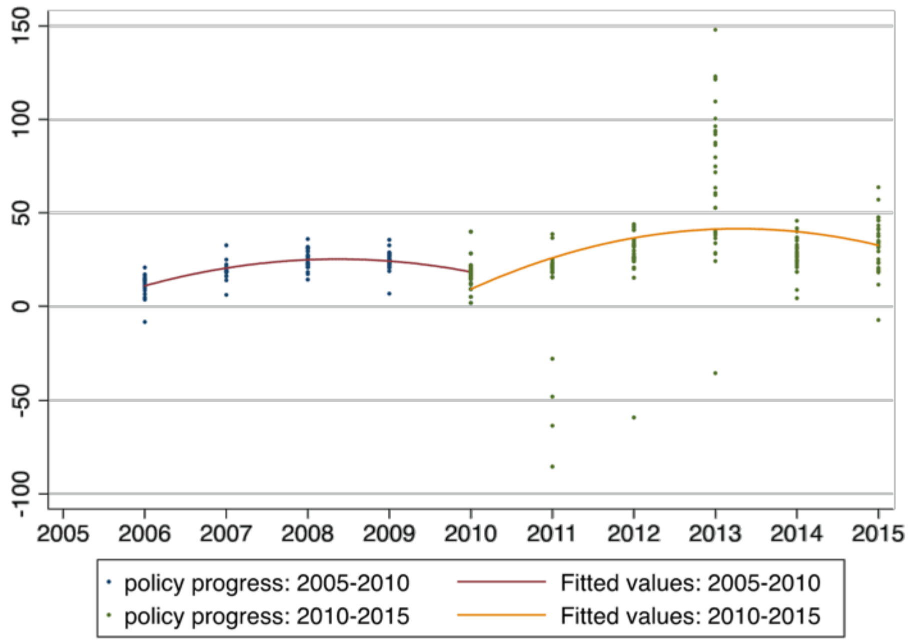
t statistics in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

The results in Columns (2), (4), and (6) reveal that the completion of mitigation targets does, in fact, lower the stringency of policy implementation in subsequent years. Regression (2) shows that if the overall mitigation targets of the FYP are completed in advance, the reduction rate of energy consumption per unit of GDP this year will drop by 4.546%. Regressions (4) and (6) indicate that the completeness of the mandatory target in a previous year not only slows the complete progress in the next year, but also lowers the probability that 20% of the total mandatory target would be reached in the next year. The results in Columns (1), (3), and (5) indicate that policy stringency over time has an inverted U-shaped distribution for both the eleventh and twelfth FYPs. The estimated years at the top of the curve are 3.06, 2.99, and 3.03 years, respectively. Regression (1) shows that the reduction rate of energy consumption per unit of GDP presents an inverted U-shaped distribution with time. Regressions (3) and (5) also reveal that policy implementation strictness first increases and subsequently falls.

These results indicate that completion often exceeds the average in the early stages. However, when the overall target is accomplished, there are no further incentives to continue strong policy implementation, resulting in less stringent policy implementation in later years. The inverted U-shaped distribution of (a) the reduction rate of energy intensity and (b) annual completion proportion of the overall mandatory target is presented in Figure 3.



(a) Reduction Rate in Energy Consumption per unit of GDP (in %).



(b) Annual Completion Proportion of Overall FYP Targets (in %).

Figure 3. Implementation Intensity of Mitigation Policies, 2005 to 2015.

Therefore, every province does, in fact, ease its mitigation stringency after the achievement of its overall target for the FYP. Once mandatory targets from directive policies are accomplished, governments lack the incentive to maintain the previous implementation intensity. Subsequent mitigation intensity will therefore decrease.

7. Conclusions and Policy Implications

This paper analyzes the actual effectiveness of mitigation policy in China through the analysis of macro-panel data at the provincial level. It studies the impact of mitigation policy on different calibers and components of carbon emissions, the impact of policy implementation intensity on production- and consumption-based emissions, and policy effectiveness across time.

This paper finds that not only have consumption- and production-based emissions grown over time, but so too have inter-regional emissions transfers increased over time. The empirical analysis focused on how the implementation of mandatory targets influenced emissions. Firstly, more stringent policy implementation can significantly reduce production-based emissions but has little impact on consumption-based emissions. Secondly, stricter mitigation policy increases the possibility that a province will transfer more emissions to other areas, thus, causing a net emissions outflow. Thirdly, once a mandatory mitigation target is achieved, subsequent policy implementation intensity will fall. Policy implementation intensity shows an inverted U-shaped distribution over time.

In general, the directive mitigation policies of the FYP significantly control carbon emissions. More stringent policy implementation reduces production-based emissions significantly, making it a highly effective tool. This indicates that a variety of mandatory targets might be considered comprehensively in the future, including both production- and consumption-based emissions controls, using absolute emissions and emissions-intensity controls, emissions-growth controls as well as other aspects. Meanwhile, the impact of mitigation policy on induced inter-provincial carbon transfers and lower stringency after the realization of mitigation targets requires more refined policy design and supplementation.

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Appendix A. Concordance of Industries

Table A1. Concordance of Industries from Different Data.

	Merged Data	CEADS Data	2007 Input-	2012 Input-	Aggregate
1	Farming, Forestry, Animal Husbandry, Fishery	1	1	1	1
2	Coal Mining and Dressing	2	2	2	2
3	Petroleum and Natural Gas Extraction	3	3	3	3
4	Ferrous Metals Mining and Dressing	4、5	4	4	4、5
5	Nonmetal Minerals Mining and Dressing	6、7	5	5	6
6	Food Processing	9、10、11、12	6	6	7、8、9、10
7	Textile Industry	13	7	7	11、12
8	Garments and Other Fiber Products	14、15	8	8	13
9	Logging and Transport of Wood and Bamboo	8、16、17	9	9	14、15
10	Papermaking and Paper Products	18、19、20	10	10	16、17、18
11	Petroleum Processing and Coking	21	11	11	19
12	Raw Chemical Materials and Chemical Products	22、23、24、25、26	12	12	20、21、22、23
13	Nonmetal Mineral Products	27	13	13	24
14	Smelting and Pressing of Ferrous Metals	28、29	14	14	25、26
15	Metal Products	30	15	15	27
16	Ordinary Machinery	31、32	16	16、17、24	28、29
17	Transportation Equipment	33	17	18	30
18	Electric Equipment and Machinery	34	18	19	31
19	Electronic and Telecommunications Equipment	35	19	20	32
20	Instruments, Meters, Cultural and Office	36	20	21	33
21	Other Manufacturing Industry、Scrap and waste	37、38	21、22	22、23	34
22	Production and Supply of Electric Power, Steam	39	23	25	35
23	Production and Supply of Gas	40	24	26	36
24	Production and Supply of Tap Water	41	25	27	37
25	Construction	42	26	28	38
26	Transportation, Storage, Post and	43	27、28、29	30、32	39
27	Wholesale, Retail Trade and Catering Services	44	30	29	40
28	Others	45	31-42	31、33-42	41

Appendix B. Provinces' Net Carbon Transfers and Carbon Intensity

In order to further illustrate the relationship between provinces' net carbon transfer and carbon intensity, Figure B1 employs a bubble map to show net carbon emissions transfers, the log of GDP, and carbon emissions intensity between the years of 2005 and 2015. It is worth noting that in order to clearly see the provinces in each figure, the sizes of the bubbles are comparable within one single year and not comparable across different years, and the bubbles sizes are comparable in the total figure. The results reveal that: (1) the bubbles are smaller with larger log GDP values on the right side, indicating a decreasing trend in carbon emissions intensity with economic growth; (2) the variance between net carbon transfers is smaller on the left side with smaller GDP values; however, the net carbon transfer becomes more divergent on the right side of the figure with larger GDP values. The net carbon transfer is divided into two categories (either positive or negative) when GDP increases, two different models for carbon emissions growth and economic growth; (3) the bubble size tends to be smaller on the upper part of the figure compared to the lower half. This indicates that emissions intensity might be relatively smaller in provinces that have a positive net emissions transfer. However, there is no significant difference between the sizes of the bubbles, as we can see in Figure B2.

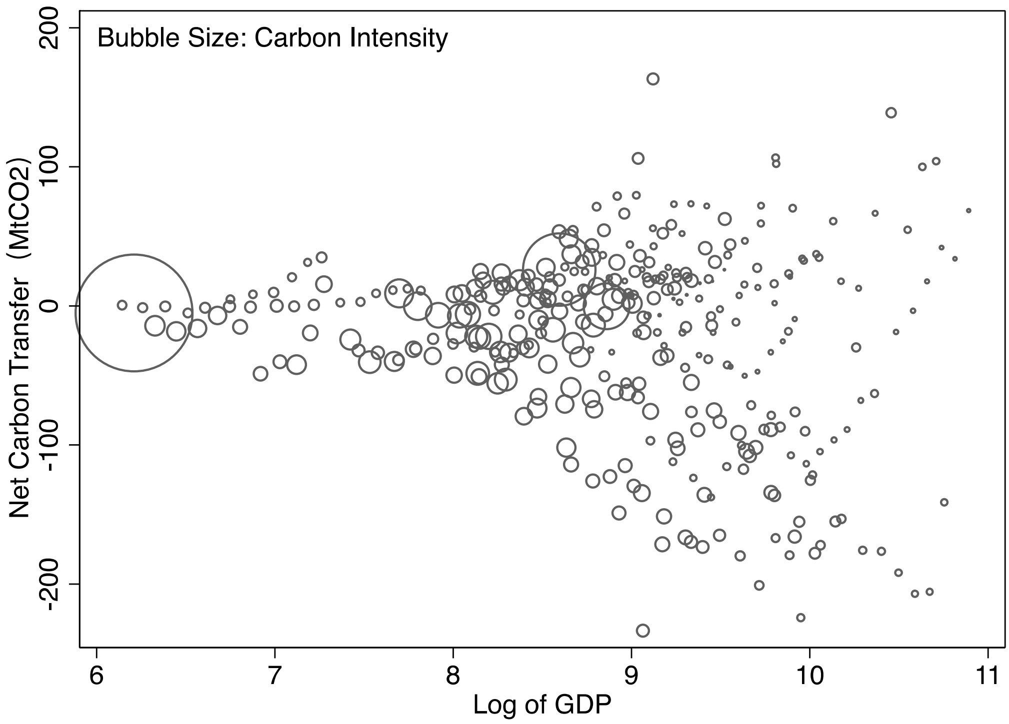

Figure B1. Provinces' Net Carbon Transfers, Logs of GDP, and Carbon Intensity.

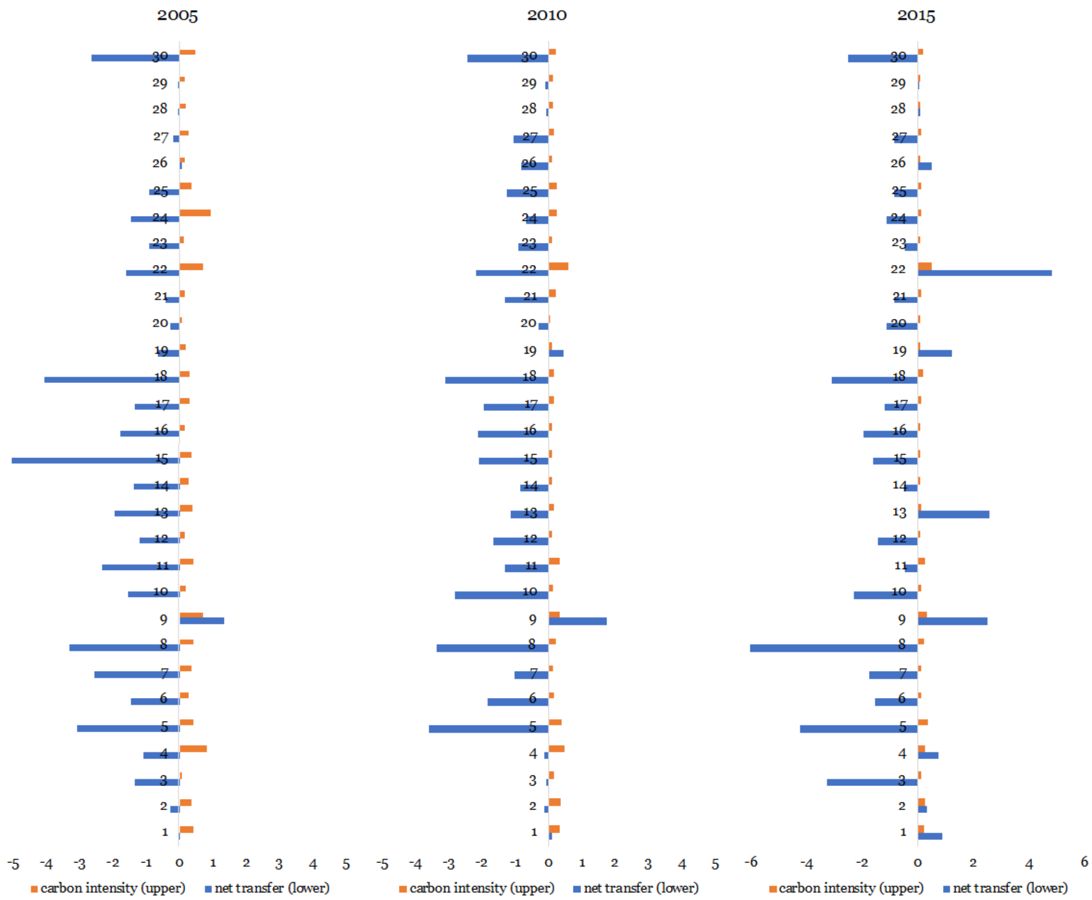

Figure B2. Net Carbon Transfers and Carbon Intensity, 2005 to 2015.

Figures B3 and Figure B4 present the net carbon transfers of two typical regions, Beijing, which has a positive net carbon transfer, and Hebei, which has a negative net carbon transfer. Figures B3 and B4 divide the annual net carbon transfer into three sectors: agriculture, manufacturing, and the service industry. Beijing is a typical region with positive net carbon emissions transfer and low carbon intensity. As in Figure B3, Beijing's carbon emissions surplus has continued to grow since 2000. After its peak in 2003, it has basically maintained the same level of emissions, with a slight downward trend. Despite the occasional carbon emissions deficit, as in 2010, it has continued to show a pattern of positive net carbon transfer. From the perspective of the sub-sectors, the proportion of carbon emissions transfer raised by the agricultural sector is the smallest, which has little impact on aggregate results; the proportion for the industrial sector is the highest, as the carbon emissions surplus is positive and plays an important leading role; the service sector is opposite to the other two categories, and has a negative net carbon transfer. On the contrary, as shown in Figure B4, Hebei is a typical province with a negative net carbon emissions transfer and high carbon intensity. The (negative) net carbon emissions transfer for Hebei Province has been increasing continuously since the year 2000; it peaked in 2004 and then remained at the same level with small fluctuations ever since. From the perspective of the sub-sectors, the net carbon transfer is negative for agriculture, manufacturing, and the service sector, respectively.

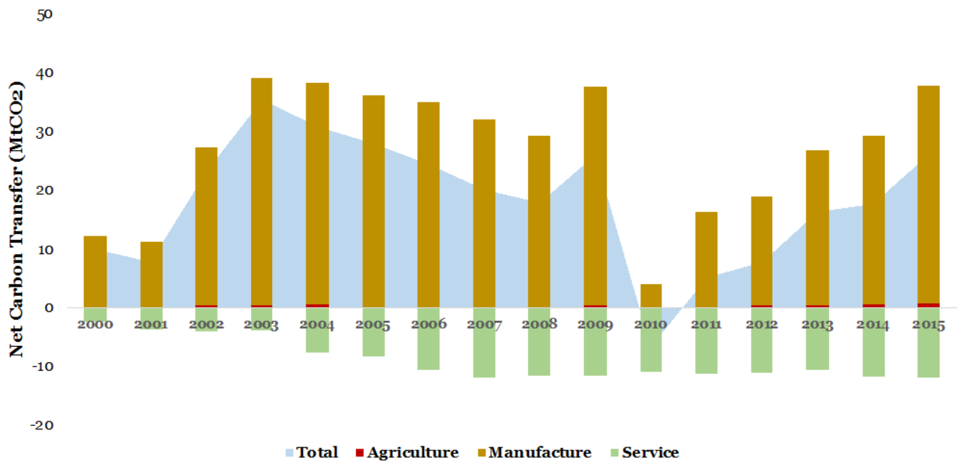

Figure B3. Net Carbon Transfer: Amount and Structure of Beijing.

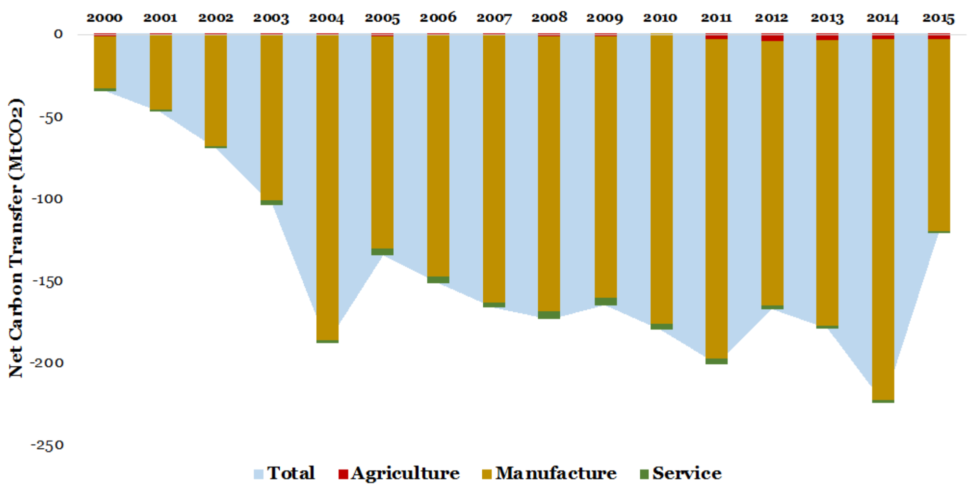

Figure B4. Net Carbon Transfer: Amount and Structure of Hebei.