# Carbon Leakage in Carbon Taxes and Emissions Trading Scheme Taking China as an Example

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## Abstract

This paper uses a computable general equilibrium model to analyze how the economic and environmental effects of an industry-wise carbon tax and domestic emissions trading in the Chinese economy are affected by the expansion of the target sectors. The results confirm that emissions trading for all sectors has the most negligible economic burden. If emissions trading is implemented in eight sectors, as is planned for China, it may be possible to reduce the economic burden by excluding petroleum/coal products.

Furthermore, it is observed that the expansion of the target sectors impacts carbon leakage. While lower coal prices bring about carbon leakage in non-reduced sectors, $CO_2$ emission reductions in the electricity sector promote $CO_2$ emission reductions from the coal sector. Furthermore, $CO_2$ emission reductions in the petroleum/coal products sector promote $CO_2$ emission reductions from the transportation sector and households (negative carbon leakage). If energy-intensive sectors are not target sectors, the effects of carbon leakage exceed those of negative carbon leakage, and China experiences domestic carbon leakage. When energy-intensive sectors are targeted for reduction, the latter's effects outweigh the former's, and domestic carbon leakage may not occur. However, ironically, it was found that global carbon leakage occurs through international trades when domestic carbon leakage does not occur in China.



## Keywords:

computable general equilibrium model, GTAP model, carbon tax, emissions trading scheme, carbon leakage, China


## Abbreviation List

| | |
|---|---|
| CGE | Computable general equilibrium |
| $CO_2$ | Carbon dioxide |
| ETS | Emission trading scheme |
| EU | Europe union |
| EV | Equivalent variation |
| GDP | Gross domestic product |
| GTAP | Global Trade Analysis Project |
| ICT | Industry-wise carbon tax |

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## 1. Introduction

In September 2020, Chinese President Xi Jinping formally declared in a video speech at the United Nations Summit on Biodiversity that the country aims to reach peak carbon ($CO_2$) emissions by 2030 and $CO_2$ neutrality by 2060. In recent years, various measures have been implemented to achieve these goals. One of these measures is emissions trading. In 2013 and 2014, two provinces and five cities, including Shanghai, Beijing, and Guangdong, began emission trading pilot projects, with Fujian and Sichuan provinces joining later in 2018. July 2021 saw the launch of China's National ETS (Emissions Trading Scheme) for its electric power sector, the world's largest in terms of emissions. In the first year after its launch, the cumulative trading volume was about 194 million tons of $CO_2$, and the total trading value was about 8.492 billion RMB (1.25 billion USD)(Yang 2022). In addition, during the 14th Five-Year Plan period (2021–2025), the scheme will be expanded to include petrochemicals, chemicals, construction materials, steel, non-ferrous metals, papermaking, and aviation as soon as possible[1].

This paper uses a multiregional, multisectoral computable general equilibrium (CGE) model to estimate how the economic and environmental effects of an industry-wise carbon tax and the domestic emissions trading in China differ for each sector. We also consider carbon leakage in non-target sectors in China and carbon leakage outside China.

## 2. Prior research

The design of emissions trading schemes has been studied from various perspectives. Considering the EU-ETS (European Union Emissions Trading System), Dijkstra et al. (2011) used a two-country, three-sector partial equilibrium model incorporating international emissions trading. The authors demonstrated that in theory, total economic welfare is maximized when all sectors are subject to emissions trading.

Several analyses have been presented based on a dynamic CGE model with China's ETS in mind. Mu et al. (2018) indicated that an ETS covering the entire industry minimizes its negative impact on GDP and that an ETS with only eight sectors, which the Chinese government has proposed for emissions trading, would significantly negatively affect GDP. They stated that as many energy-intensive industries as possible should be included in the ETS system. Jiang et al. (2022) suggested that an ETS that includes electricity, chemicals, non-ferrous metals, crude oil, transportation, and construction sectors would have the least negative impact on GDP, assuming that electricity,

[1] For more information on China's emissions trading scheme, see ICAP (2022).

chemicals, and non-ferrous metals sectors participate in the ETS. This is because chemicals and non-ferrous metals are capital-intensive, so the substitution of energy for capital would increase investment and mitigate the negative effect on GDP. In addition, Lin and Jia (2017) observed that ETS sector coverage was insignificant in the negative effect on GDP. However, Lin and Jia (2020) revised the original conclusion by the same authors to argue that, in general, having more sectors covered by the ETS mitigates the negative effect on GDP and lowers the ETS price.

Thus, while there may be some consensus that the economic burden is minimized when all sectors are subject to the ETS, there is not always agreement on which sectors should be included when the ETS is only partially implemented. Therefore, to clarify the factors that cause differences in the economic effects of different ETS target industries, this paper assumes 16 hypothetical scenarios with different ETS target industries and analyzes their effects on China's domestic and international environment and economy.

## 3. Model and data

### 3.1 GTAP-E model

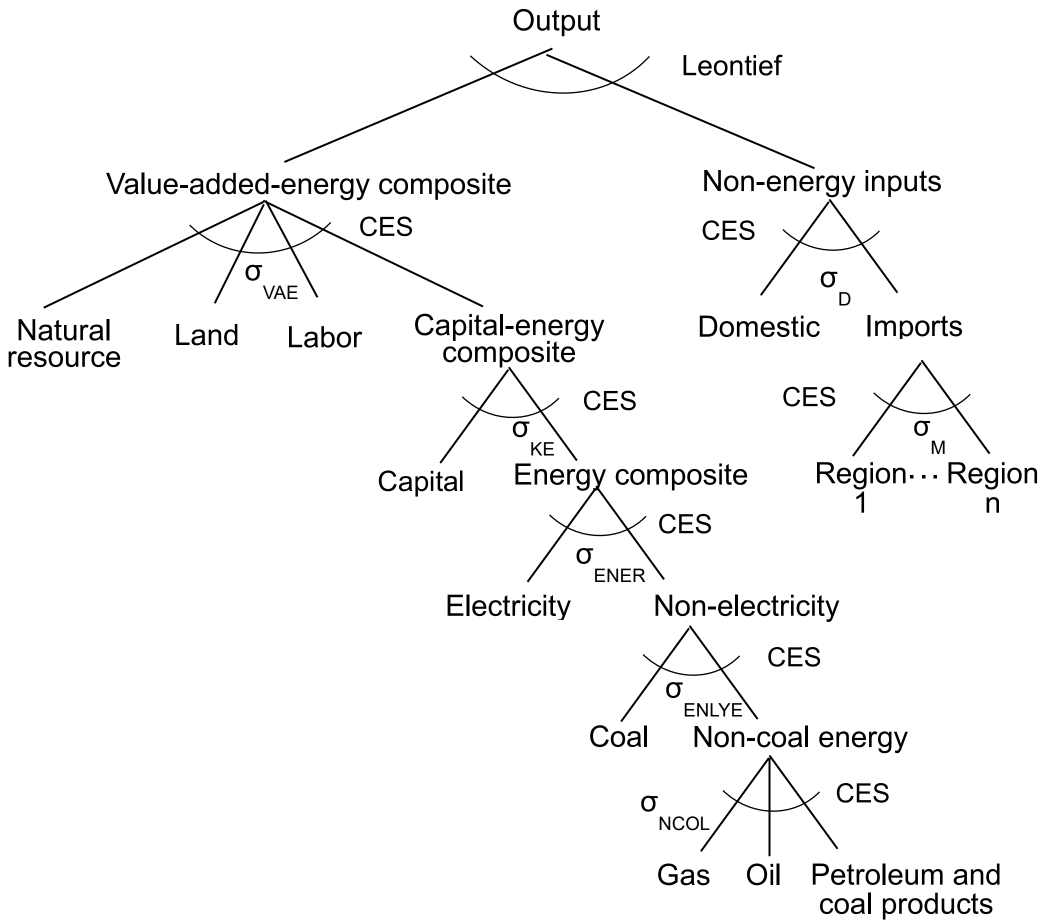
This paper uses Truong's version of the GTAP-E model (Truong, 2007)[2], which is one of the CGE models that includes economic, energy, and environmental interdependence. The model consists of the following equilibria: goods market equilibrium, factor market equilibrium, zero-profit condition, and emissions trading market equilibrium. Savings and investment are in equilibrium globally, with global investment being equal to global savings. A global bank is assumed to invest the savings from each country, and the global bank decides to invest in each country so that the expected rate of change in the rate of return on each country's investment is equal. If emissions trading is assumed, the equilibrium equation for the emissions trading market is added to the model.

It is necessary to understand the production function to interpret the simulation results. Figure 1 depicts the production function in the GTAP-E model. At the top, value-added-energy composites and non-energy inputs produce output with fixed coefficients. The rest are functions of the constant elasticity of substitution (CES), where the value-added-energy composites comprise natural resources, land, labor, and capital-energy composites. Furthermore, energy composites consist of gas, petroleum/coal products, coal, and electricity in three stages, as illustrated in Figure 1.

[2] The GTAP-E model is based on the GTAP model, a CGE model developed by the Global Trade Analysis Project (GTAP) at Purdue University. It is a model that links energy and the environment to economic activity. For details of the model, see Hertel (1997), Burniaux and Truong (2002). The model used here is available in the study by Truong (2007).

The Armington assumption[3] is also imposed, and an import composite is formed by selecting an import source that minimizes costs and comparing the price of the domestic good to that of the import source to select the optimal combination.

Figure 1 Structure of production function in GTAP-E




Source: prepared by the author based on the study by Burniaux and Truong (2002).

Note: Leontief in the figure indicates that the aggregate is a linear function; CES indicates that the aggregate is a CES function. In addition, σ represents the elasticity of substitution of the CES function.

## 3.2 Data

For analysis, we used the GTAP-E Database 10A, which corresponds to the global economy in 2014. We integrated it into 14 regions and 29 sectors, as presented in tables 1 and 2. In the regional classification, the United Kingdom is included in EUEFTA. CAC consists of Kazakhstan, Kyrgyzstan, Tajikistan, other former Soviet Union countries (Turkmenistan and Uzbekistan aggregated), Armenia, Azerbaijan, and Georgia.

[3] Under Armington assumptions, goods in the same industry are not in a relationship of perfect substitution but have a certain elasticity of substitution depending on the producing country; see Armington (1969)

Table 1 Regional Integration of GTAP Model

| No. | Code | Description | No. | Code | Description |
|---|---|---|---|---|---|
| 1 | OCE | Oceania | 8 | US | United States of America. |
| 2 | Chn | China & Hong Kong | 9 | Latin | Latin America |
| 3 | Jpn | Japan | 10 | EUEFTA | EU & European Free Trade Association |
| 4 | Kor | Korea | 11 | Rus | Russia |
| 5 | ASEAN | Association of Southeast Asian Nations | 12 | CAC | Central Asia & Caucasus |
| 6 | Ind | India | 13 | MENA | Middle East and North Africa |
| 7 | Can | Canada | 14 | ROW | Rest of the world |

Source: Prepared by the author based on GTAP-E Database 10A

Table 2 Departmental Integration in the GTAP Model

| No. | Code | Description | No. | Code | Description |
|---|---|---|---|---|---|
| 1 | Agri | Grains and Crops | 16 | NMM | Other mineral prod |
| 2 | Lvstc | Livestock | 17 | I_S | Iron/steel |
| 3 | Forest | Forestry | 18 | Auto | Automobile and parts |
| 4 | Fish | Fishing | 19 | T_Equ | Transportation equipment |
| 5 | Coal | Mining of Coal | 20 | E_Equ | Electronics equipment |
| 6 | Oil | Extraction of crude oil | 21 | M_Equ | Machin equipment |
| 7 | Gas | Extraction of natural gas and distribution | 22 | O_Mnf | Other manufacturing |
| 8 | PPP | Papermaking/publishing | 23 | Water | Water |
| 9 | P_C | Petroleum/coal products | 24 | Const | Construction |
| 10 | Ely | Electricity | 25 | Trade | Trade |
| 11 | Mining | Other mining | 26 | A_Trs | Air transport service |
| 12 | Food | Processed food | 27 | W_Trs | Water transport service |
| 13 | Tex | Textiles/wearing apparel | 28 | L_Trs | Land transport service |
| 14 | NFM | Non-ferrous metals | 29 | Svc | Other Services |
| 15 | Chm | Chemical products | | | |

Source: Prepared by the author based on GTAP-E Database 10A

Next, we examine the parameter values critical for interpreting the simulation results and each sector's $CO_2$ emissions and energy mix.

For the production structure in Figure 1, the price elasticity of demand for non-coal energy composites consisting of gas, oil, and petroleum/coal products $\sigma_{NCOL}$; the elasticity of non-electricity composites consisting of coal and non-coal energy composites $\sigma_{NELY}$; the elasticity of energy composites consisting of electricity and non-electricity composites $\sigma_{ENER}$; and the elasticity of capital-energy composites consisting of capital input and energy composites, $\sigma_{KE}$, by industry are summarized in Table 3. The most notable feature is that the values of elasticity of energy and capital substitution regarding coal, gas, and petroleum/coal products are set to zero, or not substitutable with other inputs as is shown in Table 3.

The elasticity $\sigma_{VAE}$ of value-added-energy composites consisting of natural resources, land, labor, and capital-energy composites is 1.26 for most sectors, including the electricity sector. However, some sectors, such as gas, have different values in different countries[4]. Armington elasticity takes large values for products such as gas and oil, for which the differences between countries are minor[5].

Table 3 Elasticity of energy and capital substitution in the GTAP-E model

| | $\sigma_{KE}$ | $\sigma_{ENER}$ | $\sigma_{NELY}$ | $\sigma_{NCOL}$ |
|---|---|---|---|---|
| Coal | 0 | 0 | 0 | 0 |
| Gas | 0 | 0 | 0 | 0 |
| Oil | 0 | 0 | 0 | 0 |
| P_C | 0 | 0 | 0 | 0 |
| Electricity | 0.5 | 0 | 0.5 | 1 |
| Other Industries | 0.5 | 1 | 0.5 | 1 |

Source: Prepared by the author based on GTAP-E Database 10A

Table 4 Industry Characteristics of China's Top 15 $CO_2$-Emitting Industries

| | $CO_2$ emissions M ton | Share % | $CO_2$ intensity Tons/1 million USD | Energy intensity toe/1 million USD |
|---|---|---|---|---|
| Ely | 4,061.7 | 53.9 | 8,206.3 | 2,298.0 |
| NMM | 716.9 | 9.5 | 838.3 | 274.5 |
| I_S | 558.1 | 7.4 | 423.0 | 181.7 |
| L_Trs | 459.0 | 6.1 | 501.2 | 187.9 |
| Chm | 383.6 | 5.1 | 226.7 | 153.3 |
| Svc | 209.1 | 2.8 | 33.9 | 18.6 |
| P_C | 196.9 | 2.6 | 318.4 | 1,929.0 |
| Coal | 129.3 | 1.7 | 635.8 | 210.7 |
| Food | 102.7 | 1.4 | 65.4 | 27.1 |
| W_Trs | 84.9 | 1.1 | 608.5 | 214.9 |
| A_Trs | 81.4 | 1.1 | 771.4 | 272.9 |
| O_Mnf | 75.8 | 1.0 | 36.0 | 26.8 |
| NFM | 73.2 | 1.0 | 92.4 | 85.2 |
| Mining | 46.3 | 0.6 | 125.7 | 75.9 |
| PPP | 44.5 | 0.6 | 126.0 | 69.5 |

Source: Prepared by the author based on GTAP-E Database 10A

[4] For example, the $\sigma_{VAE}$ for the gas sector in China, Japan, and the United States are 0.15, 0.01, and 0.33, respectively.

[5] $\sigma_D$ and $\sigma_M$ for Chinese gas and oil are 11.74 and 5.20, and 32.92 and 10.40, respectively.

Table 5 Energy (Mtoe) Composition of China's Top 15 $CO_2$ Emitting Industries: %

| | Coal | Oil | Gas | P_C | Ely |
|---|---|---|---|---|---|
| Ely | 92.0 | 0.0 | 1.9 | 2.6 | 3.6 |
| NMM | 73.0 | 0.0 | 2.5 | 10.6 | 13.9 |
| I_S | 36.7 | 0.0 | 1.6 | 36.5 | 25.2 |
| L_Trs | 2.0 | 0.0 | 13.2 | 81.0 | 3.8 |
| Chm | 26.2 | 1.5 | 8.3 | 36.9 | 27.1 |
| Svc | 30.8 | 0.1 | 11.1 | 16.6 | 41.5 |
| P_C | 36.9 | 42.1 | 0.8 | 18.9 | 1.3 |
| Coal | 72.3 | 0.0 | 0.0 | 7.3 | 20.4 |
| Food | 58.4 | 0.0 | 4.5 | 4.1 | 33.0 |
| W_Trs | 0.4 | 0.0 | 0.4 | 98.9 | 0.3 |
| A_Trs | 0.5 | 0.0 | 0.1 | 98.6 | 0.7 |
| O_Mnf | 26.5 | 0.3 | 4.0 | 14.2 | 55.0 |
| NFM | 19.9 | 0.0 | 3.7 | 10.3 | 66.1 |
| Mining | 27.0 | 0.0 | 2.2 | 22.1 | 48.7 |
| PPP | 44.8 | 0.0 | 2.9 | 3.2 | 49.1 |

Source: Prepared by the author based on GTAP-E Database 10A

Table 4 presents the $CO_2$ emissions of China's top 15 industries and their $CO_2$ and energy intensity per unit of output. The top three $CO_2$ emitters are electricity, non-metallic mineral products, and iron/steel. These sectors constitute 70.8% of total industry emissions and 87.3% of the eight sectors expected to be included in China's ETS.

Table 5 presents the energy composition of China's major sectors. A high share of coal demand characterizes the electricity, non-metallic mineral products, and coal sectors. The three transportation sectors (land, water, and air) are characterized by a high ratio of demand for petroleum/coal products. The non-ferrous metals sector is characterized by a high demand ratio of electricity.

## 4. Simulation scenario

Table 6 indicates each simulation scenario, where ICT represents industry-wise carbon tax and ETS denotes Emissions Trading Scheme. The numbers in the latter half of the scenario name indicate the number of industries covered by the scheme. The values in the table are reduction rates (%), which are set to reduce the total $CO_2$ emissions of the non-target sectors by 1,223.2 million tons. In other words, for ICT01, only the electric power sector will be reduced by 30.1%. For ICT08, each of the eight sectors will be reduced by 20%. The same applies to ETS, with ETC02 reducing only the electricity and ceramics (non-metallic mineral products) sectors by 30.1%.

Table 6 $CO_2$ reductions for each simulation scenario (%)

| | Ely | NMM | NFM | I_S | Chm | PPP | P_C | A_Trs | Others |
|---|---|---|---|---|---|---|---|---|---|
| ICT01 | −30.1 | | | | | | | | |
| ICT02 | −25.6 | −25.6 | | | | | | | |
| ICT03 | −25.2 | −25.2 | −25.2 | | | | | | |
| ICT04 | −22.6 | −22.6 | −22.6 | −22.6 | | | | | |
| ICT05 | −21.1 | −21.1 | −21.1 | −21.1 | −21.1 | | | | |
| ICT06 | −21.0 | −21.0 | −21.0 | −21.0 | −21.0 | −21.0 | | | |
| ICT07 | −20.3 | −20.3 | −20.3 | −20.3 | −20.3 | −20.3 | −20.3 | | |
| ICT08 | −20.0 | −20.0 | −20.0 | −20.0 | −20.0 | −20.0 | −20.0 | −20.0 | |
| ETS02 | −25.6 | −25.6 | | | | | | | |
| ETS03 | −25.2 | −25.2 | −25.2 | | | | | | |
| ETS04 | −22.6 | −22.6 | −22.6 | −22.6 | | | | | |
| ETS05 | −21.1 | −21.1 | −21.1 | −21.1 | −21.1 | | | | |
| ETS06 | −21.0 | −21.0 | −21.0 | −21.0 | −21.0 | −21.0 | | | |
| ETS07 | −20.3 | −20.3 | −20.3 | −20.3 | −20.3 | −20.3 | −20.3 | | |
| ETS08 | −20.0 | −20.0 | −20.0 | −20.0 | −20.0 | −20.0 | −20.0 | −20.0 | |
| ETS29 | −20.0 | −20.0 | −20.0 | −20.0 | −20.0 | −20.0 | −20.0 | −20.0 | 0.0 |

Note: In the table, reduction rates are shown to one decimal place, but in reality, impacts are set to six decimal places. A value of 0.0 for Others in ETS29 indicates that $CO_2$ emissions in each sector other than the eight sectors are constrained to maintain the status quo.
Source: Prepared by the author based on GTAP-E Database 10A

When all industries are targeted, carbon taxes and emissions trading are two sides of the same coin. For carbon tax, if the carbon tax rate is determined first, the amount of $CO_2$ reduction is determined by the price effect of the demand function. Furthermore, in emissions trading, if the amount of $CO_2$ reduction is determined first and then emissions trading is conducted, the price of carbon is determined as a result of market equilibrium.

However, the assumptions made for the industry-wise carbon tax simulations in this paper are somewhat different from those for a regular carbon tax. The industry-wise carbon tax simulations (ICT01 to ICT08) calculate the industry-wise carbon tax needed to achieve the industry's $CO_2$ reduction target. In other words, the carbon tax rate differs for each industry. Moreover, the emissions trading simulations (ETS02 to ETS29) are the same as usual, and calculations are done for the carbon price necessary to achieve the $CO_2$ reduction target under the condition that emissions trading is permitted.

## 5. Carbon pricing and emissions trading

### 5.1 Carbon pricing

Table 7 presents the industry-wise carbon tax and carbon prices in emissions trading for each scenario. In this paper carbon price means not the price of ton-$CO_2$ but the price of ton-C. The first comparison of carbon prices for each sector in the ICT08 scenario reveals that petroleum/coal products has the highest carbon price, followed by air transportation. Conversely, papermaking/publishing has the lowest carbon price, followed by non-metallic mineral products. The main factors that define the carbon price are the value of the energy-related elasticity of substitution (Table 3) and the energy composition of each sector (Table 5). The GTAP-E model in this paper assumes no capital or energy substitution in petroleum/coal products, resulting in higher carbon prices for these products. In the air transportation sector, petroleum/coal products constitute 98.6% of the energy input, so there is no room for substitution with low-carbon energy sources such as gas, resulting in a high carbon price. In papermaking/publishing, coal and electricity constitute a relatively large share of the energy input, and thus a lower carbon price is possible through coal-to-electricity substitution. In the non-metallic mineral products industry, the share of coal is large, and the shares of electricity and petroleum/coal products are also relatively large, so substitution away from coal will lead to a lower carbon price.

Table 7 Carbon Price (US$/ton-C)

| | ICT | | | | | | | | ETS | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Ely | NMM | NFM | I_S | Chm | PPP | P_C | A_Trs | | |
| ICT01 | 26.0 | | | | | | | | | |
| ICT02 | 20.7 | 19.7 | | | | | | | ETS02 | 20.5 |
| ICT03 | 20.4 | 19.2 | 27.8 | | | | | | ETS03 | 20.3 |
| ICT04 | 17.9 | 16.2 | 23.8 | 31.8 | | | | | ETS04 | 18.5 |
| ICT05 | 16.5 | 14.7 | 21.7 | 28.5 | 26.4 | | | | ETS05 | 17.4 |
| ICT06 | 16.4 | 14.6 | 21.5 | 28.2 | 26.1 | 12.4 | | | ETS06 | 17.2 |
| ICT07 | 16.7 | 12.0 | 16.1 | 17.7 | 18.7 | 11.4 | 486.8 | | ETS07 | 17.0 |
| ICT08 | 16.4 | 11.8 | 15.9 | 17.5 | 18.5 | 11.2 | 467.0 | 68.9 | ETS08 | 17.0 |
| | | | | | | | | | ETS29 | 12.6 |

Source: Prepared by the author based on GTAP-E Database 10A

In the ICT scenario described in this paper, the carbon price decreases as the number of sectors increases. This is because the abatement burden for each sector decreases[6].

Next, comparing ETS02 to ETS29, which have the same total amount of reduction obligations for target sectors, we see that the carbon price also decreases as the number of target sectors increases. Incidentally, the average of each industry-wise carbon tax in the simulation is calculated as follows: ICT02: $20.5, ICT03: $20.3, ICT04: $19.2, ICT05: $18.1, ICT06: $17.9, ICT07: $31.7, ICT08: $31.3[7]. Thus, comparing the industry-wise carbon tax and the emissions trading scenarios, we can say that the carbon price is lower for emissions trading than for the carbon tax as the number of sectors covered increases.

## 5.2 Emissions trading

Table 8 indicates the change in $CO_2$ emissions and the amount of emissions trading under each scenario. A positive number in the table means that $CO_2$ allowances are sold,

[6] The exception is that the carbon price in the electricity sector increases from ICT06 to ICT07. This is because petroleum/coal products is included in the carbon tax in ICT07, and the price of petroleum/coal products increases while the price of coal decreases, which requires a higher carbon tax on electricity, which has a higher share of coal and a lower share of petroleum/coal products.

[7] The average of each industry-wise carbon tax was calculated by dividing the total carbon tax revenue by the total emissions of the relevant sector.

while a negative number means that $CO_2$ allowances are purchased.

Table 8 Domestic emissions trading (M ton-$CO_2$)

| | ETS02 | ETS03 | ETS04 | ETS05 |
|---|---|---|---|---|
| Ely | −5.8 | −2.7 | 29.0 | 42.6 |
| NMM | 5.8 | 7.0 | 15.3 | 18.9 |
| NFM | | −4.3 | −3.3 | −2.9 |
| I_S | | | −41.0 | −36.3 |
| Chm | | | | −22.3 |
| | **ETS06** | **ETS07** | **ETS08** | **ETS29** |
| Ely | 39.7 | 60.9 | 69.1 | −98.2 |
| NMM | 18.6 | 23.3 | 24.8 | −3.8 |
| NFM | −2.9 | −2.3 | −2.2 | −4.6 |
| I_S | −36.1 | −31.5 | −30.3 | −44.3 |
| Chm | −22.2 | −19.3 | −18.5 | −28.9 |
| PPP | 2.9 | 3.1 | 3.2 | 1.1 |
| P_C | | −34.0 | −33.3 | −31.7 |
| A_Trs | | | −12.9 | −13.7 |
| Others | | | | 224.0 |

Source: Prepared by the author based on GTAP-E Database 10A

Few industries become sellers, with only the following three industries taking on the role. Papermaking/publishing is a seller in the ETS06 and later scenarios, non-metallic mineral products is a seller in all besides the EST29 scenario, and electric power is a seller in the ETS04 through ETS08 scenarios.

In the ETS29 scenario, all industries subject to emissions trading are buyer industries except for papermaking/publishing, and all other industries are sellers. The top five seller industries with the largest supply of allowances are coal mining (49.0 million tons), service (44.7 million tons), land transportation (32.8 million tons), food (22.9 million tons), and gas extraction (13.8 million tons).

Theoretically, industries with lower marginal abatement costs become sellers, and sectors with higher marginal abatement costs become buyers. In this sense, the rate of the industry-wise carbon tax provides an indication of the difference in marginal abatement costs by industry. The industry-wise carbon tax in Table 7 for ICT08 indicates that the tax rate decreases for the papermaking/publishing, non-metallic mineral products, and electricity sectors in this order. These sectors are as a result the sellers in the ETS08 scenario of emissions trading.

# 6. Macro impact

## 6.1 Macroeconomic impact

Table 9 lists the macroeconomic impacts on GDP, equivalent variation (EV), wages, and capital rental rates. In the case of the industry-wise carbon tax simulation, the impact on GDP and EV is not significantly different in the ICT01 to ICT06 industry-wise carbon scenarios. However, the impact on GDP and EV is slightly more significant in ICT07 and ICT08 when petroleum/coal products is included in the emissions reductions. This is because the GTAP-E model assumes that capital and energy are mutually not substitutable in petroleum/coal products. Hence, the economic impact is more prominent when the petroleum/coal products industry is included in the reductions. The impact on the wage and capital rental rates does not differ for the ICT01 to ICT06 scenarios and is slightly larger for ICT07 and ICT08.

Furthermore, the impact of domestic emissions trading on GDP and EV is largest in ETS02 and smallest in ETS29. The economic burden is not as significant in ETS07 as in the ICT scenario for the carbon tax, even if petroleum/coal products is included in the reduction targets. The impact on the wage and capital rental rates does not decrease as much in the ETS scenario as in the ICT scenario, even if petroleum/coal products is included in the abatement. The wage and capital rental rates decrease is the smallest in ETS29.

The effects of emissions trading are estimated by comparing the ICT carbon tax scenarios with the ETS emissions trading scenarios. The impacts on GDP, EV, wage rates, and capital rental rates tend to be mitigated by the introduction of emissions trading[8]. The degree of mitigation is greater in the scenarios in which petroleum/coal products is targeted for reductions.

Table 9 Impact on the Chinese macroeconomy

| | GDP, % | EV, Mill. USD | Wage rate, % | Capital rental rate, % |
|---|---|---|---|---|
| ICT01 | −0.29 | −45,904.0 | −1.28 | −2.26 |
| ICT02 | −0.26 | −42,208.7 | −1.18 | −2.06 |
| ICT03 | −0.26 | −42,232.4 | −1.21 | −2.08 |
| ICT04 | −0.26 | −42,030.4 | −1.30 | −2.12 |
| ICT05 | −0.26 | −41,331.6 | −1.37 | −2.17 |
| ICT06 | −0.26 | −41,110.5 | −1.37 | −2.16 |
| ICT07 | −0.47 | −62,903.2 | −2.05 | −3.43 |
| ICT08 | −0.46 | −61,404.5 | −2.05 | −3.43 |
| ETS02 | −0.26 | −42,210.2 | −1.18 | −2.06 |
| ETS03 | −0.26 | −42,184.6 | −1.20 | −2.07 |
| ETS04 | −0.26 | −41,312.0 | −1.25 | −2.07 |
| ETS05 | −0.25 | −40,609.0 | −1.30 | −2.11 |
| ETS06 | −0.25 | −40,364.4 | −1.30 | −2.10 |
| ETS07 | −0.25 | −40,649.0 | −1.32 | −2.14 |
| ETS08 | −0.25 | −40,429.8 | −1.33 | −2.16 |
| ETS29 | −0.22 | −35,273.7 | −1.16 | −2.02 |

Source: Prepared by the author based on GTAP-E Database 10A

## 6.2 Carbon leakage

The total $CO_2$ emission reductions for all industries subject to reduced emissions in the simulation scenarios in this paper are set to 1,223.2 million tons in each case. The

[8] The exceptions are the EV of ICT02 and ETS02, with ETS02 being slightly worse. This is since the two sectors are electricity and non-metallic mineral products, with no difference in industry-wise carbon taxes, which are both estimated around $20.

difference in the overall reductions in China under each simulation scenario results from differences in carbon leakage to industries and households not obligated to reduce their $CO_2$ emissions. The industry-specific impacts in the next section reveal that $CO_2$ reduction policies affect $CO_2$ emissions through various pathways. However, a crucial channel of $CO_2$ leakage to non-target sectors is through the effect of lower coal prices. $CO_2$ reductions in the power sector reduce coal demand, lowering coal prices. Lower coal prices increase demand for coal in non-target sectors, increasing $CO_2$ emissions.

Table 10 $CO_2$ changes and carbon leakage in China

| | $CO_2$ changes | | | | Carbon leakage | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Domestic total | | Industry total | | Non-target industries | Household | Overseas | Domestic | Overseas |
| | M ton | % | M ton | % | M ton | M ton | M ton | % | % |
| ICT01 | −1,164.3 | −14.4 | −1,179.2 | −15.7 | 44.1 | 14.9 | −7.6 | 4.8 | −0.6 |
| ICT02 | −1,190.4 | −14.7 | −1,204.2 | −16.0 | 19.1 | 13.7 | −3.7 | 2.7 | −0.3 |
| ICT03 | −1,196.2 | −14.8 | −1,209.9 | −16.1 | 13.4 | 13.7 | −2.7 | 2.2 | −0.2 |
| ICT04 | −1,213.9 | −15.0 | −1,227.1 | −16.3 | −3.8 | 13.2 | 4.8 | 0.8 | 0.4 |
| ICT05 | −1,228.4 | −15.2 | −1,241.7 | −16.5 | −18.4 | 13.3 | 6.6 | −0.4 | 0.5 |
| ICT06 | −1,231.2 | −15.2 | −1,244.6 | −16.5 | −21.3 | 13.3 | 6.6 | −0.7 | 0.5 |
| ICT07 | −1,340.6 | −16.6 | −1,334.5 | −17.7 | −111.3 | −6.1 | 38.2 | −9.6 | 2.9 |
| ICT08 | −1,331.3 | −16.5 | −1,325.8 | −17.6 | −102.5 | −5.5 | 42.8 | −8.8 | 3.6 |
| ETS02 | −1,190.7 | −14.7 | −1,204.4 | −16.0 | 18.8 | 13.7 | −3.5 | 2.7 | −0.3 |
| ETS03 | −1,196.4 | −14.8 | −1,210.0 | −16.1 | 13.2 | 13.6 | −2.8 | 2.2 | −0.2 |
| ETS04 | −1,212.1 | −15.0 | −1,225.5 | −16.3 | −2.3 | 13.4 | 1.8 | 0.9 | 0.1 |
| ETS05 | −1,226.3 | −15.2 | −1,239.9 | −16.5 | −16.6 | 13.6 | 3.3 | −0.2 | 0.3 |
| ETS06 | −1,229.3 | −15.2 | −1,242.9 | −16.5 | −19.6 | 13.6 | 3.3 | −0.5 | 0.3 |
| ETS07 | −1,233.0 | −15.2 | −1,245.9 | −16.5 | −22.7 | 12.9 | 4.6 | −0.8 | 0.4 |
| ETS08 | −1,233.0 | −15.2 | −1,245.9 | −16.5 | −22.7 | 12.9 | 6.4 | −0.8 | 0.5 |
| ETS29 | −1,217.2 | −15.0 | −1,223.2 | −16.2 | 0.0 | 6.1 | 7.3 | 0.5 | 0.5 |

Note: The domestic carbon leakage rate is the ratio of the total change in $CO_2$ emissions from non-target sectors and households divided by the reductions in non-target sectors. The global carbon leakage rate is the ratio of the change in $CO_2$ emissions from outside China divided by the reduction in domestic $CO_2$ emissions.
Source: Prepared by the author based on GTAP-E Database 10A

Consider the ICT scenario. $CO_2$ emissions from coal mining, a non-target industry, are reduced in both scenarios, as indicated in tables 14 and 15. However, in scenarios ICT01 to ICT03, the substitution effect for coal in non-target industries exceeds the effect of the reduction in coal production, resulting in carbon leakage to the non-target sectors. In scenarios following ICT04, energy-intensive industries such as iron, steel, and chemical are targeted for reduction. Thus, the decrease in coal production has a greater effect, meaning that carbon leakage does not occur. Instead, negative carbon leakage occurs, whereby $CO_2$ emissions are reduced even in non-target industries. Furthermore, negative carbon leakage is maximized in ICT07, where petroleum/coal products is targeted for reduction. In the ICT08 scenario, the air transportation sector, which had previously contributed to the negative carbon leakage to non-target industries, is included in the reduction target, resulting in lesser negative carbon leakage.

In the ETS scenarios, $CO_2$ emissions from the coal mining sector decrease. However, in ETS02 and ETS03, the effect of substituting coal for energy exceeds that of reducing coal production, resulting in carbon leakage. However, in the scenarios after ETS04, the effect of the reduction in coal production becomes larger, resulting in negative carbon leakage. In the ETS scenario, however, the negative carbon leakage is not as large as in the ICT scenario, even though petroleum/coal products is subject to reductions. The reason is that the increase in petroleum and coal product prices is lower than that in the ICT scenario. Like the industry-wise carbon tax, carbon leakage changes as the number of industries covered by the tax expands. Naturally, in the ETS29 scenario, carbon leakage is limited to the household portion and is very small.

Let us also look at carbon leakage to other countries. A sign of carbon leakage to foreign countries is the opposite direction of that for the domestic non-target industry sector. In the low-target industry scenarios, exports from energy-intensive goods industries, such as chemicals and iron/steel in China, grow due to lower production factor prices. This will result in a decrease in production in those industries abroad, leading to negative carbon leakage. As the scope of emission reductions in China increases, exports from China will decrease and production abroad will increase, leading to carbon leakage. By country, there is no significant change in $CO_2$ emissions. However, there is a relatively noticeable negative carbon leakage of approximately −0.1% for Japan, Korea, Canada, and CAC in the ICT01 and ICT02 scenarios and a 0.3% positive carbon leakage for EUEFTA and MENA in the ICT07 and ICT08 scenarios.

China dominates the global $CO_2$ emissions trends, with the largest reductions being −4.3% (−1,302.4 million tons) in the ICT07 scenario in ICT and −4.1% (−1,226.6 million tons) in the ETS08 scenario in the ETS.

# 7. Impact by industry

## 7.1 Impact on the energy sector

Changes in energy prices and production are summarized in Table 11. The $CO_2$ reduction policy increases the price of electricity and decreases its production. The coal sector experiences lower prices and production due to weaker demand for coal from the power sector. Gas, which has a higher cost share of electricity, will increase in price and decrease in production. These phenomena occur in all scenarios.

Petroleum and coal products constitute a small share of electricity, so the impact of electricity price increases is small. However, a carbon tax on petroleum/coal products would increase their prices greatly. In the first three scenarios, the production of petroleum/coal products increases due to the substitution effect from electricity. However, when sectors with relatively high-cost shares of petroleum/coal products, such as iron/steel in sector 4 and chemicals in sector 5, are subject to reductions, demand and production decrease.

The impact on oil price caused by electricity price increase is relatively small because of its low-cost share of electricity, and oil prices decline in the scenarios after sector 4. Oil production tends to increase slightly due to substitution for electricity but decreases in ICT07 and ICT08 when the production of petroleum/coal products declines dramatically.

Table 11 Impact on Chinese domestic energy prices (%)

| Number of sectors | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 29 |
|---|---|---|---|---|---|---|---|---|---|---|
| Coal | ICT | −2.0 | −2.2 | −2.3 | −2.4 | −2.5 | −2.5 | −3.4 | −3.4 | --- |
| | ETS | --- | −2.2 | −2.3 | −2.3 | −2.4 | −2.5 | −2.5 | −2.5 | −1.2 |
| Oil | ICT | 0.4 | 0.2 | 0.1 | −0.2 | −0.4 | −0.4 | −4.8 | −4.8 | --- |
| | ETS | --- | 0.2 | 0.1 | −0.1 | −0.2 | −0.2 | −0.4 | −0.4 | −0.6 |
| Gas | ICT | 2.7 | 1.7 | 1.6 | 1.0 | 0.3 | 0.2 | 1.7 | 1.5 | --- |
| | ETS | --- | 1.7 | 1.6 | 1.1 | 0.5 | 0.5 | 0.4 | 0.3 | 1.9 |
| P_C | ICT | 0.5 | 0.3 | 0.2 | 0.0 | −0.1 | −0.1 | 18.3 | 17.5 | --- |
| | ETS | --- | 0.3 | 0.2 | 0.1 | 0.0 | 0.0 | 0.7 | 0.6 | 0.4 |
| Ely | ICT | 18.9 | 15.2 | 14.9 | 13.0 | 11.9 | 11.8 | 12.4 | 12.1 | --- |
| | ETS | --- | 15.1 | 14.8 | 13.5 | 12.6 | 12.5 | 12.4 | 12.3 | 9.4 |

Source: Prepared by the author based on GTAP-E Database 10A

Table 12 Impact of China's domestic energy on production (%)

| Number of sectors | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 29 |
|---|---|---|---|---|---|---|---|---|---|---|
| Coal | ICT | −17.1 | −17.5 | −17.5 | −17.7 | −17.9 | −17.9 | −22.9 | −22.6 | --- |
| | ETS | --- | −17.5 | −17.5 | −17.7 | −17.9 | −17.9 | −18.1 | −18.1 | −17.0 |
| Oil | ICT | 0.9 | 0.8 | 0.8 | 0.5 | 0.4 | 0.4 | −3.8 | −3.7 | --- |
| | ETS | --- | 0.8 | 0.8 | 0.6 | 0.5 | 0.5 | 0.4 | 0.4 | −0.3 |
| Gas | ICT | −14.5 | −12.9 | −13.0 | −12.8 | −15.6 | −15.8 | −19.0 | −18.7 | --- |
| | ETS | --- | −12.9 | −13.0 | −13.2 | −15.7 | −15.9 | −17.3 | −17.2 | −44.2 |
| P_C | ICT | 1.0 | 0.6 | 0.4 | −0.7 | −1.1 | −1.1 | −16.2 | −16.0 | --- |
| | ETS | --- | 0.5 | 0.4 | −0.2 | −0.6 | −0.6 | −1.3 | −1.4 | −2.2 |
| Ely | ICT | −13.1 | −10.6 | −10.4 | −8.9 | −8.1 | −8.0 | −7.4 | −7.3 | --- |
| | ETS | --- | −10.5 | −10.3 | −9.3 | −8.7 | −8.6 | −8.5 | −8.4 | −6.5 |

Source: Prepared by the author based on GTAP-E Database 10A

## 7.2 Impact on prices, imports and exports, and production

Table 13 presents the effects on prices, imports/exports, and production in the target sectors under the eight sector scenarios. Typically, $CO_2$ reduction policies cause higher prices, lower exports, higher imports, and lower production in target sectors. For imports, the overall reduction in production due to $CO_2$-reducing policies lowers import demand, but the import-increasing effect of higher prices for domestic goods prevails. These trends are generally observed in all scenarios except for the eight sector scenario.

However, the opposite is observed in the papermaking/publishing sector. This is because electricity and petroleum/coal products account for a smaller share of total costs in the industry. In addition, the impact of lower prices on wage and capital rental rates outweighs the impact of higher prices for these products due to $CO_2$ reduction policies[9]. Similarly, non-ferrous metals, which have a lower cost share of electricity and petroleum/coal products, experience smaller price increases under the ICT08 scenario and lower prices relative to their overseas counterparts. This leads to higher exports and lower imports[10]. Papermaking/publishing and non-ferrous metals production will increase due to export growth. Furthermore, the increased production of non-ferrous metals is also linked to the increased production of electronic equipment[11].

Imports also decrease in non-metallic mineral products in the ICT08 scenario[12]. This may be related to a reduction (−4.3%) in production in the construction sector. In the ETS08 scenario, the price increase rate of petroleum/coal products is suppressed due to emissions trading, which has a smaller effect on the increase in imports. Imports of petroleum/coal products decrease due to a drop in demand caused by general economic stagnation.

Table 13 Impacts on prices, imports/exports, and production by industry in China (8 sector scenarios) %

| | Price | | Export | | Import | | Production | |
|---|---|---|---|---|---|---|---|---|
| | ICT08 | ETS08 | ICT08 | ETS08 | ICT08 | ETS08 | ICT08 | ETS08 |
| PPP | −0.4 | −0.0 | 4.0 | 1.5 | −2.2 | −0.8 | 0.4 | 0.1 |
| P_C | 17.5 | 0.6 | −45.0 | −1.8 | 12.3 | −0.8 | −16.0 | −1.4 |
| Ely | 12.1 | 12.3 | −38.2 | −39.4 | 15.2 | 14.4 | −7.3 | −8.4 |
| NFM | 0.1 | 0.4 | 1.5 | −1.0 | −0.4 | 0.5 | 0.8 | 0.1 |
| Chm | 1.1 | 0.4 | −4.0 | −0.8 | 1.2 | 0.1 | −1.3 | −0.4 |
| NMM | 0.9 | 1.3 | −2.0 | −3.9 | −0.4 | 1.6 | −3.3 | −2.2 |
| I_S | 1.7 | 0.9 | −5.8 | −3.0 | 1.5 | 0.6 | −2.7 | −1.6 |
| A_Trs | 6.9 | 0.7 | −15.1 | −1.1 | 7.5 | 0.2 | −7.3 | −0.7 |

Source: Prepared by the author based on GTAP-E Database 10A

Carbon reduction policies also negatively impact output in non-target sectors. However, production in agriculture, food, textiles/wearing apparel, electronics, and other manufacturing industries increases in both ICT08 and ETS08 scenarios due to export growth. Although carbon reduction policies typically reduce output in non-target

[9] The top five shares of total costs for electricity and petroleum/coal products are as follows. Gas 39.6%, petroleum/coal products 29.2%, air transportation 21.6%, water transportation 17.2%, and land transportation 13.6%. Papermaking/publishing and non-ferrous metals constituted 3.2% and 5.6%, respectively.

[10] Outside of China, wage rates and capital rental rates increase and most output prices rise. The price changes for nonferrous metals are 0.4% for Japan, 0.3% for Korea, 0.3% for ASEAN, 0.5% for the U.S., and 0.4% for the EU in the ICT08 scenario.

[11] The cost share of non-ferrous metals in the cost of electronic equipment is as high as 10.0%.

[12] The decrease in imports of non-ferrous metals and non-metallic mineral products, which is observed in eight sector scenarios, is only observed in the scenario where petroleum/coal products is targeted. The increase in production of non-ferrous metals occurs only in ICT05, 06, 07, and 08, where demand from exports and the electronics sector is high

industries, production in industries that gain international competitiveness from lower factor prices may increase[13].

## 7.3 $CO_2$ Emissions by Industry

Tables 14 and 15 indicate the change in $CO_2$ emissions for the major industries. $CO_2$ emissions in non-target sectors decrease regardless of the existence of emissions trading. Paper products/publishing and non-ferrous metals see decreased $CO_2$ due to energy substitution, despite the expansion of production.

$CO_2$ emissions from coal and water/land transportation decrease in all scenarios. The decrease in coal emissions is particularly pronounced.

$CO_2$ emissions increase in most non-target industries except coal, water/land transportation, especially in the case the number of target sectors is small. However, in ICT07 and ICT08, $CO_2$ emissions decrease in many sectors as the rise in the price of petroleum/coal products gives grate negative impact on the production of many sectors.

Table 14 Change in $CO_2$ emissions by major industries in the ICT scenario (M ton-$CO_2$)

| | ICT01 | ICT02 | ICT03 | ICT04 | ICT05 | ICT06 | ICT07 | ICT08 |
|---|---|---|---|---|---|---|---|---|
| Ely | −1,223.2 | −1,039.7 | −1,024.0 | −918.4 | −857.6 | −851.1 | −823.3 | −812.3 |
| NMM | 17.5 | −183.5 | −180.8 | −162.1 | −151.4 | −150.2 | −145.3 | −143.4 |
| NFM | 6.0 | 5.2 | −18.5 | −16.6 | −15.5 | −15.3 | −14.8 | −14.6 |
| Iron | 15.7 | 13.0 | 12.8 | −126.2 | −117.8 | −116.9 | −113.1 | −111.6 |
| Chm | 14.6 | 13.4 | 13.5 | 13.2 | −81.0 | −80.4 | −77.8 | −76.7 |
| PPP | 3.6 | 3.2 | 3.2 | 3.0 | 2.9 | −9.3 | −9.0 | −8.9 |
| P_C | 1.6 | 1.1 | 0.8 | −1.1 | −1.7 | −1.7 | −39.9 | −39.4 |
| A_Trs | 0.2 | 0.2 | 0.2 | 0.3 | 0.4 | 0.4 | −5.6 | −16.3 |
| W_Trs | −0.3 | −0.2 | −0.2 | −0.2 | −0.2 | −0.2 | −5.7 | −5.6 |
| L_Trs | −5.0 | −4.2 | −4.2 | −4.0 | −3.7 | −3.7 | −36.3 | −35.2 |
| Coal | −41.8 | −40.9 | −40.9 | −40.7 | −40.7 | −40.7 | −51.7 | −50.9 |
| Other Industries | 31.9 | 28.4 | 28.1 | 25.7 | 24.6 | 24.5 | −11.9 | −10.9 |
| Non-target industries | 44.1 | 19.1 | 13.4 | −3.8 | −18.4 | −21.3 | −111.3 | −102.5 |

Source: Prepared by the author based on GTAP-E Database 10A

[13] The growth rates of production in ICT08 and ETS08 are 0.6% and 0.5% for agriculture, 0.1% and 0.2% for food, 2.4% and 1.5% for textiles/wearing apparel, 3.0% and 1.8% for electronics, and 0.1% and 0.1% for other manufacturing, respectively.

Table 15 Change in $CO_2$ emissions by major industries under ETS scenario (M ton-$CO_2$)

| | ETS02 | ETS03 | ETS04 | ETS05 | ETS06 | ETS07 | ETS08 | ETS29 |
|---|---|---|---|---|---|---|---|---|
| Ely | −1,033.9 | −1,021.3 | −947.4 | −900.2 | −890.8 | −884.2 | −881.5 | −714.2 |
| NMM | −189.3 | −187.7 | −177.4 | −170.3 | −168.9 | −168.6 | −168.2 | −139.6 |
| NFM | 5.2 | −14.2 | −13.2 | −12.6 | −12.4 | −12.5 | −12.4 | −10.1 |
| Iron | 12.9 | 12.8 | −85.2 | −81.5 | −80.8 | −81.6 | −81.4 | −67.4 |
| Chm | 13.4 | 13.4 | 13.2 | −58.7 | −58.1 | −58.4 | −58.2 | −47.8 |
| PPP | 3.2 | 3.2 | 3.1 | 3.0 | −12.2 | −12.1 | −12.1 | −10.0 |
| P_C | 1.0 | 0.9 | −0.3 | −0.8 | −0.7 | −5.9 | −6.1 | −7.7 |
| A_Trs | 0.2 | 0.2 | 0.3 | 0.3 | 0.3 | 0.1 | −3.4 | −2.6 |
| W_Trs | −0.2 | −0.2 | −0.2 | −0.2 | −0.2 | −0.4 | −0.4 | −2.7 |
| L_Trs | −4.2 | −4.2 | −3.9 | −3.7 | −3.7 | −4.9 | −4.9 | −32.8 |
| Coal | −40.9 | −40.9 | −40.8 | −40.9 | −40.9 | −41.3 | −41.2 | −49.0 |
| Other Industries | 28.2 | 28.1 | 26.5 | 25.6 | 25.5 | 23.9 | 23.8 | −139.5 |
| Non-target industries | 18.8 | 13.2 | −2.3 | −16.6 | −19.6 | −22.7 | −22.7 | 0.0 |

Source: Prepared by the author based on GTAP-E Database 10A

## 8. Discussion

Similar to the results of previous studies, this paper also shows that industry-wide emissions trading has the lowest economic impact. Even loose constraints on $CO_2$ emissions seem to lower the overall economic impact by inducing sellers to become buyers in the emissions trading market.

The simulations in this paper were analyzed by including each industry targeted for $CO_2$ reduction one at a time. As such, the results may differ if the order of the additions was different. However, the economic burden of including petroleum/coal products in the reduction targets is likely to remain high. This result is not necessarily consistent with those of previous studies, which may be due to differences in the assumption of the elasticity of substitution of energy as an input good and the elasticity of substitution of imported goods among countries.

The GTAP-E Database 10A used in this study is a database that incorporates the international interdependence of each country’s trade. Therefore, the simulation results reflect the change in international trades affected by China’s $CO_2$ reduction policies. For example, under the carbon reduction policy, China’s production in most sectors declines, but some sectors experience increased production, such as electronics and textiles wearing apparel. This is because the carbon reduction policy lowers wage and capital rental rates and increases exports. We also found that as China’s energy-intensive goods sectors become target sectors for emission reductions, overseas production in these sectors increases, creating carbon leakage in a global context.

There are many issues with this study. First, it does not consider the initial allocation method, which is critical to the design of the ETS. The GTAP-E model is a fee-based allocation in which sectors with reduction obligations pay an emissions surcharge for the entire amount of $CO_2$ they emit, and other allocation methods are not considered.

Second, although this paper has chosen between a carbon tax and emissions trading, one possible approach to eliminate domestic carbon leakage is to divide industries into those that trade emissions and those that do not and to add a carbon tax to those that do not. Under these circumstances, in addition to the issue of how to distinguish between the two, the ratio of emission allowances allocated to the emissions trading industry and the carbon tax industry would also pose an issue[14].

## 9. Conclusion

This paper used a CGE analysis to analyze how the economic and environmental effects of an industry-wise carbon tax and domestic emissions trading are affected by the expansion of the sectors covered by the tax and trading in the Chinese economy. The main conclusions of the paper are as follows.

Emissions trading covering all industries was shown to have the smallest economic impact. If partial emissions trading is implemented in the eight or so sectors the Chinese government has proposed, it may be preferable to mitigate the macro impacts of emissions trading by excluding petroleum/coal products, which have high marginal abatement costs.

This paper found that carbon leakage is affected by the expansion of the target sectors. While there is carbon leakage in non-target sectors due to lower coal prices, $CO_2$ reductions in the electricity sector have significant negative carbon leakage (i.e., lower $CO_2$ emissions) effects on the coal sector. In turn, $CO_2$ reductions in the petroleum/coal products sector have significant negative carbon leakage (i.e., lower $CO_2$ emissions) effects on the transportation sectors and households. When many energy-intensive sectors are non-target sectors, the effects of carbon leakage exceed those of negative carbon leakage, resulting in carbon leakage within China. As the number of industries targeted for emission reductions increases, the latter’s effect exceeds the former's, and domestic negative carbon leakage can occur.

Ironically, however, when negative carbon leakage occurs in China, carbon leakage occurs overseas. This is because when China imposes $CO_2$ emission limits on many energy-intensive goods and production declines, the overseas production of energy-intensive goods increases to take their place. This suggests that in today’s highly globalized economy, it is not enough for a country to set domestic $CO_2$ emission changes as a policy target when implementing carbon reduction policies. International policy coordination that also takes international carbon leakage into account is required.

[14] Studies that are focused on the EU-ETS with this issue in mind include those by Bernard et al. (2004), Böhringer & Rosendahl (2009), and Malueg & Yates (2009).

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## Reference

Armington, P. S. (1969). A theory of demand for products distinguished by place of production. *International Monetary Fund Staff Papers*, *XVI*, 159–178.

Bernard, A., Vielle, M., & Viguier, L. (2004). Modeling the European directive establishing a scheme for greenhouse gas allowance trading and assessing the market power of firms. presented in The 7th Annual Conference on Global Economic Analysis, Washington DC, United States. Retrieved October 12, 2021 from https://www.gtap.agecon.purdue.edu/resources/download/1754.pdf

Böhringer, C. & Rosendahl, K.E. (2009). Strategic partitioning of emission allowances under the EU emission trading scheme. *Resource and Energy Economics*, 31(3),182–197. https://doi.org/10.1016/j.reseneeco.2009.04.001

Burniaux, J. M. & Truong T. P. (2002). GTAP-E: An Energy-Environmental Version of the GTAP Model. *GTAP Technical Paper, 16*. Retrieved June 10, 2020 from https://www.gtap.agecon.purdue.edu/resources/download/1203.pdf.

Dijkstra, B.R., Manderson, E. & Lee, TY. (2011). Extending the sectoral coverage of an international emission trading scheme. *Environmental and Resource Economics*, 50, 243–266. https://doi.org/10.1007/s10640-011-9470-1

Hertel, T. W. (ed.). (1997). *Global Trade Analysis: Modeling and Applications*. Cambridge: Cambridge University Press. https://doi.org/10.1017/CBO9781139174688

International Carbon Action Partnership (ICAP) (2022). Emissions Trading Worldwide: Status Report 2022. International Carbon Action Partnership. Retrieved May 10, 2022 from https://icapcarbonaction.com/en/publications/emissions-trading-worldwide-2022-icap-status-report

Jiang, H., Liu, L., Dong, K., & Fu, Y. (2022). How will sectoral coverage in the carbon trading system affect the total oil consumption in China? A CGE-based analysis. *Energy Economics*, 110, 105996. https://doi.org/10.1016/j.eneco.2022.105996

Lin, B., & Jia, Z. (2017). The impact of emission trading scheme (ETS) and the choice of coverage industry in ETS: A case study in China. *Applied Energy*, 205, 1512-1527. https://doi.org/10.1016/j.apenergy.2017.08.098

Lin, B., & Jia, Z. (2020). Does the different sectoral coverage matter? An analysis of China's carbon trading market. *Energy Policy*, 137(12),111164. https://doi.org/10.1016/j.enpol.2019.111164

Malueg, D.A., & Yates, A.J. (2009). Strategic behavior, private information, and decentralization in the European Union Emissions Trading Scheme. *Environmental and Resource Economics*, 43, 413–432. https://doi.org/10.1007/s10640-009-9274-8

Mu, Y., Evans, S.G., Wang, C., & Cai, W. (2018). How will sectoral coverage affect the efficiency of an emissions trading system? A CGE-based case study of China. *Applied Energy*, 227, 403-414. https://doi.org/10.1016/j.apenergy.2017.08.072

Truong, T., (2007). GTAP-E: An Energy-Environmental Version of the GTAP Model with Emission Trading - USER'S GUIDE. GTAP Resource #2509. Retrieved June 10, 2020 from https://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=2509

Yang, Y (2022) China's carbon emission trading market to celebrate 1 year anniversary, China Daily, Global Edition. Retrieved June August 7, 2022 from https://global.chinadaily.com.cn/a/202207/15/WS62d133dda310fd2b29e6ca1b.html