Linking Emissions Trading Schemes: Economic Valuation of a Joint China–Japan–Korea Carbon Market

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Abstract: Linking carbon emissions trading systems across countries has become an important tool for global emission reduction. The three high-emission Asian countries, China, Japan, and South Korea (ROK), all have initiated carbon trading and published ambitious Intended Nationally Determined Contribution targets. Since 2016, the three countries have discussed establishing a long-term unified market for carbon emissions trading, and have sought a scheme for such exchange. This study aimed to investigate whether linking the carbon emissions trading systems of these three countries could potentially achieve more ambitious emission reduction targets. A dynamic energy-environmental version of the Global Trade Analysis Project model was used to simulate carbon market linkages across the three countries. The results indicated that a linked China–Japan–ROK carbon market would be highly cost-effective, have positive economic benefits for all three countries, and improve the carbon market’s liquidity and transaction scale. Under a scenario with no carbon market linking, the economic losses in China, Japan, and ROK would be $51.55 billion, $13.55 billion, and $74.19 billion, respectively. Meanwhile, with carbon trading linking, the losses would be reduced to $47.08 billion, $5.37 billion, and $9.10 billion, respectively. Therefore, a joint China–Japan–ROK carbon market could greatly promote the adoption of market-based tools for emission reduction.

Keywords: carbon emissions trading scheme; GTAP-E (an energy-environmental version of the Global Trade Analysis Project model); economic valuation; cost-effectiveness

1. Introduction

Since the creation of the world’s first major carbon market in 2005 by the European Union (EU), carbon trading markets have increasingly come to be regarded as scientific and effective market-based tools for emission reduction [1]. By the end of 2017, there were 19 carbon trading markets worldwide, accounting for more than seven billion tons of greenhouse gas emissions (approximately 15% of the global total) [2]. Following the Paris Agreement, the Intended Nationally Determined Contributions (INDCs) of over 100 countries included carbon trading systems, carbon taxes, and other carbon pricing mechanisms. As such, the number of regions covered by the carbon market is expected to rise. With the worldwide spread of emissions trading schemes (ETRs) and the need for international cooperation on climate change, there is growing interest in linking ETSs [3]. The global carbon market is an important tool for effectively achieving global emission reduction targets at a low cost. According to the World Bank model, a global carbon market could reduce global abatement costs by one-third in 2030 and by half in 2050 [4]. At the same time, carbon market linkages can accelerate knowledge dissemination and technology cooperation among countries.
China, Japan, and South Korea (ROK) had a combined gross domestic product (GDP) of $1.766 trillion USD (2010 price) and combined carbon emissions of 10.96 billion tons of CO\(_2\) in 2017, accounting for 22.06% and 33.19% of the global total, respectively. All three countries have launched carbon trading, with Japan starting in 2010 and ROK and China starting in 2012. The proximity and economic integration of the three countries provide a basis for a potentially linked carbon market [5]. Additionally, disparities in carbon reduction costs and the already existing carbon pricing mechanisms in the three countries support the potential and feasibility of a linked carbon market. If successful, such a carbon market would be the largest of its kind. In September 2016, China’s National Development and Reform Commission, Korea’s Ministry of Strategy and Finance, and Japan’s Ministry of the Environment met in Beijing and decided to hold annual meetings on carbon emissions trading. These meetings are intended to cover the development of a long-term unified market for carbon emissions trading, unified emissions testing methods, and a scheme for carbon emissions exchange among the three countries. Exploring ETSs linkages at the regional level in the short and medium term could establish a basis for linkage at the international level [6]. In such a context, research on the linkage between China, Japan, and ROK is of great significance for promoting the development of the global carbon market.

Carbon market linkage can have both political and economic benefits. Politically, carbon market linkage will motivate regions to achieve more ambitious emission reduction targets. Trading funds can also be reinvested in emission reduction projects to foster further emission reductions [7]. The climate finance model supported by carbon market linkage serves as an important price signal that attracts investment in sustainable infrastructure and clean technology, especially for developing countries [8,9]. However, carbon market linkages could be hindered when countries have different levels of emission reduction targets [10,11]. By contrast, linking carbon markets among partners with comparable emission reduction targets and similar mid- and long-term emission trends could lead to even more effective emission reductions [12–16].

The economic benefits of carbon market linkage are mainly threefold. First, carbon market linkage can reduce abatement costs in entire economic bodies covering multiple countries [17–20]. A carbon market linking more countries can lead to larger reductions in abatement costs [21–24]. However, a carbon market linking regions with similar abatement costs may have limited reductions in abatement costs [25–27]. Second, carbon market linkage can increase market liquidity and transaction scales while reducing market fluctuation and avoiding price manipulation [28–30]. Third, carbon market linkage can reduce competitive losses. In linked carbon markets, the participating countries face the same carbon price, which alleviates the carbon leakage problem [31,32].

Previous research has found that carbon market linkage is, indeed, an effective way for countries to mitigate climate change through cooperation. However, to our knowledge, the feasibility of an integrated China–Japan–ROK carbon market has yet to be investigated. Therefore, this study conducted a quantitative economic analysis of carbon market linkages among those three countries. The rest of this study is organized as follows: Section 2 presents the theoretical framework. Section 3 shows the model and scenarios. Section 4 presents the simulation results. Finally, Section 5 concludes the study.

2. Methodology and Model

2.1. Theoretical Model

A theoretical model was established assuming that the carbon markets of China, Japan, and ROK are linked. The problem each country faces is assumed to be profit maximization under emission quotas [33], which is expressed as follows:

\[
\max_{[a_i, q_i, b_i]} \tau_i = B(q_i) - C_i(q_i, a_i) - P^T b_i,
\]

\[s.t. e_i - a_i - b_i = w_i\]
where $i$ refers to country; $a_i$ (ton of CO$_2$) is domestic emission reduction in country $i$; $q_i$ (U.S. dollar, USD) is the economic value of products in country $i$; $\pi_i$ (USD) is the profit function of country $i$; $B(q_i)$ (USD) is the cost of carbon emission reduction in country $i$, which is a function of domestic emission reduction ($a_i$) and production level ($q_i$); $P^T$ (USD/ton of CO$_2$) is the price of international emission rights; $b_i$ (ton of CO$_2$) is the volume of emission rights purchased by country $i$, $b_i > 0$ indicates the amount of emission rights purchased by country $i$, $b_i < 0$ indicates the amount of emission rights sold by country $i$; $P^T b_i$ (USD) refers to purchase costs for extra emission rights; $e_i$ (ton of CO$_2$) is the greenhouse gas emissions of country $i$; and $w_i$ (ton of CO$_2$) is the emission quota faced by country $i$.

Therefore, Equation (2) represents the constraint condition for country $i$. The Lagrangian function of the above problem is as follows:

$$L_i = \pi_i + \lambda_i (w_i - e_i + a_i + b_i), \quad \text{and}$$

$$\frac{\partial L_i}{\partial b_i} = 0 \Rightarrow \lambda_i = P^T$$

where $\lambda_i$ (USD/ton of CO$_2$) refers to the shadow price of emission rights. The first-order condition is as follows:

$$\frac{\partial L_i}{\partial a_i} = 0 \Rightarrow \frac{\partial C_i}{\partial a_i} = P^T$$

Since the price of emission rights equals the marginal abatement costs of the entire China–Japan–ROK region, China’s marginal abatement costs are expected to be lower than those of Japan and ROK. Therefore, the actual emissions ($e_i - a_i$) of Japan and ROK will be lower than their quotas ($w_i$). According to Equation (2), the amount ($b_i$) of emission rights purchased by Japan and ROK will be positive. Japan and ROK are purchasers of emission rights, while China is expected to be a seller.

2.2. GTAP-E Model

The energy-environmental version of the Global Trade Analysis Project (GTAP-E) is a static general equilibrium model for energy and climate change developed by Purdue University’s Global Trade Center. The GTAP-E model has several extensions that allow for linking the economy, energy, and climate change. First, the model encompasses the energy used in various economic activities and the amount of carbon dioxide emitted by fossil fuel combustion. There are five types of energy commodities: coal, crude oil, natural gas, petroleum refinement, and electricity. Second, constant elasticity of substitution (CES) is used to characterize the energy substitution of economic agents. Third, the construction of an international emissions trading system [34] allows scholars to simulate the linkages of carbon markets across countries. This study applied a dynamic GTAP-E model (GTAP-E-DYN), which is an extended version of GTAP-E that includes cross-border capital flows, capital accumulation, and investment-related adaptive expectations [35].

This study used the latest GTAP database (ninth edition), which is based on the 2011 social accounting matrices of 140 countries and 57 commodities. Based on the research objective, the database was aggregated into six regions and 11 sectors, as shown in Table 1.
Table 1. Aggregated energy-environmental version of the Global Trade Analysis Project (GTAP-E) database used in this study. EU: European Union, ROK: South Korea.

| Country/Region | Sector                | Factor            |
|----------------|-----------------------|-------------------|
| China          | Agriculture           | Land              |
| Japan          | Coal                  | Unskilled labor   |
| ROK            | Oil                   | Skilled labor     |
| United States  | Natural gas           | Capital           |
| EU             | Energy-intensive industry | Natural resources |
| Other countries| Other industries      | Petroleum products|
|                |                       | Building materials|
|                |                       | Steel             |
|                |                       | Electric power    |
|                |                       | Service industry  |

3. Scenario Setting

3.1. Baseline Scenario

Under the baseline scenario, China’s and ROK’s total carbon dioxide emissions are still on the rise. By 2030, China’s and ROK’s carbon dioxide emissions will be 12.49 billion tons and 850 million tons, respectively, accounting for increases of 105.6% and 63.2%, respectively, compared to 2005. Japan’s carbon dioxide emissions peaked around 2015 and will see a slight annual decline. In 2030, Japan’s carbon dioxide emissions will be 1.03 billion tons, down 19.5% from 2005. This means that 77% of Japan’s INDC targets can be achieved under the baseline scenario, since Japan’s INDC target is to reduce carbon emissions by 25.4% by 2030 compared to 2005.

Next, the carbon intensities of China, Japan, and ROK will continue to decline. By 2030, China, Japan, and ROK will have carbon intensities of 0.66, 0.15, and 0.48 tons of CO_2/thousand dollars, respectively, which will decrease by 61%, 33.6%, and 17.7%, respectively, compared to 2005 levels (Figure 1).

![Figure 1](image-url)

**Figure 1.** Forecast of China’s, Japan’s, and ROK’s 2030 baseline scenarios; (a) gross domestic product (GDP); (b) carbon emission; (c) carbon intensity.

3.2. Policy Scenarios

First, according to the INDC report submitted by China, Japan, and ROK, China committed to an intensity target, namely, reducing carbon intensity by 65% in 2030 compared to the 2005 level.
By contrast, Japan and ROK committed to total control targets of 25.4% and 37% reductions in carbon emissions by 2030, compared to the 2005 levels and baseline levels, respectively. Due to heterogeneous development, the three countries adopted different commitment methods. To make them comparable, the INDC targets of the three countries were transformed into one (Table 2).

Table 2. Carbon emissions under different reduction targets in 2030. INDC: Intended Nationally Determined Contribution.

| Country | Reduction Targets | I   | II  | III | IV  |
|---------|-------------------|-----|-----|-----|-----|
| INDC    |                   |     |     |     |     |
| China   | A1                | 11,211.98 | −10.3 | 84.5 | −65 |
| Japan   | B1                | 952.45   | −7.4 | −25.4 | −38.5 |
| ROK     | C1                | 535.88   | −37.0 | 2.8 | −48.1 |
| Enhanced|                   |     |     |     |     |
| China   | A2                | 10,571.43 | −15.4 | 73.9 | −67 |
| Japan   | B2                | 802.75   | −21.9 | −37.1 | −48.2 |
| ROK     | C2                | 425.30   | −50.0 | −18.4 | −58.8 |

Note: I: Carbon emissions of INDC targets in 2030 (unit: million tons of CO₂); II: compared to the total emissions of the baseline scenario in 2030 (unit: %); III: compared to total emissions in 2005 (unit: %); IV: compared to emission intensity in 2005 (unit: %); A1: carbon intensity decreased by 65% in 2030 compared to 2005; B1: carbon emissions in 2030 are 25.4% lower than in 2005; C1: carbon emissions in 2030 are 37% lower than the baseline scenario; A2: carbon intensity decreased by 67% in 2030 compared to 2005; B2: carbon emissions in 2030 are 48.2% lower than in 2005; C2: carbon emissions in 2030 are 50% lower than the baseline scenario.

Table 2 shows the carbon emission reductions under the three countries’ INDC targets. Compared to the baseline scenario in 2030, the total emissions under the INDC 2030 targets will decrease by 10.3%, 7.4%, and 37%, respectively, for China, Japan, and ROK. Compared to the emissions levels in 2005, the total emissions of China and ROK should increase by 84.5% and 2.8%, respectively, while those of Japan decrease by 25.4%. Compared to the emission intensity in 2005, the INDC 2030 targets for China, Japan, and ROK are set to decrease by 65%, 38.5%, and 48.1%, respectively. In this study, the emission reductions of the three countries’ INDC emissions in 2030 relative to their baseline scenarios in 2030 were used to set the quota target for carbon trading.

In addition to the INDC goals, an enhanced version of the INDC target was also used to analyze the effect of increased emission reduction targets on carbon market linkage. Table 2 shows that carbon intensities in 2030 are 67%, 48.2%, and 58.8% lower than the 2005 levels for China, Japan, and ROK, respectively.

Second, three policy scenarios were designed to analyze and compare the influence of carbon trading linkage among China, Japan, and ROK on emission reductions and economy. The first scenario assumes a carbon market without linkage (i.e., China, Japan, and ROK operate their own carbon markets separately). The second scenario assumes a carbon market linkage that allows carbon emission rights to be traded among China, Japan, and ROK, which are set to achieve emission reduction targets (INDC targets) accordingly. Adding to the second scenario, the third scenario involves an enhanced INDC carbon trading linkage. Table 3 shows the national reduction targets in the three simulation scenarios. The emission reduction targets of each country were calculated according to the absolute emission reduction range of the committed target relative to the baseline scenario, where the negative value represents the reduction commitment that the country must achieve. The emission reductions for scenarios 1 and 2 are −10.3% for China, −7.4% for Japan, and −37% for ROK. The emission reductions in scenario 3 are −15.4% for China, −21.9% for Japan, and −50% for ROK.

Table 3. National reduction target under different policy scenarios in 2030.

| Scenario | China (%) | Japan (%) | ROK (%) |
|----------|-----------|-----------|---------|
| Scenario 1 | −10.3     | −7.4      | −37.0   |
| Scenario 2 | −10.3     | −7.4      | −37.0   |
| Scenario 3 | −15.4     | −21.9     | −50.0   |
4. Results

4.1. Carbon Emission Reduction

Table 4 shows the simulation results for carbon emission reductions in each country. Countries participating in international emissions trading could achieve promised reduction targets in two ways: economic restructuring and purchasing emission quotas from other countries. In Table 4, the negative values in domestic reduction represent the emission reduction from domestic production, whereas the negative (positive) value in emission purchase represents the purchasing (selling) of emission rights. The sum of domestic reduction and emission purchase (selling) is the outcome.

| Scenario | Scenario 1 | Scenario 2 | Scenario 3 |
|----------|------------|------------|------------|
|          | China (%)  | Japan (%)  | ROK (%)    |
| Domestic reduction | -10.3 | -7.4 | -37.1 |
| Emission purchase | 0.0 | 0.0 | 0.0 |
| Domestic reduction | -14.0 | -2.3 | -3.9 |
| Emission purchase | 3.7 | -5.1 | -33.2 |
| Domestic reduction | -19.0 | -3.5 | -5.7 |
| Emission purchase | 3.6 | -18.4 | -44.3 |

Table 4 shows that in scenarios 2 and 3, China becomes the sole seller of emission rights due to its lower abatement costs, whereas Japan and ROK are the buyers. China’s emission reduction under INDC and enhanced INDC are estimated to be 10.3% and 15.4%, respectively. In scenarios 2 and 3, China’s domestic reductions are 14% and 19%, respectively, both exceeding the committed targets. This is because China sells emission rights to Japan and ROK.

The results for Japan and ROK show that emission reductions in Japan and ROK will be realized by purchasing Chinese quotas from the linked carbon markets. In scenario 2, emission quotas purchased by Japan and ROK account for 68.7% and 89.4% of the total emission reductions, respectively. In scenario 3, the figures are 84.1% and 88.6%, respectively, for Japan and ROK.

4.2. Carbon Trading Volume

In scenario 2, China sells total carbon dioxide emission rights of 334 million tons (worth $2.213 billion) to Japan (52 million tons) and ROK (282 million tons). In scenario 3, China sells 566 million tons of emission rights worth $5.786 billion, among which 189 million tons are sold to Japan and 377 million tons are sold to ROK (Figure 2).
4.3. Carbon Price

Table 5 shows the simulated carbon prices. In scenario 1, the carbon prices in China, Japan, and ROK are 5.4 USD, 23.9 USD, and 121.2 USD per ton of carbon dioxide, respectively, which are determined by their marginal abatement costs when carbon market linkage is absent. ROK has the highest carbon price due to its largest reduction in emissions. A comparison of scenarios 1 and 2 shows that carbon market linkage significantly reduces carbon prices for Japan and ROK. The carbon price in the entire trading area is only 6.6 USD per ton of carbon dioxide, suggesting that China’s involvement in the carbon market has increased the supply of emission rights, but the demand for emission rights from Japan and ROK is rather limited. In scenario 3, although the INDC emission reduction is greatly enhanced compared to the existing targets, the carbon price of the entire region is only $10.2 per ton of carbon dioxide due to the lower emission reduction costs in China.

| Scenario | China (USD/ton of CO₂) | Japan (USD/ton of CO₂) | ROK (USD/ton of CO₂) |
|----------|------------------------|------------------------|----------------------|
| Scenario 1 | 5.4                    | 23.9                   | 121.2                |
| Scenario 2 | 6.6                    | 6.6                    | 6.6                  |
| Scenario 3 | 10.2                   | 10.2                   | 10.2                 |

4.4. Economy Development

Figure 3 shows the effects of carbon market linkage on the three countries’ GDP, welfare, consumption, investment, exports, and imports. Carbon market linkage reduces GDP losses caused by carbon emission reductions. China’s GDP losses are −0.27% and −0.25%, respectively, in scenarios 1 and 2. Japan’s losses are 0.19% and 0.08% of its GDP, and ROK’s losses are −2.09% and −0.51% of its GDP for scenarios 1 and 2, respectively. Due to the greater reduction in emissions, the aggregated GDP losses of the three countries in scenario 3 are higher than those in scenario 2. Other macroeconomic indicators have similar characteristics, and thus are not discussed.
4.5. Abatement Costs

Table 6 shows the results for the average abatement costs of carbon dioxide. The average abatement cost per ton of carbon dioxide emission reduction refers to the sum of actual GDP losses and the purchase costs of emission rights. The results shown in Table 6 are threefold. The first part is the total abatement cost. The second set of results concerns the total carbon emission reductions, including domestic reduction plus emission rights purchases. The third is the average emission reduction cost, which is calculated by dividing the total abatement cost by the total carbon emission reduction. It can be seen in scenario 2 that the average abatement costs of China, Japan, and ROK drop from 39.6, 172.5, and 235.4 USD/ton of CO\textsubscript{2} in scenario 1 to 34.5, 75.0, and 34.8 USD/ton of CO\textsubscript{2}, respectively.

Table 6. Average abatement costs of carbon dioxide in China, Japan, and ROK in 2030.

|                | China       | Japan       | ROK         |
|----------------|-------------|-------------|-------------|
|                | S1          | S2          | S3          | S1        | S2        | S3        | S1          | S2          | S3          |
| A (million USD)| Total abatement cost | 51,554 | 44,870 | 57,364 | 13,146 | 5715 | 11,703 | 74,194 | 10,964 | 15,553|
|                | Real GDP loss | 51,554 | 47,083 | 63,150 | 13,146 | 5369 | 9767 | 74,194 | 9097 | 11,704|
|                | Purchase of emission rights | 0.0 | -2213.7 | -5785.7 | 0.0 | 346.8 | 1936.1 | 0.0 | 1866.9 | 3849.6|
| B (million tons CO\textsubscript{2}) | Total CO\textsubscript{2} reduction | 1301.9 | 1301.9 | 1840.0 | 76.2 | 76.2 | 225.3 | 315.2 | 315.2 | 425.3|
|                | Domestic reduction | 1301.9 | 1636.3 | 2406.3 | 76.2 | 23.8 | 35.8 | 315.2 | 33.1 | 48.5|
|                | Purchase of emission rights | 0.0 | -334.4 | -566.3 | 0.0 | 52.4 | 189.5 | 0.0 | 282.1 | 376.8|
| C=A/B (USD/ton CO\textsubscript{2}) | Average abatement cost | 39.6 | 34.5 | 31.2 | 172.5 | 75.0 | 51.9 | 235.4 | 34.8 | 36.6|
4.6. Industry Output

Figure 4 shows the changes in industry outputs in China, Japan, and ROK. It can be seen that the output of a majority of industries is reduced compared to the baseline scenario due to the rising costs of carbon emitted by economic activities. The output of the coal industry declines the most, followed by oil. Next, energy-intensive industries are strongly affected by higher carbon prices, causing a significant reduction in production. However, the impacts on these industries vary according to different energy densities. The negative effects on agriculture and services are small. Comparing scenarios 1 and 2, it can be seen that after carbon markets are linked, the outputs of China’s energy products and energy-intensive industries decline with the increase in China’s domestic emissions reductions. However, the negative effect on output from other industries is weakened. The negative effects on all industries in Japan and ROK decline after the carbon markets are linked.

![Figure 4. Changes in the outputs of various industries in China, Japan, and ROK in 2030.](image)

5. Discussion and Conclusions

The following conclusions can be drawn from the analysis of the simulation results:

1. Carbon market linkage among China, Japan, and ROK will significantly reduce the cost of carbon dioxide abatement in the entire region. If the three countries implemented the same emission reduction targets, the GDP losses in China, Japan, and ROK would be 51.55, 13.55, and 74.19 billion USD, respectively, in scenario 1 (no carbon market linking); while the losses would be reduced to 47.08, 5.37, and 9.10 billion USD, respectively, in scenario 2 (carbon trading linking). The average abatement costs of China, Japan, and ROK drop from 39.6, 172.5, and 235.4 USD/ton of CO₂ in scenario 1 to 34.5, 75.0, and 34.8 USD/ton of CO₂ in scenario 2.

Due to heterogeneity in the energy and industrial structures of the three countries, the cost of carbon dioxide abatement will be significantly reduced after carbon market linkage. Furthermore, due to its lower cost of carbon dioxide abatement, China will become the main seller of quotas. Consequently, a linked China–Japan–ROK carbon market will bring about more emission choices for the three countries, a reduced impact on enterprises, and coordinated action on the reduction of carbon leakage. However, putting a linked carbon market into practice faces challenges such as legal establishment; monitoring, reporting, and verification (MRV); and offset mechanisms. Importantly,
disparities in political systems and competition among the three countries also compound the difficulties of implementing a coordinated carbon market.

(2) In a situation where China, Japan, and ROK increase their emission reduction targets (i.e., enhanced INDC targets), carbon prices will not increase substantially, and the negative effects on the economy will be marginal. The carbon prices in the entire trading area are 6.6 and 10.2 USD per ton of CO₂ under INDC and enhanced INDC targets, respectively. The main reason is that China’s higher emissions and lower abatement costs reduce the emission reduction costs of the entire region. Therefore, carbon market linkage ensures that Japan and ROK can further increase their emission reduction targets by trading actively in the carbon market.

(3) Although China–Japan–ROK carbon market linkage will significantly reduce abatement costs, the energy costs of the entire region will continue to rise. To prevent carbon leakage, it is recommended that China, Japan, and ROK establish a renewable energy guidance fund to support renewable energy development. Utilizing renewable energy has great significance for promoting energy structure transformation, reducing carbon emissions, keeping carbon prices stable, and facilitating global sustainable development.

This study investigated carbon allocation at the state level, but did not consider carbon quota allocation for specific industries. As such, the operating mechanism of the real carbon market was not well simulated. Moreover, the linking of a real carbon market will face the high costs of unified MRV standards, which were not considered in this study. Future studies should address this limitation and improve the model to account for the effects of an integrated carbon market on specific industries.

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