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Risk of Carbon Leakage and Border Carbon Adjustments under the Korean Emissions Trading Scheme

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Abstract

Purpose – This paper examines South Korea's potential status as a carbon leakage country, and the level of risk posed by the Korean emissions trading scheme (ETS) for Korean industries. The economic effects of border carbon adjustments (BCAs) to protect energy-intensive Korean industries in the process of achieving the carbon reduction target by 2030 through the Korean ETS are also analyzed.

Design/methodology – First, using the Korean Input–Output (IO) table, this paper calculates the balance of emissions embodied in trade (BEET) and the pollution terms of trade (PTT) to determine Korean industries' carbon leakage status. Analyses of the risk level posed by carbon reduction policy implementation in international trade are conducted for some sectors by applying the EU criteria. Second, using a computable general equilibrium (CGE) model, three BCA scenarios, exemption regulations (EXE), reimbursement (REB), and tariff reduction (TAR) to protect the energy-intensive industries under the Korean ETS are addressed. Compared to the baseline scenario of achieving carbon reduction targets by 2030, the effects of BCAs on welfare, carbon leakage, outputs, and trading are analyzed.

Findings – As Korea's industrial structure has been transitioning from a carbon importing to a carbon leaking country. The results indicate that some industrial sectors could face the risk of losing international competitiveness due to the Korean ETS. South Korea's industries are basically exposed to risk of carbon leakage because most industries have a trade intensity higher than 30%. This could be interpreted as disproving vulnerability to carbon leakage. Although the petroleum and coal sector is not in carbon leakage, according to BEET and PTT, the Korean ETS exposes this sector to a high risk of carbon leakage. Non-metallic minerals and iron and steel sectors are also exposed to a high risk of carbon leakage due to the increased burden of carbon reduction costs embodied in the Korean ETS, despite relatively low levels of trade intensity. BCAs are demonstrated to have an influential role in protecting energy-intensive industries while achieving the carbon reduction target by 2030. The EXE scenario has the greatest impact on mitigation of welfare losses and carbon leakage, and the TAF scenario causes a disturbance in the international trade market because of the pricing adjustment system. In reality, the EXE scenario, which implies completely exempting energy-intensive industries, could be difficult to implement due to various practical constraints, such as equity and reduction targets and other industries; therefore, the REB scenario presents the most realistic approach and appears to have an effect that could compensate for the burden of economic activities and emissions regulations in these industries.

Originality/value – This paper confirms the vulnerability of the Korean industrial the risk of carbon leakage, demonstrating that some industrial sectors could be exposed to losing international competitiveness by implementing carbon reduction policies such as the Korean ETS. The contribution of this paper is the identification of proposed approaches to protect Korean industries in the process of achieving the 2030 reduction target by analyzing the effects of BCA scenarios using a CGE model.

Keywords: Border Carbon Adjustments, Carbon Leakage, Korean Emissions Trading Scheme(ETS), Post-2020

JEL Classifications: F18, F68, Q54

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1. Introduction

Carbon leakage is a phenomenon in which carbon reduction policies in a set of countries may move or substitute production processes to countries without such controls, causing emissions to increase in those countries. This results from differences in the stringency of carbon reduction policies between countries or regions. Under the Kyoto Protocol, this represented an issue between Annex B and non-Annex B countries. Annex B countries are the 37 countries that set binding emissions reduction targets over the five year period 2008–2012(the first commitment period) in the Kyoto Protocol, primarily including developed countries and regions such as the USA, the EU, and Japan. South Korea is one of the non-Annex B countries in the Kyoto Protocol. By implementing the carbon reduction policies in Annex B countries, relocating a portion of production activities to non-Annex B countries for export to Annex B countries results in Annex B countries losing international competitiveness in certain industrial sectors. This is caused by the phenomenon of carbon leakage, and referred to as the risk of carbon leakage (Kuik and Hofkes, 2010; Martin et al., 2014). Furthermore, global emissions continue to increase in the Kyoto Protocol regime, which was the reason for transitioning to the Paris Agreement regime.

Examining the transition from the Kyoto Protocol to the Paris Agreement, this study explores whether the industrial structure and sectoral characteristics of South Korea without any carbon reduction policies was originally in a state of carbon leakage or carbon influx. This inquiry serves as a reference point for determining whether implementing the Korean emissions trading scheme (ETS) causes or exacerbates carbon leakage. Furthermore, how the efforts to achieve the carbon reduction target affect the risk of carbon leakage in South Korea's industries is also investigated.

As previously mentioned, international trade and carbon reduction policies are intrinsically connected; however, in the Kyoto Protocol, any border carbon adjustments (BCAs) to the risk of carbon leakage caused by carbon reduction policies were considered to be Annex B countries'—so-called developed countries'—actions to protect domestic industries, and in violation of WTO agreements (Brewer, 2004). Research regarding BCAs has been very limited and has been minimally pursued.

The biggest difference between the Kyoto Protocol and the Paris Agreement is that each participant (191 members of the United Nations Framework Convention on Climate Change are parties to the agreement) defines its own reduction targets and policies to collaboratively reduce global emissions.

Since nationally determined contributions (NDCs) vary widely, not only in the level of reduction target but also the type of target, the issue of carbon leakage emerged as a critical issue in the Paris Agreement regime. In the Paris Agreement, the risk of carbon leakage is no longer an issue unique to Annex B countries, but an issue faced by all countries or regions implementing asymmetrical carbon reduction policies. This results in potential impact on the competition and carbon leakage of all members.

In addition, the EU and USA have recently been discussing the imposition of costs according to the amount of carbon emitted from the production of imports as a BCA tool. In July 2021, the EU included BCAs when announcing climate change policy legislation to achieve the European Green New Deal. The main content of the BCA proposal is the imposition of costs according to carbon emissions on items imported by the EU. The USA also announced a similar policy stance, proposing the introduction of a carbon fee to imports of certain sectors such as aluminum, cement, iron, and steel starting in January 2024.

The reason that the EU and the USA can explicitly present the BCA issue is growing concerns regarding loss of domestic industries' international competitiveness caused by carbon leakage becoming a common shared issue. The risk of carbon leakage can happen to all parties in the Paris Agreement through achieving their own carbon reduction targets. All countries implementing relatively stringent carbon reduction policies to achieve strong carbon reduction targets will also need to consider BCAs to compensate for loss of domestic industries' international competitiveness.

Korea, which is highly trade intensive in industry, has serious concerns regarding the economic impact of BCA implementation from major trading partners. However, prior to, or in response to, trading partners' policies, it is also necessary to understand Korea's carbon emissions and trade structure. In other words, whether South Korea also faces the risk of carbon leakage under the Korean ETS, it is necessary to investigate BCAs on imports from major trading partners to protect domestic industries' competitiveness. Effective strategic policy responses, depending on whether major trading partners implement BCAs, are required.

This paper is related to two strands of literature on risk of carbon leakage and the impacts of BCAs. Previous studies on the risk of carbon leakage are primarily focused on the case of the EU ETS (Martin, Muûls and Wagner, 2016; Joltreau and Sommerfeld, 2019) and the impacts on individual industries.[1] Compared to these studies, this paper uses indicators to measure carbon leakage (Ahmand and Wycokoff, 2013) and overall quantitative risk tests (Marcu, Egenhofer and Stoefs, 2013) to determine the effects on the entire economic structure and comparison between industries. In particular, this paper seeks to determine whether South Korea is a carbon leakage country, and the level of risk for domestic industries related to Korean ETS implementation.

Second, the impact of BCAs has been explored in a wider strand of literature. Böhringer, Rutherford, and Balistreri (2012) find that a BCA on imports can significantly reduce carbon leakage to external regions. Fischer and Fox (2012) provide a detailed model-based economic comparison of different approaches to BCA implementation, finding a combined import- and export-BCA to be most effective at combating carbon leakage. Most studies focus on the design of BCAs, comparing the effects of differing types of BCAs. This study focuses on the mutual impact of several countries considering BCAs at the same time.

This paper focuses on the risk of carbon leakage in South Korea and analyzes the effect of implementing BCAs in several countries by constructing a global computable general equilibrium (CGE) model. The model provides a range of estimates on welfare, carbon leakage, and production activities such as output, exports, and imports depending on the assumptions made on factors such as the price elasticity of demand, the elasticity of trade substitution, and returns to scale (Babiker, 2005; Babiker and Rutherford, 2005; Böhringer, Balistreri and Rutherford, 2012). This analysis addresses three types of BCAs for South Korea's energy-intensive industries, including exempting energy-intensive industries from the Korean ETS, rebating all costs of the Korean ETS for energy-intensive industries, and tariffs on imports of energy-intensive industries. This allows the assessment of which type of BCAs works properly to compensate for the negative effects of carbon leakage.

The primary contribution of this paper is investigating the risk of carbon leakage and the

[1] Dechelеprêtre and Sato (2017) provide useful review of these studies.

consequent impact of implementation of BCAs in terms of protecting South Korea's industries. These results indicate the needs and roles of compensatory adjustments to protect domestic industries from the risk of carbon leakage under the Paris Agreement regime, which international efforts to reduce carbon emissions are increasing. The findings also elicit policy suggestions and implications for preliminary discussions regarding BCAs to protect Korean industries and implementing the Korean ETS.

The remainder of this paper is organized as follows: Section 2 determines the status of carbon leakage under the Korea ETS. Section 3 presents the effects of the BCAs. Section 4 concludes.

2. Risk of Carbon Leakage Under the Korean ETS

2.1. Carbon Leakage and Measurement

Carbon leakage is caused by differing carbon reduction policies and regulations between countries. The balance of emissions embodied in trade (BEET) and the pollution terms of trade (PTT) are used to measure carbon leakage (Ahmad and Wyckoff, 2003). Under the assumption that products embody pollution through production processes, the amount of emissions embodied per product unit is determined by an emissions intensity coefficient.

These indicators are calculated to determine the carbon leakage status of the industries in South Korea. Following Leontief (1970) and Miller and Blair (1985), the total output of each country or sector is calculated as equation (1).

$$x = {(I - A^d)}^{-1} y \tag{1}$$

where $(I - A^d)^{-1}$ is the $N \times N$ Leontief inverse with elements b_{ij} that describe the output generated in each domestic sector i for the production of one unit of the final demand of sector y; x is an $N \times 1$ vector of gross outputs with elements x_i, $i = 1,2,3, \dots N$ for each sector i; and y is an $N \times 1$ vector of final demands with elements y_i, including household consumption, government consumption, investment, stocks, and exports to the rest of the world (which can be further detailed according to export destination countries).

The total embodied CO_2 emissions (direct and indirect) for each sector is calculated by applying the CO_2 emissions intensity coefficient matrix Ω.

$$f = \widehat{\Omega} x = \widehat{\Omega}(I - A^d)^{-1} y \tag{2}$$

where f is an $N \times 1$ vector of CO_2 emissions volume for each sector i, and Ω is an $N \times N$ diagonal matrix where elements on the diagonal $z_{ij}(i = j)$ represent the CO_2 emissions intensity coefficient of sector i and the element of zero is on the off-diagonal section.

Using these equations, South Korea's CO_2 emissions embodied in exports and imports can be calculated as equations (3) and (4),

$$f^x = \widehat{\Omega}((I - A^d)^{-1} ex \tag{3}$$

$$f_a^m = \widehat{\Omega}((I - A^d)^{-1} im \tag{4}$$

where ex is an $N \times 1$ vector of the amount of exports for each sector i and im is an $N \times 1$ vector of the amount of imports. f_a^m indicates how much South Korea avoids emissions through imports based on the nation's own emissions intensity level. Therefore, the emissions levels that South Korea imports by trade are separately calculated using these equations for the amount of emissions embodied for exports and imports of each country and each sector. Determination of the imported embodied emissions for South Korea can be calculated as:

$$f^m = \sum_k f_k = \sum_k (\widehat{\Omega}_k ((I - A_k^d)^{-1} y_k) \quad (5)$$

where f_k is the amount of embodied emissions imported to South Korea from country k, and each import from country k's embodied emissions following their own emissions intensity level, Ω_k.

$$BEET_i = f_i^x - f_i^m \quad (6)$$

where $BEET_i > 0$ indicates an emissions surplus and emissions in sector i increase through trade. In contrast, $BEET_i < 0$ is a deficit of emissions and emissions avoidance through trade.

$$PTT_i = \frac{f_i^x / ex_i}{f_i^m / \sum_k im_{i,k}} \quad (7)$$

where PTT_i is the ratio between embodied emissions in exports and imports. If the level is greater than 1, it means that emissions intensity in exports is greater than that of imports.

GTAP9 data on output, trade, energy demand, and sectoral emissions are used to calculate BEET and PTT. The emissions intensity coefficient on exports is assumed to be equal to that of domestic output. The amount of embodied emissions in imports to country S is the summation of the amount of embodied emissions in exports of all exporting countries to country S. The results of BEET and PTT for the main countries are presented in Table 1, revealing that the BEET for Annex B countries is consistently smaller than 0. This indicates that the embodied emissions of total imports are greater than those of exports, as these countries have a strong tendency to import goods that emit more in production processes. BEET is based on the absolute quantity of embodied emissions. At national and industrial sector levels, these countries avoid emissions in production processes through import.

In comparison to BEET, PTT is a measure of emissions intensity. As it refers to the ratio of intensity of embodied emissions in exports to intensity of embodied emissions in imports, when PTT is less than 1, it indicates that domestic emissions in production processes are avoided through trade. In the case of the EU and Japan, PTT is smaller than 1 at both national and industrial sector levels. Interestingly, PTT at the US national level is greater than, 1 like non-Annex B countries except South Korea. This indicates that the intensity of embodied emissions in exports is greater than the intensity of emissions embodied in imports. It can be inferred that in sectors such as agriculture, excluding the industrial sectors in the USA, the intensity of embodied emissions of exports is far greater than that of imports. BEET and PTT for South Korea show the same result as the EU and Japan, which have implemented strict carbon reduction regulations in past decades. Domestic emissions tend to be avoided and emissions embodied in imports are relatively higher than other developing countries. The structure related to emissions for South Korea is close to the EU, USA, and Japan, even without carbon reduction regulations. This means that South Korea should assume a similar approach to Annex B countries that have implemented regulations for the past decades related to these issues, such as carbon leakage and BCAs.

Table 1. BEET and PTT at National and Energy/Manufacturing Sector Levels

		National Level		Energy and Manufacturing Sector Level	
		BEET	PTT	BEET	PTT
Annex B Countries	USA	−16.98	1.34	−74.39	0.94
	EU	−71.93	0.9	−157.21	0.57
	Japan	−41.58	0.53	−39.71	0.38
Non-Annex B Countries	South Korea	−14.00	0.81	−25.69	0.41
	China	60.12	1.18	14.47	1.00
	India	20.75	2.22	13.52	2.67
	Mexico and Chile	9.55	1.16	1.45	0.98
	Russia	40.28	1.99	22.64	1.87

BEET and PTT in South Korea strongly demonstrate that the nation avoids emissions through international trade and emits through imports. Most sectors in energy and manufacturing have the same results in BEET and PTT with the national level, with a tendency of all sectors to avoid emissions through international trade and highly emissions intensive imports. In contrast, textiles and apparel and transport vehicles and parts sectors, which are highly dependent on international trade, show different results from the national average and other sectors. These sectors emit more through production than demand, and are relatively more export emissions intensive. Most other sectors show results that are consistent with the national level. These results suggest that it is necessary to design separate carbon reduction policies for textiles and apparel and transport vehicles and parts sectors, which are traditionally highly trade intensive. In the case of the petroleum and coal products sector, BEET is greater than 0, but PTT is smaller than 1. A BEET greater than 0 indicates that petroleum and coal products generate more emissions through domestic production; however, the PTT is smaller than 1 because emissions intensity in imports is greater than emissions intensity in exports. This means that emissions intensity in the production processes of the petroleum and coal products sector in South Korea have relatively lower emissions intensity than trading partners. South Korea's petroleum and coal products have relatively lower emissions intensity in production and greater in international competitiveness compared to trading partners, under the Korean ETS, this sector could be more negatively affected on productivity and international competitiveness than the carbon reduction effect.

Table 2. BEET and PTT for Korean Industrial Sectors

Sectors	BEET	PTT
Coal	−1.89	0.00
Oil	−3.62	6.11
Gas	−2.70	0.00
Mineral nec	−3.34	1.19
Food and Beverage	−0.90	0.63
Textiles and Apparel	0.15	1.34
Wood and Paper	−0.38	0.61
Petroleum and Coal Products	0.05	0.52
Chemicals, Rubber, and Plastic	−3.11	0.46
Non-metallic Minerals	−2.89	0.95
Iron and Steel	−5.99	0.38
Non-ferrous Metal	−1.68	0.25
Fabricated Metal Products	−0.15	0.29
Transport Vehicles and Parts	1.31	1.22
Electronic Equipment	−0.05	0.51
Machinery and Equipment nec	−0.40	0.46
Manufacturers nec	−0.10	0.34

2.2. Risk of Carbon Leakage for Korean Industry Sectors

The risk of carbon leakage can differ for each sector depending on increases in the total costs of production from regulations and the potential to pass through carbon costs. Marcu, Egenhofer, and Stoefs (2013) show an overview of the quantitative risk tests used in various carbon reduction schemes. In the case of the EU ETS, the factors to increase the risk of carbon leakage for industry are increased carbon costs and trade intensity (TI) for each sector. This means that the risk of carbon leakage for sectors depends on disadvantages in international competitiveness compared to trading partners that are not regulated. The criteria for the risk of carbon leakage are I) more than 5% increased carbon reduction costs (CC) and higher than 10% TI, II) more than 30% increased CC, and III) higher than 30% TI.

Increased CC from the ETS are defined as

$$CC_i = \frac{(DCO2_i + IDCO2_i) \times EA}{GVA_i} \tag{8}$$

where $DCO2$ is direct CO_2 emissions, $IDCO2$ is indirect CO_2 emissions, EA is the expected ETS price, and GVA_i is value added for each sector. The general definition for TI is applied. Theoretically, increased production costs negatively affect the comparative advantage for sectors in international trade.

$$TI_i = \frac{M_i + X_i}{Y_i + M_i} \tag{9}$$

where M_i is imports, X_i is exports, and Y_i is total output for each sector.

Table 3. Increased Carbon Reduction Costs (CC) and Trade Intensity (TI) for Korean Industrial Sectors

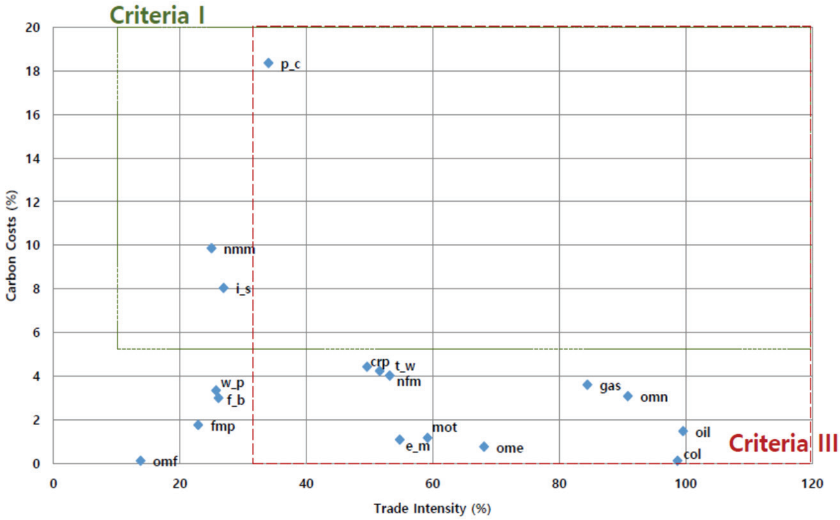
Sectors	CC	TI
Coal (col)	0.13	98.73
Oil (oil)	1.49	99.60
Gas (gas)	3.61	84.45
Mineral nec (omn)	3.09	90.86
Food and Beverage (f_b)	3.01	26.11
Textiles and Apparel (t_w)	4.24	51.61
Wood and Paper (w_p)	3.36	25.73
Petroleum and Coal Products (p_c)	18.35	34.03
Chemicals, Rubber, and Plastic (crp)	4.44	49.61
Non-metallic Mineral (nmm)	9.87	25.00
Iron and Steel (i_s)	8.05	26.92
Non-ferrous Metal (nfm)	4.03	53.21
Fabricated Metal Products (fmp)	1.77	22.90
Transport Vehicles and Parts (mot)	1.18	59.20
Electronic Equipment (e_m)	1.10	54.79
Machinery and Equipment nec (ome)	0.78	68.13
Manufacturers nec (omf)	0.13	13.78

Note: 1. Only direct CO_2 emissions ($DCO2$) are used as carbon costs and the Korean ETS price for 2019, ₩38,100 is applied to EA, as transferred to US dollar.
2. () is the label of each sector for Fig.1.

Using the GTAP9 database, industries in South Korea are divided into 26 sectors, and among which, 17 sectors that include the Korean ETS are analyzed. The results indicate that no sector has more than a 30% increase in CC from regulations, but most sectors have higher than 30% of TI. This means that the trade-intensive industrial structure of South Korea is basically risky under carbon reduction policies. Particularly the textiles and apparel and transport vehicles and parts sectors are in an influx of carbon emissions, but it is expected to face the risk of carbon leakage because of high TI. The petroleum and coal products sector does not show any carbon leakage through BEET, but this sector becomes highly risky under the Korean ETS by the combined criteria, of more than 5% increased CC and higher than 10% of TI. The petroleum and coal sector is the only sector that meets both criteria I and III, and is expected to increase production costs by implementing the Korean ETS and have high TI. The iron and steel sector also increases about 8% in production costs from the Korean ETS, with about 27% TI. This sector has relatively low TI, but increased CC would be concerning. Since the production costs of non-metallic minerals are also increased by more than 5% and the sector has high TI, there are concerns regarding the burden of carbon leakage risk due to the Korean ETS. These two sectors are also in carbon leakage status. For the chemicals, rubber, and plastic and electric equipment sectors, the high degree of TI causes the risk of carbon leakage rather than increase in production costs due to the Korean ETS.

In contrast, although the fabricated metal products sector is found to be in carbon leakage status by BEET and PTT, it faces no carbon leakage risk under the Korean ETS. This demonstrates why carbon reduction policies must not be determined by carbon leakage status, but by industrial structure assessing production costs and TI. The sectors with higher than 80% TI are those related to energy and resources, and South Korea leans on imports for these products. The results regarding how vulnerable each sector is to carbon reduction policies indicate that each sector should be considered separately.

Fig. 1. The Risk of Carbon Leakage for Korean Industrial Sectors



Note: Criteria I is more than 5% of carbon reduction costs (CC) and higher than 10% of trade intensity (TI), Criteria III is TI higher than 30%.

3. Simulations on the Effect of BCAs

3.1. Model

This section will examine the impact of BCA implementation by main trading partners, with particular focus on protecting South Korea's domestic industries exposed to the risk of carbon leakage under the Korean ETS. To do so, this paper adopts a multi-region and multi-commodity CGE model referencing Babiker and Rutherford (2005). The model was originally established to compare and contrast the effectiveness and the welfare implications of various border adjustment measures in the context of the Kyoto Protocol. The model is adjusted to investigate the effects of BCAs for Korean industries under the assumption of all other countries achieving post-2020 carbon reduction targets and South Korea implementing an ETS.

The model of the world economy has three parts: production, final demand, and market clearance. Production structures are divided into two types: fossil fuel (crude oil, coal, and natural gas) and non-fossil fuel production. The production of non-fossil fuel good, Y_N is associated with a nested Constant-Elasticity-of-Substitution (CES) function based on non-energy intermediates Z_N, an energy component E_N, and a primary factor composite V_N. Given the prices of these inputs, each producer minimizes production costs for the given level of output subject to the technology constraint:

$$Y_N = \min\,[Z_N, [\beta_N E_N^{\rho^E} + \theta_N V_N^{\rho^E}]^{1/\rho^E}]$$

In this function, the non-energy intermediate inputs enter at the top nest in fixed proportions among inputs. In the second nest, the model accounts for the substitution between the energy component and primary factor composite through ρ^E. In turn, the primary factor composite V_N is a Cobb–Douglas aggregation of land, labor, and capital, and the energy component E_N is a nested constant elasticity aggregation of electricity and non-electricity energy inputs (oil, natural gas, and coal).

In contrast, the production of fossil fuel good, Y_F is associated with a nested CES function based on a fuel-specific resource R_F, primary factors V_F, and intermediate inputs Z_F. Given the prices of these inputs, producers also minimize production costs, subject to the constraint:

$$Y_F = [\alpha_F R_F^{\rho^F} + \beta_F(\min\{V_F, Z_F, E_F\})^{\rho^F}]^{1/\rho^F}$$

In this function, production is characterized by resources in fixed-supply that trade off against the remaining inputs in the top nest according to substitution elasticity $\sigma^R = \frac{1}{(1-\rho^F)}$, and the remaining inputs enter in fixed proportions in the second nest.

Outputs, $Y_i(i = N, F)$ are the shares of domestic and foreign sales, and are determined by relative prices. The allocation of domestic and foreign sales is characterized by the Constant-Elasticity-of-Transformation function:

$$Y_i = [\alpha_i D_i^{\eta} + \beta_i X_i^{\eta}]^{1/\eta}$$

where the transformation elasticity between domestic sales and foreign exports is given by $\sigma^{tr} = \frac{1}{1+\eta}$.he applied elasticities are presented in Table 4.

The representative consumer chooses C to maximize the utility function subject to the budget constraint that consumption expenditure equals income:

$$\max U(C_i)$$

$$s.t. \sum_i p_i^C C_i = M - p^G G - p^I I$$

where p^C, p^G, and p^I are price indices for household consumption, government consumption, and new vintage capital, respectively. G is the government expenses, and I is the investment in new vintage capital. M is factor earnings and tax revenue. The preferences of the representative consumer are represented by the CES utility function:

$$U = [\alpha(\sum_{i \in E} C_i^{\theta_i})^{\rho^E} + \beta(\sum_{i \notin E} C_i^{\theta_i})^{\rho^E}]^{1/\rho^E}$$

where i indexes all goods, E represents energy goods (electricity, natural gas, coal, and oil), θ is the consumption value shares for each i, and α and β are share coefficients associated with the energy and the non-energy composite in the CES function. The elasticity of substitution between these two composites is given by $\sigma^E = \frac{1}{1-\rho^E}$.

Intermediate and final consumption goods are differentiated following the Armington assumption. For each demand class, the total supply of good i is a CES composite of domestic and imported components. Given the domestic and the import prices, economic behaviors act competitively to maximize profits subject to the composition constraint: =

$$Z_i = [\alpha_i ZD_i^{\rho^D} + \beta_i ZM_i^{\rho^D}]^{1/\rho^D}$$

$$C_i = [\alpha_i CD_i^{\rho^D} + \beta_i CM_i^{\rho^D}]^{1/\rho^D}$$

where Z denotes intermediate demands, C denotes final consumption demand, and D and M denote domestic and imported components, respectively. In these expressions, the Armington substitution elasticity between domestic and the imported components is $\sigma^D = \frac{1}{1-\rho^D}$.

Output for the domestic market is either consumed or invested, and import supply equals the domestic demand for the imported good to producers and representative consumer:

$$D_i = ZD_i + CD_i$$

$$M_i = ZM_i + CM_i$$

Finally, international trade between regions r in each good must balance:

$$\sum_r X_{ir} = \sum_r M_{ir}$$

Table 4. The Main Elasticities in the Model

Parameters	Description	Value	
σ^{tr}	Transformation elasticity between domestic and export markets	∞	
σ^E	Substitution elasticity between energy and non-energy in intermediated and final demand	0.5	
σ^D	Armington substitution between domestic and imports	2	For energy goods
		4	For non-energy goods

Source: Babiker and Rutherford (2005), Table (a).

The model is divided into ten regions, and industries are divided into seven sectors, as shown in Table 5. Nine countries, including Annex B countries, are South Korea's main trading partners, and the remaining countries are left as the rest of the world (ROW). The sectors are divided considering energy goods that are closely related to carbon intensity and degree of substitution. The energy-intensive industries (EIT) include five sectors of petroleum and coal products, chemicals, rubber, and plastic, non-metallic minerals, iron and steel, and non-ferrous metal. These sectors face the risk of carbon leakage according to the previous analysis and are strictly regulated by the Korean ETS.[2]

The GTAP9 database is applied, of which the base year is 2011. The GTAP database is appropriate for the application of a CGE model, as it contains economic information such as outputs, inputs, exports, imports, and taxes for each sector in each country, as well as organizationally linked emissions between countries. The base year could be adequate for this investigation because it predates the Paris Agreement, when there were no policies to reduce carbon emissions in most countries; therefore, there are barely disturbing events to simulate the scenarios. This multi-regional equilibrium problem is formulated and solved as a Mixed Complementarity Problem using the GAMS/MPSGE.

Table 5. Division of Regions/Countries and Sectors for CGE model

Countries/Regions		Industries	
EU	EU	COL	Coal
MEX	Mexico	OIL	Oil
USA	United States	GAS	Gas
RUS	Russia	ELY	Electricity
CAN	Canada	EIT	Energy-Intensive Industries
CHA	China	OTH	Other industries
KOR	South Korea	SVR	Service
JAP	Japan		
AUS	Australia		
ROW	Rest of the World		

3.2. Scenarios

The base year for the static model is 2011, and the baseline for 2030 is generated using the economic growth expectation and energy demand from International Energy Outlook (EIA, 2014). The economy is expanded following the expected economic growth rate and the ratio of carbon emissions are altered by the portion of energy demand in each year. Then, base scenarios (REF) for comparing the simulation results are established. REF represents the scenarios in which the nine countries achieve individual carbon reduction targets by 2030.[3] In reality, each country has different paths to reducing carbon emissions, but for model simplicity, the target level of reduction is transferred to the level compared to business-as-usual (BAU) in the model. It is also assumed that the goal of emissions reduction only concerns CO_2 even though the intended nationally determined contributions include decreasing all greenhouse gas emissions through land use, land use change, and forestry. All emissions are assumed to be CO_2 and the targets are achieved through economic activity in the model. This means these countries could have carbon leakage for achieving the carbon reduction targets by 2030.

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[2] Although the textiles and apparel sector was previously determined to be exposed to high risk of carbon leakage, this sector is excluded from the EIT industries because of its relatively low absolute emissions and less impact from the Korea ETS.

[3] The carbon reduction target for each country is based on the first submitted nationally determined contributions (NDC) in 2016.

Table 6. Carbon Reduction Targets for Nine Countries

Countries/Regions	NDCs (greenhouse gas emissions reduction targets by 2030)
EU	40% below 1990
Mexico	22% below BAU
USA	26–28% below 2005
Russia	6–11% below 1990
Canada	21% below 2005
China	60–65% below 2005 (intensity target)
South Korea	37% below BAU
Japan	26% below 2013
Australia	16.4–24.6% below 2005

Note: 1. These reduction targets are based on the first NDCs submitted in 2016 when formally joining the Paris Agreement.
2. The target for the USA is by 2025.

The scenarios are combined with which countries are implementing BCAs and the type of BCAs applied.

Three scenarios are applied for the simulations: 1) only Annex B countries implementing BCAs, 2) Annex B and South Korea implementing BCAs, and 3) all nine countries implementing BCAs. The first scenario is to determine the impact on South Korea's industries when main trading partners are implementing BCAs, focusing on the EU and the USA, which are currently announcing BCAs. The second scenario focuses on South Korea also being exposed to the risk of carbon leakage and the loss of international competitiveness. This scenario analyzes the impact of South Korea's BCAs implementation as a way to protect its domestic industries in the context it currently faces. The last scenario references the Paris Agreement regime in which all countries set individual carbon reduction targets, and all participating countries can be at the risk of carbon leakage and may consider BCAs in response.

The three scenarios for types of BCAs are: 1) EXE (exempt: exempt from the Korean ETS for energy-intensive sectors), 2) REB (rebate: rebate all Korean ETS costs for energy-intensive sectors), and 3) TAR (tariffs: tariffs on imports from energy-intensive sectors). These three scenarios can generally be considered approaches for BCAs to protect domestic industries from loss of competitiveness in international trade due to efforts to reduce emissions (Fischer et al., 2015; Keen et al., 2021). Each type has its own advantage, disadvantage, and challenge. Tariffs are a direct way to impose a fee on imports' embodied emissions. This is a narrow concept of BCA to compensate the shadow price in domestic products by reducing emissions. Rebate and exempt present broader concepts BCAs, and alternatives to imposing import fees. Tariffs on imports impose a fee on imported energy-intensive sectors to control price competitiveness. Rebates are similar to subsidized payments to energy-intensive sectors on their production. Exemption removes the original factor of the risk of carbon leakage.

Table 7. Scenarios

Countries' Scenarios	Type of BCAs
REF (Base Scenarios)	
1. Annex B (EU, USA, Japan, Canada, Australia)	EXE (exempt)
2. Annex B + South Korea	REB (rebate)
3. All nine countries (scenario 2 +China, Mexico, Russia)	TAR (tariffs)

3.3. Results

The effects of BCAs in post-2020 (carbon reduction targets by 2030) are presented in Tables 8 and 9 as equivalent variation welfare (EV welfare) level. In the base scenario, REF, welfare decrease 0.03%–1.21% compared to the case of not reducing all countries' CO_2 emissions. These results could be lower than previous studies based on the Kyoto Protocol due to more countries applying carbon reductions targets by 2030, but it could also be higher than reality because ROW does not apply any carbon reduction targets in this model, but they actually participate in the carbon reduction targets of the Paris Agreement.

Countries' scenarios show an increase in the welfare of South Korea in the scenarios (Scenarios 2 and 3) in which BCAs in South Korea are implemented in response to the BCAs of Annex B countries. South Korea is one of the countries with the greatest decrease in welfare due to the BCA implementation of Annex B countries in Scenario 1. However, by implementing BCA, welfare increases by 0.06%p–0.24%p. This result remains consistent regardless of the type of BCA implemented.

Comparing the results of the three scenarios, EXE adjustment has highest increase in welfare. In the case of TAR, the level of welfare falls the most. Due to the tariffs imposed on imported goods from energy-intensive sectors, the price of imports rises in the domestic market and relative incomes decrease, leading to the greatest reduction in welfare. In the results of EXE and REB, domestic products have price competitiveness because they are subsidized by EXE and REB; therefore, welfare loss is relatively low in these scenarios because the effect of EXE and REB simultaneously increases consumption. For this reason, these two scenarios are less harmful on welfare than the TAR scenario.

Table 8. Effects on Welfare and Carbon Leakage by BCAs (Scenarios 1 and 2)

(%)	REF	EXE	REB	TAR
EV Welfare (Countries Scenario 1)				
EU	−0.03	0.00	0.00	−0.01
Mexico	−1.21	−1.68	−1.88	−1.34
USA	−0.04	−0.01	−0.01	−0.04
Russia	−0.11	−0.15	−0.18	−0.17
Canada	−0.03	−0.01	−0.01	−0.02
China	−0.04	−0.04	−0.04	−0.06
South Korea	−0.48	−0.51	−0.53	−0.71
Japan	−0.17	−0.17	−0.18	−0.18
Australia	−0.45	−0.41	−0.39	−0.40
EV Welfare (Countries Scenario 2)				
EU	−0.03	0.00	0.00	−0.01
Mexico	−1.21	−1.68	−2.04	−1.33
USA	−0.04	−0.02	−0.01	−0.04
Russia	−0.11	−0.15	−0.18	−0.17
Canada	−0.03	−0.01	−0.01	−0.02
China	−0.04	−0.05	−0.04	−0.09
South Korea	−0.48	−0.45	−0.45	−0.47
Japan	−0.17	−0.18	−0.19	−0.18
Australia	−0.45	−0.41	−0.39	−0.40

For carbon leakage, the carbon leakage of the ROW is summed up because all countries except ROW in the model implement policies to reduce CO_2 emissions. In the model, for the REF scenario, 15.21% carbon leakage occurred, and there is no act or adjustment to protect domestic sector for any countries in this case; therefore, the largest carbon leakage occurs in this case. EXE scenarios show the largest reduction of carbon leakage compared to other scenarios, like welfare change. EXE is the most effective policy for reducing carbon leakage because this adjustment leads domestic energy-intensive sectors not to move or stop production processes or replace them with imports.

Examining the effects of BCAs on welfare and carbon leakage, the TAR scenario seems to disrupt the flow of trade between countries in terms of pricing policy. The compensating effect for welfare loss through carbon leakage is the least, and is not large enough to reduce carbon leakage. The EXE scenario is determined to be the most effective approach because it protects the energy-intensive sectors that have the greatest domestic burden of reduction and are directly exposed to carbon leakage. In reality, it might be impossible to completely exempt energy-intensive industries from emissions regulations, but policies such as the REF scenario that can compensate for the burden of economic activities and emissions regulations for these industries seem to be most realistic and effective.

Table 9. Effects on Welfare and Carbon Leakage by BCAs (Scenario 3)

(%)	REF	EXE	REB	TAR
EV Welfare				
EU	−0.03	−0.01	−0.01	−0.02
Mexico	−1.21	−0.93	−0.99	−1.16
USA	−0.04	−0.03	−0.03	−0.04
Russia	−0.11	−0.09	−0.11	−0.11
Canada	−0.03	−0.01	−0.01	−0.02
China	−0.04	0.00	−0.01	−0.03
South Korea	−0.48	−0.42	−0.44	−0.47
Japan	−0.17	−0.19	−0.19	−0.17
Australia	−0.45	−0.41	−0.41	−0.44
Carbon Leakage				
ROW	15.21	12.37	14.29	13.54

Implementing policies such as the Korean ETS to achieve emissions reduction targets can cause carbon leakage in energy-intensive industries, which negatively affects economic activities in industrial sectors. The previous section also demonstrated how risky the structure of Korean industries is under the Korean ETS. The economic effects of carbon reduction policies in South Korea are expected to be large, as the proportion of energy-intensive industries is high and most industries are trade intensive. The effect of BCAs on the economic activities of Korean energy-intensive industries is also examined. In the REF scenario, the output of energy-intensive sectors decreases by 3.27%, exports decrease by 6.04%, and imports increase by 0.39%. Similar to effects on welfare and carbon leakage, the EXE scenario consistently shows the lowest decrease in output, and the TAF scenario has the largest.

Table 10. Changes in Output and Trade of Korea's Energy-Intensive Sectors

(%)	REF	EXE	REB	TAR
Output	−3.27	−2.11	−2.85	−3.11
Exports	−6.04	−3.92	−4.01	−5.65
Imports	0.39	1.47	1.21	0.98

4. Conclusion

The analysis of this study is motivated by concerns regarding the loss international competitiveness of industries in South Korea through carbon leakage caused by efforts to achieve voluntary carbon reduction targets. Achieving voluntary carbon reduction targets requires policies such as ETSs to reduce carbon emissions, which increase industries' production costs. Any country that implements carbon reduction policies generates the risk of carbon leakage for domestic industries. To protect domestic industries' international competitiveness, the European Commission recently adopted the BCAs, which may no longer be just the case of EU. Transitions to the new climate regimes lead all participating countries to the voluntary carbon reduction targets to examine the relationship between carbon leakage, international trade, and the risk of carbon leakage for domestic industries. The purpose of this paper is to analyze the risk of carbon leakage faced in South Korea in the new climate regime to reduce carbon emissions by implementing the Korea ETS since 2015 and appropriate BCA scenarios for the industrial structure in South Korea.

First, the status of Korean industries for carbon leakage was calculated. The results indicate that national and energy and manufacturing industry levels in South Korea are obviously vulnerable to carbon leakage, even without any carbon reduction regulations. This means that South Korea must take a similar stand to the EU, the USA, and Japan related to carbon leakage and BCAs. Sectoral structures are found to differ in terms of carbon leakage; some sectors reveal carbon leakage, whereas others indicate carbon influx. Therefore, some sectors have a preexisting carbon leakage structure even without any regulations, while others would not be concerned about carbon leakage. Considering the structure of Korean industries, the study next examines how much carbon reduction policies, such as the Korean ETS, could damage industrial sectors in the international trade market. Interestingly, the results are not completely consistent with the analysis of carbon leakage, as some sectors that have a carbon leakage structure do not appear to have any risk of carbon leakage from carbon reduction regulations. In contrast, some sectors determined as carbon influx structure could face the risk of carbon leakage due to carbon reduction regulations. For example, textiles and apparel and transport vehicles and parts sectors are definitely in influx of carbon, but are expected to face the risk of carbon leakage because of high TI. Petroleum and coal products do not show any carbon leakage through BEET, but this sector becomes highly risky under the Korean ETS by the combined criteria, "more than 5% increased CC and higher than 10% of TI." These results are because the proportion of CC, which increases due to carbon reduction regulations, to value added differs. It is also because the TI of South Korean industrial sectors is very high, predominantly exceeding 30%. This can be interpreted as disproving South Korea's trade-intensive industrial structure as fundamentally vulnerable to carbon leakage. In the case of the chemicals, rubber, and plastic and electric equipment sectors, the high degree of TI exposes the risk of carbon leakage rather than increasing production costs due to the Korean ETS. The impact of carbon reduction regulation on sectors, such as the Korean ETS, was found to vary. These results suggest that it is imperative to strategically develop and apply complementary policies according to the risk of carbon leakage that consider sectors' characteristics if there are concerns regarding the loss of competitiveness in international trade.

Finally, to protect domestic industry from the risk of carbon leakage, three scenarios of border carbon adjustments are assumed, including exemption from the Korean ETS for energy-intensive industries (EXE), rebate all Korean ETS costs for energy-intensive industries (REB), and tariffs on imports of energy-intensive industries (TAR). These three scenarios could be considered BCAs to protect South Korean energy-intensive sectors against loss of competitiveness in international trade market under the Korean ETS. Compared to the reference scenario achieving the carbon reduction target by 2030 without any BCAs, the EXE scenario consistently demonstrated the highest efficiency in mitigating welfare loss and carbon leakage as well as economic activity, such as output, exports, and imports. Nevertheless, in reality, the EXE scenario is also the most impossible scenarios among the BCAs because energy-intensive industries, which are the major carbon emitters, would be difficult to exempt from the Korean ETS. The implication of the analysis of BCAs scenario is that EXE is most effective scenario to directly relieve the burden of economic activities and carbon emissions regulations in these industries. In addition, any policies to affect prices, such as tariffs, would not sufficiently protect the economic activities of domestic industries and would cause a loss in the order of relative price competition in the international trade market. These results suggest that the REB scenario is the most reasonable form of BCAs for Korean industries under the Korean ETS.

The limitations of this paper is that BCA is applied equally to all energy-intensive industries, and a more in-depth analysis of the types of BCA was not carried out. More specific BCAs scenarios according by industrial sectors or trading partners can be conducted in the future.

Based on the analysis on the South Korea's carbon emissions and international trade industrial structure, the author asserts that implementation of the Korean ETS requires strategic consideration of BCAs to protect domestic industries, uncovering the appropriate form of BCAs for the Korean industries using a CGE model. This research contributes the first analysis of carbon leakage and BCAs for South Korea's industries. Hopefully, this study will serve as a preliminary foray to expand the investigation of countermeasures according to the new climate regime, and practical policy contributions can be expected.

References

Ahmad, N. and A. Wyckoff (2003), Carbon Dioxide Emissions Embodied in International Trade of Goods, OECD Science, Technology and Industry Working Papers, No. 2003/15.

Babiker, Mustafa H. (2005), "Climate Change Policy, Market Structure, and Carbon Leakage", *Journal of International Economics*, 65(2), 421-445.

Babiker, Mustafa H., and Thomas F. Rutherford (2005), "The Economic Effects of Border Measures in Subglobal Climate Agreements”, *The Energy Journal*, 26(4), 99-125.

Barker, T., S. Junankar, H. Pollitt and P. Summerton (2009), “The Effects of Environmental Tax Reform on International Competitiveness in the European Union: Modelling with E3ME”. In M.S. Andersen and P. Ekins (Eds.), Oxford: Oxford University Press.

Brewer, T. L. (2004), “The WTO and the Kyoto Protocol: interaction issues”, *Climate Policy*, 4(1), 3-12.

Böhringer, C., E. J. Balistreri and T. F. Rutherford (2012), “The Role of Border Carbon Adjustment in Unilateral Climate Policy: Overview of an Energy Modeling Forum Study (EMF 29)”, *Energy Economics*, 34, S97-S110.

Böhringer, C., J. C. Carbone and T. F. Rutherford (2018), “Embodied Carbon Tariffs”, *The Scandinavian Journal of Economics*, 120(1), 183-210.

Böhringer, C., C. Fischer and K. E. Rosendahl (2010), “The Global Effects of Subglobal Climate Policies”, *The B.E. Journal of Economic Analysis & Policy*, 10(2), 1-35.

Böhringer, C., T. F. Rutherford and E. J. Balistreri (2012), The Role of Border Carbon Adjustment in Unilateral Climate Policy: Insights from a Model-Comparison Study, Discussion Paper, 2012-54, Harvard Project on Climate Agreements, Belfer Center.

Böhringer, C., T. F. Rutherford and W. Wiegard (2003), Computable General Equilibrium Analysis: Opening a Black Box, ZEW Discussion Papers 03-56, ZEW-Leibniz Centre for European Economic Research.

Carbon, J. and Rivers, N. (2017), “The impacts of unilateral climate policy on competitiveness: Evidence from computable general equilibrium models”, *Review of Environmental Economics and Policy*, 11(1), 24-42.

Condon, M. and A. Ignaciuk (2013), Border Carbon Adjustment and International Trade: A Literature Review, OECD Trade and Environment Working Papers, NO. 2013/06, OECD Publishing, Paris.

Davis, S. J. and K. Caldeira (2010), “Consumption-based Acounting of CO2 Emissions”, Proceedings of the National Academy of Sciences of the United States of America, 107(12), 5687-5692.

Dechezleprêtre, A. and Sato, M. (2012), “The impacts of environmental regulations on competitiveness”, *Review of Environmental Economics and Policy*, 11(2), 183-206.

Dellink, R., G. Briner and C. Clapp (2011), “The Copenhagen Accord/Cancun Agreements Emission Pledges for 2020: Exploring Economic and Environmental Impacts”, *Climate Change Economics*, 02(01), 53-78.

Ecorys (2013), Carbon Leakage Evidence Project: Factsheets for Selected Sectors, Rotterdam: Author.

Ekins, P. (2012), “Sustainable Growth Revisited: Technology, Economics and Policy”, *Mineral Economics*, 24, 59-77.

Ellis, J., D. Nachtigall and F. Venmans (2020), “Carbon pricing and competitiveness: are they at odds?”, Climate Policy, 20(9), 1070-1091.

Evans S., M. A. Mehling, R. A. Ritz and R. Sammon (2021), “Border carbon adjustments and industrial competitiveness in a European Green Deal”, Climate Policy, 21(3), 307-317.

Fischer, C. and A. K. Fox (2012), “Comparing Policies to Combat Emissions Leakage: Border Carbon Adjustments versus Rebates”, *Journal of Environmental Economics and Management*, 64(2), 199-216.

Fischer, C., R. Morgenstern and N. Richardson (2015), “Carbon taxes and energy-intensive trade-exposed industries”, Implementing A US Carbon Tax, 159-177.

Gerlagh, R. and O. Kuik (2007), Carbon Leakage with International Technology Spillovers, Fondazione Eni Enrico Mattei (FEEM) Working Paper NO. 33.2007.

He, J. and J. Fu (2014), "Carbon Leakage in China's Manufacturing Trade: An Empirical Analysis Based on the Carbon Embodied in Trade", *The Journal of International Trade & Economic Development*, 23(3), 329-360.

Intergovernmental Panal on Climate Change (IPCC) (2014), Climate Change 2014: Mitigation of Climate Change, Working Group III Contribution to the Fifth Assessment Report.

Jaffe, A. B., S. R. Peterson and P. R. Portney (1995), "Environmental Regulation and the Competitiveness of U.S. Manufacturing: What does the Evidence Tell Us?", *Journal of Economic Literature*, 33(1), 132-163.

Jakob, M., J. C. Steckel and O. Edenhofer (2014), "Consumption- versus Production-based Emission Policies", *Annual Review of Resource Economies*, 6(1), 297-318.

Joure, J., G. Houssein and S. Monjon (2013), Border Carbon Adjustment in Europe and Trade Retaliation: What would be the Cost for the European Union?, CEPII Working Paper 2013-34, CEPII.

Keen, M., I. Parry and J. Roaf (2021), Border Carbon Adjustments: Rationale, Design and Impact, IMF Working Paper(WP/21/239)

Kejun, J., A. Cosbey and D. Murphy (2008, June 18-20), "Embodied Carbon in Traded Goods", Trade and Climate Change Seminar, Copenhagen, Denmark.

Kuik, O., and M. Hofkes (2010), "Border Adjustment for European Emissions Trading: Competitiveness and Carbon Leakage", *Energy Policy*, 38(4), 1741-1748.

Marcu, A., C. Egenhofer, S. Roth and W. Stoefs (2013), Carbon Leakage: An Overview, CEPS Special Reports, No. 79/December 2013.

Marcu, A., C. Egenhofer, S. Roth and W. Stoefs (2014), Carbon Leakage: Options for the EU, CEPS Special Reports, No.83/March 2014.

Marcu, A., C. Egenhofer, S. Roth and W. Stoefs (2016), "The impact of the European Union emissions trading scheme on regulated firms: What is the evidence after ten years?", *Review of Environmental Economics and Policy*, 10(1), 129-148.

Markusen, J. R. (1975), "International Externalities and Optimal Tax Structures", *Journal of International Economics*, 5(1), 15-29.

Martin, R., M. Muûls, L. B. de Preux and U. Wagner (2014), "Industry Compensation under Relocation Risk: A firm-level Analysis of the EU Emissions Trading Scheme", *American Economic Review*, 104(8), 2482-2508.

Matthes, F. C. (2008), "What Makes a Sector with Significant Cost Increase Subject to Leakage?". In K. Neuhoff and F. C. Matthes (Eds.), The Role of Auctions for Emissions Trading, Cambridge: Climate Strategies, 29-34.

Matthes, F. C., and S. Monjon (2008), "Free Allowance Allocation to Tackle Leakage". In K. Neuhoff and F. C. Matthes (Eds.), The Role of Auctions for Emissions Trading, Cambridge: Climate Strategies, 41-48.

Mattoo, A., A. Subramanian, D. Van der Mensbrugghe and J. He (2009), Reconciling Climate Change and Trade Policy, Center for Global Development Working Paper 189.

Sato, M. (2014), "Embodied Carbon in Trade: a Survey of the Empirical Literature", *Journal of Economic Surveys*, 28(5), 831-861.

Peters, G. P., and E. G. Hertwich (2008), "CO2 Embodied in International Trade with Implications for Global Climate Policy", *Environmental Science &Technology*, 42(5), 1401-1407.

Quirion, P., and S. Monjon (2011), "A Border Adjustment for the EU ETS: Reconciling WTO Rules and Capacity to Tackle Carbon Leakage", *Climate Policy*, 11(5), 1212–1225.

Reinaud, J. (2008), Issues behind Competitiveness and Carbon Leakage-Focus on Heavy Industry, International Energy Agency (IEA) Information Paper, IEA/OECD Paris.

Reinaud, J. (2009), Trade, Competitiveness and Carbon Leakage: Challenges and Opportunities, Energy, Environment and Development Programme Paper: 09/01, Chatham House.

Roy, J., D. Ghosh and S. Ghosh (2013), Leakage Risks in South Korea: Potential Impacts on Global Emissions, Climate Strategies.

Zaklan, A. and B. Bauer (2015), Europe's Mechanism for Countering the Risk of Carbon Leakage, DIW Roundup: Politik im Fokus 72, DIW Berlin, German Institute for Economic Research.

Zhang, Z. (2012), Competitiveness and Leakage Concerns and Border Carbon Adjustments, FEEM Working Paper NO.80.

Zhou, X. and S. Kojima (2010), Carbon Emissions Embodied in International Trade: An Assessment Based on the Multi-region Input-output Model, Institute for Global Environmental Strategies (IGES).