1. Introduction

The Japanese government plans to introduce a nationwide emissions trading scheme for CO$_2$ emissions. Because emissions trading imposes a price on CO$_2$ emissions, each industry covered by the emissions trading scheme must bear additional costs based on the carbon intensity of its products. Focusing on the relationship between emissions trading and waste recycling, emissions trading could stimulate the use of recyclable materials, even if the recyclable materials are not technologically perfect substitutes for virgin materials, because in many cases it is less carbon-intensive to use recyclable materials than to use the corresponding virgin materials.

However, one must also consider the negative effects of emissions trading on the demand for recyclable materials. In other words, economic shrinkage resulting from the implementation of emissions trading could reduce the demand for products made from recyclable materials. This, in turn, could lead to a decrease in the demand for recyclable materials under the emissions trading scheme.

This study aims to examine whether the absolute amount of steel scrap used in Japan increases under an emissions trading scheme using an economic simulation model known as the computable general equilibrium model.

This study’s computable general equilibrium model is a single-country, multi-sector model. An important feature of our model is that the iron and steel manufacturing sector is disaggregated in detail. The disaggregation is based on differences in production methods and types of steel products.

In our simulation, although demand for electric arc furnace steel products in Japan increases in response to the implementation of emissions trading because of their low carbon intensity, the absolute amount of steel scrap used decreases. This is because the price substitution effect between electric arc furnace steel products and blast furnace–basic oxygen furnace steel products is dominated by the economic scale effect stemming from the negative economic impacts of emissions trading.

2. Methodology

2.1 Overview

Several studies have estimated and forecasted the flow of steel scrap in Japan using a material flow analysis framework. Daigo et al.\(^1\) estimated the amount of steel scrap generated in Japan and its concentration of tramp metal during the 1990–2030 period using a population balance model. Igarashi et al.\(^2\) predicted future steel consumption and obsolete scrap generation in Japan and Asia using a population balance model and a leaching model. These studies estimated the scrap flow in detail under various economic scenarios imposed exogenously. However, countless economic scenarios could be imagined. Therefore, it is important to simulate plausible economic conditions using economic simulation models and to estimate the material effects of emissions trading.

EAF steel products are more scrap-intensive than BF–BOF products, although both are produced using steel scrap. Before presenting the CGE model analysis, two opposing expected results are offered. The first is that the absolute amount of steel scrap used could increase in response to the implementation of an emissions trading scheme. This would be expected because BF–BOF steel products could become more expensive than EAF steel products as a result of the tightening of the “cap” on CO$_2$ emissions. As a consequence, EAF steel products would be preferred. This expected result would suggest that the implementation of emissions trading has strong price substitution effects between EAF and BF–BOF steel products. The second is that the absolute amount of steel scrap used could decrease as a result of emissions trading, because emissions trading could cause the economy to shrink, resulting in a decrease in the demand for steel products. This expected result suggests that the implementation of emissions trading has a strong economic scale effect on the demand for steel products.
flows that correspond to these conditions. Our study simultaneously simulates the economic conditions that result from emissions trading and the corresponding material flow using a CGE model. In short, our study simulates the policy-induced change in the flow of steel scrap.

2.2 Model

2.2.1 General description of CGE models

This section begins with a general description of CGE models. CGE models are economic simulation models used worldwide to assess the economic impacts of climate change and trade policies. CGE models are based on the General Equilibrium theory of economics, and each CGE model is composed of a system of nonlinear simultaneous equations that represents market interactions between economic agents, such as households, industries (production sectors), and governments.

The interactions that are described by CGE models are depicted in Fig. 1. Households supply labor and capital to their respective markets to earn income. Households also maximize their utility through consumption choices subject to their income constraints. Production sectors supply products to each market and demand intermediate products, labor, and capital to use in production. Production sectors also minimize their unit production costs through their choices of inputs. Government consumption is financed by taxes levied on the production sectors and households. A portion of the products supplied to the domestic market is invested for domestic fixed capital formation. The level of investment mainly depends on national savings levels.

CGE models also incorporate foreign trade. Products supplied to domestic markets include not only domestic products but also imported products. Moreover, a portion of domestic products is exported. However, a single-country model treats foreign countries as an integrated virtual trade partner.

In general equilibrium theory, equilibrium is characterized by a set of prices and levels of production in each industry such that market demand equals market supply for all products. Price adjustments in each market ensure equilibrium.

The parameters of the equations in a CGE model are estimated using an input–output table describing actual economic transactions. Parameter values are specified to reproduce actual economic transaction data described in the input–output table as a benchmark (initial) equilibrium solution. This study examines how the benchmark values change in response to exogenous changes in the parameters of our interest.

2.2.2 Features of our model

Our single-country CGE model focuses on the Japanese economy and consists of 38 production sectors, 53 products, 3 final demand sectors (consumers, the government, and investors), and international trade (exports and imports). The parameters of the model’s equations are estimated using the 2005 input–output table for Japan. One of the most important features of our model is that the iron and steel sector is disaggregated in detail. The purpose of disaggregation is to capture differences in production methods (BF–BOF or EAF) and differences in types of steel products. The classification of the types of products is based on the basic sector classification in the 2005 input–output table for Japan. Figure 2 depicts the processes of iron and steel production in our model.

In our model, steel scrap is generated in three ways: first, “home scrap”, is generated by the steel manufacturing sector; second, industrial scrap, which consists of cut or drilled pieces of metal, is generated by the machinery sector; third, obsolete scrap is collected.

2.2.3 Structure of our model

Our model consists of production functions, demand functions, and equilibrium constraints, the essentials of which are explained in this subsection. Variables in our model are indicated by italic capital letters.

Our CGE model describes the production functions of the production sectors using a set of Constant Elasticity of Substitution (CES) functions. In eq. (1), subscripts i and j represent the production sector and the goods that are demanded as inputs by production sectors proportional to their output levels, respectively; $X_i$ represents the output level of sector i; and $X_{INT}$ and $EV$ represent sector i’s input level of good j (e.g., agricultural products) and an energy-value-added composite, respectively. The parameters of eq. (1), $\alpha_{ij}$ and $\epsilon_i$, are sector i’s input coefficients (input per output) of good j and the composite of aggregate energy input and value-added input, respectively, all of which are calculated based on the 2005 input–output table for Japan. The aggregate energy input $E_i$ and the value-added input $V_i$ are aggregated using eq. (2), in which $\sigma_{QV}$ determines the degree of the elasticity of substitution between the aggregate
energy input and the value-added input. The degree of elasticity of substitution in CES functions represents the percentage change in the relative input quantity demanded in response to a 1% change in relative price. The degree of elasticity of substitution ranges from 0 to $\infty$. A CES function with zero elasticity of substitution indicates that no possibility for substitution exists among the inputs, which is asymptotically consistent with eq. (1). The aggregate energy input $E_i$ is the composite of electric input $XINT^\text{"electricity"},i$ and aggregate fossil fuels input $FE_i$, as described in eq. (3). Equations (4) and (5) are functions that aggregate substitutable fossil fuel inputs $XINT_{f,i}$, and labor input $L_i$ and capital input $K_i$, respectively, where subscript $f$ indicates the types of fossil fuels that are substitutable for each other (i.e., coal, crude oil, natural gas, kerosene, heavy oil A, heavy oils B and C, and LPG).

The parameters in these equations, $\alpha_{f,i}$, $\alpha_l$, $\eta_i$, $\eta_f$, $\sigma_{EF}$, $\sigma_{EV}$ and $\eta_{EV}$, are determined using a calibration method in a manner consistent with the 2005 input–output table for Japan. The calibration method determines parameter values in a way that reproduces the actual economic transaction data described in the 2005 input–output table for Japan as a benchmark (initial) equilibrium solution in our CGE model.

The nested structures of the CES functions in our model are described in Fig. 3. This model primarily uses the same values for the degree of elasticity of substitution as the ones used in the MIT emissions prediction and policy analysis model.

Given these production functions, production sectors minimize their production costs through their choice of input levels. Solving the cost-minimization problem of the production sectors, we obtain the demand functions of the production sectors for each input, through (14). The demand functions indicate that demand for each input is a function of the output level and the prices of the inputs. In eqs. (8) and (9), $P_{F E}$ and $P_{V}$ denote the sector-specific unit prices of energy input $E_i$ and value-added input $V_i$, respectively. $P_{F E}$ is sector-specific. $P_{Q_e}$ in eq. (12) denotes the unit price of fossil fuel input $XINT_{f,i}$, where subscript $f$ is another expression of subscript $k$. In eqs. (13) and (14), $PK$ and $PL$ are the unit prices of labor input $L_i$ and capital input $K_i$, respectively.

$$XINT_{j,i} = \alpha_{j,i}X_i$$

$$EV_i = \eta_i(\theta_i^{EV} - \sigma_{EV})^{\frac{\sigma_{EV}}{1 - \sigma_{EV}}} V_i$$

$$E_i = \gamma_i(\delta_i^{EF} - \sigma_{EF})^{\frac{\sigma_{EF}}{1 - \sigma_{EF}}} F_i$$

$$FE_i = \alpha_l \left( \sum \phi_{l,i}^{EF} XINT_{f,i} \right)^{\frac{1}{1 - \sigma_{EF}}}$$

$$V_i = v_i L_i^{\mu_i} K_i^{1 - \mu_i}$$

$$E_i = \frac{\theta_i^{EV} - \sigma_{EV}}{\eta_i(\theta_i^{EV} - \sigma_{EV})^{\frac{\sigma_{EV}}{1 - \sigma_{EV}}}} V_i$$

$$V_i = \frac{(1 - \theta_i)^{\sigma_{EV}} - \sigma_{EV}}{\gamma_i(\delta_i^{EF} - \sigma_{EF})^{\frac{\sigma_{EF}}{1 - \sigma_{EF}}}} F_i$$

$$FE_i = \frac{(1 - \delta_i)^{\sigma_{EF}} - \sigma_{EF}}{\phi_i \left( \sum \phi_{l,i}^{EF} XINT_{f,i} \right)^{\frac{1}{1 - \sigma_{EF}}}}$$

$$L_i = \frac{1}{v_i} \left( \frac{\mu_i}{1 - \mu_i} \right)^{1 - \mu_i} V_i$$

$$K_i = \frac{1}{v_i} \left( \frac{1 - \mu_i}{\mu_i} \right)^{\mu_i} V_i$$

Our model assumes that CO$_2$ is emitted in proportion to the use of fossil fuels and coke. In eqs. (15) and (16), $EM$ and $e_{coef}$ represent the level of CO$_2$ emissions and a corresponding emissions coefficient, respectively. Subscript $s$ represents non-substitutable fossil fuels (i.e., gasoline, jet fuel, and light oil) and coke, for which no substitutes exist in the industrial activities described in our model. These emissions coefficients are calculated as CO$_2$ emissions per input using the 2005 input–output data for Japan.

$$EM_{s,i} = e_{coef} XINT_{s,i}$$

$$EM_{f,i} = e_{coef} XINT_{f,i}$$

Provided that one unit of $EM$ requires a permit for one unit of emissions under an emissions trading scheme, the unit-
user prices of fossil fuels and coke can be written as \( PQ_s + e_{cof_s}PEM \) and \( PQ_e + e_{cof_e}PEM \), respectively, where \( PQ_s \) denotes the unit input prices of non-substitutable fossil fuels and coke and \( PEM \) denotes the unit price of the emissions permit. In our model, sector i’s price equations (eqs. (17)–(21)), which are obtained by substituting the demand functions into the zero profit conditions that ensure the equality of the total production cost and total sales in each production sector,\(^7\) indicate that an increase in the price of an emissions permit leads to an increase in the prices of products. In eq. (17), \( PX_i \) represents the price of a product produced by sector i, and subscript m denotes the goods that are represented by subscript j excluding the goods that are represented by subscript s.

\[
PX_i = \sum_{m} \alpha_{m,i} PQ_m + \sum_{s} (\alpha_{s,i} PQ_s + e_{cof_s}PEM) + \alpha_0 PEV_i
\]

(17)

\[
PEV_i = \frac{1}{\eta_i} \left( \theta_{\eta}^{\text{electricity}} PQ_{\text{electricity}}^{1-\eta_i} + (1 - \theta_{\eta})^{\text{electricity}} PV_{i}^{1-\eta_i} \right) \frac{1}{1-\eta_i}
\]

(18)

\[
PE_i = \frac{1}{\eta_i} \left( \delta_{\eta}^{\text{electricity}} PQ_{\text{electricity}}^{1-\eta_i} + (1 - \delta_{\eta})^{\text{electricity}} PFE_i^{1-\eta_i} \right) \frac{1}{1-\eta_i}
\]

(19)

\[
PFE_i = \frac{1}{\omega_h} \left( \sum_{i} \phi_{i,j}(PQ_i + e_{cof_i}PEM)^{1-\omega_h} \right) \frac{1}{1-\omega_h}
\]

(20)

\[
PV_i = \frac{1}{\omega_i} \left( \frac{PL}{\mu_i} \right)^{\mu_i} \left( \frac{PL}{\mu_i - 1} \right)^{1-\mu_i}
\]

(21)

Our model assumes that because industries, such as the petroleum product, coal product, and chemical product industries, use fossil fuels or petroleum products as raw materials rather than as sources of energy, there is no possibility of input substitution among intermediate products. It also assumes that no substitutes for electricity exist in EAF crude steel production. Figure 4 depicts the production structures of these industries. In addition, there are no substitutes for coke in any of the production sectors, despite the fact that coke is used not only as a reducing agent in smelting iron ore in a BF process but also as a fuel.

As was explained in the general description, each price variable in the CGE model is endogenously determined by solving a system of nonlinear equations, such that market demand equals market supply for the product. The equilibrium constraint conditions, as described in eq. (22), ensure that good \( Q_s \), which is supplied to the domestic market, is demanded by the production sectors and the final demand sectors, where subscript g represents all tradable goods,\(^8\)

\[
\sigma_t = 0 \quad \text{Output}
\]

\[
\sigma_s = 1 \quad \text{Value added}
\]

\[
\sigma_v = 1 \quad \text{Labor}
\]

\[
\sigma_e = 1 \quad \text{Capital}
\]

\[
\text{Intermediate inputs}
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sector i’s constant scrap coefficient (scrap-generation/output), which is estimated by the 2005 input–output table for Japan; and \( OB_h \) denotes the volume of obsolete scrap that final demand sector \( h \) holds. Note that the model assumes that \( OB_h \) is exogenously provided and does not change in response to the emissions reduction.

In eq. (27), \( Q_{\text{scrap}}^s \) denotes the volume of scrap supplied to Japan’s steel scrap market, which is equal to the volume of domestically generated scrap minus exports, \( EX_{\text{scrap}}^s \), plus corresponding imports, \( IM_{\text{scrap}}^s \). In our model, the exports and imports of steel scrap are modeled as described in eqs. (28) and (29), respectively.\(^{10}\) In these equations, \( EX_{\text{scrap}}^0 \) and \( IM_{\text{scrap}}^0 \) represent the base quantity of steel scrap exported and imported, respectively, and are exogenous variables. \( PEX_{\text{scrap}}^0 \) and \( PIM_{\text{scrap}}^0 \) represent the base prices of steel scrap exported and imported, respectively, and are also exogenous variables. However, \( PEX_{\text{scrap}} \) and \( PIM_{\text{scrap}} \), as well as \( EX_{\text{scrap}} \) and \( IM_{\text{scrap}} \), are endogenous variables; they represent the unit price of the exports and imports of steel scrap, respectively. \( \sigma_{E,t} \) denotes the price elasticity of steel scrap exports. It equals 2.95, which is the same value as the one given for steel products in the Global Trade Analysis Project database.\(^{11}\) The price elasticity of steel scrap imports, which is denoted by \( \sigma_{M,t} \), takes a hypothetical value of 1 in our model.

\[
D_{\text{scrap}} = \sum_i \text{coef}_i X_i + \sum_h OB_h \quad (26)
\]

\[
Q_{\text{scrap}}^s = D_{\text{scrap}} - EX_{\text{scrap}}^s + IM_{\text{scrap}}^s \quad (27)
\]

\[
\frac{EX_{\text{scrap}}^0}{EX_{\text{scrap}}} = \left( \frac{PEX_{\text{scrap}}^0}{PEX_{\text{scrap}}} \right)^{\sigma_{E,t} \text{scrap}} \quad (28)
\]

\[
\frac{IM_{\text{scrap}}^0}{IM_{\text{scrap}}} = \left( \frac{PIM_{\text{scrap}}^0}{PIM_{\text{scrap}}} \right)^{\sigma_{M,t} \text{scrap}} \quad (29)
\]

The equilibrium constraint condition, as described in eq. (30), ensure that \( Q_{\text{scrap}}^s \) is demanded by the production sectors, which are, in fact, composed of EAF crude steel, BOF crude steel, pig iron, and chemical products.

\[
Q_{\text{scrap}}^s = \sum_i XINT_{\text{scrap}^s,i} \quad (30)
\]

Our model assumes that, regardless of the source of scrap generation, all steel scraps have the same quality; therefore, there is one common price that is determined by the steel scrap market. In addition, as in conventional CGE models, we defined a new physical unit that is worth one yen in the base year.\(^{12}\) In order to obtain simulation results in the conventional mass unit, the ton, the model output in the new physical unit is divided by the average price of one ton of steel scrap in Japan in 2005.\(^{13}\) Our model’s base levels of steel scrap supply and demand, which are also the equilibrium solution of the non-emission reduction case, are listed in Table 1.

<table>
<thead>
<tr>
<th>Steel scrap supply</th>
<th>Steel scrap demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obsolete scrap collection</td>
<td>28087343t</td>
</tr>
<tr>
<td>Cold-finished and coated steel</td>
<td>5580368t</td>
</tr>
<tr>
<td>Hot rolled steel (BF-BOF)</td>
<td>4564613t</td>
</tr>
<tr>
<td>Transport equipment</td>
<td>3455007t</td>
</tr>
<tr>
<td>General machinery</td>
<td>2521020t</td>
</tr>
<tr>
<td>Metal products</td>
<td>2180767t</td>
</tr>
<tr>
<td>Hot rolled steel (EAF)</td>
<td>1645003t</td>
</tr>
<tr>
<td>Other iron or steel products</td>
<td>1483054t</td>
</tr>
<tr>
<td>Construction</td>
<td>987563t</td>
</tr>
<tr>
<td>Steel pipes and tubes</td>
<td>947900t</td>
</tr>
<tr>
<td>Electrical equipment</td>
<td>675380t</td>
</tr>
<tr>
<td>Cast and forged steel products</td>
<td>273130t</td>
</tr>
<tr>
<td>Precision instruments</td>
<td>129242t</td>
</tr>
<tr>
<td>Information and communication equipment</td>
<td>95559t</td>
</tr>
<tr>
<td>Miscellaneous manufacturing products</td>
<td>54187t</td>
</tr>
<tr>
<td>Electronic components</td>
<td>6224t</td>
</tr>
<tr>
<td>Ceramic, stone, and clay products</td>
<td>5614t</td>
</tr>
<tr>
<td>Coal products</td>
<td>976t</td>
</tr>
<tr>
<td>Pulp, paper, and paper products</td>
<td>366t</td>
</tr>
<tr>
<td>Non-metallic ore</td>
<td>244t</td>
</tr>
<tr>
<td>Import</td>
<td>181476t</td>
</tr>
</tbody>
</table>

Table 1 Supply and demand of steel scrap in Japan in the model’s base case.
parameter represented by eq. (33), and its value represents a percentage change in the relative market shares of the EAF and BF–BOF steel products in the market for steel product \( t \) in response to a 1% change in their relative prices. Our model sets all \( \lambda_t \) to \(-1.5\). This value is used in the corresponding equations in the second generation model to represent the substitution possibility between EAF crude steel, BF–BOF crude steel, and other methods in Germany. The base market shares of the EAF and BF–BOF steel products in each steel product market are set based on information from the Japan Metal Daily website and on annual statistics for steel products. The base market shares are listed in Table 2.

Note that although the approach described above can capture the technological difference between the BF–BOF method and the EAF method as a difference in production cost structure, it cannot sufficiently capture the functional differences between BF–BOF steel products and EAF steel products.

\[ S_{E,t} = \frac{\delta_{E,t} P_{E,t}^{b}}{\delta_{E,t} P_{E,t}^{b} + \delta_{B,t} P_{B,t}^{b}} \] (31)

\[ S_{B,t} = \frac{\delta_{B,t} P_{B,t}^{b}}{\delta_{E,t} P_{E,t}^{b} + \delta_{B,t} P_{B,t}^{b}} \] (32)

\[ \lambda_t = \frac{\partial (S_{E,t} / S_{B,t})}{\partial (P_{E,t} / P_{B,t})} \left( \frac{S_{E,t}}{S_{B,t}} \right) \] (33)

### 3. Simulations and Results

Given the model and data presented above, a number of simulations are performed. This study mainly aims to examine whether the absolute amount of steel scrap used in Japan increases under emissions trading and to consider the reasons for this. To this purpose, the study simulates changes in domestic demand and supply of steel scrap, changes in the exportation and importation of steel scrap, the ratio of EAF to total crude steel production, and various prices, including the scrap price under various \( \text{CO}_2 \) emissions reduction requirements. Our simulation set the emissions reduction requirements from a case of no reduction to a case of a 30% reduction, in relation to the actual emissions levels in Japan in 2005. For example, a 14% reduction from 2005 levels corresponds to an approximate 6% reduction relative to 1990 levels, which is the Japanese obligation under the Kyoto Protocol. In our simulations, each emissions reduction requirement is achieved through emissions trading between agents consuming fossil fuels (coal, crude oil, and natural gas), petroleum products (gasoline, jet fuel, kerosene, light oil, heavy oil, and liquefied petroleum gas), and coal products (coke) as sources of energy or as a reducing agent in smelting iron ore in a BF process.

Simulation results are shown in Figs. 6–13. Figure 6 depicts the changes in the domestic demand for steel scrap in response to the various emissions reduction requirements. As the emissions requirements are tightened from no reduction to a 30% reduction, total domestic scrap demand decreases from about 45.3 million t to about 43.4 million t, which represents a decrease in demand of approximately 4.2% due to a 30% reduction in emissions. Although the demand from EAF in tons increases by about 2.5%, the demand from BOF decreases by 19.4% as a result of a 30% reduction.

Figure 7 depicts the changes in the domestic supply of steel scrap in response to emissions reduction requirements. As emissions reduction requirements tighten from no reduction to a 30% reduction, the total domestic supply of steel scrap decreases from about 52.7 million t to about 50.4 million t. The domestic supply decreases by about 4.4% as a result of a 30% emissions reduction.

Figure 8 depicts the changes in the amount of steel scrap exported and imported. As the emissions reduction requirements tighten from no reduction to a 30% reduction, the amount of exported steel scrap decreases by about 405 kt and the amount imported increases by about 3.3 kt. The total domestic scrap supply decreases slightly faster than the total domestic scrap demand in response to tighter emissions reduction requirements. Consequently, the amount of exported steel scrap decreases in our simulation results.

Figure 9 depicts the changes in EAF share of total crude steel production. EAF share is about 27% in the baseline case. However, this share increases to about 32% after imposition of an emissions reduction requirement of 30%.

To understand the results presented above, it is necessary to examine how prices respond to the various emissions reduction requirements. Figure 10 depicts price changes for the raw materials used by the iron and steel sectors that result from the emissions reduction requirements.

The prices of iron ore and coke decrease as a result of the decrease in demand for these materials in proportion to the decrease in demand for BF–BOF steel products. Note that in our model, the cost of coke to its users increases tenfold.

Table 2 Base market share of the EAF product and the BF-BOF product.

<table>
<thead>
<tr>
<th>Section steel</th>
<th>Steel plate and strip</th>
<th>Steel bar</th>
<th>Other hot rolled steel</th>
<th>Hot rolled special steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAF</td>
<td>71.3%</td>
<td>2.9%</td>
<td>98%</td>
<td>67.1%</td>
</tr>
<tr>
<td>BF-BOF</td>
<td>28.7%</td>
<td>97.1%</td>
<td>2%</td>
<td>32.9%</td>
</tr>
</tbody>
</table>

Fig. 6 Changes in domestic steel scrap demand.
because coke users are required to buy emissions permits in proportion to their coke inputs. In our simulation, the price of an emissions permit at a 30% emissions reduction is about 44,133 yen per ton of CO$_2$.

Figure 11 depicts the changes in unit prices of each type of crude steel. The unit price of BF–BOF crude steel is higher than that of EAF crude steel for all reduction levels. The unit price increase in BF–BOF crude steel stems mainly from the
increase in the user cost of coke. The unit price increase in EAF crude steel stems from the price increase in electricity. This price gap between BF–BOF crude steel and EAF crude steel results in a rise in the share of EAF crude steel.

In recognition of the fact that the above simulation results could depend on the values of the substitution parameters between the EAF and BF–BOF steel products, a sensitivity analysis is conducted for the parameter $\lambda_t$. Figure 12 shows the results of the sensitivity analysis. As EAF and BF–BOF steel products become more substitutable (i.e., the value of $\lambda_t$ becomes smaller), a greater amount of steel scrap is demanded and traded within the domestic market at all reduction levels. However, at all values of $\lambda_t$, the absolute amount of steel scrap demanded is reduced in comparison to the case of no reduction. Figure 13, which shows the changes in EAF share and the price of BF–BOF and EAF crude steel at different values of $\lambda_t$, indicates that as EAF and BF–BOF steel products become more substitutable, EAF crude steel acquires additional market share. However, the value of $\lambda_t$ has little impact on the gap in prices between BF–BOF crude steel and EAF crude steel.

4. Discussion

The simulation results presented above indicate that emissions trading would not necessarily increase the absolute amount of recyclable material used, even if the recycled products made from such materials were less carbon-intensive than the corresponding virgin products.

As was mentioned in the introduction, two effects determine whether the absolute amount of steel scrap used increases: One is the price substitution effect between the recycled products and the corresponding virgin products, and the other is the economic scale effect resulting from the negative economic impacts of emissions trading. The simulation results are understandable given the effects mentioned above. (1) If only the price substitution effect exists, domestic scrap demand will increase. (2) The economic scale effects of the implementation of emissions trading will reduce demand for both steel products. Considering the two effects, in our simulation, the economic scale effect dominates the price substitution effect.

The results of the sensitivity analysis verified the robustness of our conclusions to some extent. However, one limitation to the robustness is that our CGE model uses the values of the substitution parameters between the EAF and BF–BOF steel products, which are not estimated using actual Japanese steel market data. Future research must endeavor to overcome the difficulty that is presented by current data restrictions in estimating the actual values of the parameters to allow the CGE model to be based on the actual values of these substitution parameters.

REFERENCES


8) The names of goods indicated by subscript g include the names of goods indicated by the subscripts j and f and the name of goods “electricity”. The names of goods indicated by j include the names of goods indicated by subscripts s and m.


11) B. Narayanan and T. L. Walmsley: *Global Trade, Assistance, and Production: The GTAP 7 Data Base*, (Purdue University’s Center for Global Trade Analysis, U.S.A., 2008).


13) The average price of traded steel scrap is calculated by dividing the total monetary value of traded steel scrap by the total mass quantity of traded steel scrap. This calculation is performed based on the 2005 monetary and physical input–output data for Japan. The average price of traded steel scrap in Japan in 2005 was 8194 yen per ton.

