Balance of CO2 Emissions Embodied in International Trade: Can Korean Carbon Tax on its Imported Fossil Fuels Make Any Difference in BEET?[1]

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Abstract

For international emission trading (ET) a la Kyoto Protocol to be effective, it presupposes that an emitter will have to purchase emission permit if emitting above its cap. However, some countries may rather choose to produce emission-intensive goods less domestically yet to import more from abroad instead. Whether a country does so or not can be revealed partly by its balance of emissions embodied in trade (BEET). Earlier studies on BEET relied on few selected countries in a partial equilibrium context. This paper is an attempt to examine BEET in a worldwide CGE context and to simulate its sensitiveness to a domestic policy measure such as carbon tax, with a special emphasis on Korea. Our tentative conclusion is that carbon tax is not an effective policy tool to control domestic CO2 emissions as well as BEET for a country like Korea with little domestic energy resources.

Key Words: Climate Change, Balance of Emissions Embodied in Trade
JEL Classification: F1, Q4

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Preface

We estimate in this paper CO2 emissions embodied in international trade for 9 disaggregated regions of the world and explore the role of carbon tax on imported fossil fuel for a country like South Korea. The analysis is carried out in a global trade CGE model developed by Global Trade Analysis Project (GTAP). In our GTAP model, the world is divided broadly into two groups, Annex I and non-Annex I, the former further aggregated into 5 regions consisting of US, EU, Japan (JPN), Eastern Europe and Former Soviet Union(EEFSU) and Rest of Annex I(RoA1) and the latter into Energy Exporting Countries(EEX), China(CHN), Korea(KOR) and the Rest of the World(ROW). The justification for including Korea as a separate region is that South Korean economy is the 12^{th} largest in the world in terms of its GDP, its imports of fossil fuels (coal and crude oil) being one of three largest and GHGs emissions the 9^{th} largest GHGs in the world[3], and its per-capita energy consumption surpassing that of Japan, Germany, Italy, UK and other western European countries according to IEA(2002).

International emission trading(ET) a la Kyoto Protocol presupposes that an emitter will purchase emission permit if it is emitting above its cap, rather than producing energy-intensive goods less domestically yet importing more from abroad instead. Whether a country as a whole does so or not will be revealed by its balance of emissions embodied in trade (BEET). Understanding the balances of emissions embodied in international trade (BEET) is, therefore, very important for the effective operation of the Kyoto mechanism, because it shows the extent of the carbon leakage. For an example, suppose that a country decides to import emission-intensive goods instead of producing them domestically. By doing so, it will reduce domestic emissions but instead increase emissions abroad. To be specific, let's assume that country A

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[3] See KEEI, *Energy in Korea*, 2001.9.

exports iron & steel to country B, which in turn exports agricultural goods to country A. Country B uses the imported iron & steel to manufacture automobiles for its domestic transportation. In such a case, domestic GHGs emissions occur in country A in the process of producing iron & steel and exporting them to country B. Meanwhile, domestic emissions in country B occur due to its domestic consumption, i.e. use of automobiles as a means of transportation. In this situation, both countries emit GHGs domestically, but country A's emissions are mainly due to the country B's import demand for iron & steel. After all, country B is responsible for emissions in both two countries, because they are all induced by demand in country B.

UN Framework Convention on Climate Change (UNFCCC) and economic incentive systems espoused by Kyoto protocol all stipulate Annex I countries' emission reduction targets based on the amounts of each country's domestic emissions regardless of its demand orientation. Emissions reduction mainly from domestic production of each country is the primary concern of UN Framework Convention on Climate Change (UNFCCC) and Kyoto Protocol. For this reason, it could easily lead to "carbon leakage" if a country can reduce its GHG emissions "artificially" by producing certain carbon-intensive goods less but importing them more from abroad instead. Hence, it is argued in this paper that the Kyoto mechanism as related to emission trading can be improved when the demand side of greenhouse gases (GHGs) emissions is treated with an equal emphasis as with the supply side. To strike a balance is to compare the emissions embodied in exports (EEX) with emissions embodied in imports (EEM) for each country in terms of its BEET. For that matter, BEET will be able to show in part what constitute the differences between emissions due to domestic production and domestic demand for each country. We believe that it has a significant implication in terms of allocation and distribution of international responsibilities of global warming.

As mentioned before, BEET is defined as difference between CO2 emissions related to domestic production and those related to domestic demand, or as the difference between emissions embodied in exports (EEX) and emissions embodied in imports (EEM) in international trade. We go about measuring EEX, EEM, and BEET using GTAP model and GTAP-E dataset. GTAP is supplemented by a recursive dynamic model like SGM, because the former is comparative static in its nature based on cross section data. In a time series analysis covering 1976-1994 period for a few selected countries, Muradian et al (2001) suggests a positive relationship between EEM and time, implying the environmental Kuznets curve hypothesis, i.e. of decreasing pollution intensity as income per capita increases.

Carbon dioxide emissions embodied in foreign trade were analyzed earlier by Ahmad and Wyckoff (2003), Antweiler(1999), Bosi and Riey (2002), Lenzen(1998), Machado et al (2001), Muradian et al (2002), and Wyckoff and Roop(1994). For example, Bosi and Riey(2002) estimated emissions embodied in foreign trade of energy commodities, where EEX are GHGs emitted in the process of extracting fugitive emission in oil wells. Lenzen (1998) tried to show GHGs embodied in Australian final consumption, while Machado and Worrel (2001) did similar research on Brazil's exports and imports. Muradian et al (2002) estimated embodied pollutions in trade for 18 industrialized countries from 1976 to 1994 in terms of BEET and emission terms of trade (ETT). Ahmad and Wyckoff (2003) estimated balances of CO2 emissions embodied in international trade of a few selected countries. Wyckoff and Roop(1994) estimates the amount of carbon embodied in the imports of manufactured goods for six OECD countries. All of these studies did not fully take into account the fact that international trade is mutually interdependent transactions in a global general equilibrium context. In other words, a country's import is the other country's exports and increase in one reflected in the increase of the other and vice versa. This study tries to incorporate the interrelationship of international trade and emissions embodied therein in an applied general equilibrium model for global trade. Emission data rely on GTAP-E dataset which includes energy balance and GHGs emissions data. We attempt to simulate how carbon tax on energy use will affect BEET for the 9 major regions. We supplement the GTAP[4] dataset with GTAP-E data on CO2 emissions.

Chapter 1 explains statistical data and briefly discusses methodology. Chapter 2 shows structure of BEET for the selected 9 regions. We simulate sensitiveness of BEET to carbon tax introduced in S. Korea on its imported energy sources. Summary and conclusion follow afterward.

1. Statistical Data and Methodology

Analysis in this study of emissions embodied in international trade for 9 regions is based on GTAP5 and GTAP-E Database. The countries are grouped into 9 regions : United States (US), European Union(EU), Japan(JPN), Eastern Europe and the Former Soviet Union (EEFSU), Rest of Annex 1 Countries(RoA1), Energy

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[4] Global Trade Analysis Project (GTAP) Model is an applied computable general equilibrium model particularly well-suited for analyzing global trade issues. It is developed by Global Trade Analysis Project of Department of Agricultural Economics, Purdue University, USA.

Exporting Countries (EEX), China(CHN), South Korea (KOR), and the Rest of the World (ROW). GTAP model[5] so constructed with the 9 regions trading each other was applied to similarly aggregated GTAP-E data[6] enabling us to calculate emissions embodied in bilateral trade between each pair of the countries.

According to Ahmad and Wyckoff (2003), one way to measure CO2 emissions embodied in international trade is to measure total direct and indirect CO2 emissions embodied within products used domestically to satisfy total domestic demand, whether imported or produced domestically. Their approach is to calculate, for each country (A):

(1) CO2 emitted during the domestic production of manufactured goods and embodied with:

(1.a) Manufactured goods and services consumed in country (A), (and exports of services)

(1.b) Exports of manufactured products from country (A).

(2) CO2 emitted (by other countries) during the production of manufactured goods for exports to country (A), and embodied within:

(2.a) Manufactured goods and services consumed in country (A) (and exports of services).

(2.b) Exports of manufactured products from country (A).

In this way it is possible to define the following aggregates for country (A):

. Domestic consumption of CO2 emissions = (1.a) + (2.a)

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[5] See T. Hertel(1997) for GTAP model and Dimaranan and McDougall(2002) for the structure of GTAT dataset.

[6] Lee(2002) explains newly compiled energy and emission data in GTAP-E.

. Domestic production CO2 emissions (1.a) + (2.b)

. Total exports of embodied emissions = (1.b) + 2.b)

. Total imports of embodied emissions = (2.a) + (2.b)

. Net trade balance in embodied emissions = (1.b) – (2.a)

In order to compute the emissions aggregates, domestic emission coefficients for each industrial sector were first estimated using sectoral emissions statistics of GTAP-E dataset. Under the assumption that production of exports in each industrial sector has the same emission coefficients as its production for domestic consumption, we applied the same emission coefficients to bilateral exports matrix for 9 regions to arrive at a matrix of emissions embodied in bilateral exports of each country. Since exports of country A to B is the same as imports of country B from A, the same matrix can be used to calculate balance of emission embodied in bilateral trade between any pair of countries. Using these emissions data and scenarios for tax on imported energies, we are able to simulate effects on BEET of the Korea's import tax a la carbon contents.[7]

<Table 1> shows how the same tax rate based on carbon contents results in different effect on imported primary energy prices before tariff. The after-tax price increase is applied in addition to any existing tariff on the same goods. Therefore, our simulation of the import tax on energies based on their carbon content measures their combined effects. As can be seen, the same tax per ton of

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[7] Our analysis is confined to emissions of CO2, because CO2 comprises most of GHGs emissions (about 80%) and being emitted mostly from burning fossil fuels its data are most reliable and easy to compare internationally.

carbon will result in higher import price the more carbon content an imported energy good has for a given unit value. For example, $50 tax per ton of carbon will raise the price of imported crude oil by $5.8 or 33.3%, while imported coal price with more carbon content per unit value will rise by $35.7 or 99%. However, the same import tax per ton of carbon in natural gas will raise price of imported natural gas at the similar rate as crude oil. It is because the unit value of the former is higher, even though its carbon content is lower.

< table 1 >

Import Tax on Carbon Content and Effect on Imported Price

Energy goods	Price: US$/unit	Carbon content per unit	Price after $50 tax per ton-C (%)	Price after $100 tax per ton-C (%)
Imported Crude oil	$17.38/bbl	0.1157tC/bbl	$23.17/bbl (33.29%)	$28.95/bbl (66.57%)
Imported natural gas	$2.22/MBtu	0.01447tC/MBtu	$2.94/MBtu (32.59%)	$3.67/MBtu (65.18%)
Imported Coal	$36/ton	0.7135 tC/ton	$71.68/ton (99.10%)	$107.35/ton (198.19%)

Source: Bosi and Riey(2002, p.35). Carbon content data are for Japanese energy imports in 1999.

2. CO2 Embodied in Trade and BEET

In <figure 1> below we show balance of emissions embodied in international trade (BEET) for 9 countries/regions of the world under different scenarios. Baseline is no tax case with business as usual and the other two scenarios are one for $50 tax and the other for $100 tax based on carbon contents of imported energy sources in South Korea. Different rates of price increase due to the import tax on carbon contents as shown in <table 1> are applied for the two scenarios. In the figures below, country or region is denoted by numbers from 1 through 9. United States is denoted by number 1, EU by 2, Japan(JPN) by 3, Eastern Europe and Former Soviet Union(EEFSU) by 4, Rest of Annex 1 countries (RoA1) by 5, energy exporting countries (EEX) by 6, China (CHN) by 7, South Korea (KOR) by 8, and the Rest of the World (ROW) by 9. BEET here is defined as emissions embodied in exports (EEX) less emissions embodied in imports (EEM). In <figure 1> it is shown as proportions of total domestic emissions of respective region or country. In general tax on imported fossil fuels will dampen import demand for the taxed commodities and tend to improve taxing country's balance of current accounts while worsening energy exporting country's balance of current accounts. In case of South Korea without any domestic energy resources, its demand for imported fossil fuels are very price-inelastic and effects of import tax on import demand for fossil fuels are minimal. And so are its effects on Korea's balance of current accounts and on energy exporting countries'. As a result, Korea's import tax on fossil fuel based on carbon contents has only a minor impact on BEET of Korea and other countries/regions. This implies that carbon tax in South Korea may not be an effective policy instruments for Korea to reduce its domestic emissions or to improve its BEET,[8] suggesting other alternative such as domestic emission trading. However, we do not attempt to tackle this issue in this short paper. Thus, we will use figures below to compare BEET of various regions, mostly based on baseline characteristics.

Based on the statistics behind the figures, EU has a deficit in BEET of about 108 Mtons-CO2 at the baseline. It means in the process of meeting its total internal demand EU as a whole emits this amount more outside the region than regions outside EU emit inside EU. In other words, a total of 2,819 Mtons-CO2 was emitted within and without the EU to meet total demand of EU countries, while 2,711 Mtons-CO2 was emitted within EU for its internal production process. It means again that EU's EEX exceeds EEM by 108 Mtons-CO2, which is about 3.9% of its emissions within the region. By the same logic, Japan induces a total of 1,078 Mtons of CO2 emissions in the world including emissions of 1,005 Mtons within the Japan itself. The difference (73Mtons) is Japanese BEET deficit, which is 7.2% of its domestic emissions, a relatively large magnitude. As for Korea, its BEET deficit is about 0.7Mtons-CO2, or 0.2% of its domestic emissions (that is, 382Mtons-CO2).

The United States emits a total of 4,761Mtons domestically, which is about 1.7 times the EU and about 4.7 times Japan. However, BEET deficit of the United

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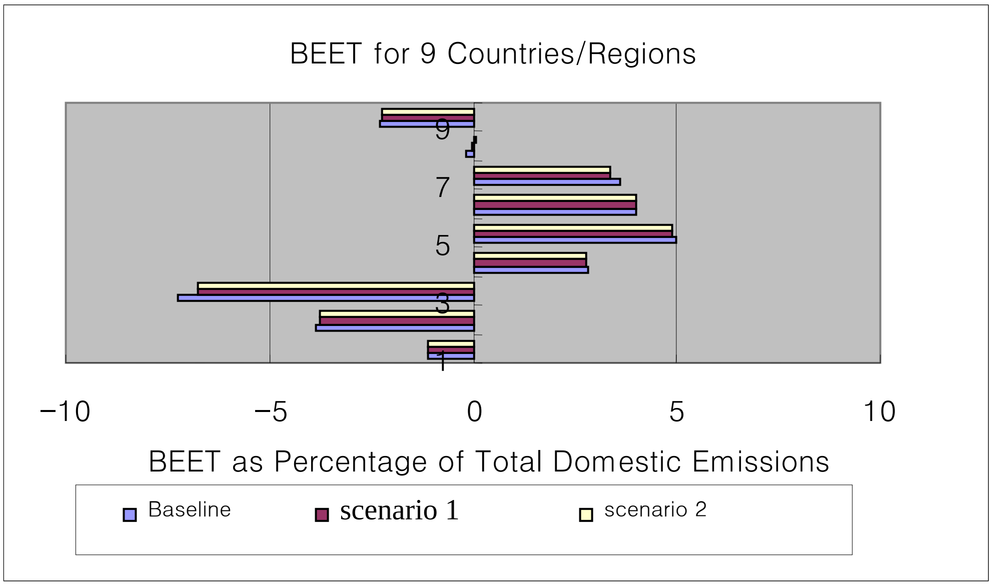
[8] We can show the same is true for a country like Japan, which has some similarity in the sense it has also few domestic fossil fuel endowment except coal. In case of the United States, carbon tax is equally unviable policy measures because of political reason. New carbon tax that will increase gasoline price is highly unlikely in the US where automobile is an indispensable means of transportation.

States, 52 Mtons-CO2, is only 1.1% of its total domestic emissions. It means that total emissions of the United States are mostly to meet its own demand, without causing emissions abroad. This is in contrast to the case of Japan and EU. (For details, see appended table 1). It implies that the responsibility for global warming can be viewed differently depending on whether the emissions are measured in terms of production or demand. In terms of demand-induced emissions, the United States seems to have less liability than Japan or EU, which partly explain the US' distant position regarding the Kyoto protocol.

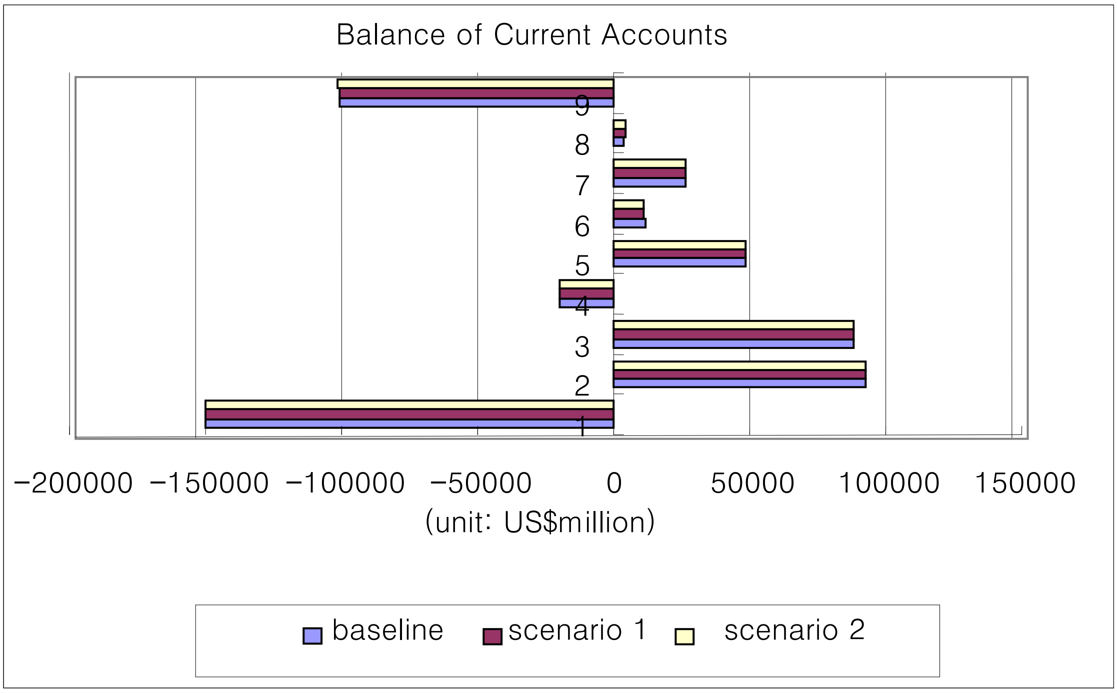
<Figure 1>



To explain this argument, let us assume that country H, an Annex B party, can reduce 10Mtons-CO2 equivalent by closing down its emission intensive domestic production facility as a part of its emission reduction efforts. Also suppose that it imports from abroad the emission intensive goods which used to be produced by its closed-down domestic plants. As a result of this import-substitution, country H will induce increased productions and emissions in the exporting country, say, country G. The world as a whole has the same amount of emissions after this change in international trade structure. According to the Kyoto Protocol, however, country H will get credit for her emission reduction equivalent to 10Mtons-CO2. If this reduction in emissions is recognized as emission allowances internationally tradable, it may end up with net increase in emissions. This is an example of carbon leakage. It shows international trade can be used as a vehicle of carbon leakage.

As shown above, BEET deficits of 7.2% for EU and 3.9% for Japan as proportion of their domestic emissions are significant magnitude compared to 5.2% average reduction target set for the 1st commitment period(2008-12) for all the Annex B countries. It means that the Kyoto mechanism cannot meet its targeted emission reduction without considering the carbon leakage through emissions embodied in international trade. This leakage may occur mostly in non-Annex B countries through international trade of emission intensive goods between Annex B and non-Annex B countries. The baseline emission reduction targets could have been set 7.2% and 3.9% points higher for Japan and EU respectively, if their emissions were measured in terms of demand-induced rather than production-related emissions. By the same argument, the emission reduction target figures for EEFSU and RoA1 could have been set 2.8% and 5.0% lower.

<figure 2>



Comparing <figure 1> with <figure 2>, we can see that Japan is in surplus with its current accounts while in deficit with BEET, which means its imports are more emission-intensive than its exports. It is also demonstrated by its emission terms of trade (ETT), 0.31. (see <appendix table 4> for details). The same is true for EU but in a lesser degree with its ETT being 0.78. As for the United States, its BEET is in deficit by a small magnitude, even though it runs much bigger deficit in current accounts.

In contrast with EU and Japan, EEFSU runs deficit in current accounts and surplus in BEET, because its exports are much more emission intensive than its imports. It is evidenced by its ETT of 1.53. After the collapse of the former Soviet Union, hot air was expected to occur in the region due to its economic slump and consequent reduction in emissions below the allocated emission level by the Kyoto Protocol. If the emission level were measured by its domestic demand rather than domestic production, the possibility of hot air would have been even greater. As for China, its BEET and balance of current accounts are both in surplus. Its ETT is as high as 2.7, implying that Chinese exports is greatly emission intensive compared to its imports. In case of South Korea, its current accounts are in slight surplus while its BEET is slightly in deficit. It implies that its exports are a little more emission-intensive than its imports. However, the relative emission intensity is seen by its EET of 1.06.

<Figure 3> and <figure 4> show bilateral BEET and bilateral balances of current accounts for the 9 countries/regions.[9] By comparing two figures it can be seen which country exports emission-intensive goods to which country. To be specific, the United States record surpluses in current accounts with EEFSU and Korea and deficit with Japan, RoA1, China, and ROW. EU runs deficit in current accounts with US, Japan and China, while running in surplus with the rest of the

[9] Statistics in GTAP Database are sometimes inconsistent with official statistics of respective countries. For example, official Korean statistics records small deficit in its current account in 1995, while GTAP database for 1995 records rather a small surplus. This discrepancy arises in part from different nature of compiling international trade statistics and balance of payment statistics. For an instance, value of imports is measured in CIF, while that of export is in FOB for trade statistics. In balance of payment statistics, freight and insurance are separately dealt as export or import of services and thus recorded in the service account. Bilateral balances of current accounts in <figure 4> are measured by bilateral export matrix, where exports are valued in international market price. If exports are measured by importing country's domestic market price, value of exports will show in bigger number to the extent of freight, insurance and import tariff, which will be also reflected in BEET. EEX in our study is smaller in amount compared to the same in Ahmad and Wyckoff(2003), because the former does not include emissions from household sectors and also exports are valued in international market price.

world. Japan reaps surplus in trade with most countries except in trade with EEFSU, RoA1, and EEX. As shown in these instances, a country runs into surplus with some countries but deficit with some other countries as far as balance of current accounts are concerned. However, BEETs do not follow this pattern.

As can be seen in <figure 4>[10] Japan runs into deficit in BEET with all the countries/regions. This means that Japan imports more emission-intensive commodities than its exports to all the countries/regions. EU has similar patterns in BEET, except with Japan. On the other hand, almost all countries show deficit in BEET with EEFSU. And all countries except EEFSU run deficit in BEET with China. This means that EEFSU and China export mostly emission-intensive commodities to the rest of the world compared to their imports.

As for the United States, its BEET shows deficit with EEFSU, RoA1, EEX, China and ROW, while its BEET is in surplus with EU, Japan, and Korea. It means that the United States exports emission-intensive commodities to EU, Japan and Korea while importing them from with EEFSU, RoA1, EEX, China and ROW. Korea's BEET is in deficit with EEFSU, RoA1, EEX and China, and in surplus with EU, Japan and ROW.

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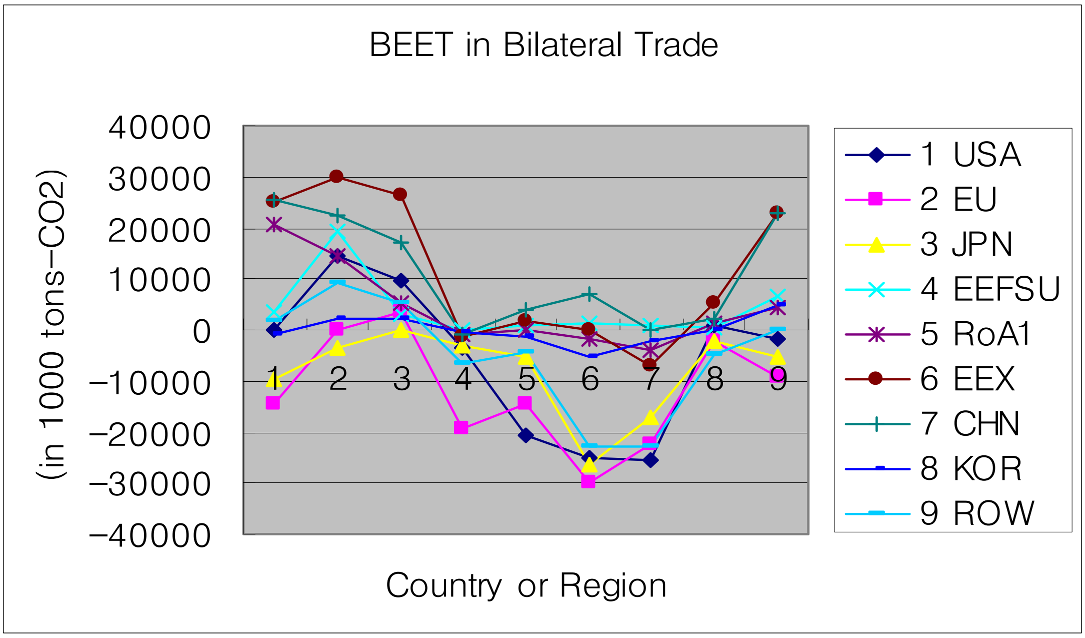
[10] <Figure 4> is based on <appendix table 2>.

<figure 3>



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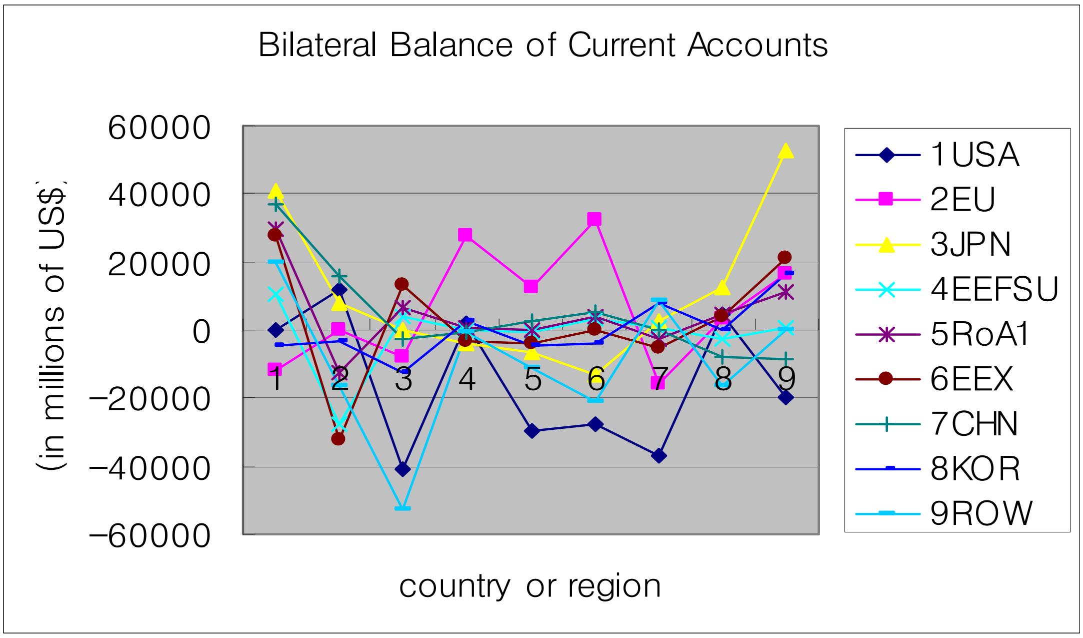

3. Korea's bilateral BEET with its trading partners

Out of Korea's 382.2 Mtons-CO2 emissions in baseline year, about the half is accounted for by electricity generation and energy-intensive industries. To break it down, the former takes 133Mtons or 35% and the latter 59Mtons or 15%. (see <appendix table 7> for details). By energy types, coal burning contributes to 126Mtons, of which 21Mtons are due to production of exports. Petroleum and coal products are the major source of CO2 emissions, accounting 230.2Mtons or 60% of the total. Natural gas adds only 25.7Mtons. Emissions of CO2 embodied in exports (EEX) are 40.3 Mtons while those embodied in imports (EEM) are 40.3Mtons, the difference of 0.7Mtons making deficit in BEET.

Bilateral BEETs between Korea and each of the other 8 regions are shown in <figure 9>[11]. It depicts that Korea exports energy-intensive commodities to EU, Japan and ROW, more than its imports from US, RoA1, EEX and China. It is shown as BEET surplus with EU, Japan and ROW and deficit with US, RoA1, EEX and China. Korea's imposition of new tax on its imported energy based on its carbon content affects Korea's close trading partners such as Japan(3) and China(7), particularly on their bilateral BEETs.

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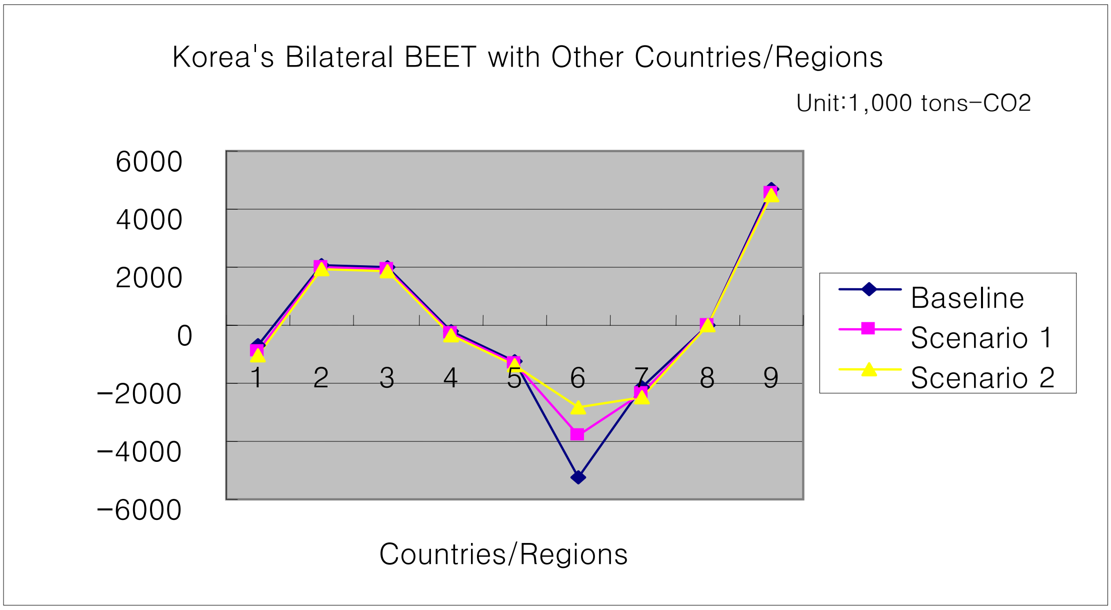
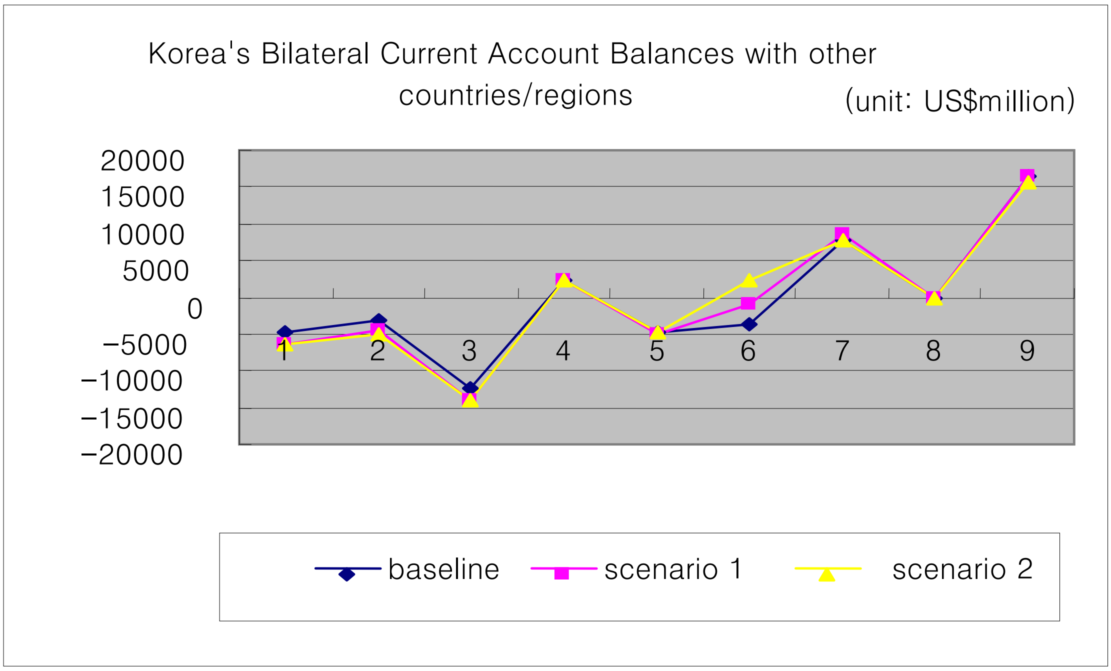
[11] <Figure 5> is based on <appendix tables 2, 5, 6>, particularly the corresponding Korea rows.

<figure 5>



<figure 6>



According to <figure 6>, Korea makes deficit in its current accounts with US, EU, Japan, RoA1 and EEX. In spite of Korea's deficit in current accounts with EU and Japan, however, its BEET shows surplus, implying Korea's exports to these countries are more emissions intensive than its imports. On the other hand, Korea makes surplus in current accounts, but deficit in BEET for its trade with China. It implies Korea's imports from China are more emission-intensive than its exports. Korea's new tax on its imported energy based on carbon content slightly worsens its bilateral balance of current accounts balance with most of its trading partners except with EEX countries with which it improves somewhat. It improve Korea's bilateral balance of current accounts with EEX as Korean consumers facing higher energy price try to economize on fossil fuel use, while Korea's balance of bilateral current accounts balances with other regions get worsened because of higher cost of domestic production due to higher energy cost. However, the impact on BEET is much weaker than on the balance of current accounts, because the former depends on long-run factors such as industrial structure and energy efficiency. To repeat, Korea's new tax on imported energy improves its balance of current accounts in its bilateral trade with EEX countries, and worsens it in trade with US(1), EU(2) and Japan(3). Meanwhile, Korea's deficit position of BEET improves in bilateral trade with EEX(6) and worsens with China(7) and US(1).

However, the effects of taxation imposed on Korea's imported energy are limited in reducing domestic emissions and improving its bilateral BEET. The reason seems to lie in the fact that demand for imported energy is quite price-inelastic for Korea at least in short run, due to unavailability of alternative domestic energy sources. This implies that policy options open to Korea to reduce emissions are also limited. Korea may well have to rely on emission trading based on quota rather than carbon tax. As mentioned before, however, Kyoto mechanism particularly its emission trading system cannot function well unless carbon leakage through international trade can be taken care. The extent of possible carbon leakage for individual country or region is indicated by its BEET. As a trade dependent country, Korea's position in negotiating the terms and conditions to join Annex B in the future cannot be rightly asserted without taking emissions embodied in trade and BEET into consideration.

Summary and Conclusion

South Korea, even though not a current member of Annex I countries in the UN Framework Convention on Climate Change (UNFCCC), is not less concerned with reducing green house gases (GHGs), particularly CO2 emission. Being the 12^{th} large economy in terms of GDP and similarly ranked in terms of GHGs emissions in the world, it is one of leading importers of primary energies such as coal, crude oil and natural gas. Its energy requirements totally depend on foreign resources, therefore, reduction of domestic CO2 emissions in Korea is itself serious problem, because it is tantamount to saving its energy and import bill. Not only for the sake of taking part in international efforts to mitigating the global warming and but also for its own sake of solving energy problem, Korea is supposed to join the Annex I group in near future and make use of the Kyoto mechanism in meeting its own emission target.

Without any domestic alternative energy resources, Korea faces very inelastic demand for imported energy. As such its demand for energy is not so responsive to price mechanism that carbon tax on imported energy is not an effective policy tool to control CO2 emissions from burning the fossil fuels. Domestic and international emission trading seems to be the other viable alternatives for Korea to keep it within the allocated emission allowances.

For an international emission trading system to be effective in the sense that it is inductive to less emission, however, there should be no carbon leakage through international trade of emission intensive commodities. In other words, it presuppose that an emission intensive industry will purchase emission permit if emitting above its cap in the process of more production, rather than curtailing domestic production and instead importing from abroad. Whether or not a country as a whole does so or not will be revealed by its emissions leakage through international trade. It can be measured by embodied in its exports (EEX) and imports (EEM), and its balance of emissions embodied in trade (BEET).

So far, studies on BEET and related subject are on a individual country or on selected countries in a partial equilibrium context, mostly in relation to emission embodied in international trade of energies rather than on emission embodied on traded goods. This paper intends to estimate such BEET in a computable worldwide general equilibrium context. It also tried to simulate sensitiveness of a country's BEET to a domestic policy measure to control emission such as carbon tax. This research is one of new efforts to study BEET in CGE framework in a worldwide context, though comparative static in its nature. It derives policy implications particularly for a small but major energy importing country like South Korea.

We showed that a country can emit much domestically yet does not induce other countries to emit by its domestic demand, like US and Korea. On the other hand, a country's domestic emissions may be moderate, but can induce other countries to emit more instead by its import demand for emission-intensive commodities like Japan and EU. BEET figures can be used as evidence for this kind of argument. This has implications that future negotiation on target emission allowance under Kyoto Protocol must take into consideration the emissions due to production as well as demand, the difference of which is reflected partly in such measurements as BEET and EET.

References

1) Ahmad, Nadim and Adrew Wyckoff, *Carbon dioxide emissions embodied in international trade of goods, OECD*, Directorate for Science, Industry STI Working Paper 2003/15, 3 Nov. 2003

2) Antweiler, W.,"The Pollution Terms of Trade," *Economic Systems Research*, Vol. 8, 1999, no.4, pp. 361-365

3) Bosi, Martina and Benedicte Riey, *Greenhouse Gas Implications of International Energy Trade,* IEA Information Paper at COP 8, New Delhi, 23 Oct. - 1 Nov., 2002, 63 p. www.iea.org

4) Chung, Hyun-Sik, "Industrial Structure and Source of Carbon Dioxide Emissions in East Asia: Estimation and Comparison," *Energy and Environment*, Vol.9, No. 5, 1998, Multi-science Publications, pp. 509-534.

5) Chung, Hyun-Sik & Rhee, Hae-Chun, "Carbon Dioxide Emission of Korea and Japan and Its Transmission via International Trade", *International Economic Journal,* Vol. 15, No. 4, Dec., 2001, pp. 117-136.

6) Chung, Hyun-Sik & Rhee, Hae-Chun, "A Residual-free Decomposition of the Sources of Carbon Dioxide Emissions: A Case of the Korean Industries", *Energy: The International Journal*, Vol. 26, No. 1, 2001, Elsevier Science, Feb., pp. 15-30.

7) Dimaranan, Betina V. and Robert A. McDougall, ed. *Global Trade, Assistance and Production: The GTAP 5 Data Base,* Center for Global Trade Analysis, Purdue University, 2002.

8) Global Trade Analysis Programs (GTAP) Dataset V5

9) Hertel, Thomas, ed. *Global Trade Analysis: Modeling and Applications*, New York, Cambridge University Press, 1997

10) Hey-Lin Lee, *An Emission Data Base for Integrated Assessment of Climate Change Policy Using GTAP*. GTAP Working Paper, Oct. 2002 (Draft))

11) IEA, *Energy Balances of OECD Countries*, 2001

12) IEA, *Energy Balances of Non-OECD Countries*, 2001

13) IEA, *CO2 Emissions from Fuel Combustion, 1971-1999*, IEA/OECD, Paris, 2001

14) Lenzen, Manfred, "Primary energy and green house gas embodied in Australian final

consumption: an input-output analysis," *Energy Policy*, vol. 26, no.6., 1998, pp. 495-506.

15) Machado, Giovani, Roberto Schaeffer, and Ernst Worrel, "Energy and carbon embodied in the international trade of Brazil: an input-output approach," *Ecological Economics*, vol. 39, issue 3, Dec. 2001, pp. 409-424.

16) Malcom, Gerard and Trung Phuoc Trung, *The Process of Incorporating Energy Data into GTAP*, Draft GTAP Technical Paper, Nov. 1, 1999

17) Muradian, R., O'Connor, M., and Martinez-Alier, J., "Embodied Pollution in Trade: Estimating the ' Environmental Load Displacement ' of Industrialized Countries, " *Ecological Economics*, Vol. 41, 2002, pp. 51-67

18) Paltsev, Sergey, "The Kyoto Protocol: Regional and Sectoral Contributions to the Carbon Leakage," *The Energy Journal*, Vol. 22, no.4, 2001, pp. 53-79

19) Sands, R.D., T.Y. Jung, and S. Jo. *Second Generation Model for Korea*. PNL-SA-33775. Pacific Northwest National Laboratory, 2000.

20) Vinals, J. M. "Energy-Capital Substitution, wage flexibility and aggregate output supply," *European Economic Review*, Vol. 26, No. 1-2, Oct.-Nov. 1984, 229-245

21) Wyckoff, Andrew and Joseph Roop, "The Embodiment of Carbon in Imports of Manufactured Product–Implications for International Agreements on Greenhouse Gas Emissions," *Energy Policy*, vol. 22, no.3, March 1994, pp. 187-260.

Appendices

<Appendix 1>

BEET and Total Domestic Emissions for 9 Countries/Regions): Baseline case

unit:1,000 tons-CO_2, %

Countries/Regions	BEET	Total Domestic Emissions	BEET as % of Total Domestic Emissions
1 USA	-51596.1	4760724	-1.08379
2 EU	-108381	2811596	-3.85479
3 JPN	-72659.9	1004920	-7.23041
4 EEFSU	35854.03	1273814	2.8147
5 RoA1	39496.93	788470.5	5.00931
6 EEX	102901.7	2559818	4.019884
7 CHN	100053.3	2778560	3.600904
8 KOR	-737.851	382195.6	-0.19306
9 ROW	-44932.6	1986923	-2.26142

<Appendix 2>

Emissions Embodied in Exports (EEX) Matrix (EEX of Row Countries to Column Countries)

unit: 1,000tons-CO2

	1 USA	2 EU	3 JPN	4 EEFSU	5 RoA1	6 EEX
1 USA	9.371159	41990.97	18750.62	3190.741	32012.18	32390.91
2 EU	27648.61	231073.6	9961.069	24562.09	30026.39	25959.91
3 JPN	8963.263	6410.094	0	408.185	1866.72	4453.403
4 EEFSU	6782.177	44033.48	3504.268	51450.14	4001.191	4683.397
5 RoA1	52883.67	44466.53	7216.489	3140.178	3713.978	5801.319
6 EEX	57334.59	55946.24	30880.56	3264.152	7677.233	19336.96
7 CHN	30835.5	26344.11	21101.25	2728.779	5918.952	11701.99
8 KOR	5928.118	5617.29	4744.458	1279.885	1619.563	5591.161
9 ROW	31904.44	43405.53	14964.16	4995.279	8352.706	25918.58
합계	222289.7	499287.9	111122.9	95019.43	95188.91	135837.6

	7 CHN	8 KOR	9 ROW	Total
1 USA	5515.768	6613.174	30219.76	170693.6
2 EU	4053.17	3530.7	34091.24	390906.8
3 JPN	3975.323	2766.059	9619.848	38462.97
4 EEFSU	3450.837	1515.307	11452.6	130873.5
5 RoA1	2039.193	2836.147	12588.5	134685.8
6 EEX	4622.936	10805.35	48873.2	238739.3
7 CHN	0	7656.138	37921.9	144208.6
8 KOR	5522.453	0	9325.43	39628.34
9 ROW	14975.66	4643.313	38468.19	187628.1
합계	44155.34	40366.19	232560.7	1475827

<Appendix 3>

Bilateral BEET Matrix (Row Country/Region' EEX – Column Countries/Region's EEM): baseline

unit: 1,000tons-CO2

	1 USA	2 EU	3 JPN	4 EEFSU	5 RoA1	6 EEX
1 USA	0	14342.36	9787.352	-3591.44	-20871.5	-24943.7
2 EU	-14342.4	0	3550.975	-19471.4	-14440.1	-29986.3
3 JPN	-9787.35	-3550.97	0	-3096.08	-5349.77	-26427.2
4 EEFSU	3591.436	19471.4	3096.083	0	861.0135	1419.245
5 RoA1	20871.49	14440.14	5349.768	-861.014	0	-1875.91
6 EEX	24943.68	29986.33	26427.15	-1419.24	1875.914	0
7 CHN	25319.73	22290.94	17125.93	-722.058	3879.759	7079.052
8 KOR	-685.056	2086.59	1978.399	-235.421	-1216.58	-5214.19
9 ROW	1684.679	9314.292	5344.317	-6457.33	-4235.8	-22954.6

	7 CHN	8 KOR	9 ROW	Total
1 USA	-25319.7	685.0559	-1684.68	-51596.2
2 EU	-22290.9	-2086.59	-9314.29	-108381
3 JPN	-17125.9	-1978.4	-5344.32	-72660
4 EEFSU	722.0576	235.4214	6457.325	35853.98
5 RoA1	-3879.76	1216.584	4235.796	39497.09
6 EEX	-7079.05	5214.19	22954.62	102903.6
7 CHN	0	2133.685	22946.24	100053.3
8 KOR	-2133.69	0	4682.117	-737.83
9 ROW	-22946.2	-4682.12	0	-44932.8

<Appendix 4>

Emission Terms of Trade (ETT) (= Emission Embodied in Unit Export of Row Country to Column Country / Emission Embodied in Unit Import of Row Country from Column Country)						
	1 USA	2 EU	3 JPN	4 EEFSU	5 RoA1	6 EEX
1 USA	1	1.440155	3.088931	0.422279	0.714758	0.663991
2 EU	0.69437	1	1.704108	0.449173	0.615744	0.377968
3 JPN	0.323737	0.586817	1	0.192183	0.324312	0.18039
4 EEFSU	2.368102	2.226313	5.203372	1	1.40093	1.006189
5 RoA1	1.399075	1.624051	3.08345	0.713812	1	0.643361
6 EEX	1.506045	2.645726	5.54354	0.993849	1.554337	1
7 CHN	2.213508	4.411521	5.641584	0.860877	2.223969	1.808126
8 KOR	1.063182	1.800455	3.116374	0.478816	0.983266	0.605912
9 ROW	0.924774	1.38244	2.875989	0.451652	0.89048	0.645898
Total	1.057569	1.280333	3.240756	0.651709	0.756065	0.570464

	7 CHN	8 KOR	9 ROW	Total
1 USA	0.451772	0.940573	1.081346	0.945565
2 EU	0.226679	0.555415	0.723358	0.781047
3 JPN	0.177255	0.320886	0.347706	0.30857
4 EEFSU	1.161607	2.088483	2.214096	1.534428
5 RoA1	0.449647	1.017019	1.12299	1.322638
6 EEX	0.553059	1.650406	1.548232	1.752959
7 CHN	1	2.488247	3.028847	2.697737
8 KOR	0.401889	1	1.003396	1.058941
9 ROW	0.330159	0.996615	1	0.950087
Total	0.370681	0.94434	1.052535	1

<Appendix 5>

Bilateral BEET Matrix (=Row Country's EEX – Column Country's EEM) : Scenario 1 unit:1,000tons-CO2										
	1 USA	2 EU	3 JPN	4 EEFSU	5 RoA1	6 EEX	7 CHN	8 KOR	9 ROW	total
USA	0	14332.09	9810.568	−3591.26	−20888.5	−25149.9	−25313.6	911.9618	−1683	−51571.6
EU	−14332.1	0	3565.819	−19462.3	−14445.7	−30116.5	−22281	−1999.9	−9302.9	−108375
JPN	−9810.57	−3565.82	0	−3100.86	−5359.07	−26472.9	−17152.9	−1913.71	−5363.86	−72739.8
EEFSU	3591.264	19462.3	3100.864	0	859.5034	1389.197	721.8474	288.6387	6456.925	35870.54
RoA1	20888.47	14445.68	5359.071	−859.503	0	−1908.76	−3875.63	1313.734	4240.295	39603.35
EEX	25149.94	30116.49	26472.93	−1389.2	1908.762	0	−7002.56	3785.955	23111.92	102154.2
CHN	25313.57	22280.96	17152.93	−721.847	3875.634	7002.562	0	2360.502	22947.39	100211.7
KOR	−911.962	1999.902	1913.709	−288.639	−1313.73	−3785.95	−2360.5	0	4558.423	−188.757
ROW	1682.996	9302.903	5363.86	−6456.92	−4240.3	−23111.9	−22947.4	−4558.42	0	−44965.2
total	51571.63	108374.5	72739.75	−35870.5	−39603.3	−102154	−100212	188.7568	44965.19	0

<Appendix 6>

Bilateral BEET Matrix (= Row Country's EEX – Column Country's EEM) : Scenario 2 unit:1,000tons-CO2										
	1 USA	2 EU	3 JPN	4 EEFSU	5 RoA1	6 EEX	7 CHN	8 KOR	9 ROW	total
USA	0	14325.87	9824.002	-3591.96	-20891.2	-25281.3	-25310.3	1043.085	-1682.14	-51563.9
EU	-14325.9	0	3574.648	-19456.3	-14441.8	-30201.9	-22275	-1951.85	-9296.04	-108374
JPN	-9824	-3574.65	0	-3103.66	-5364.44	-26499.8	-17168.6	-1877.52	-5375.27	-72788
EEFSU	3591.96	19456.3	3103.659	0	859.2782	1370.347	722.3128	319.8072	6456.915	35880.58
RoA1	20891.18	14441.8	5364.445	-859.278	0	-1931.55	-3874.25	1369.88	4241.295	39643.53
EEX	25281.31	30201.89	26499.83	-1370.35	1931.55	0	-6952.07	2850.526	23213.04	101655.7
CHN	25310.31	22275.05	17168.63	-722.313	3874.253	6952.071	0	2488.726	22947.77	100294.5
KOR	-1043.09	1951.852	1877.525	-319.807	-1369.88	-2850.53	-2488.73	0	4488.611	245.9631
ROW	1682.141	9296.035	5375.267	-6456.92	-4241.29	-23213	-22947.8	-4488.61	0	-44994.2

<Appendix 7>

S. Korea's Domestic CO2 Emissions by Energy Types and by Industrial Sectors (unit: 1,000tons-CO2)									
	Agriculture	Coal	Crude Oil	Natural Gas	Petroleum-Coal Products	Electricity Generation	Energy Intensive Industries	Other Industries and Services	Total
Coal	70.19404	0.000135	5.98E-06	0.450417	0	87419.46	35094.38	3448.318	126032.8
Crude Oil	2.16E-07	5.57E-07	0.000893	0.001139	0	0.003055	0.002023	0.00041	0.007521
Natural Gas	4523.946	8.61E-06	0.000357	3.22E-06	0.007168	15313.01	1428.071	4437.179	25702.22
Petroleum-Coal Products	10087.4	0.035805	0.000177	4.992504	14379.87	30187.18	22192.26	153345.9	230197.6
Electricity	0	0	0	0	0	0	0	0	0
Town Gas	0.449848	2.93E-13	1.87E-10	2.3E-09	1.33E-10	63.15906	0.017902	199.3256	262.9524
Total	14681.99	0.035949	0.001432	5.444063	14379.88	132982.8	58714.73	161430.7	382195.6