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Evaluation of sectoral and regional CO2 emissions: production-based and consumption-based accounting measurements

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Abstract

This study evaluates the regional and sectoral CO2 emissions estimated by different CO2 emissions accounting methodologies. The widely used methodology for CO2 emissions accounting is the measurement of CO2 emissions generated inside a country. When a country imports goods, virtual CO2 emissions that are emitted in their production and distribution processes outside the country are accompanied. Thus, the international trade must be taken into account for consumption-based CO2 emissions measurements. The GTAP (Ver.6) input-output tables and bilateral trade matrix database of goods and services are utilized for estimating the consumption-based CO2 emissions in this study. The result is that the consumption-based CO2 emissions gradually increased in the developed countries more than domestic emissions for the 2001, and the emissions in developing countries show the opposite trend. From the conceptual viewpoint of human welfare and equity, the international framework of emissions reduction should be based on the consumption-based emissions because former type of emissions naturally represent the magnitude of domestic consumption more fairly than the latter type of emissions. From the practical viewpoint of carbon leakage, the international framework based on the consumption-based emissions is more preferable than that based on the domestic one because developed countries who have to reduce their consumption-based emissions must do so not only by reducing their domestic emissions but also by reducing virtual emissions. The former framework will lead to improvements of energy efficiency and carbon intensity in developing countries, and thus technology transfer and not dirty-industry transfer to developing countries.

Keywords: global warming, input-output table, emissions measurement, carbon leakage

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1.Introduction

The international framework on tackling climate change beyond 2012 —post-Kyoto regime— has been discussed. The COP13 in December 2007 led to an agreement known as the Bali roadmap. The roadmap summarized a new negotiation process of the international framework on climate change to be concluded by 2009. The framework should pay attention to real benefits not only at the global level but also at the country level, and also should consider the importance of the comprehensive strategies of long-term GHGs emissions or its concentration stabilization levels at the global level, and the intensities of GHGs emissions and energy consumptions at the country- and sector-levels.

Most of discussions are based on the authorized measuring methodology of GHGs emissions in guidelines for national greenhouse gas inventories by IPCC (2007a). However, it is doubtful that whether the currently applied standard of the GHGs emissions measurement is acceptable for the emissions reductions efforts. An alternative methodology has been considered from the viewpoint of equity. In last December, Helm *et al.* (2007) reported that UK's GHGs emissions have fallen by 15% since 1990 on the IPCC measurement, while those have risen by 19% over the same period on a consumption-based measurement. The report suggests the differences between accounting methodologies of GHGs emissions can exert a substantial impact on implementations of coherent emission reduction policies across countries.

The widely used methodology for measuring CO2 emissions in IEA (2007a) and IPCC (2007b) is production-based; CO2 that is emitted inside the nation is counted. The IPCC methodology focuses on the CO2 emissions that are generated inside a region regardless of the types of generation activities, production or consumption. The idea of the IPCC methodology is that the country should place responsibility for the CO2 emissions derived only from the internal combustion of fossil fuels.

The alternative methodology for measuring CO2 emissions is consumption-based. The consumption-based CO2 measurement focuses on the CO2 emissions generated to produce the goods that are consumed inside a region regardless of the production site locations, and inevitably

imports and exports of goods must be taken into account. Most of countries certainly consume not only domestic goods but also imported goods, and produce not only domestic goods and but also goods to export. It follows that the countries import and export not only real goods but also accompanying consumption-based CO2 emissions generated in the process of their production. The idea of the consumption-based measurement is that the country should place responsibility for the consumption-based CO2 emissions accompanied with imported goods for domestic consumption but be free from the CO2 emissions generated to produce goods to export and be consumed outside the country. The measurement is naturally affected by the ratios of self-sufficiency which represents the dependence on imported goods for each region and sector.

The consumption-based CO2 emissions are not necessarily equal to the domestic ones. It follows that the international trade is one of the most important factors in consumption-based CO2 emissions measurements. Their measurement requires the consideration of both disaggregated regions and sectors because the CO2 intensities and self-sufficiency ratio differ across region and sector. Taylor (2007) reported that through the international allocations of industry developing regions produced dirty (pollution intensive) goods and developed regions produced clean goods.

Some past studies focused on consumption-based GHGs emissions. Peters *et al*. (2008) indicated that although their study was not a quantitative analysis the consumption-based measurements have more attractive features than production-based measurements and that a detailed global analysis on consumption-based measurements is lacking. Bosi and Riey (2002), and Ahamad and Wyckoff (2003) have investigated consumption-based CO2 emissions for the energy products in the IEA countries, and for the manufactured goods in the Annex I and selected countries of Annex II, respectively. These studies assumed the common proximate CO2 emission intensities for many countries because of focusing on only selected countries but not all the countries. Helm *et al.* (2007) reported the time-series UK's GHG emissions on a consumption-based measurement by using the macro trade balance as one whole economic sector for simplicity and did not consider the differences of sectoral CO2 intensities in a region. There is little information available for comparisons of consumption-based CO2 emissions at the region-

and sector levels across the regions and sectors.

The consumption-based measurements are important for allocation of emissions reduction from the viewpoint of equity. Peters *et al*. (2008) reported that the consumption-based measurements have advantages to avoid carbon leakage, increase options for mitigation, encourage environmental comparative advantage, address competitiveness concerns, and naturally encourage technology diffusion." Most of studies and discussions on equity of emissions have been conducted in order to establish the desirable framework on global warming. The measurements methodology of emissions would influence the emission reduction framework, especially the emission allocation base. The consumption-based measurement corresponds to the concept that a country should have a responsibility for the environmental burden generated even in the production processes outside the country as long as the produced goods are imported to satisfy the domestic consumption. The differences between the two measurements can be taken from the issue of principle on emissions responsibilities; the consumption-based measurement corresponds to "beneficiary pays principle" while measurement of the domestic emissions to "polluter pays principle".

The purpose of this study is to evaluate the CO2 emissions at the region- and sector-levels by two types of measuring methodologies and to discuss virtues of reduction targets based on consumption-based CO2 emissions. The accurate estimation of the consumption-based CO2 emissions requires the consideration of differences in the CO2 intensities of both sectors and regions.

The structure of the paper is as follows. Section 2 outlines the methodology of CO2 emissions measurement. Section 3 describes the results by a consumption-based measurement and compares them with the domestic ones. Section 4 discusses which type of emissions should the reduction targets be based on. Finally, Section 5 presents the conclusions.

2.Methodology

In this study, we define "domestic emissions" as emissions generated inside a country, and "consumption-based emissions" as emissions generated to produce the goods that are

consumed inside a region regardless of the production site locations. Domestic emissions correspond to the emissions used in the past emissions reduction framework in the UNFCCC such as Kyoto protocol. “Virtual CO2 emissions” are defined as the CO2 emissions that are generated in the production process of goods and considered to be embedded in the goods, and they move across the national border, accompanying the international trade. This study focuses on the CO2 emissions only from the combustions of fossil fuels and excludes the international aviation and marine bunkers sectors. These exclusions correspond to the CO2 sectoral approach proposed by IEA (2007a).

The accurate consumption-based CO2 emissions should consider the regional and sectoral differences in CO2 intensities. Estimation of the sectoral and regional consumption-based CO2 emissions requires the comprehensive and consistent economic database including production, consumption, imports and exports for each country and goods.

Firstly, we estimated domestic and consumption-based CO2 emissions for the year 2001. The GTAP dataset (Ver.6) of the international input-output tables and the bilateral trade matrix on goods and services by monetary unit were utilized for estimating the consumption-based CO2 emissions for the year 2001. The dataset of exports and imports are based on the FOB-prices. The sectoral and regional domestic CO2 emissions correspond to the CO2 emissions database by IEA CO2 sectoral approach. Table 1 shows the regional coverage in this study. This study disaggregated the world into the 27 regions. Table 2 shows the sectoral coverage in this study. This study disaggregates the whole economy into 18 non-energy sectors, residential and energy transformation sectors defined in IEA (2007a). It is noted that IEA (2007a) and GTAP database basically correspond to the UN-ISIC (International Standard Industry Code) classifications.

The domestic CO2 emissions were measured as followings. The domestic CO2 emissions from electricity and heat sectors were transferred to the sectors in which the electricity and heat are consumed. This transfer was made based on their consumption shares. The service sector classified by the IEA includes both commercial and public services while this study distinguishes the two sectors. Therefore, the IEA data of the service sector need to be disaggregated into the two service

sectors—business and social service— for this study. The allocation of the IEA service sector to the two service sectors of this study was conducted based on the shares of domestic productions of the two service sectors in the input-output tables.

The consumption-based CO2 emissions were measured as followings. The consumption-based CO2 emissions are determined on the principle of domestic consumption. The goods for domestic consumptions are supplied from the domestic production and the import while a part of domestic production is exported for the external consumption. Firstly, for each sector, the CO2 emissions from the consumptions of the domestic goods are estimated by using the CO2 emissions in the production processes of the domestic goods and the ratios of the internal consumption to total domestic productions. The measurement requires the ratios of self-sufficiency which corresponds to the above ratios. The ratios of self-sufficiency are obtained from input-output tables in the GTAP database. Secondly, the CO2 emissions from the consumptions of imported goods are estimated by using the CO2 emissions generated in the production processes of the origin country of the goods and the domestic consumptions ratios of the imported goods to the total imports; the sectoral CO2 intensities in the origin region of imported goods are one of the determinants of the consumption-based emissions. Finally, the consumption-based CO2 emissions are obtained by summing up the CO2 emissions from the domestic consumptions of the domestic goods and imported goods by region and by sector.

The world total consumption-based CO2 emissions are equal to the world total domestic CO2 emission. The consumption-based CO2 emissions at the region- and sector levels are affected by the imports and exports, their trade ratios and the regions of origin for each sector and region. The regional consumption-based CO2 emissions are not necessarily equal to the regional domestic CO2 emissions. The consumption-based CO2 emissions at the sector- and region- levels are equal to the domestic CO2 emissions only in the case of zero net exports of virtual CO2 emissions such as the 100% self-sufficiency ratio. However, for the residential sector and the energy transformation sector we assumed that the two kinds of emissions are equal because they are the sectors of final consumptions of goods and energy.

As for the methodology, the differences between this study and Helm et al. (2007) are described as followings. As mentioned previously, this study took into account the differences of emissions intensities among sectors while they used a common intensity for a whole economy. They used the macro trade balance as one whole economic sector. Since the emissions intensities vary largely by sector and trade matrices are not uniform across sectors, their treatment is not sufficient for good quantitative evaluation of consumption-based emissions.

3.Results and discussions

Figures 1 shows the CO2 emissions estimated by the two measurements in the year 2001. From the result, the domestic CO2 emissions are different from the consumption-based CO2 emissions in many regions and the magnitudes of differences are dependent on region and sector. The trend is that the consumption-based CO2 emissions are larger in most of the developed regions than the domestic emissions. Conversely, the consumption-based emissions are lower in most of the developing and economic transition regions than the domestic ones. The differences between the domestic and consumption-based CO2 emissions in the developed regions indicate the goods with considerable consumption-based CO2 emissions are imported to meet the heavy domestic consumptions. The gap in emissions is wider between the developed and developing regions by using the consumption-based emissions than the domestic emissions.

Figure 2 shows the relations between trade balances in total goods and services and the consumption-based CO2 emissions in the year 2001. With relatively high consumption-based CO2 emissions as compared to domestic CO2 emissions, some developed regions — USA and GBR — have trade deficits in real goods and services as a whole while some developed regions —FRA, GER, JPN and EU15— have trade surplus. The consumption-based CO2 emissions in USA and JPN having relatively large GDP are +4% and +7% higher than the domestic emissions, respectively. Especially, the result indicates that most of Western Europe regions have larger differences between the consumption-based CO2 emissions and the domestic CO2 emissions than other developed regions. The consumption-based CO2 emissions in GBR, FRA and GER are +16%,

+12%, and 7% higher than the domestic emissions, respectively. This trend is consistent with the previous work by Helm *et al.* (2007) with regard to UK who is making a fast progress toward deindustrialization. The small and rich regions such as OWE also have more remarkable differences between the consumption-based CO2 emissions and the domestic CO2 emissions to meet their consumptions through imported goods.

The resources suppliers and developed regions —CAN and ANZ— have the trade surplus in real goods and services with relatively lower consumption-based CO2 emissions as compared to domestic emissions. The smaller consumption-based emissions in CAN and ANZ show a sharp contrast to other developed countries. The roles of CAN and ANZ in the international trade are characterized as primary resources suppliers in the world.

The economic transition and developing regions —FSU, CHN and IND—, having trade surplus in real goods and services exported mainly toward the developed regions, have relatively low consumption-based CO2 emissions relative to domestic CO2 emissions. The consumption-based CO2 emissions in FSU, CHN, and IND are –8%, –1%, and –16% lower than the domestic emissions, respectively. From the GTAP database used in this study, the economic transition and developing regions have higher CO2 intensities than the developed regions. The result indicates that the economic transition and developing regions export considerable amount of higher CO2-intensity goods and import considerable amount of lower CO2-intensity goods. Conversely, most of developed regions import and consume considerable amount of higher CO2-intensity goods produced mainly in developing regions instead of producing them domestically by themselves, resulting in less energy consumption and less CO2 emissions to meet their consumption.

Figure 3 shows the differences between the two emissions and sectoral contributions to the differences for the year 2001. The Other manufacturings and Iron and steel sectors have the large contributions to the differences between the domestic and consumption-based emissions. The differences between the two emissions are sensitive to their exports and imports because most of Other manufacturings and Iron and steel in the regions have relatively high domestic CO2

emissions among industrial sectors. It is noted that the IEA (2007a) describes that the consumption data of Other manufacturings, corresponding to "non-specified industry" in the statistics, should be used with caution because of difficulties in supplying an industrial breakdown of fuels inside the sector for most countries. Although the data of Other manufacturings sector might have lower reliability, this study used this data set.

4. Which type of emissions should the reduction targets be based on?

The above results show that there exist considerable amounts of differences between the consumption-based emissions and the domestic emissions. Although the domestic CO2 emissions have been used in the past emissions reduction framework, it is doubtful whether the continuation of this practice is beneficial to the world or not. There are two viewpoints from which the future selection between the two types of emissions should be considered for the international framework of emissions reduction; 1) conceptual viewpoint related to human welfare and equity and 2) practical viewpoint of carbon leakage. We first discuss the aspect of human welfare and equity which is accompanied with the control of two types of emissions.

As observed in the previous chapter, consumption-based emissions are, in general, larger than domestic emissions for developed countries while the opposite is true for developing countries. This roughly means that developed countries import CO2 intensive goods for their domestic consumption from developing countries and developing countries produce CO2 intensive goods to export for developed countries to satisfy the consumption of the latter. This trend has been caused by past international industry structure changes based on the regional productivity differences, natural resources distribution etc., and the trend is considered to continue at least for the next few decades. On the other hand, economics tells us that human welfare is related most to consumption utility. Consumption-based CO2 emissions naturally represent the magnitude of domestic consumption more fairly than the domestic CO2 emissions, and, therefore, the former type of emissions is linked more closely to welfare than the latter type of emissions. It is further argued that regions whose consumption-based emissions are larger than their domestic emissions increase

their welfare, through the purchase of CO2 intensive goods from outside, at the welfare sacrifice of regions whose consumption-based emissions are smaller than their domestic emissions. Thus, from the viewpoint of human welfare and equity, the international framework of emissions reduction should be based on the consumption-based CO2 emissions.

Next, the carbon leakage problem is discussed. UNFCCC stipulates the international commitments of emissions reduction in Article 4: "Common but differentiated responsibilities" among developed and developing countries, and it is expected that emissions reduction targets will be differentiated among developed and developing countries in terms of marginal emissions reduction costs, stringency etc. if any agreement will be reached in the near future. In case that the target emissions are based on the domestic emissions and not on the consumption-based emissions, developed countries whose reduction targets will be more stringent than developing countries' can reduce their emissions by transferring CO2 intensive industries to developing countries, and the carbon leakage takes place easily. In contrast, in case that the targets are based on the consumption-based emissions, developed countries who have to reduce their consumption-based emissions must do so not only by reducing their domestic emissions but also by reducing virtual emissions that come into account with the imported goods which are to be domestically consumed to satisfy their desire and increase their welfare; developed countries will not be able to evade emissions reduction while keeping or increasing their welfare in case of the consumption-based emissions. Improvements of energy efficiency and carbon intensity in developing countries will help reduce the CO2 emissions in developed countries, and technology transfer and not dirty-industry transfer to developing countries may be facilitated in case that the consumption-based emissions are adopted in the international framework of emissions reduction.

Recently, studies on sectoral approach for emissions reduction have been made for the reason of its ease in reaching the international agreement and also its clarity of implementation actions. Akimoto *et al.* (2008) developed a technology-oriented global energy model with a high regional resolution and with energy intensive sectors disaggregated in detail, and using the model evaluated the amounts of emissions reduction when sectoral energy and carbon intensity targets are

introduced. They also point out that the scheme of sectoral intensity targets is helpful to avoid the carbon leakage. We will not discuss here which scheme is more useful to alleviate the leakage problem, but it is sure that the framework based on the consumption-based emissions helps avoid the carbon leakage problem as compared to that based on the domestic emissions, and that this framework is more preferable from the viewpoint of equity.

5. Conclusions

This study compared the domestic CO2 emissions generated inside a country and the consumption-based CO2 emissions by region and sector for the years 2001. Domestic CO2 emissions are different from consumption-based CO2 emissions in many regions, and the magnitudes of differences are dependent on region and sector. The result is that consumption-based emissions are, in general, larger than domestic emissions for developed countries while the opposite is true for developing countries. This indicates that developed regions import CO2 intensive goods from developing regions to meet their consumptions instead of producing these goods domestically.

From the conceptual viewpoint of human welfare and equity, the international framework of emissions reduction should be based on the consumption-based CO2 emissions. Human welfare is considered to be represented by consumption utility in economics and consumption-based CO2 emissions naturally represent the magnitude of domestic consumption more fairly than the domestic CO2 emissions. The former type of emissions is, therefore, considered linked more closely to welfare than the latter type of emissions. From the practical viewpoint of carbon leakage, the framework based on the consumption-based emissions helps avoid the carbon leakage problem as compared to that based on the domestic emissions, and that this framework is more preferable. In case that the targets are based on the consumption-based emissions, developed countries who have to reduce their consumption-based emissions must do so not only by reducing their domestic emissions but also by reducing virtual emissions that come into account with the imported goods which are to be domestically consumed to satisfy their desire and increase their welfare. The

framework whose reduction targets are based on consumption-based emissions will lead to improvements of energy efficiency and carbon intensity also in developing countries for achievement of emissions reduction in developed countries, and therefore will facilitate technology transfer and not dirty-industry transfer to developing countries. On the other hand, in case that the target emissions are based on the domestic emissions, developed countries whose reduction targets will be more stringent than developing countries' can reduce their emissions by transferring CO2 intensive industries to developing countries, and eventually the carbon leakage takes place.

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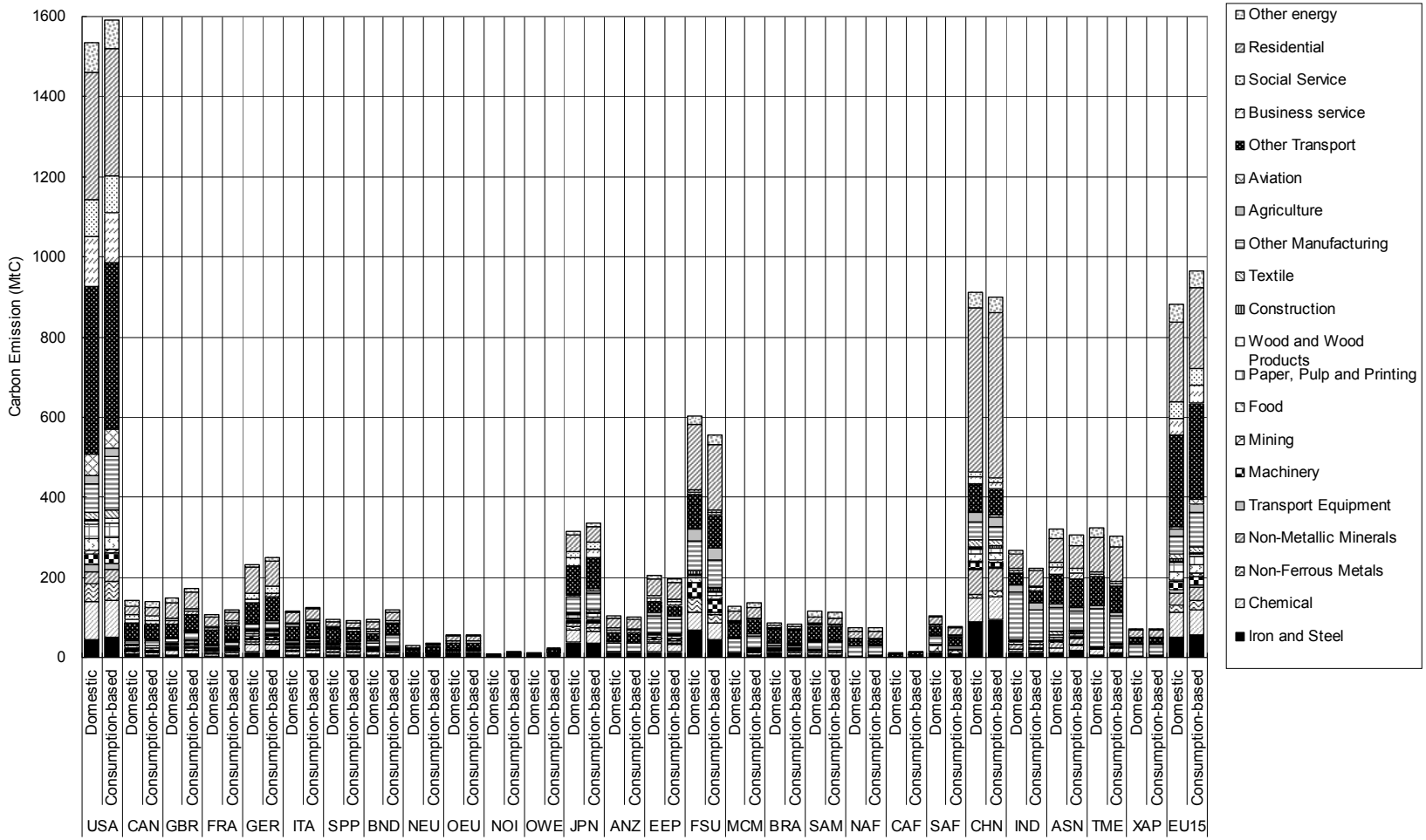
Table 1. Assumed 27 regions

No.	Regional code	Description
1	USA	USA
2	CAN	Canada
3	GBR	UK
4	FRA	France
5	GER	Germany
6	ITA	Italy
7	SPP	Spain, and Portugal
8	BND	Belgium, Netherlands, and Denmark
9	NEU	North Europe: Sweden and Finland
10	OEU	Other EU: Austria, Greece, Ireland and Luxembourg
11	NOI	Norway, Iceland
12	OWE	Other Western Europe: Switzerland and Malta
13	JPN	Japan
14	ANZ	Australia and New Zealand
15	EEP	Eastern Europe
16	FSU	Former Soviet Union
17	MCM	Mexico and other central America countries
18	BRA	Brazil
19	SAM	Southern America countries excluding Brazil
20	NAF	Northern Africa
21	CAF	Central Africa
22	SAF	Southern Africa
23	CHN	China including Taiwan
24	IND	India
25	ASN	Korea, Malaysia, Singapore, Indonesia, Thailand, Philippines, Viet Nam, and Cambodia
26	TME	Turkey and Middle East countries
27	XAP	Rest of world defined in GTAP (2006)

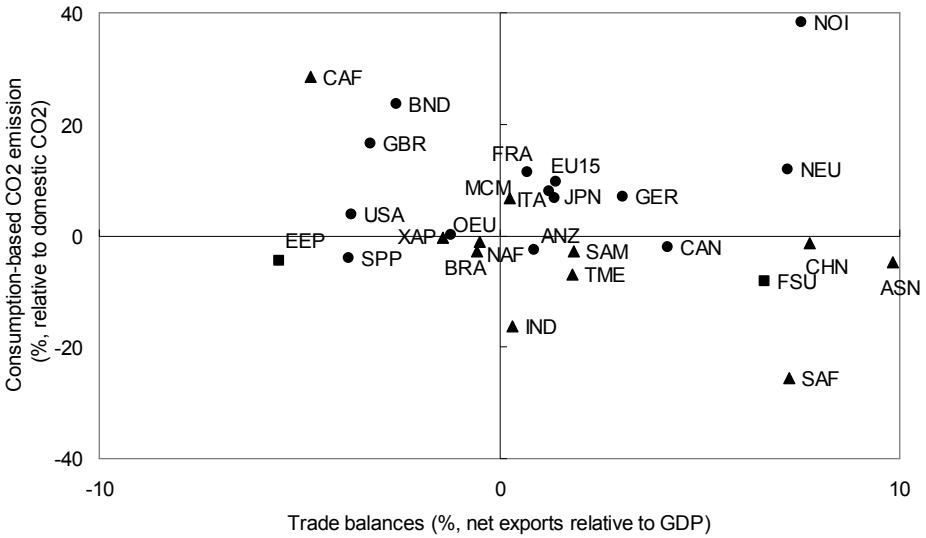
Table 2. Assumed 20 sectors

No.	Sectoral code	Description
1	Iron and Steel	Iron and Steel
2	Chemical	Chemical and Petrochemical
3	Non-Ferrous Metals	Non-Ferrous Metals
4	Non-Metallic Minerals	Non-Metallic Minerals
5	Transport Equipment	Transport Equipment
6	Machinery	Machinery
7	Mining	Mining and Quarrying
8	Food	Food and Tobacco
9	Paper and Pulp	Paper, pulp and paper products
10	Wood and Wood Products	Wood and Wood Products
11	Construction	Construction
12	Textile	Textile and Leather
13	Other Manufacturings	Other Manufacturings
14	Agriculture	Agriculture, forestry, and fishing
15	Aviation	Aviation excluding international aviation
16	Other Transport	Road, rail and navigation
17	Business Service	Trade, insurance, and other business services
18	Social Service	Recreation, dwellings, and other services
19	Residential	
20	Other energy	Energy transformation



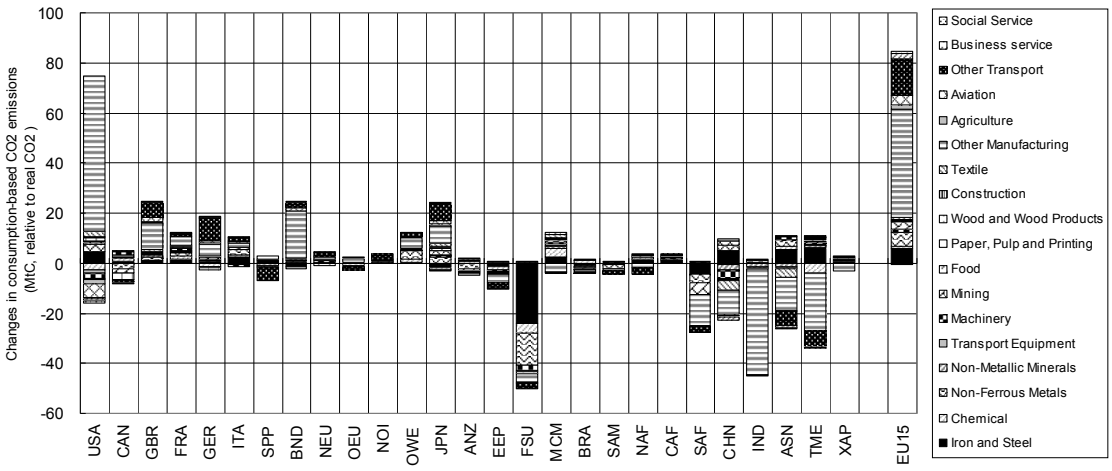
Note: EU15 consists of GBR, FRA, GER, ITA, SPP, BND, NEU and OEU.

Fig. 1. Domestic and consumption-based CO2 emissions for the year 2001



Note: EU15 consists of GBR, FRA, GER, ITA, SPP, BND, NEU and OEU.; The circle, square, and triangle express the developed, economic transition, and developing regions, respectively. The trade balances (5%) and consumption-based CO2 emissions (99%) in OWE are excluded for reasons of simplicity.

Fig. 2. Consumption-based CO2 emissions and trade balances for the year 2001



Note: EU15 consists of GBR, FRA, GER, ITA, SPP, BND, NEU and OEU.

Fig. 3. Differences between domestic and consumption-based CO2 emissions