Analysis of the Effects of the Carbon Taxes Based on Imputed Prices of Carbon

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Abstract

The effects of the worldwide differentiated-rate carbon tax based on the imputed price of carbon (ICT) are discussed in this paper. In order to reduce CO_2 emissions cost-effectively, the worldwide uniform-rate carbon tax (UCT) is one of the best methods. However, it is unacceptable for developing countries due to the heavy economic burdens. Then, the effects of ICT and UCT are compared here. Concretely speaking, ICT and UCT imposed on either all industrial sectors or the upper sectors respectively, namely two types of ICT and two types of UCT are compared from the policy viewpoint regarding influences on CO_2 emissions and GDP using the applied general equilibrium model.

Consequently, although less CO_2 emissions are reduced under the two ICT cases than UCT that imposed on the upper sectors (UUCT), ICT generates positive GDP effects on developing countries unlike UUCT. Considering the importance of the worldwide introduction of CO_2 abating policies and avoidance of excessive economic burdens on developing countries, ICT, especially that imposed on the upper sectors, have higher economic fairness among regions and policy effectiveness than UUCT.

Key Words: Global Warming, Carbon Tax, Imputed Price, Economic Fairness, Applied General Equilibrium Analysis

1. Introduction

When the Kyoto Protocol (KP) came into effect on February 16, 2005, the Annex B countries that ratified the KP accepted the obligation to reduce a certain amount of greenhouse gases (GHG) emissions. However, GHG emissions from most of these countries are still increasing even after the base year of the KP[1].

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[1] In the case of Japan, about 1.34 billion t-CO_2 of GHG was emitted in 2003 and it is 8.3% above the base (about 1.24 billion t-CO_2), according to Ministry of the Environment (2005).

Therefore, it will be difficult for them to achieve the targets of the KP[2] during the first commitment period, 2008-2012, if they do not plan additional measures. Then, some early actions will be necessary. In addition, considering the post-KP after the first commitment period, GHG emissions reduction not only by developed countries but also by developing countries will become the pivotal issue.

Under the circumstances, because CO_2 is the most influential GHG on global warming, carbon taxes are drawing attention as a method to reduce CO_2 emissions by market mechanisms cost-effectively. To date, some studies have analyzed the effects of carbon taxes[3]. Also, it is mentioned that the introduction of provisions or policies against CO_2 emissions globally is more effective than implementation regionally due to carbon leakage[4]. However, because a worldwide uniform carbon tax imposes excessive economic burdens on developing countries, they will oppose it. Moreover, it goes against the viewpoint of "common but differentiated responsibilities (Article 3)" of UNFCCC (United Nations (1992)).

From these viewpoints, we focused on economic fairness among countries and evaluated the effects of "the differentiated-rate carbon tax among countries and regions," which does not heavily burden developing countries economically, by comparing the carbon tax applying the concept of the imputed price of carbon (ICT) and the worldwide uniform-rate carbon tax (UCT) from the perspective of policy effectiveness (Matsumoto (2005a, 2005b), Matsumoto and Fukuda (2006, forthcoming)). The effects of tax imposition on all industrial sectors were analyzed in Matsumoto (2005b) and Matsumoto and Fukuda (2006), and the effects of that on the upper industrial sectors[5] were analyzed in Matsumoto (2005a) and Matsumoto and Fukuda (forthcoming). However, tax imposition on all sectors and that on the upper sectors were evaluated separately in the studies above. Because several levels to impose carbon taxes can be considered (e.g. upper industrial sectors, lower industrial sectors, and the hybrid types) and each have advantages and disadvantages (Adachi (2004)), it is necessary to understand the effects of carbon taxes on the various levels to introduce.

Then, based on these studies, the environmental and the economic influences (changes in CO_2 emissions and GDP respectively) brought about by all

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[2] In the case of Japan, since the target is 6% below the base, about 14% must be reduced substantially.

[3] Schelling (1992), Gaskins and Weyant (1993), Nordhaus and Yang (1996), and Masui et al. (2004) are examples.

[4] For example, Golombek (1994), Ban et al. (1998), Barrett (1998), and Stavins (1998) are describing carbon leakage.

[5] The upper sectors are those producing coal, oil, and natural gas, and these correspond to COA, OIL, and GAS in Table 1 below.

cases mentioned above are evaluated simultaneously from the perspective of policy effectiveness.

Concretely speaking, the four cases below are considered.

- Case 1 (AICT): ICT imposed on all industrial sectors (standard case).
- Case 2 (AUCT): UCT imposed on all industrial sectors.
- Case 3 (UICT): ICT imposed on the upper industrial sectors.
- Case 4 (UUCT): UCT imposed on the upper industrial sectors.

This simulation analysis is achieved using the multi-sectoral / multi-regional applied general equilibrium model (MMAGE). In this study, AICT is placed as the standard case. Then the other three taxes are set in order to attain the identical "world equivalent variant" to the standard case as a result of the analyses. The tax revenue is treated as revenue for regional households.

2. Methodology

2.1 Multi-sectoral / Multi-regional Applied General Equilibrium Model

Usually, national, regional, or world economies are divided into several sectors and regions in MMAGE. Then, the model analyzes the influences on resources and income distribution, economic welfare, industrial and economic structures, and so on caused by behavioral changes of economic entities along with economic policy changes within the framework of Walras' Law. Recently, it has also been utilized to analyze the influences of environmental policies. GTAP (Global Trade Analysis Project) model is used as MMAGE in this study. GTAP model was developed by Thomas W. Hertel of Purdue University in 1992 in order to analyze international trade. It is a static model, and internal and international sectoral trades, interactions among regional households and industrial sectors, and behavior of the international transportation and the international bank are described[6]. Figure 1 shows the framework of GTAP model. Although regional households are composed of private households and government, they are shown separately for convenience in the figure. In the regional household, the income is sum of income from factors owned by private households and various tax revenues minus capital wastage. Then, the income is assigned to consumption of private households and government, and savings. The expenditures for each are regarded constant. Savings are defined as the income for regional households minus the consumption expenditures, and are balanced with net investments through the international bank. Industrial sectors produce goods and services using factors

[6] Details of the GTAP are in Center for Global Trade Analysis (2005a) and descriptions of the model are in Hertel (1996).

and intermediate inputs. Also, the produced goods and services are traded with foreign countries and the international transport sector plays a role of the related transportations.

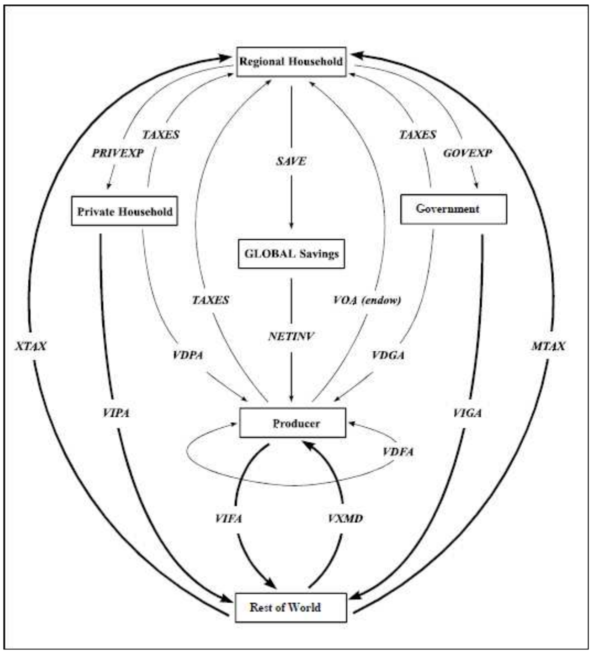

Figure 1. Framework of GTAP Model (From Figure 6 in Brokmeier (2001))

The present database (GTAP Version 6), based on the world economy of 2001[7], uses a classification of 57 industrial sectors and 87 regions. Tables A1 and A2 in appendix show those sectoral and regional structures. However, if a "57 × 87 model" is used, it will take considerable time to simulate and the fundamental outcomes can be lost when analyzing the results. Therefore, the sectors are aggregated into 15 and the regions are to 14 when modeling ("15 × 14 model" is used) regarding the computation time and the adequacy of the analyses. Tables 1 and 2 show the aggregated sectoral and regional structures. Since this study intends to analyze carbon taxes, the sectors are aggregated considering their CO_2 emissions, energy use, and characteristics. Also, regions are aggregated depending on their CO_2 emissions and geographical locations. From AUS to WEU in Table 2 are regarded as developed countries, and the others are regarded as developing countries.

[7] In order to adjust to the GTAP database, data in 2001 are used as much as possible in this study.

Table 1. Aggregated Sectoral Structure

Code	Name	Member Sectors (GTAP Original Code*)
COA	Coal	coa
OIL	Oil	oil
GAS	Natural Gas	gas
P_C	Petroleum & Coke	p_c
ELY	Electricity	ely
GDT	Gas Distribution	gdt
CRP	Chemical Rubber Products	crp
AGR	Agriculture & Fishery	pdr, wht, gro, v_f, osd, c_b, pfb, ocr, ctl, oap, rmk, wol, fsh
FRS	Forestry	frs
OMN	Other Mining	omn
PRC	Processing	cmt, omt, vol, mil, prc, sgr, ofd, b_t, tex, wap, lea, lum, ppp
MNF	Manufacturing	nmm, i_s, nfm, fmp, mvh, otn, ele, ome, omf
CNS	Construction	cns
TRP	Transportation	otp, wtp, atp
SVC	Other Services	wtr, trd, cmn, ofi, isr, obs, ros, osg, dwe

*See Table A1 in appendix.

Table 2. Aggregated Regional Structure

Code	Name	Member Regions (GTAP Original Code*)
AUS	Australia	AUS
N_Z	New Zealand	NZL
JPN	Japan	JPN
USA	United States of America	USA
CAN	Canada	CAN
E_U	15 EU Countries	AUT, BEL, DNK, FIN, FRA, DEU, GBR, GRC, IRL, ITA, LUX, NLD, PRT, ESP, SWE
WEU	Other Western European Countries	CHE, XEF
HAR	Russia & Eastern European Countries	BGR, CYP, CZE, HUN, MLT, POL, ROM, SVK, SVN, EST, LVA, LTU, RUS, XSU
CHN	China	CHN
OAS	Other Asian Countries	HKG, KOR, TWN, XEA, IDN, MYS, PHL, SGP, THA, VNM, XSE, BGD, IND, LKA, XSA
OAM	Other American Countries	MEX, XNA, COL, PER, VEN, XAP, ARG, BRA, CHL, URY, XSM, XCA, XFA, XCB
OEU	Other European Countries	XER, ALB, HRV, TUR
M_E	Middle East	XME
ROW	Rest of the World	XOC, MAR, TUN, XNF, BWA, ZAF, XSC, MWI, MOZ, TZA, ZMB, ZWE, XSD, MDG, UGA, XSS

*See Table A2 in appendix.

2.2 Setup of Carbon Tax Rates

ICT, equivalent to the imputed price of carbon, is calculated from Eq. (1), Uzawa Formula[8] [9].

[8] Eq. (1) is from Uzawa (2003).

[9] The abridged description of the introduction of Uzawa Formula is in Matsumoto et al (2006) and the details are in Uzawa (1991, 2003).

$$IT_r = \frac{1}{(\delta - \rho) + \mu} \frac{-\phi'(D)}{\phi(D)} NY_r \quad \text{for all } r \tag{1}$$

r: regions (See Table 2), IT_r: ICT in region r (\$ / t-C), N: world population, Y_r: per capita net national income (NNI) in region r (\$), D: Atmospheric CO_2 stock (t-C), δ: discount rate, ρ: population growth rate, μ: CO_2 absorption rate of by marine surface layer ($0.02 \leq \mu \leq 0.04$), $\phi(D)$: environmental influencing function.

Then, Eq. (2) is used as the environmental influencing function $\phi(D)$ in Eq. (1)[10 11]. Eq. (2) indicates the degrees of influences on people (decreases of utility) due to increases of atmospheric CO_2.

$$\phi(D) = (V - D)^{\beta} \tag{2}$$

$\phi(D)$ can be defined when $0 \leq D \leq V$.
V: critical level of CO_2 stock (t-C), β: environmental influencing parameter ($0 < \beta < 1$).

Then, Eq. (3) to calculate ICT in this study is obtained from Eqs. (1) and (2).

$$IT_r = \frac{1}{(\delta - \rho) + \mu} \frac{\beta}{(V - D)} NY_r \quad \text{for all } r \tag{3}$$

As seen from Eqs. (1) and (3), since the imputed price of carbon is proportional to per capita NNI, ICT becomes much higher for developed countries than for developing countries.

Table 3 shows the values of the parameters and the variables except for per capita NNI used in Eq. (3).

Table 3. Values of parameters and variables in Eq. (3)

Parameters / Variables	Values
δ*	0.05
μ*	0.04
β*	0.1
ρ**	0.0125
D (t-C) ***	792 billion (equivalent to 369.6ppm)
V (t-C) *	1.20 trillion (equivalent to 560ppm)
N***	6.15 billion

*From Uzawa (2003).
**Calculated from Food and Agriculture Organization (2005).
***Estimated from Ad Hoc Committee of the International Strategy about Climate Change, Global Environment Division of Central Environmental Council (2005).

[10] Eq. (2) is from Uzawa (2003).
[11] Uzawa Formula is modelized by capturing the complex relations among CO_2 emissions, CO_2 stock, and global warming simply.

Then, Table 4 shows NNI, population, per capita NNI, and ICT by regions.

Table 4. NNI, Population, Per Capita NNI, and ICT by Regions

Regions	NNI (million$)*	Population (thousand)**	Y_r ($)	IT_r ($ / t-C)
AUS	299805	19352	15492.20	301.22
N_Z	41701	3815	10930.80	212.53
JPN	3375317	127271	26520.71	515.66
USA	8892100	288025	30872.67	600.28
CAN	586146	31025	18892.70	367.34
E_U	6811926	378441	17999.97	349.98
WEU	369677	11985	30845.00	599.74
HAR	705338	386768	1823.67	35.46
CHN	1109184	1285426	862.89	16.78
OAS	1607279	1995105	805.61	15.66
OAM	1731662	527915	3280.19	63.78
OEU	160968	93645	1718.92	33.42
M_E	511823	173651	2947.42	57.31
ROW	453780	821473	552.40	10.74

*Calculated from United Nations (2003a, 2003b). However, since the data for NNI for some regions was lacking, they were estimated from the regression equation of logarithm of NNI and gross national income (GNI, million$) in United Nations (2005b). The regression equation was log_NNI = 1.039 × log_GNI − 0.630, and the correlation coefficient is 0.993.
**Calculated from Food and Agriculture Organization (2005) and United Nations (2005a).

As the values in Table 4 is used to calculate AICT, AUCT, UICT, and UUCT are set to make the worldwide economic welfares equal for all cases in order to compare with the standard case (AICT) as described above. Therefore, in the case of UICT, although the proportional relationship of the regional ICT in Table 4 is retained, the values are modified. Table 5 shows UICT by regions.

Table 5. UICT by Region ($ / t-C)

Regions	UICT
AUS	78.80
N_Z	55.60
JPN	134.89
USA	157.03
CAN	96.09
E_U	91.55
WEU	156.89
HAR	9.28
CHN	4.39
OAS	4.10
OAM	16.68
OEU	8.74
M_E	14.99
ROW	2.81

In the same way, AUCT corresponding to the standard case becomes $444.17 / t-C and the corresponding UUCT becomes $98.33 / t-C for all regions.

Comparing the four carbon taxes, because ICT exceeds UCT (comparing

AICT and AUCT, and UICT and UUCT) in only three regions, JPN, USA, and WEU, it is considered that relatively high UCT is set.

2.3 Implementation of Carbon Tax in Models

In order to implement the four carbon taxes mentioned in 2.2 in the model, the percentage rates (ad valorem tax) of each carbon tax against each sector of each region are calculated from Eqs. (4-1) - (6).

- Case 1 (AICT): $T_{sr} = \gamma ES_s IT_r^1$ for all r & s (4-1)

- Case 2 (AUCT): $T_s = \gamma ES_s UT^1$ for all s (4-2)

- Case 3 (UICT): $T_{ur} = EP_u IT_r^2$ for all r & u (4-3)

- Case 4 (UUCT): $T_u = EP_u UT^2$ for all u (4-4)

where

$$ES_s = \frac{\sum_{i \in s} ES_i DP_i}{\sum_{i \in s} DP_i} \quad \text{for all } s \tag{5}$$

$$EP_u = \frac{EM_u}{FP_u} \quad \text{for all } u \tag{6}$$

i: 407 sectors in input-output table of Japan, s: sectors in this study (See Table 1)、u: upper sectors、ES_i: emission intensity in sector i (Kondo and Moriguchi (1997), t-C / ¥), ES_s: emission intensity in section s (t-C / ¥), DP_i: national production in sector i (Kondo and Moriguchi (1997), ¥), EP_u: CO_2 emissions per price from energy produced by sector u (t-C / $)、$EM_u$: CO_2 emissions per unit from energy produced by sector u (t-C / unit), FP_u: price per unit of energy produced by sector u ($ / unit), T_{sr}: percentage rate of AICT in sector s of region r (%), T_s: percentage rate of AUCT in sector s (%), T_{ur}: percentage rate of UICT in sector u of region r (%), T_u: percentage rate of UUCT in sector u, IT^1_r: rate of AICT in region r ($ / t-C), IT^2_r: rate of UICT in region r ($ / t-C), UT^1: rate of AUCT ($ / t-C), UT^2: rate of UUCT ($ / t-C), γ: exchange rate (¥ / $).

Eqs. (4-1) – (4-4) are used to calculate the percentage rates of AICT, AUCT, UICT, and UUCT respectively. Eq. (5) is used to aggregate the emission intensity of 407 sectors, which is the original data, to the emission intensity of 15 sectors by implementing weighted average using domestic production. The correspondences from 407 sectors to 15 sectors are judged from Center for Global Trade Analysis

(2005b) and Kondo and Moriguchi (1998). Then, Eq (6) is used to calculate CO_2 emissions per energy prices.

Due to the constraint of data, the emission intensity of each sector is thought to be equal in all regions. Also, the Exchange rate is set ¥121.53 / $ (calculated from United Nations (2005b)).

Table 6 shows the emission intensity calculated from Eq. (5). Table 7 shows CO_2 emissions per unit and the energy prices per unit used in Eq. (6).

Table 6. Emission Intensity of Each Sector (t-C / million¥)

Sectors	ES_s
COA	1.24
OIL	0.59
GAS	0.62
P_C	1.13
ELY	6.40
GDT	0.36
CRP	1.32
AGR	0.65
FRS	0.47
OMN	1.18
PRC	0.68
MNF	1.57
CNS	0.76
TRP	1.59
SVC	0.28

Table 7. CO_2 Emissions Per Unit and Prices Per Unit of Coal, Oil, and Natural Gas

	EM_i*	FP_i**
COA	0.654 (t-C / t)	39.33 ($ / t)
OIL	0.713 (t-C / kl)	149.38 ($ / kl)
GAS	0.734 (t-C / t)	229.26 ($ / t)

*Calculated from Department of Global Environment, Ministry of the Environment (2003).
**Calculated from The Energy Data and Modeling Center, The Institute of Energy Economics, Japan (2004).

Then, Tables 8 and 9 show the percentage rates of the carbon taxes calculated from Eqs. (4-1) - (4-4).

Table 8. Percentage Rates of Carbon Taxes Based on AICT (AUS-ROW) and AUCT (%)

	COA	OIL	GAS	P_C	ELY	GDT	CRP	AGR	FRS	OMN	PRC	MNF	CNS	TRP	SVC
$T_{s\ AUS}$	4.55	2.17	2.26	4.12	23.45	1.31	4.85	2.39	1.72	4.30	2.48	5.75	2.78	5.83	1.04
$T_{s\ N\_Z}$	3.21	1.53	1.60	2.91	16.54	0.92	3.42	1.69	1.21	3.04	1.75	4.06	1.96	4.11	0.73
$T_{s\ JPN}$	7.79	3.71	3.87	7.06	40.14	2.24	8.29	4.10	2.94	7.37	4.24	9.84	4.76	9.98	1.78
$T_{s\ USA}$	9.06	4.32	4.51	8.21	46.72	2.61	9.66	4.77	3.42	8.58	4.94	11.46	5.55	11.62	2.07
$T_{s\ CAN}$	5.55	2.64	2.76	5.03	28.59	1.60	5.91	2.92	2.09	5.25	3.02	7.01	3.39	7.11	1.27
$T_{s\ E\_U}$	5.28	2.52	2.63	4.79	27.24	1.52	5.63	2.78	1.99	5.00	2.88	6.68	3.23	6.77	1.21
$T_{s\ WEU}$	9.06	4.31	4.50	8.21	46.68	2.61	9.65	4.76	3.42	8.57	4.93	11.45	5.54	11.61	2.07
$T_{s\ HAR}$	0.54	0.25	0.27	0.49	2.76	0.15	0.57	0.28	0.20	0.51	0.29	0.68	0.33	0.69	0.12
$T_{s\ CHN}$	0.25	0.12	0.13	0.23	1.31	0.07	0.27	0.13	0.10	0.24	0.14	0.32	0.16	0.32	0.06
$T_{s\ OAS}$	0.24	0.11	0.12	0.21	1.22	0.07	0.25	0.12	0.09	0.22	0.13	0.30	0.14	0.30	0.05
$T_{s\ OAM}$	0.96	0.46	0.48	0.87	4.96	0.28	1.03	0.51	0.36	0.91	0.52	1.22	0.59	1.23	0.22
$T_{s\ OEU}$	0.50	0.24	0.25	0.46	2.60	0.15	0.54	0.27	0.19	0.48	0.28	0.64	0.31	0.65	0.12
$T_{s\ M\_E}$	0.87	0.41	0.43	0.78	4.46	0.25	0.92	0.46	0.33	0.82	0.47	1.09	0.53	1.11	0.20
$T_{s\ ROW}$	0.16	0.08	0.08	0.15	0.84	0.05	0.17	0.09	0.06	0.15	0.09	0.21	0.10	0.21	0.04
T_s	6.71	3.19	3.33	6.08	34.57	1.93	7.14	3.53	2.53	6.35	3.65	8.48	4.10	8.60	1.54

Table 9. Percentage Rates of Carbon Taxes Based on UICT (AUS-ROW) and UUCT (%)

	COA	OIL	GAS
$T_{u\ AUS}$	131.00	37.59	25.24
$T_{iu\ N\_Z}$	92.43	26.52	17.81
$T_{u\ JPN}$	224.25	64.35	43.20
$T_{u\ USA}$	261.05	74.91	50.29
$T_{u\ CAN}$	159.75	45.84	30.78
$T_{u\ E\_U}$	152.20	43.67	29.32
$T_{u\ WEU}$	260.82	74.84	50.25
$T_{u\ HAR}$	15.42	4.42	2.97
$T_{u\ CHN}$	7.30	2.09	1.41
$T_{u\ OAS}$	6.81	1.95	1.31
$T_{u\ OAM}$	27.74	7.96	5.34
$T_{u\ OEU}$	14.53	4.17	2.80
$T_{u\ M\_E}$	24.92	7.15	4.80
$T_{u\ ROW}$	4.67	1.34	0.90
T_u	163.47	46.91	31.49

When implementing each tax into the model, boarder tax adjustment is applied considering international competitiveness of industries[12].

2.4 Calculation of CO_2 emissions

In this study, CO_2 emissions only from energy consumption (COA, OIL, GAS, P_C, and GDT are involved)[13] are calculated and the changes through the simulations are analyzed. However, the data of CO_2 emissions before and after the simulations, and those of energy consumption after the simulations are not obtained directly from the simulations. Therefore, they are estimated from Eqs. (7)

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12 According to Seventh Ad Hoc Committee of the Global Warming Taxation System, Consortium of Comprehensive Policy Division and Global Environment Division of Central Environmental Council (2001) and Adachi (2004), arguments whether border tax adjustment is justified remain.

13 Electricity is one of the energy resources. However, since it emits CO_2 indirectly, it is not included in the calculations below to avoid double counting.

- (11). Eq. (9) is based on Houghton et al. (1997), the IPCC guideline.

$$P_{jkr} = \frac{CV_{jkr}^{0}}{Q_{jkr}^{0}} \quad \text{for all } j,\ k,\ \&\ r \tag{7}$$

$$Q_{jkr}^{1} = \frac{CV_{jkr}^{1}}{P_{jkr}} \quad \text{for all } j,\ k,\ \&\ r \tag{8}$$

$$E_{jkr} = Q_{jkr}(1-\sigma_{jkr})\omega_j \varepsilon_j \eta_j \quad \text{for all } j,\ k,\ \&\ r \tag{9}$$

$$E_r = \sum_j \sum_k E_{jkr} \quad \text{for all } r \tag{10}$$

$$E = \sum_r E_r \tag{11}$$

j: energy resources, k: industrial sectors (s) and households, P_{jkr}: base price of energy j in sector k of region r (\$ / Mtoe), CV^0_{jkr}: real value of energy j consumed in sector k of region r before simulations (\$), CV^1_{jkr}: real value of energy j consumed in sector k of region r after simulations (\$), Q^0_{jkr}: amount of energy j consumed in sector k of region r before simulations (Mtoe), Q^1_{jkr}: amount of energy j consumed in sector k of region r after simulations (Mtoe), Q_{jkr}: Q^0_{jkr} and Q^1_{jkr}(Mtoe), E_{jkr}: CO_2 emissions from energy j in sector k of region r (t-CO_2), E_r: total CO_2 emissions from region r (t-CO_2), E: worldwide CO_2 emissions (t-CO_2), σ_{jkr}: feedstock ratio of energy j in sector k of region r, ω_j: calorific value of energy j (TJ / Mtoe), ε_j: emission coefficient of energy j (t-CO_2 / TJ), η_j : ratio of carbon oxidation of energy j.

Eq. (7) is used to estimate energy prices by sectors and households, and regions. Eq. (8) is used to estimate the amount of energy used after simulations. Then, Eq. (9) is used to estimate CO_2 emissions by energy resources, sectors and households, and regions. Eqs. (10) and (11) are used to sum up the estimated values from Eq. (9).

Table 10 shows the values of the regionally common parameters used in Eq. (9) and Table 11 shows those of the regionally different parameters.

Table 10. Regionally Common Parameters in Eq. (9)

Sectors	ω_j (TJ / Mtoe)	ε_j (t-CO_2 / TJ)*	η_j **
COA	41868	90.60	0.980
OIL	41868	68.40	0.990
GAS	41868	49.40	0.995
P_C	41868	67.10	0.990
GDT	41868	59.80	0.995

*From Department of Global Environment, Ministry of the Environment (2003).
**From Houghton et al. (1997).

Table 11. Regionally Different Parameters in Eq. (9)

Regions	$\sigma_{COA\ P\_C\ r}$	$\sigma_{OIL\ P\_C\ r}$	$\sigma_{GAS\ GDT\ r}$	$\sigma_{GAS\ CRP\ r}$	$\sigma_{P\_C\ CRP\ r}$
AUS	1.000	1.000	1.000	0.261	0.872
N_Z	1.000	1.000	1.000	1.000	0.000
JPN	1.000	1.000	1.000	0.000	0.941
USA	1.000	1.000	1.000	0.000	0.953
CAN	1.000	1.000	1.000	0.442	0.989
E_U	1.000	1.000	1.000	0.400	0.878
WEU	1.000	1.000	1.000	0.000	0.902
HAR	1.000	1.000	1.000	0.325	0.257
CHN	1.000	1.000	1.000	0.556	0.749
OAS	1.000	1.000	1.000	0.447	0.621
OAM	1.000	1.000	1.000	0.181	0.591
OEU	1.000	1.000	1.000	0.777	0.642
M_E	1.000	1.000	1.000	1.000	1.000
ROW	1.000	1.000	1.000	0.871	0.174

Source: Lee (2002). The other values of parameter σ_{jkr} are 0.000.

3. Results and Discussions

Figures 2 and 3 show the results of the analyses. Figure 2 shows the changes in CO_2 emissions and Figure 3 shows the changes in GDP.

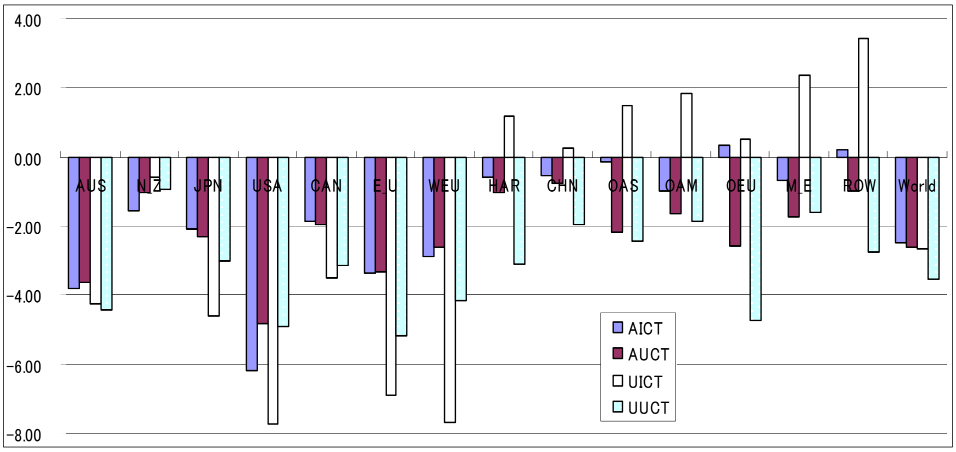

Figure 2. Percentage Changes in CO_2 Emissions by Regions (%)

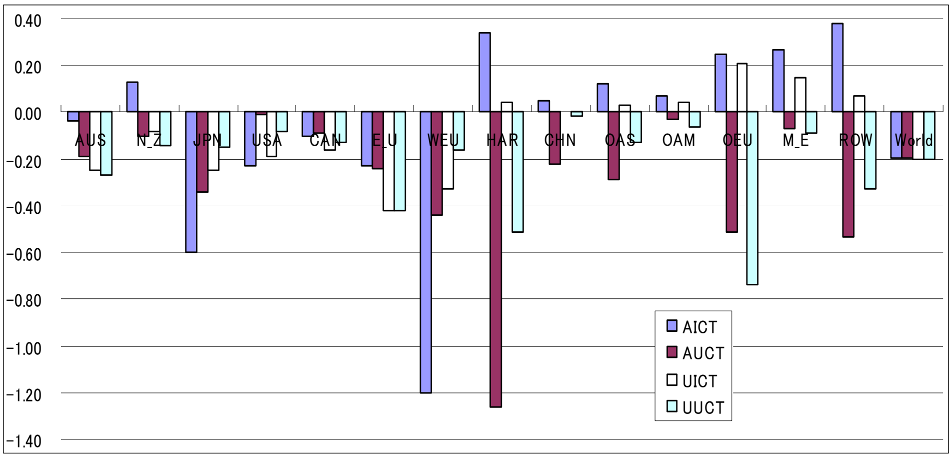

Figure 3. Percentage Changes of GDP by Regions (%)

As Figure 2 indicates, a 2.49% reduction in CO_2 emissions is brought about by AICT, a 2.62% reduction is brought about by AUCT, a 2.66% reduction is brought about by UICT, and a 3.52% reduction is brought about by UUCT globally. From these results, assuming the identical world equivalent variant, the carbon taxes imposed on the upper sectors tend to contribute more to the total CO_2 emissions reduction than those imposed on all sectors. In addition, UCT tends to reduce more CO_2 emissions than ICT. The factor of the former is that imposing the taxes directly on fossil fuels spread to all sectors through increases of the energy prices. Consequently, the incentive to use less amount of energy and to use lower-carbon energy is promoted. The factor of the latter is that since ICT, which impose differentiated tax rates throughout the world, generates differences of marginal CO_2 emissions reduction among regions, especially among developed countries and developing countries, CO_2 emissions are reduced rather inefficiently. It is also indicated in Matsumoto (2005a, 2005b) and Matsumoto and Fukuda (2006, forthcoming). Although carbon leakage occurs in developing countries under the two ICT cases, it is due to the low-rate carbon taxes on them.

Comparing the changes in GDP in Figure 3, those by all cases are equivalent, about -0.20%. However, looking at the changes regionally, they indicate different tendencies between ICT and UCT. Under the two ICT cases, although negative influences on GDP are observed in developed countries (-0.31% with AICT and -0.28% with UICT), positive influences are observed in developing countries (+0.16% with AICT and +0.05% with UICT). On the other hand, Under the two UCT cases, negative influences are observed in all regions (-0.16% with AUCT and -0.21% with UUCT in developed countries, and -0.32% with AUCT and -0.16% with UUCT in developing countries) and some developing countries such as

OEU and ROW are damaged more than developed countries.

Taking the results above into consideration, UUCT is certainly more proper than the others as a carbon tax from the environmental perspective. However, considering the economic aspects as well, the suitability of UUCT diminishes. That is to say, a trade-off between economic equity and CO_2 emissions reduction efficiency occurs. Because UUCT tends to impose excessive economic burdens on developing countries, it opposes Article 3 of UNFCCC. Moreover, there is a risk that developing countries would deny the introduction of such a burdensome carbon tax policy. If a carbon tax policy is accepted without them, a part of CO_2 emissions reduction in developed countries will be canceled out by carbon leakage in developing countries more than that would occur under the two ICT cases. In contrast, because developing countries do not bear heavy economic burdens under the two ICT cases, there is economic fairness among developed countries and developing countries regarding their states of economic development. Therefore, there is a higher feasibility that the carbon tax policy can be introduced throughout the world and a certain CO_2 emissions reduction can be achieved though inferior to UUCT by the carbon taxes based on the imputed price of carbon. Comparing the two cases of ICT, since UICT brings positive GDP effects on developing countries though inferior to AICT, it is superior to AICT about CO_2 emissions reduction and GDP decreases in developed countries, and there are also no big differences of GDP burdens among developed countries, it is regarded that UICT is better than AICT. Although some carbon leakage is observed under the two ICT cases as described, the influences would be small considering the present amount of CO_2 emissions in developing countries. Even under UUCT, there will be chances to mitigate the economic burdens on developing countries by aid policies such as money transfers from developed countries as described in Hoel (2001). However, with additional cost and time required for consultation and negotiations (compromise will be difficult to achieve), it is hard to say that the efficiency of CO_2 emissions reduction achieved by the original UUCT can be retained.

Consequently, taking account of the difficulty of introducing UUCT globally, it can be considered that ICT, especially UICT, which is more feasible policy than UUCT, has more policy effectiveness even though the environmental effect is slightly inferior to UUCT.

4. Conclusions

In this study, environmental and economic influences of the four kinds of carbon taxes, namely the carbon tax based on the imputed price of carbon imposed on all industrial sectors and the upper sectors, and the worldwide uniform-rate carbon tax imposed on all industrial sectors and the upper sectors were evaluated from the policy viewpoint by simulation analyses using a multi-sectoral / multi-regional applied general equilibrium model. As a result of the analyses, although ICT achieved less CO_2 emissions reduction than UUCT, it is a more policy effective method when considering the effects on GDP in developing countries. Especially, regarding the environmental effects and the economic influences on developed countries as well, UICT is superior to AICT. However, since the problem of carbon leakage accompanies ICT, pursuit of the solutions, for example increasing rates on developing countries to some extent with minimum economic damages, remain for future investigation.

This study investigated the scenario in which a carbon tax was introduced as a CO_2 emissions reduction policy with the tax revenue being utilized for regional households. Therefore, in future investigation, impact analyses of the four carbon taxes for cases in which tax revenue is used for subsidies for provisions to global warming or for reduction in existing taxes, such as social security premiums and income taxes, should be implemented. Also, the impact of the simultaneous introduction of other CO_2 emissions reduction policies, such as emissions trading, should also be studied. In addition, it is important to evaluate the dynamic effects of the four carbon taxes, considering that the present study has targeted static analyses.

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Appendix

Tables A1 and A2 show the sectoral and regional structures of GTAP Version 6 respectively.

Table A1. Sectoral Structure of GTAP Model (Version 6)

Code	Name	Member Sectors
pdr	Paddy Rice	unhusked rice, husked rice
wht	Wheat	wheat and meslin
gro	Other Grains	maize (corn), barley, rye, oats, other cereals
v_f	Vegetables & Fruit	vegetables, fruit and nuts
osd	Oil Seeds	oil seeds and oleaginous fruit
c_b	Cane & Beet	plants used for sugar manufacturing
pfb	Plant Fibers	raw vegetable materials used in textiles
ocr	Other Crops	live plants, cut flowers and flower buds, flower seeds and fruit seeds, vegetable seeds, beverage and spice crops, unmanufactured tobacco, cereal straw and husks, unprepared, whether or not chopped, ground, pressed or in the form of pellets, swedes, mangolds, fodder roots, hay, lucerne (alfalfa), clover, sainfoin, forage kale, lupines, vetches and similar forage products, whether or not in the form of pellets, plants and parts of plants used primarily in perfumery, in pharmacy, or for insecticidal, fungicidal or similar purposes, sugar beet seed and seeds of forage plants, other raw vegetable materials
ctl	Cattle	bovine cattle, sheep and goats, horses, asses, mules, and hinnies, live, bovine semen
oap	Other Animal Products	swine, poultry and other animals, live, eggs, in shell, fresh, preserved or cooked, natural honey, snails, live, fresh, chilled, frozen, dried, salted or in brine, except sea, snails, frogs' legs, fresh, chilled or frozen, edible products of animal origin n.e.c., hides, skins and fur skins, raw, insect waxes and spermaceti, whether or not refined or colored
rmk	Raw Milk	raw milk
wol	Wool	raw animal materials used in textile
for	Forestry	forestry, logging and related service activities
fsh	Fishing	hunting, trapping and game propagation including related service, activities, fishing, operation of fish hatcheries and fish farms, service activities, incidental to fishing
col	Coal	mining and agglomeration of hard coal, mining and agglomeration of lignite
oil	Oil	extraction of crude petroleum and natural gas (part), service activities incidental to oil and gas extraction excluding surveying(part), mining and agglomeration of peat
gas	Gas	extraction of crude petroleum and natural gas (part), service activities incidental to oil and gas extraction excluding surveying (part)
omn	Other Mining	mining of uranium and thorium ores, mining of metal ores, other mining and quarrying
cmt	Cattle Meet	meat of bovine animals, fresh or chilled, meat of bovine animals, frozen, meat of sheep, fresh or chilled, meat of sheep, frozen, meat of goats, fresh, chilled or frozen, meat of horses, asses, mules or hinnies, fresh, chilled or frozen, edible offal of bovine animals, swine, sheep, goats, horses, asses, mules, or hinnies, fresh, chilled or frozen, fats of bovine animals, sheep, goats, pigs and poultry, raw or rendered, wool grease
omt	Other Meat	meat of swine, fresh or chilled, meat of swine, frozen, meat and edible offal, fresh, chilled or frozen, n.e.c., preserves and preparations of meat, meat offal or blood, flours, meals and pellets of meat or meat offal, inedible, greaves, animal oils and fats, crude and refined, except fats of bovine animals, sheep, goats, pigs and poultry
vol	Vegetable Oils	soy-bean, ground-nut, olive, sunflower-seed, safflower, cotton-seed, rape, colza and mustard oil, crude, palm, coconut, palm kernel, babassu and linseed oil, crude, soy-bean, ground-nut, olive, sunflower-seed, safflower, cotton-seed, rape, colza and mustard oil and their fractions, refined but not, chemically modified, other oils obtained solely from olives and sesame, oil, and their fractions, whether or not refined, but not chemically modified, maize (corn) oil and its fractions, not chemically modified, palm, coconut, palm kernel, babassu and linseed oil and their fractions, refined but not chemically modified, castor, tung and jojoba oil and fixed vegetable fats and oils (except maize oil) and their fractions n.e.c., whether or not refined, but

		not chemically modified, margarine and similar preparations, animal or vegetable fats and oils and their fractions, partly or wholly hydrogenated, inter-esterified, re-esterified or elaidinised, whether or not refined, but not further prepared, cotton linters, oil-cake and other solid residues resulting from the extraction of vegetable fats or oils, flours and meals of oil seeds or oleaginous fruits, except those of mustard, vegetable waxes, except triglycerides, degras, residues resulting from the treatment of fatty substances or animal or vegetable waxes
mil	Milk	dairy products
pcr	Processed Rice	rice, semi- or wholly milled
sgr	Sugar	sugar
ofd	Other Food	prepared and preserved fish, prepared and preserved vegetables fruit juices and vegetable juices, prepared and preserved fruit and nuts, wheat or meslin flour, cereal flours other than of wheat or meslin, groats, meal and pellets of wheat, cereal groats, meal and pellets n.e.c., other cereal grain products (including corn flakes), other vegetable flours and meals, mixes and doughs for the preparation of bakers' wares, starches and starch products, sugars and sugar syrups n.e.c., preparations used in animal feeding, bakery products, cocoa, chocolate and sugar confectionery, macaroni, noodles, couscous and similar farinaceous products, food products n.e.c.
b_t	Beverages & Tobacco	beverages, tobacco products
tex	Textiles	manufacture of textiles, manufacture of man-made fibers
wap	Wearing Apparel	manufacture of wearing apparel, dressing and dyeing of fur
lea	Leather	tanning and dressing of leather, manufacture of luggage, handbags, saddlery, harness and footwear
lum	Lumber	manufacture of wood and of products of wood and cork, except furniture, manufacture of articles of straw and plaiting materials
ppp	Paper & Paper Products	manufacture of paper and paper products, publishing of books, brochures, musical books and other publications, publishing of newspapers, journals and periodicals, publishing of recorded media, other publishing (photos, engravings, postcards, timetables, forms, posters, art reproductions, etc.), printing and service activities related to printing, reproduction of recorded media
p_c	Petroleum & Coke	manufacture of coke oven products, manufacture of refined petroleum products, processing of nuclear fuel
crp	Chemical Rubber Products	manufacture of basic chemicals, manufacture of other chemical products, manufacture of rubber and plastics products
nmm	Non-Metallic Minerals	manufacture of other non-metallic mineral products
i_s	Iron & Steel	manufacture of basic iron and steel, casting of iron and steel
nfm	Non-Ferrous Metals	manufacture of basic precious and non-ferrous metals, casting of non-ferrous metals
fmp	Fabricated Metal Products	manufacture of fabricated metal products, except machinery and equipment
mvh	Motor Vehicles	manufacture of motor vehicles, trailers and semi-trailers
otn	Other Transport Equipment	manufacture of other transport equipment
ele	Electric Equipment	manufacture of office, accounting and computing machinery, manufacture of radio, television and communication equipment and apparatus
ome	Other Machinery & Equipment	manufacture of machinery and equipment n.e.c., manufacture of electrical machinery and apparatus n.e.c., manufacture of medical, precision and optical instruments, watches and, clocks
omf	Other Manufacturing	manufacturing n.e.c., recycling
ely	Electricity	production, collection and distribution of electricity
gdt	Gas Distribution	manufacture of gas, distribution of gaseous fuels through mains, steam and hot water supply
wtr	Water	collection, purification and distribution of water
cns	Construction	construction
trd	Trade	sales, maintenance and repair of motor vehicles and motorcycles, retail, sale of automotive fuel, wholesale trade and commission trade, except of motor vehicles and motorcycles, non-specialized retail trade in stores, retail sale of food, beverages and tobacco in specialized stores, other retail trade of new goods in specialized stores, retail sale of second-hand goods in stores, retail trade not in stores, repair of personal and household goods, hotels and restaurants
otp	Other Transport	land transport, transport via pipelines, supporting and auxiliary transport activities, activities of travel agencies
wtp	Water Transport	water transport
atp	Air Transport	air transport

cmn	Communications	post and telecommunications
ofi	Other Financial Intermediation	financial intermediation, except insurance and pension funding, activities auxiliary to financial intermediation
isr	Insurance	insurance and pension funding, except compulsory social security
obs	Other Business Services	real estate activities, renting of transport equipment, renting of other machinery and equipment, renting of personal and household goods n.e.c., computer and related activities, research and development, other business activities
ros	Recreation & Other Services	recreational, cultural and sporting activities, other service activities, private households with employed persons
osg	Other Services (Government)	public administration and defense, compulsory social security, education, health and social work, sewage and refuse disposal, sanitation and similar activities, activities of membership organizations n.e.c., extra-territorial organizations and bodies
dwe	Dwellings	ownership of dwellings

Source: McDougall and Dimaranan (2002).

Table A2. Regional Structure of GTAP Model (Version 6)

Code	Name	Member Regions
AUS	Australia	Australia
NZL	New Zealand	New Zealand
XOC	Rest of Oceania	American Samoa, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Federated States of Micronesia, Nauru, New Caledonia, Norfolk Island, Northern Mariana Islands, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, Wallis and Futuna
CHN	China	China
HKG	Hong Kong	Hong Kong
JPN	Japan	Japan
KOR	Korea	Republic of Korea
TWN	Taiwan	Taiwan
XEA	Rest of East Asia	Macau, Mongolia, Democratic People's Republic of Korea
IDN	Indonesia	Indonesia
MYS	Malaysia	Malaysia
PHL	Philippines	Philippines
SGP	Singapore	Singapore
THA	Thailand	Thailand
VNM	Viet Nam	Viet Nam
XSE	Rest of Southeast Asia	Brunei Darussalam, Cambodia, Lao People's Democratic Republic, Myanmar, Timor Leste
BGD	Bangladesh	Bangladesh
IND	India	India
LKA	Sri Lanka	Sri Lanka
XSA	Rest of South Asia	Afghanistan, Bhutan, Maldives, Nepal, Pakistan
CAN	Canada	Canada
USA	United States of America	United States of America
MEX	Mexico	Mexico
XNA	Rest of North America	Bermuda, Greenland, Saint Pierre and Miquelon
COL	Colombia	Colombia
PER	Peru	Peru
VEN	Venezuela	Venezuela
XAP	Rest of Andean Pact	Bolivia, Ecuador
ARG	Argentina	Argentina
BRA	Brazil	Brazil
CHL	Chile	Chile
URY	Uruguay	Uruguay
XSM	Rest of South America	Falkland Islands (Malvinas), French Guiana, Guyana, Paraguay, Suriname
XCA	Central America	Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, Panama
XFA	Rest of Free Trade Area of the Americas	Antigua & Barbuda, Bahamas, Barbados, Dominica, Dominican Republic, Grenada, Haiti, Jamaica, Puerto Rico, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Trinidad and Tobago, U.S. Virgin Islands
XCB	Rest of the Caribbean	Anguilla, Aruba, Cayman Islands, Cuba, Guadeloupe, Martinique, Montserrat, Netherlands Antilles, Turks and Caicos, British Virgin Islands,
AUT	Austria	Austria
BEL	Belgium	Belgium
DNK	Denmark	Denmark
FIN	Finland	Finland
FRA	France	France
DEU	Germany	Germany
GBR	United Kingdom	United Kingdom
GRC	Greece	Greece
IRL	Ireland	Ireland
ITA	Italy	Italy
LUX	Luxembourg	Luxembourg
NLD	Netherlands	Netherlands
PRT	Portugal	Portugal
ESP	Spain	Spain
SWE	Sweden	Sweden
CHE	Switzerland	Switzerland
XEF	Rest of EFTA	Iceland, Liechtenstein, Norway
XER	Rest of Europe	Andorra, Bosnia and Herzegovina, Faroe Islands, Gibraltar, the former Yugoslav Republic of Macedonia, Monaco, San Marino, Serbia and Montenegro

ALB	Albania	Albania
BGR	Bulgaria	Bulgaria
HRV	Croatia	Croatia
CYP	Cyprus	Cyprus
CZE	Czech Republic	Czech Republic
HUN	Hungary	Hungary
MLT	Malta	Malta
POL	Poland	Poland
ROM	Romania	Romania
SVK	Slovakia	Slovakia
SVN	Slovenia	Slovenia
EST	Estonia	Estonia
LVA	Latvia	Latvia
LTU	Lithuania	Lithuania
RUS	Russian Federation	Russian Federation
XSU	Rest of Former Soviet Union	Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Republic of Moldova, Tajikistan, Turkmenistan, Ukraine, Uzbekistan
TUR	Turkey	Turkey
XME	Rest of Middle East	Bahrain, Islamic Republic of Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Occupied Palestinian Territory, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, Yemen
MAR	Morocco	Morocco
TUN	Tunisia	Tunisia
XNF	Rest of North Africa	Algeria, Egypt, Libyan Arab Jamahiriya
BWA	Botswana	Botswana
ZAF	South Africa	South Africa
XSC	Rest of South African Customs Union	Lesotho, Namibia, Swaziland
MWI	Malawi	Malawi
MOZ	Mozambique	Mozambique
TZA	Tanzania	United Republic of Tanzania
ZMB	Zambia	Zambia
ZWE	Zimbabwe	Zimbabwe
XSD	Rest of Southern African Development Community	Angola, the Democratic Republic of the Congo, Mauritius, Seychelles
MDG	Madagascar	Madagascar
UGA	Uganda	Uganda
XSS	Rest of Sub-Saharan Africa	Benin, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Cote d'Ivoire, Djibouti, Equatorial Guinea, Eritrea, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Mali, Mauritania, Mayotte, Niger, Nigeria, Reunion, Rwanda, Saint Helena, Sao Tome and Principe, Senegal, Sierra Leone, Somalia, Sudan, Togo

Source: Center for Global Trade Analysis (2005b).