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Costs and benefits of regional market-based environmental policy: East Asian carbon market

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Introduction

The dominant greenhouse gas (GHG) is CO_2, and the shares of CO_2 emissions in the world in 2004 based on the GTAP (Global Trade Analysis Project) database are shown in Figure 11.1. The United States, European Union, Japan and other developed nations are so-called "Annex I countries" that each have a CO_2 emission quota in the Kyoto Protocol concluded at the 1997 conference of the UN Framework Convention on Climate Change, while the other countries/regions, which approximately correspond to developing nations, have no CO_2 emission quota. As seen, the share of developing countries/regions is almost half the total emissions. Given that CO_2 emissions should be reduced by half to stabilize the current climate, it is practically impossible to realize this reduction by the efforts of Annex I countries/regions alone, since their emissions cannot be negative. The cooperation of developing countries/regions, China in particular, is absolutely necessary to reduce CO_2 emissions and stabilize the global climate.

Economic linkages among East Asian nations have become tighter, especially after 2000, and also the linkage of environmental load. Therefore, one possible measure to reduce CO_2 emissions is to create a common carbon market for East Asian economies.

This chapter introduces a case study to show the economic and environmental effects of GHG emission trade in East Asia, including Japan, China, the Republic of Korea and ASEAN (Association of Southeast

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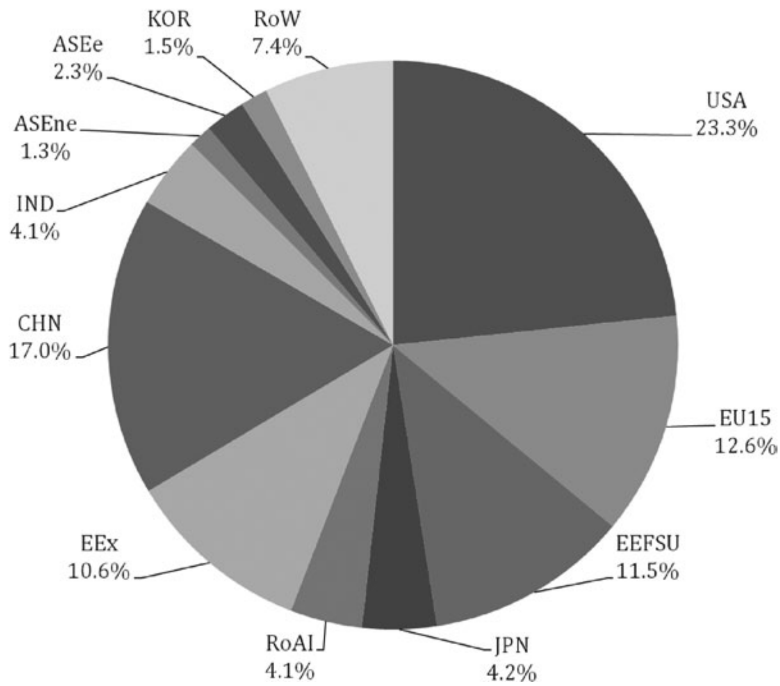

Figure 11.1 CO_2 emissions by country/region, 2004.
Source: Based on Lee (2008a, 2008b).
Note:
USA = United States
EU15 = 15 EU member countries (as of 2004)
EEFSU = Eastern Europe and former Soviet Union
JPN = Japan
RoAI = rest of Annex I countries
EEx = net energy-exporting countries in non-Annex I
CHN = China
IND = India
ASEne = non-energy-exporting ASEAN countries
ASEe = energy-exporting ASEAN countries
KOR = Republic of Korea
RoW = rest of the world

Asian Nations). Simulation analyses on an imaginary Asian emission trade scheme are done using the GTAP-E model: the first simulation addresses same-rate reduction in each industry in East Asian economies; the second tests the introduction of domestic emission trade; and the third determines the impact of the creation of international emission

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trade. The chapter concludes by describing policy implications based on results of the simulation analyses.

Previous studies

Previous studies have handled similar problems.[1] As mentioned, the framework of the Kyoto Protocol, where only developed (Annex I) countries have emission quotas, is not enough to reduce GHG emissions globally taking further economic growth of developing countries and carbon leakage to them into account. Hamasaki (2010) evaluates the "Kyoto-type accord" after 2013: GHG emissions in 2020 will be lower than BAU (business as usual) by 18.8 per cent but the Intergovernmental Panel on Climate Change scenario of 650 parts per million, which is 1990 ±0, will not be attained if only Annex I countries have emission quotas, while if non-Annex I countries have a quota at the current level and participate in an international carbon market, GHG emissions in 2020 will be lower than BAU by 33.9 per cent, the economic burden of Annex I countries will decrease and non-Annex I countries can get funds from the international carbon market.[2] Burniaux and Truong (2002) and Hamasaki and Truong (2002) came to similar conclusions that transactions in a broader market are efficient for stakeholders to reduce CO_2 emissions.

Hamasaki (2011) analyses bilateral cooperation on GHG emission reduction in Asia using a dynamic CGE model based on an idea that bilateral cooperation is an easier way for the world to decrease emissions, since US efforts for global warming mitigation cannot be expected after the mid-term election in 2010 and Kyoto-based multilateral international cooperation is likely to stagnate. Hamasaki (ibid.) shows that marginal abatement cost of GHG emissions can be reduced through bilateral cooperation of Japan with other Asian nations such as China, the Republic of Korea and India rather than continuing the Kyoto Protocol.

On the other hand, Babiker, Reilly and Viguier (2004) show, as a result of a dynamic CGE analysis, that all countries under the EU Emissions Trading Scheme (EU-ETS) may not benefit in applying the theory of "second best" (Lipsey and Lancaster, 1956) and "miserizing growth" (Bhagwati, 1958). When there are distortions, for example distortionary energy taxes, the optimal policy could differ from that in a non-distorted economy. In the current EU-ETS, therefore, some permit-selling countries may become worse off since the post-trading permit price is higher than the pre-trading one in these countries, implying an increase in the price of goods which will reduce the real wage rate and competitiveness. When these negative effects overweigh the primary income gains from

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the EU-ETS, the selling countries will be worse off. Babiker, Reilly and Viguier (2004) also show that most countries become better off with international emission trading when pre-existing distortionary energy taxes are removed.

This chapter considers how economic variables in each country change as a result of GHG trading in a virtual market in Asia. It uses the GTAP-E model (Truong, 2007; see the Appendix), the GTAP 7 database and the corresponding CO_2 emission data (Lee, 2008a, 2008b) for quantitative analysis.

Simulation analysis

Basic assumptions of the simulations

The purpose of this simulation analysis is to show the economic and environmental effect of CO_2 emission trade in Asia. Table 11.1 shows the country/region aggregation in this research. It is assumed that only East Asian countries such as Japan, China, the Republic of Korea and ASEAN have a quota of CO_2 emissions. The share of CO_2 emissions in the world total in this assumption is 26.4 per cent, which is comparable with the coverage of the Kyoto Protocol of 32.5 per cent.

Table 11.2 shows the industry aggregation in this research. It is assumed that energy-intensive industries such as electricity, paper products, chemical products, non-metal minerals (NMM) and iron have a quota of CO_2 emissions, and their assumed quota in Japan, China, the Republic of Korea and ASEAN is 70 per cent of the 2004 emission level (i.e. a 30 per cent reduction).

In the simulation analysis, the measure used to reduce CO_2 emissions is to impose a carbon tax on these energy-intensive industries. The introduction of a carbon tax changes the relative price structure. It will change the demand structure of households depending on price elasticity, while it changes the production structure depending on the elasticity of substitution of primary inputs such as labour, capital and energy. It is important to note that the price changes of various kinds of energy differ depending on their carbon contents.

Three schemes of simulation analyses as to tradability of CO_2 are implemented in this research.

- *Individual carbon tax (ICT)*. The first simulation is a 30 per cent reduction by each industry in each country. All the industries which have a quota are required to reduce CO_2 emissions by 30 per cent. In other words, the tax rate is different among the industries and countries.

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Table 11.1 Country/region aggregation

	Code	Meaning	Emission quota
1	USA	United States	No quota
2	EU15	Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom	No quota
3	EEFSU	Eastern Europe and former Soviet Union: Cyprus, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Slovakia, Slovenia, Albania, Bulgaria, Belarus, Croatia, Romania, Russian Federation, Ukraine, rest of Eastern Europe, Kazakhstan, Kyrgyzstan, rest of former Soviet Union, Armenia, Azerbaijan, Georgia	No quota
4	JPN	Japan	With quota
5	RoAI	Rest of Annex I countries: Australia, New Zealand, Canada, Switzerland, Norway, rest of EFTA	No quota
6	EEx	Net energy-exporting countries in non-Annex I: rest of Oceania, rest of Southeast Asia, Mexico, Argentina, Bolivia, Colombia, Ecuador, Venezuela, Iran, rest of Western Asia, Egypt, Tunisia, rest of North Africa, Nigeria, rest of Western Africa, Central Africa, South Central Africa, Madagascar, Mauritius, rest of Eastern Africa	No quota
7	CHN	China	With quota
8	IND	India	No quota
9	ASEne	Non-energy-exporting ASEAN: Cambodia, Lao People's Democratic Republic, Philippines, Singapore, Thailand	With quota
10	ASEe	Energy-exporting ASEAN: Indonesia, Myanmar, Malaysia, Viet Nam	With quota
11	KOR	Republic of Korea	With quota
12	RoW	Rest of the world	No quota

Source: Authors.

- *Domestic emission trade (DET).* The second simulation is the creation of a domestic carbon market. All the industries with a quota can trade CO_2 emissions domestically. The emission reduction of each industry is not necessarily 30 per cent, but the total reduction of all the industries which have a quota should be 30 per cent in each domestic carbon market.

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Table 11.2 Industry aggregation

	Code	Meaning	Emission quota
1	Agri	Agriculture: paddy rice, wheat, cereal grains, vegetables, fruit, nuts, oil seeds, sugar cane, sugar beet, plant-based fibres, crops, cattle, sheep, goats, horses, animal products, raw milk, wool, silkworm cocoons, forestry, fishing	No quota
2	Coal	Coal	No quota
3	Oil	Oil	No quota
4	Gas	Gas manufacture and distribution	No quota
5	OilPcts	Petroleum and coal products	No quota
6	Elect	Electricity	With quota
7	Food	Food products: meat, meat products, vegetable oils and fats, dairy products, processed rice, sugar, food products, beverages and tobacco products	No quota
8	Paper	Paper products, publishing	With quota
9	Chem	Chemical products: chemicals, rubber, plastic products	With quota
10	NMM	Non-metal minerals: mineral products	With quota
11	Iron	Ferrous metals	With quota
12	OthInd	Other industries: minerals, textiles, wearing apparel, leather products, wood products, metals, metal products, motor vehicles and parts, transport equipment, electronic equipment, machinery and equipment, manufacturing, water, construction, trade, transport, sea transport, air transport, communication, financial services, insurance, business services, recreation and other services, public administration/defence/health/education, dwellings	No quota

Source: Authors.

- *East Asian international emission trade (IET).* The third simulation presumes the creation of an East Asian international carbon market. All industries which have a quota can trade CO_2 emissions internationally among countries with a quota. The emission reduction of each country must not necessarily be 30 per cent, but the total emission reduction of all the industries which have a quota should be 30 per cent in the East Asian international carbon market.

Macro performance

Table 11.3 shows the percentage change of GDP and "equivalent variation" (EV)[3] in the simulations. Generally speaking the change in GDP is

Table 11.3 Macro performance

	% change of GDP			EV (million US$)		
Country/region	ICT	DET	IET	ICT	DET	IET
JPN	–0.13	–0.10	–0.03	–5,529	–4,515	–2,090
CHN	–0.55	–0.52	–0.68	–10,952	–10,262	–10,999
ASEne	–0.31	–0.28	–0.09	–1,114	–1,035	–716
ASEe	–0.20	–0.20	–0.11	–1,518	–1,406	–1,129
KOR	–0.26	–0.15	–0.06	–1,636	–1,056	–785

Source: Authors.

marginal. Even so, as the size of the carbon market gets larger, the loss of GDP decreases, and the same trend can be seen in EV. In other words, the negative impacts in the IET case are smaller than those in the DET case. The exception is China: because China's marginal abatement cost of CO_2 emissions is the lowest in East Asia, it is more profitable for China to sell CO_2 credit in the international carbon market than to produce goods in the IET case. In China the CO_2 price in IET is higher than in DET. China may thus choose not to participate in the East Asian emission trade market because of GDP loss. This issue is discussed later.

Generally speaking, negative impacts in DET are smaller than those for ICT, since the economy can minimize the marginal abatement cost. It is, however, interesting that the difference between two cases in ASEAN countries is marginal. This is because the tax rates in the ICT case are not very diversified in ASEAN countries, so the merit of burden sharing of the emission reduction is not very large.

Table 11.4 shows the percentage change of Japan's GDP and its components in the three cases. The main source of decrease of GDP is not export but domestic demands, including private consumption and investment in all cases. Contrary to the expectation that energy taxation may damage export competitiveness, Japanese exports on a macro basis will increase in the cases of ICT and DET. Export change by industry is discussed later.

Table 11.4 Change of Japan's GDP and its components (%)

	GDP	Government consumption	Private consumption	Investment	Export	Import (negative)
ICT	–0.13	0.00	–0.10	–0.29	0.05	0.21
DET	–0.10	0.00	–0.09	–0.25	0.06	0.18
IET	–0.03	0.00	–0.04	–0.05	–0.01	0.07

Source: Authors.

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Table 11.5 Reduction of CO_2 emissions (%)

Country/region	ICT	DET	IET
USA	0.20	0.15	0.10
EU15	0.32	0.25	0.18
EEFSU	0.28	0.21	0.16
JPN	**–14.41**	**–14.32**	**–7.82**
RoAI	0.31	0.26	0.18
EEx	0.34	0.28	0.20
CHN	**–21.93**	**–21.85**	**–24.90**
IND	0.34	0.28	0.21
ASEne	**–13.96**	**–14.09**	**–8.28**
ASEe	**–11.79**	**–11.87**	**–9.14**
KOR	**–14.54**	**–14.46**	**–9.75**
RoW	0.42	0.30	0.24
World total	–4.80	–4.83	–4.91
Countries with quota	**–19.01**	**–18.95**	**–19.08**
Countries without quota	0.29	0.22	0.16
Carbon leakage rate	4.27	3.28	2.39

Source: Authors.

Table 11.5 shows the change in CO_2 emissions. The cells in bold correspond to the countries with an emission quota in energy-intensive industries. Needless to say, the total reduction in these countries is almost same in all three cases, since the assumed reduction rate is 30 per cent. A comparison of DET and IET is interesting. China's reduction increases from 21.85 per cent to 24.90 per cent, while reductions in other countries with quotas decrease. In other words, China is the carbon credit seller to other countries.

Generally speaking, the total emission reduction in one country/region in DET is slightly smaller than that in ICT, since the former is more efficient in reaching the target. However, ASEAN countries (ASEne, ASEe) are not in this general group; here, reduction of CO_2 emissions in DET is slightly larger than in the ICT case, because the electricity price increase in ASEAN is moderate for DET compared with ICT, thus electricity's share of energy demand increases and CO_2 emissions decrease compared with ICT.

In DET the electricity industry is the main carbon credit seller in countries such as Japan, China and the Republic of Korea, while the counterpart in ASEAN is one of carbon credit buyers in the domestic CO_2 market. As seen in Table 11.6, since the domestic carbon price in DET is more expensive than the tax rate for the electricity industry in ICT in countries like Japan, China and the Republic of Korea, electricity is the main CO_2-reducing industry (or carbon credit seller in the market). On

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Table 11.6 Price of CO_2 (US$/t-$CO_2$)

Scheme		JPN	CHN	ASEne	ASEe	KOR
ICT	For electricity	31.25	11.07	37.62	24.04	24.40
	For paper	34.43	9.69	65.19	17.80	105.72
	For chemicals	107.72	20.65	45.59	33.78	223.30
	For NMM	34.48	10.64	15.81	15.29	23.78
	For iron	64.47	27.05	56.87	21.68	66.49
DET	For all industries	36.95	11.89	33.15	22.79	27.36
IET	For all countries			14.77		

Source: Authors.

the other hand, the domestic market carbon price in DET is cheaper than the tax rate for the electricity industry in ICT in ASEAN countries, thus this industry cannot be a carbon credit seller in the carbon market by reducing electricity supply in the goods market, and other industries with emission quotas are required to reduce CO_2 emissions relatively more than in other countries/regions.

The last row in Table 11.5 shows the carbon leakage rate, defined as emission increase in non-quota countries divided by the emission reduction in quota countries. This index can be regarded as a measure of inefficiency of carbon tax. It is noteworthy that the carbon leakage rate decreases as the markets are unified.

Price of CO_2 and emission trade

Price of CO_2

Table 11.6 shows the CO_2 price (rate of carbon tax or marginal abatement cost) in each simulation. First, in the ICT case, the prices are diversified among industries and countries. Comparing countries, prices are generally high in the Republic of Korea and Japan and low in China. Comparing industries, the price of CO_2 reduction for electricity is low while for chemicals and iron it is generally high.

In practice it is very difficult to introduce this type of tax in all East Asian countries since the carbon tax becomes extremely high in industries such as chemicals in Japan and the Republic of Korea. Emission trading offers a substantial decrease in the marginal abatement cost, especially for the Republic of Korea and Japan.

Emission trade of CO_2

Table 11.7 shows the trade of CO_2 emissions for industries in Japan and China. The second column in both countries is the DET case, where the

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Table 11.7 Reduction of CO_2 emissions by industry in Japan and China (million tonnes CO_2)

	Japan			China		
Industry	ICT	DET	IET	ICT	DET	IET
Electricity	–119.1	–132.1	–72.9	–690.6	–728.6	–829.4
Paper	–4.1	–4.3	–2.3	–11.8	–13.6	–15.4
Chemicals	–19.9	–10.8	–5.6	–59.6	–41.7	–48.5
NMM	–6.8	–7.0	–3.7	–112.0	–119.7	–137.1
Iron	–13.2	–8.8	–4.1	–66.5	–37.0	–43.8
Total	–163.1	–163.1	–88.7	–940.5	–940.5	–1,074.3
Difference from ICT						
Electricity	–	13.1	–46.2	–	38.0	138.9
Paper	–	0.1	–1.8	–	1.8	3.7
Chemicals	–	–9.1	–14.3	–	–18.0	–11.1
NMM	–	0.2	–3.1	–	7.7	25.0
Iron	–	–4.3	–9.0	–	–29.5	–22.7
Total	–	0.0	–74.4	–	0.0	133.8

Source: Authors.

main carbon credit seller is the electricity industry. However, if the carbon market is integrated among East Asian countries, China's electricity industry is the main carbon credit seller.

Output of each industry

Table 11.8 shows the change of output in Japan and China. In both countries, output decreases even in industries without a quota, such as electric

Table 11.8 Output change in Japan and China (%)

	Japan			China		
Industry	ICT	DET	IET	ICT	DET	IET
Electricity	–3.33	–4.31	–1.90	–12.30	–13.42	–15.78
Paper	–0.31	–0.29	–0.10	–1.39	–1.57	–2.03
Chemicals	–2.96	–1.18	–0.28	–4.49	–4.07	–5.24
NMM	0.16	0.31	0.70	–3.36	–3.46	–4.48
Iron	–1.44	–1.31	–0.05	–3.67	–2.53	–3.52
Other industries	–0.17	–0.18	–0.09	–0.54	–0.50	–0.62

Source: Authors.

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Table 11.9 CO_2 emissions (tonnes) per million dollar production

Industry	JPN	CHN	ASEne	ASEe	KOR
Electricity	2,585.0	21,464.1	7,795.7	9,404.1	6,143.8
Paper	75.9	504.3	222.3	511.2	148.6
Chemicals	170.7	655.6	246.6	482.6	72.7
NMM	298.2	3,965.2	2,752.3	3,459.1	825.1
Iron	252.6	1,193.3	407.4	1,303.6	236.3

Source: Authors' calculation based on GTAP 7 database and Lee (2008a).

machinery or automobiles (included here in "other industries"). The decrease of output is relatively small in Japan as compared to China, and gets smaller as the market size gets larger. In contrast, production decrease in China gets larger in IET. The international CO_2 price is higher than the domestic price, therefore firms get profit in the international CO_2 market by selling their redundant carbon credit.

It is interesting that the output of non-metal minerals in Japan increases, due to the remarkably high energy efficiency of Japanese NMM. Table 11.9 shows the CO_2 emissions per million dollars of production, and the especially small number in Japanese NMM. Thus the price increase of Japanese NMM is relatively low compared with NMM in other East Asian countries, which means that export from Japan to those countries will increase.

In fact, as shown in Table 11.10, export of Japanese NMM increases and the same phenomenon can be seen in its paper industry. The interesting thing is that export of "other industries" increases except in IET. The energy price excluding carbon tax generally decreases, because the demand for energy decreases when a carbon tax is imposed. Thus for industries without emission quotas, like electric machinery or automobiles, the production cost decreases and the output price also declines. As a consequence, the export of those industries increases even though output

Table 11.10 Change in export (%)

	Japan			China		
Industry	ICT	DET	IET	ICT	DET	IET
Paper	0.34	–0.56	0.16	–3.43	–4.74	–6.14
Chemicals	–8.30	–3.13	–0.68	–10.87	–9.31	–11.75
NMM	3.08	3.98	5.66	–16.39	–17.55	–22.80
Iron	–5.78	–5.16	–0.01	–16.76	–10.35	–14.82
Other industries	1.65	1.02	–0.03	3.29	3.09	3.66

Source: Authors.

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decreases due to shrinking domestic demand. This is the main reason why macro export does not decrease.

Will China participate in the East Asian carbon market?

If the CO_2 emission quota is 30 per cent reduction for energy-intensive industries, China has no economic incentive to participate in the East Asian carbon market since it has to pay a price for participation, in that its GDP decreases if it joins in this international CO_2 emission trade. As mentioned, however, China's participation is important to make the East Asian carbon market more efficient. This subsection therefore calculates how this cost for China will decrease if its emission quota is enlarged while other countries' quota remains at 30 per cent reduction (Table 11.11). The table headings show the reduction rate of CO_2 emissions for China's energy-intensive industries in the East Asia IET case. The cells in bold indicate that the cost incurred under IET is smaller than in the DET case. This means that China has an incentive to participate in the East Asian carbon market. As shown, a reduction of 24 per cent or less would be "a deal" for China.

Table 11.12 shows global CO_2 emissions corresponding to "concession to China" scenarios: the negative impact of this concession is marginal, since the world's total reduction of CO_2 emissions in the case of "China with CO_2 reduction at 24 per cent" is 4.20 per cent and that in the DET case is 4.83 per cent. The carbon leakage rate in all IET cases is lower than in DET, thus it can be argued that a concession to China would be "a deal" in East Asia.

Table 11.11 China's cost reduction by the change in its emission quota

	East Asia IET case						DET
Item	–20%	–22%	–24%	–26%	–28%	–30%	case
EV ($M)	**–5,982**	**–6,820**	**–7,735**	**–8,733**	**–9,819**	–10,999	–10,262
GDP (%)	**–0.40**	**–0.45**	**–0.50**	–0.56	–0.62	–0.68	–0.52
CO_2 (%)	**–19.06**	**–20.24**	**–21.41**	–22.58	–23.74	–24.90	–21.85
Output reduction (%)							
Electricity	**–11.39**	**–12.24**	**–13.10**	–13.98	–14.87	–15.78	–13.42
Paper	**–1.36**	**–1.49**	–1.61	–1.75	–1.89	–2.03	–1.57
Chemicals	**–3.59**	**–3.90**	–4.21	–4.54	–4.88	–5.24	–4.07
NMM	**–3.14**	**–3.39**	–3.65	–3.92	–4.20	–4.48	–3.46
Iron	**–2.40**	–2.61	–2.83	–3.05	–3.28	–3.52	–2.53

Source: Authors.

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Table 11.12 CO_2 emissions, carbon leakage and carbon price (%, US$/t-$CO_2$)

Country/region	East Asia IET case –20%	–22%	–24%	–26%	–28%	–30%	DET case
World	–3.73	–3.97	–4.20	–4.44	–4.67	–4.91	–4.83
Countries with quota	–14.48	–15.40	–16.32	–17.24	–18.16	–19.08	–18.95
Countries without quota	0.11	0.12	0.13	0.14	0.15	0.16	0.22
Carbon leakage	2.17	2.21	2.25	2.30	2.34	2.39	3.28
Carbon price	9.56	10.48	11.46	12.50	13.60	14.77	

Source: Authors.

Concluding remarks

The results of the simulation analysis, i.e. a reduction of CO_2 emissions by 30 per cent in energy-intensive industries in East Asia by introducing a carbon tax, can be summarized as follows. The aggravating effect on GDP in countries with an emission quota is marginal; in other words, carbon leakage to quota-free countries is limited. As the carbon markets are unified, the loss of GDP decreases, except in China. Consequently, China might not participate in the common carbon market because of the expected reduction of GDP.

The carbon credit seller is mainly the electricity industry in DET. On the other hand, in the East Asian common carbon market the main credit seller would be China's energy-intensive industries, because CO_2 reduction is more profitable than production of goods since the CO_2 price is higher than that in China's domestic carbon trade. It is also confirmed that to make China participate in the common market, the CO_2 reduction for China could be discounted by 6 per cent (Table 11.11).

Notes

1. The theory of emission trade was formulated by Montgomery (1972), while the idea of emission trading dates back to Dales (1968). See Weitzman (1974), Baumol and Oates (1988) or Roberts and Spence (1976) for detail.
2. Incidentally, Hamasaki (2010) also proposes that a population criterion would be better than a GDP criterion as to the initial distribution of emission quotas.
3. Equivalent variation corresponds to a benefit change evaluated in monetary terms. See the Appendix for detail.

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Appendix

Standard GTAP and GTAP-E model

Hikari Ban and Kiyoshi Fujikawa

Structure of the standard GTAP model

The Global Trade Analysis Project (GTAP) was established mainly by Professor Thomas W. Hertel (Purdue University) in 1992. The GTAP model is a computable general equilibrium (CGE) model of a multi-region type. Its origin was the SALTA (Sectoral Analysis of Liberalizing Trade in East Asia) project promoted by the Australian government. The model initially had 16 regions and 37 industrial divisions in accordance with SALTA. A unique characteristic was that it had detailed industrial classifications in the agriculture and food sectors deriving from the way SALTA dealt with Australia's trade liberalization. Japan, the United States, the European Union and international bodies such as the OECD (Organisation for Economic Co-operation and Development), the UN Conference on Trade and Development and the World Bank later came to participate in this project, and GTAP was developed. GTAP Version 7, used here, is enhanced to include 113 countries/regions and 57 industries.

The key feature of GTAP is that researchers can customize the model structure to some extent.[1] For example, researchers can integrate regional divisions and industrial classifications according to their purposes, and also adjust each parameter before implementing simulation analysis. Moreover, as Version 7 has greatly expanded its industrial classifications, especially for the service and energy sectors, the model is applicable to the effects of economic deregulation, environmental policies and so forth.

The structure of the standard GTAP model is shown in Figure A1. The

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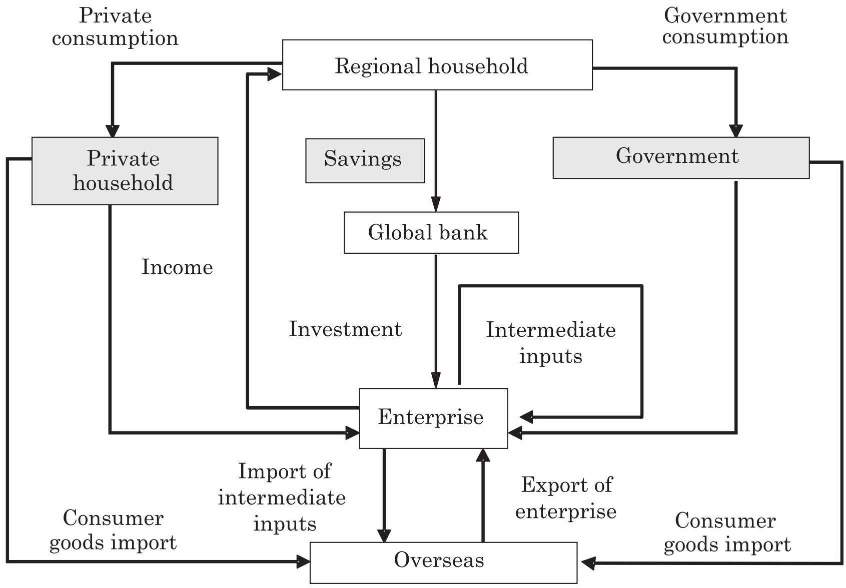

Figure A1 Macro structure of GTAP model
Source: Authors, based on Hertel (1997).

arrows in the figure indicate not the flow of goods and services but the direction of flow of funds. The domestic economy in the GTAP model is roughly divided into two sectors: "enterprise" as a production sector, and "regional household". One of the remarkable characteristics of the model's structure is the relation between government and households. The "regional household" is a kind of integrated agent of "pure household" and government, where the government's expenditure is determined based on utility maximization of households. In other words, government expenditure is an endogenous variable in the model.

Figure A2 shows the structure of the production sector of the standard GTAP model. For intermediate inputs the production scheme is of a Leontief-type fixed coefficient function: each cell of intermediate inputs is a so-called Armington good, where domestic and imported goods are substitutable by a CES (constant elasticity of substitution) function such that the share of domestic and imported goods varies contingent on the relative price. Moreover, the share of imported shipped goods changes contingent on the relative price of shipping from different source countries.[2] The value added is expressed by a CES function of primary inputs, such as labour, capital, land and natural resources, which are also mutually substitutable.

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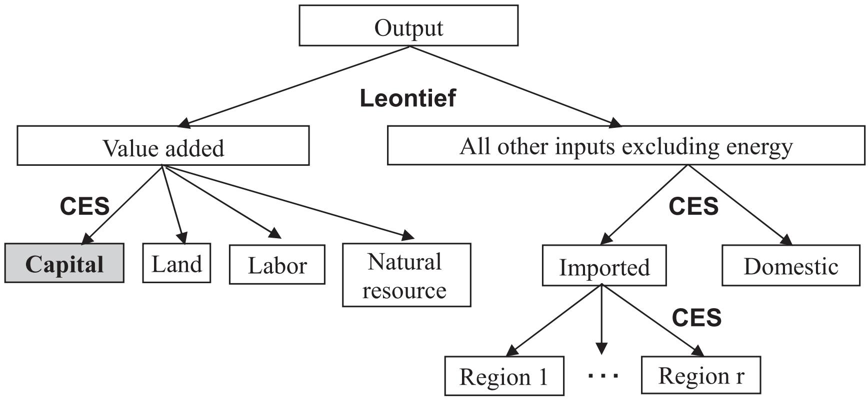

Figure A2 Production structure of GTAP model
Source: Authors, based on Hertel (1997).

After production and consumption are calculated as stated above, the amount of global investment is determined as the unconsumed residual. Since the GTAP model is for multiple countries, it is assumed that a virtual international bank decides the destination of investments in order to equalize changes in the expected rate of return of each country, and investments are distributed all over the world.

Equivalent variation

Generally speaking, the target of optimization of general equilibrium models is maximization of consumer welfare under some constraints. Therefore, it is important to measure changes of welfare in implementing shock simulations.

Equivalent variation (EV) is a measure of welfare change as an income change. Suppose we have two budgets, $(\mathbf{p}^0, I^0)$ and $(\mathbf{p}^1, I^1)$, that measure the prices $\mathbf{p}$ and incomes I that a given consumer would face under two different regimes. Let us assume that $U(\mathbf{p}^0, I^0)$ is the current utility and $U(\mathbf{p}^1, I^1)$ is the utility after a certain shock. This change corresponds to the movement of the consumption point from A^0 to A^1 as shown in Figure A3. Then the obvious measure of the welfare change is just the difference in utilities:

$$U^1 - U^0 = U(\mathbf{p}^1, I^1) - U(\mathbf{p}^0 - I^0) \qquad \text{(A-1)}$$

However, it is hard to compare the two different utilities directly since the utility is not measurable. Therefore, we define the income which real-

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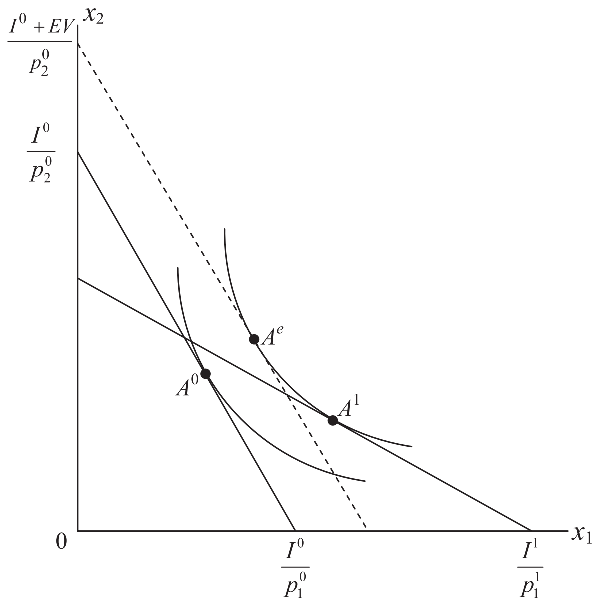

Figure A3 Equivalent variation
Source: Authors, based on Varian (1992).

izes the same utility under the same price structure as before. The calculated income change under the same price structure when the utility changes from U^0 to U^1 is called equivalent variation.

$$U^1 = U(\mathbf{p}^0, I^0 + EV) \quad \text{(A-2)}$$

In Figure A3, A^1 and A^e realize the same utility where A^e is the optimal consumption point unless the price structure changes. Thus the utility change can be measured as income change from I^0 to $I^0 + EV$.

Structure of capital-energy nest in the GTAP-E model

The standard GTAP model is designed to perform policy simulations easily, but it has limitations regarding analyses of environmental issues since energy is not substitutable with other inputs. Consequently, GTAP-E was developed as an extended version of the standard model, where energy inputs such as coal, oil, petroleum and coal products, gas and electricity are not only substitutable with other primary inputs but also mutually substitutable corresponding to relative price changes. In the GTAP-E

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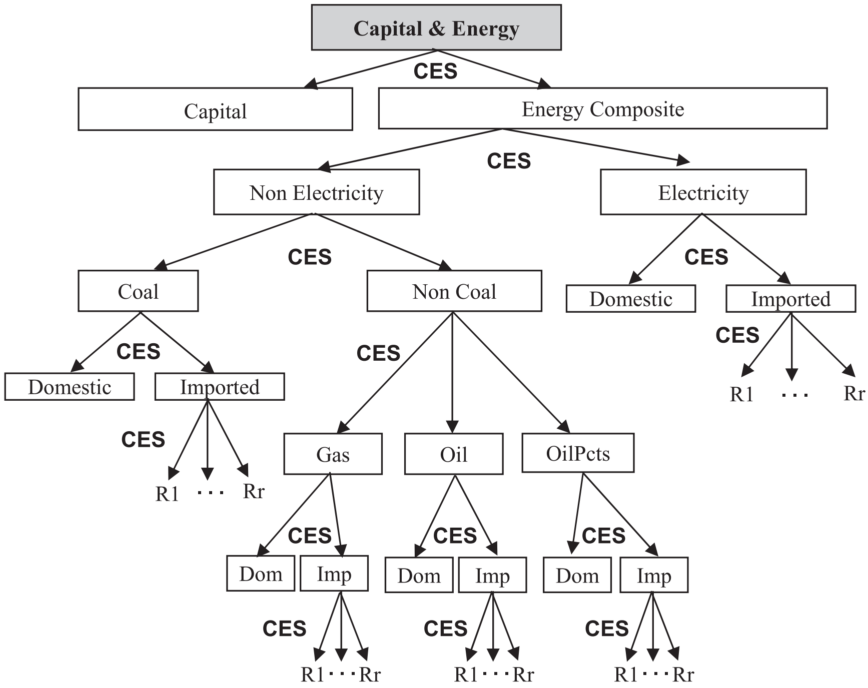

Figure A4 Capital and energy structure of GTAP-E model
Source: Burniaux and Truong (2002).

model, energy-related inputs are taken out of the "intermediate-input nest" and incorporated in the "value-added nest" (Figure A4) in two steps. First, energy commodities are separated into "electricity" and "non-electricity" groups. Some degree of substitution is allowed within the non-electricity group as well as between electricity and non-electricity groups. Next, the energy composite is combined with capital to produce an energy-capital composite, which is in turn combined with other primary factors in a value-added energy (*VAE*) nest with a CES structure.[3]

The inner elasticity of capital and energy (σ_{KE}) is assumed to be 0.5 for most industries and is set as equal to 0.0 for coal, oil, gas, and petroleum and coal products. These values of elasticity are on the whole parallel with the low to middle range of values adopted by other models, such as the OECD GREEN model (Burniaux, Nicoletti and Martins, 1992) and the carbon emissions trade model (Rutherford, Montgomery and Bernstein, 1997). The elasticities (σ_{VAE}) in the value-added nest, among which are natural resources, land, labour and the capital-energy compos-

Table A1 Production substitutability in capital and energy inputs

		Capital/ energy σ_{KE}	Electricity/ non-electricity σ_{ENER}	Coal/ non-coal σ_{NELY}	Gas/oil σ_{NCOL}
1	Agri	0.5	1.0	0.5	1.0
2	Coal	0.0	0.0	0.0	0.0
3	Oil	0.0	0.0	0.0	0.0
4	Gas	0.0	0.0	0.0	0.0
5	OilPcts	0.0	0.0	0.0	0.0
6	Elect	0.5	1.0	0.5	1.0
7	Food	0.5	1.0	0.5	1.0
8	Paper	0.5	1.0	0.5	1.0
9	Chem	0.5	1.0	0.5	1.0
10	NMM	0.5	1.0	0.5	1.0
11	Iron	0.5	1.0	0.5	1.0
12	OthInd	0.5	1.0	0.5	1.0

Source: Truong (2007).

ite, are basically the same as in the standard GTAP model, with values ranging from 0.03 to 4.00.

In the GTAP-E model, capital and energy in the "inner nest" are still assumed to be substitutable. Table A1 shows the production elasticity of substitution in "capital/energy" inputs. Substitutability of electricity/non-electricity and gas/oil is relatively high, but that of coal/non-coal is relatively small except in such energy-producing sectors as coal, oil, gas, and petroleum and coal products. For production structure in energy-producing sectors, substitution of inputs is assumed to be zero; in other words, the structure is assumed to be a Leontief type of fixed-input coefficients.

However, it is possible that energy and capital are complementary, despite inner substitutability. The relation of substitution elasticity of inner and outer is expressed as:

$$\sigma_{KE\text{-}outer} = [\sigma_{KE\text{-}inner} - \sigma_{VAE}]/S_{KE} + \sigma_{VAE}/S_{VAE} \tag{A-3}$$

where S_{KE} is the cost share for the capital-energy composite and S_{VAE} is the cost share for the value-added energy, and $\sigma_{KE\text{-}inner}$ and $\sigma_{KE\text{-}outer}$ indicate the inner and overall substitution elasticity between capital K and energy E, respectively. Therefore, provided the value of $\sigma_{KE\text{-}inner}$ is set to be smaller than σ_{VAE}, the overall substitution elasticity $\sigma_{KE\text{-}outer}$ between capital and energy could still be negative or complementary.

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Table A2 Relationship between inner and outer elasticity of substitution (Japan and China)

		Japan				China			
	$\sigma_{KE\text{-}inner}$	σ_{VAE}	S_{KE}	S_{VAE}	$S_{KE\text{-}outer}$	σ_{VAE}	S_{KE}	S_{VAE}	$S_{KE\text{-}outer}$
Agri	0.50	0.22	0.23	0.58	1.61	0.11	0.10	0.59	4.11
Coal	0.00	4.00	0.11	0.56	**–30.24**	3.99	0.20	0.65	**–13.60**
Oil	0.00	0.40	0.28	0.64	**–0.80**	0.40	0.43	0.77	**–0.41**
Gas	0.00	1.31	0.37	0.59	**–1.33**	0.87	0.92	0.94	**–0.02**
OilPcts	0.00	1.26	0.93	0.94	**–0.02**	1.26	0.91	0.93	**–0.03**
Elect	0.50	1.26	0.57	0.68	0.52	1.26	0.70	0.79	0.52
Food	0.50	1.12	0.19	0.34	0.12	1.12	0.14	0.23	0.55
Paper	0.50	1.26	0.19	0.44	**–1.08**	1.26	0.17	0.31	**–0.32**
Chem	0.50	1.26	0.23	0.37	0.09	1.26	0.22	0.31	0.62
NMM	0.50	1.26	0.25	0.47	**–0.41**	1.26	0.26	0.42	0.04
Iron	0.50	1.26	0.21	0.34	0.15	1.26	0.23	0.34	0.41
OthInd	0.50	1.35	0.23	0.55	**–1.30**	1.35	0.18	0.34	**–0.82**

Source: Authors' calculation based on GTAP 7 database.

The column $S_{KE\text{-}outer}$ in Table A2 shows an overall relationship with negative numbers in bold. Some industries in Japan and China are characterized as having an overall complementary relationship (negative sign of elasticity) between energy and capital despite the fact that the inner elasticity of substitution between them ($\sigma_{KE\text{-}inner}$) is still specified as nonnegative within the energy-capital nest.

Notes

1. For details of GTAP see Hertel (1997) or www.gtap.agecon.purdue.edu/.
2. The substitution elasticity between domestic and imported goods (σ_D), or between imported goods from different regions (σ_M), is called Armington elasticity, named after the researcher who suggested the specification, Paul Armington. The values of Armington elasticity for the GTAP-E model are basically taken from the standard model and are, generally speaking, assumed to be lower than those used in GREEN or the carbon emission trade model.
3. See Burniaux and Truong (2002) for detailed explanations of GTAP-E.

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