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THE EFFECTS OF AN ENVIRONMENTAL TAX ON TRADE: A CGE APPROACH TO THE KOREAN CASE

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I. INTRODUCTION

The adverse effects of carbon emissions resulting from the increasing use of fossil fuels on earth climate have been a hot environmental issue both in public and in science. The U. N. Framework Convention on Climate Change in 1992 requires the signatory nations to stabilize their carbon dioxide emissions at their 1990 level. Some environmental activists go further to argue that the carbon emissions should be stabilized at 80% of the 1990 level. In addition to the greenhouse effect, other environmental issues like acid rain are also associated with the use of fossil fuels. Even though the argument that the earth has been warmed up due to the greenhouse effect has not yet been proved, many people agree that the use of fossil fuels should be curbed somehow or alternative fuels should be developed and substituted for fossil fuels. The problem is that the efforts to reduce carbon emissions may slow down the economic growth and, possibly change a country's competitive position in foreign trade. In the absence of alternative fuels and technology, or when they are costly, the efforts to reduce carbon emissions may impose too much burden on an economy, in particular, a developing economy. On the part of developing countries, it may be unthinkable to give up the economic development in order to have a cleaner air and contribute to mitigating the greenhouse effect. The conflict of environmental polices with the economic development has created a tension between developing and developed nations which attempt to connect the environmental issues with international trade policies.

This paper examines the economic effects on a developing country, Korea, of a carbon tax imposed to reduce the 1990 level of carbon emissions to the 1985 level which is about 80% of the 1990 level. Since the late 1980's, the Korean government has shown a lot of concerns over the deteriorating environmental conditions, and it has tried to introduce a more strict guideline for improving the en-

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vironmental quality. Some economists and policy makers, however, show a deep concern over the uncertain and possibly adverse effects of an environmental initiative on international trade of Korea. The Korean economy depends heavily upon the foreign sector and has driven an export-promoting policy. Futhermore, it has no energy sources and imports all of petroleum and natural gas needed for the economy. The introduction of a carbon tax is sure to affect the energy-intensive industries adversely, and it may change the industrial structure and the composition of trade, possibly disrupting the competitive position of Korea in world markets. This paper investigates how the composition of exports and the production of Korean economy respond to the introduction of a carbon tax. It is hoped that the analysis provides an insight into how developing economies respond to an environmental initiative.

The appropriate approach to evaluating the effects of a carbon tax would be to use a computable general equilibrium (CGE) model. CGE models have been widely used in analyzing the effects of policy initiatives in international trade, public finance and environmental economics. The major benefits from utilizing a CGE model in policy analysis would be its full consideration of feedback effects. Especially, in capturing a change in the industrial structure and the composition of international trade, applying a CGE model is thought to be a necessity. Section II specifies a standard neo-classical CGE model used for the analysis, and Section III provides data on the elasticities of substitution and transformation for the model. Section IV discusses the simulation results.

II. THE MODEL

A standard static CGE model, neo-classical in spirit, as described in, for example, Robinson(1989) and Melo and Tarr(1992) is used for the environmental policy simulation. Korea is assumed to be a small open economy and, so, it behaves as a price-taker in world markets. All national (commodity and factor) markets are perfectly competitive with full employment of factors of production. All economic actors take market prices as given and maximize their objective function subject to their constraints. To allow the intra-industry trade, or 'cross hauling' observed in trade statistics at the aggregation level used in most CGE models, product differentiation for both imports and exports is introduced. Domestic goods are qualitatively different from imports and exports. Economic actors are assumed to demand a composite commodities, X_i which is a Constant Elasticity of Substitution (CES) function of imports, M_i, and domestic goods, D_i. The household's utility function is of a Cobb-Douglas type :

$$U=\prod_{i=1}^{n} C_i^{\alpha_i}, \qquad \sum_{i=1}^{n} \alpha_i = 1, \qquad \alpha_i \geq 0$$

where C_i is a consumption of composite good i. Government also consumes composite commodities, G_i, which is assumed to be fixed to $\overline{G}_i$ in the model. The economy produces outputs, Q_i which is a Leontief function of value added, V_i, and intermediate inputs of composite goods, IN_{ji} :

$$Q_i = \min\left[\frac{V_i}{r_{vi}}, \frac{IN_{1i}}{r_{1i}}, \frac{IN_{2i}}{r_{2i}}, \cdots, \frac{IN_{ni}}{r_{ni}}\right], \quad r_{ji} = \text{Leontief coefficient.}$$

Value added is produced by a constant elasticity of substitution(CES) technology, using labor, L_i and capital , K_i, as inputs. Produced output is transformed into exports and domestic goods according to a constant elasticity of transformation (CET) function of exports, E_i, and domestic goods, D_i.

The model has no independent investment function and aggregate savings are equal to aggregate investment. It is assumed that there is a single capital good sector and this capital good, S, is produced by a Leontief technology :

$$S_i = \min\left[\frac{Z_1}{h_1}, \frac{Z_1}{h_2}, \cdots, \frac{Z_n}{h_n}\right], \qquad h_i = \text{Leontief coefficient,}$$

where Z_i is an investment demand for composite good i. This capital good is demanded by household and government for the store of value.

As noted by Robinson(1989), the standard CGE model model under consideration is supposed to determine a stable relationship between the real exchange rate and the balance of trade. Given this relationship, a macro model should be introduced to determine any two of the nominal exchange rate and the aggregate price level, or any two of them should be set exogenously. We will fix the nominal exchange rate at unity and set the balance of trade to the base year level.

Korea produces some of coal needed, but it has no sources of oil and natural gas. Thus, the carbon tax of primary fossil fuels will be, on the most part, a tax on imports of primary fossil fuels. A specific environmental tax is imposed per ton of carbon emissions from primary fossil fuels in this paper. A specific tax on one ton of carbon emissions will imply a different tax amount per unit of each primary fossil fuel which is its carbon emissions rate multiplied by the carbon tax. The carbon tax generates the tax revenue as a by-product. As is usual in a general equilibrium model, how this tax revenue is distributed affects the results of policy simulation, often seriously. It is assumed that the tax revenue collected by the government is returned to the household in a lump-sum fashion.

The equilibrium system is described by the equations (1) – (26). There are (17n + 9) equations with (17n + 8) endogenous variables. Of these equations, only (17n + 8) are, however, independent. So, the number of independent equations is equal to the number of endogenous variables.

(1) $P_{m_i} = (1+t_i)\overline{P_{m_i}} + ctr_i,$

(2) $P_i X_i = P_{m_i} M_i P_{d_i} D_i,$

(3) $P_{q_i} Q_i = \overline{P_{e_i}} E_i + P_{d_i} D_i,$

(4) $(1 - ir_i) P_{q_i} = r_{vi} P_{vi} + \sum_{i=1}^{n} r_{ji} P_j + ctr_i,$

(5) $P_{vi} = P_L L_i + P_K K_i,$

(6) $P_s = \sum_{i=1}^{n} h_i P_i,$

(7) $\overline{P} = \sum_{i=1}^{n} \omega_i P_i,$

(8) $V_i = B_i [\beta_i L_i^{-b_i} + (1-\beta_i) K_i^{-b_i}]^{\frac{1}{b_i}},$

(9) $\frac{L_i}{K_i} = \left[\frac{P_K}{P_L} \frac{\beta_i}{(1-\beta_i)}\right]^{\frac{1}{1+b_i}},$

(10) $V_i = r_{vi} Q_i,$

(11) $Q_i = R_i [r_i E_i^{\rho_i} + (1-r_i) D_i^{\rho_i}]^{\frac{1}{\rho_i}},$

(12) $\frac{E_i}{D_i} = \left[\frac{P_{e_i}^{*}}{P_{d_i}} \frac{(1-r_i)}{r_i}\right]^{\frac{1}{\rho_i-1}},$

(13) $X_i = A_i [\delta_i M_i^{-a_i} + (1-\delta_i) D_i^{a_i}]^{-\frac{1}{a_i}},$

(14) $\frac{M_i}{D_i} = \left[\frac{P_{d_i}}{P_{m_i}} \frac{\delta_i}{(1-\delta_i)}\right]^{\frac{1}{a_i+1}},$

(15) $IN_i = \sum_{j=1}^{n} r_{ij} Q_j,$

(16) $C_i = \dfrac{\alpha_i(1-mps)Y}{P_i}$,

(17) $S = mpsY + (GR - \sum_{j=1}^{n} P_j \overline{G_j}) + TB$,

(18) $Z_i = h_i S$,

(19) $TB = \sum_{j=1}^{n} \overline{P_{m_i}} M_i - \sum_{j=1}^{n} \overline{P_{e_i}} E_i$

(20) $X_i = C_i + \overline{G_i} + Z_i + IN_i$,

(21) $\sum_{j=1}^{n} L_i = \overline{L}$,

(22) $\sum_{i=1}^{n} K_i = \overline{K}$,

(23) $ctr_i = \theta_i CTX$

(24) $\sum_{i=1}^{n} \theta_i (Q_i + M_i) = (1-rate)\, CA$,

(25) $GR = \sum_{1}^{n} t_i \overline{P_{m_i}} M_i + \sum_{i=1}^{n} ir_i P_{q_i} Q_i + dr(P_L\overline{L} + P_K\overline{K})$,

(25) $Y = (1-dr)(P_L\overline{L} + P_K\overline{K}) + \sum_{i=1}^{n} ctr_i (Q_i + M_i)$.

Endogenous Variables

X_i = composite good
Q_i = aggregate output
D_i = domestic sales
V_i = value added
S = supply of capital good

P_i = price of composite good
P_{qi} = price of aggregate output
P_{di} = price of domestic sales
P_{Vi} = price of value added
P_s = price of capital good

K_i = capital demand

L_i = labor demand

IN_i = intermediate demand

C_i = consumption demand

ctr_i = carbon (specific) tax

Z_i = investment demand

GR = government revenue

Y = disposable income

CTX = carbon tax per ton of CO_2.

P_{m_i} = domestic price of imports

P_L = wage rate of labor

P_K = rental rate of capital

$\overline{P}$ = aggregate price index

M_i= imports

E_i= exports

Exogeous Variables

$\overline{K}$ = capital supply

$\overline{L}$ = labor supply

$\overline{P_{m_i}}$ = world price of imports

$\overline{P_{e_i}}$ = world price of exports

TB = balance of trade

t_i = tariff rate

ir_i = indirect tax rate

dr = direct tax rate

mps = private saving rate

ω_i = weight for the price index

$rate$ = CO_2 reduction rate

θ_i = carbon emissions rate

CA = 1990 level of the total carbon content of primary fossil fuels

$\overline{G_i}$ = government's demand for composite good

Ⅲ. DATA

The year 1990 has been chosen as the benchmark of the model. The Korean economy has been disaggregated into 30 industrial sectors with primary fossil fuels and energy sectors finely classified. To calibrate the model, the 1990 input-output table, national income and product accounts and other tax data for the Korean economy have been consistently adjusted. The average carbon content of each primary fossil fuel has been obtained from the previous study of Jorgenson and Wilcoxen(1993). The data on Korea's imports and production of primary fossil fuels are from The Korea Energy Economics Institute(1994). We assume that imports and domestic output have the same carbon content. Table 1 gives the data on the carbon content, imports and production of each primary fossil fuel, and total carbon emissions in Korea. The carbon content of imported and domestically produced primary fossil fuels is about 63,994 thousand tons in 1990 while it is about 49,698 thousand tons in 1985.

In a standard CGE model, the various elasticities of substitution and transformation affect the results of policy simulation, sometimes seriously. But their values cannot be determined by calibrating the model against the benchmark

[Table 1] Carbon Content and Total Carbon Emissions in 1990

	Coal (ton)	Oil (barrel)	Natural gas (thousand cf)
Carbon Emissions rate(ton per unit)	0.5902	0.1241	0.0149
Imports(thousand)	23,969	308,368	95,145
Production(thousand)	17,217	0	0
Total carbon emissions	4,308	39,268	1,418

* cf = cubic feet

year and, thus, should be assumed exogenously or obtained from other studies. For the model we need the elasticities of transformation for the CET function, the elasticities of substitution between imports and domestic goods for the trade aggregation function(called as Armington function), and the elasticities of substitution between labor and capital for value added functions.

The elasticities of substitution between imports and domestic goods for Korean economy have been estimated, but the estimation results are statistically not so good except for five sectors - coal mining, metal mining, general machinery and precision instruments(see shin(1995))[1]. The elasticities of substitution between imports and domestic goods for utilities and traded services(eleven sectors in total) are set to two. The substitution elasticities for the other industries have been drawn from Deardorff and Stern(1986). The elasticities of substitution between labor and capital are also obtained from Deardorff and Stern(1986). The estimates of the elasticities of transformation between exports and domestic goods are from Melo and Tarr(1992). It has been found that the simulation results are not so sensitive to the change in the values of the elasticities of substitution and transformation within the range suggested in the literature. The elasticities of substitution and transformation used in the model are reported in Table 2.

Ⅳ. THE SIMULATION RESULTS

The policy simulation is carried out by imposing the carbon emissions target (22.3% reduction of carbon dioxide emissions from the 1990 level). The model described by the equation system (1)-(26) is supposed to endogenously compute the carbon tax required to achieve the target. The solution of the equations system (1)-(26) has been sought and found by the GAMS(General Algebraic Modeling System) program.

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[1] The estimation results can be provided upon request by the author.

[Table 2] Industries and The Elasticities of Substitution

Industry	ESKL	ESID	ESED
1. Agriculture, forestry and fisheries	0.789	1.139	3.900
2. Coal mining	1.541	2.191	2.900
3. Petroleum	–	–	–
4. Natural gas	–	–	–
5. Metal mining	1.541	1.274	2.900
6. Food, beverages and tobacco	1.746	1.133	2.900
7. Textiles, leather and apparel	1.151	2.708	2.900
8. Paper, wood and products	1.218	1.585	2.900
9. Chemicals and allied products	1.098	2.612	2.900
10. Refined oil products	2.000	2.359	2.900
11. Coal products	2.000	2.359	2.900
12. Stone, clay and glass products	1.267	1.628	2.900
13. Primary metals	1.382	1.446	2.900
14. Fabricated metal products	0.943	3.280	2.900
15. General machinery	0.677	3.066	2.900
16. Electrical and electronic equipment	0.521	2.110	2.900
17. Precision instruments	1.272	3.100	2.900
18. Transportation equipment	0.344	3.585	2.900
19. Other manufactures	1.272	1.984	2.900
20. Electricity	2.266	2.000	2.900
21. Gas utilities	2.266	2.000	2.900
22. Water utilities	2.266	2.000	2.900
23. Construction	1.105	2.000	0.700
24. Wholesale and retailing trade	2.266	2.000	0.700
25. Transportation and warehousing	1.457	2.000	0.700
26. Communications	1.087	2.000	0.700
27. Finance and insurance	1.657	2.000	0.700
28. Real estate	1.657	2.000	0.700
29. Public administration	1.087	2.000	0.700
30. Social and personal services, etc	1.087	2.000	0.700

* ESKL = elasticity of substitution between capital and labor.
ESID = elasticity of substitution between imports and domestic goods.
ESED = elasticity of transformation between exports and domestic goods.

The reduction of carbon emissions from the 1990 level to the 1985 level requires the carbon tax of U.S.$ 77.07 per ton of carbon dioxide. This carbon tax rate implies $ 45.49 per ton of coal, $ 9.56 per barrel of oil and $ 1.15 per thousand cubic feet of natural gas. The imposition of the carbon tax needed for the target carbon emissions increases the domestic prices of coal by 76.1 %, oil by 41.1% and natural gas by 23.8%. The sharp increase in the domestic prices of primary fossil fuels due to the carbon tax is accompanied by a large increase in the domestic prices of refined oil products by 34.8% and coal products by 52. 3%. The domestic price of electricity is raised by 6.4%.

The price increase due to the carbon tax induces resource reallocation away from the use of fossil fuels. The gross domestic product turns out to be reduced by 11.1%. When the carbon tax revenue is assumed to be returned to the household in a lump-sum fashion, the Hicksian equivalent variation is about (−) 573 million dollars, implying a decrease in welfare if the benefit from a cleaner air is not considered[2).

The total exports drop by 4.2 million dollars. Table 3 shows the change in trade and production due to the carbon tax. As expected, the major impact of the carbon tax is placed upon coal and refined oil products. The imposition of the carbon tax increases the production cost of these sectors, increasing imports by 54.1% and 122.2% and decreasing exports by 76.3% and 84% respectively. The imports of coal and petroleum are decreased by 14.1% and 29%. Thus, the rising price of primary fossil fuels leads to substitution of imports for the domestic production of coal and refined oil products. Also, the carbon tax turns out to reduce the production and exports of chemicals, stone and glass products, primary metals and metal products, and transportation, which are relatively energy-intensive sectors. The 48.5% of total exports in 1990 was from textiles, leather and apparel(25%), and electrical and electronic equipments (17.5%) and transportation equipment including automobiles(6%). The carbon tax for the target carbon emissions increases the exports of textiles, leather and apparel by 8. 9%, electrical and electronic equipments by 1%, and transportation equipments by 0.1%. Textiles, leather and apparel is a senecent industry while electrical equipments and transportation equipments are fast growing and strategic sectors for the Korean economy. Thus, the carbon tax tends to increase the exports of both declining and strategic sectors. On the whole, a carbon tax places a burden on energy-intensive industries and boosts less energy-intensive industries, as obviously expected. The effect of the carbon tax on utilities is rather small. In particular, the carbon tax shrinks the production of electricity only by 1.8%. This reflects the fact that more than 50% of electricity is produced by hydro and nuclear power in Korea.

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[2] Even though the simulation result in our case exhibits a welfare reduction due to the carbon tax, it should be noted, however, that there exists a 'paradoxical' possibility of increased welfare when a carbon tax is imposed. This possibility comes from the theory of second best. That is, the second best theory tells us that when economic distortions already exist in an economy, an introduction of another distortion(a carbon tax in our model) does not necessarily reduce economic welfare.

[Table 3] The Effects on Trade and Production

Industry	$\frac{\Delta M_i}{M_i}$	$\frac{\Delta E_i}{E_i}$	$\frac{\Delta Q_i}{Q_i}$
1. Agriculture, forestry and fisheries	−0.001	0.055	0.013
2. Coal mining	−0.141	0.000	−0.115
3. Petroleum	−0.290	0.000	0.000
4. Natural gas	−0.043	0.000	0.000
5. Metal mining	−0.033	−0.013	−0.026
6. Food, beverages and tobacco	−0.001	0.012	0.008
7. Textiles, leather and apparel	0.018	0.029	0.069
8. Paper, wood and products	0.001	0.012	0.006
9. Chemicals and allied products	0.029	−0.046	−0.012
10. Refined oil products	0.541	−0.762	−0.290
11. Coal products	1.222	−0.840	−0.182
12. Stone, clay and glass products	0.036	−0.082	−0.012
13. Primary metals	0.016	−0.135	−0.049
14. Fabricated metal products	0.026	−0.037	−0.014
15. General machinery	−0.002	0.000	−0.001
16. Electrical and electronic equipment	−0.002	0.010	0.006
17. Precision instruments	−0.005	0.024	0.014
18. Transportation equipment	−0.005	0.001	−0.002
19. Other manufactures	−0.007	0.029	0.013
20. Electricity	0.112	−0.179	−0.018
21. Gas utilities	0.248	−0.348	−0.043
22. Water utilities	0.007	−0.011	0.000
23. Construction	0.000	0.000	−0.001
24. Wholesale and retailing trade	−0.017	0.013	0.006
25. Transportation and warehousing	0.038	−0.048	−0.032
26. Communications	−0.027	0.020	0.008
27. Finance and insurance	−0.025	0.013	0.003
28. Real estate	−0.022	0.013	0.004
29. Public administration	−0.015	0.009	0.002
30. Social and personal services, etc	−0.008	0.006	0.002

$\Delta M_i / M_i$ = change rate in import
$\Delta E_i / E_i$ = change rate in export
$\Delta Q_i / Q_i$ = change rate in output

The simulation results may provide an insight into the response of a developing economy to an environmental initiative. However, they should be carefully interpreted since the analysis is based on the small country assumption and does not incorporate the effects of the simultaneous imposition of carbon taxes by foreign countries. If foreign countries trading with Korea also impose a carbon tax, the world commodity prices will be changed and Korean economy may be differently affected by the carbon tax. But there remains a possibility that the simulation results obtained in our analysis still apply to the large country case with the simultaneous imposition of the carbon taxes.

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