A Third Benefit of Joint Non-OPEC Carbon Taxes: Transferring OPEC Monopoly Rent

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Abstract

This paper highlights the potential for joint OECD (or non-OPEC) carbon taxes to reduce OPEC's monopoly rent and provide benefit to non-OPEC countries provided jointly agreed trigger strategies are adhered to. In traditional economic theory, the primary purpose of a carbon tax is to internalize a global negative externality. A second benefit for individual countries is that the revenue raised by carbon tax can be used to reduce other tax rates and so lower the deadweight loss of tax system. In this paper, we discuss a third benefit of carbon taxes: transferring rents from OPEC to the oil importing countries.

We develop a multi-region general equilibrium structure with endogenously determined oil supply for the purpose in which emissions are endogenously determined. We calibrate our model to 2006 data. Our analytics and numerical simulation results highlight how a uniform carbon tax used by all non-OPEC countries will increase the buyer's price of oil but decrease the supplier's price of oil, thus decreasing non-OPEC countries' oil demand, and transferring OPEC monopoly rent to non-OPEC countries. Carbon taxes reduce the welfare of OPEC and increase the welfare of non-OPEC countries. Results also show how carbon taxes reduce global emissions, but the effect is small.

JEL Code: Z19.

Keywords: carbon taxes, OECD, monopoly rent.

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1. Introduction

This paper discusses the role of jointly applied non-OPEC carbon taxes supported by appropriate trigger price mechanisms in reducing OPEC's monopoly rent. A carbon tax is an environmental tax on emissions of carbon dioxide and other greenhouse gases, the purpose of which is to slow climate change by reducing emissions. With concerns over severe effects from global warming, some major economies have paid much attention to carbon tax, and limited taxes of this type been enacted in some European Union countries, such as Sweden, Finland, the Netherlands, Norway, Italy and The United Kingdom. There are also similar proposals in U.S., Canada, and some developing countries, such as China. Another important issue is that OPEC has monopoly power in the world oil market and extracts significant monopoly rent. In this paper, we combine these issues and discuss how a jointly implemented non-OPEC countries' carbon tax can also reduce OPEC's monopoly power to the advantage of the non-OPEC.

Traditional economic theory sees pollution as a negative externality and the primary purpose of a carbon tax is to internalize such a negative externality. This was discussed by Pigou(1938) as the internalization of externalities using Pigouvian Tax. Later, Terkla(1984), Pearce(1991) and others discussed the "double dividend" from a carbon tax; a carbon tax will not only reduces the distortionary loss from the externality, the revenue raised by the tax can also be used to reduce other distortionary taxes, and so lower the deadweight loss of tax system. Globally, there is a cleaner environment with less global warming, while also improving incentives for productive activities.

In this paper, we discuss a third benefit to non-OPEC countries from a joint carbon tax with appropriate supporting trigger strategies: transferring rents from OPEC to the oil importing countries. Carbon taxes reduce the consumption of oil in importing countries, reduce OPEC's production price of oil and rents are transferred to the non-OPEC oil importing countries. Lerner (1980) proposed a plan for using taxes in this way to break OPEC. He advocated that a specific tax with trigger strategies that the United States and governments of oil-consuming countries impose a 100 percent excise tax on the difference between OPEC's price and the pre-OPEC price adjusted for inflation. Lerner's plan would double consumers' elasticity of demand causing them to demand less oil at higher prices and thus reduce the strength of the cartel. His plan was not promoted for environmental purposes and was never adopted, but our analysis is in the spirit of this proposal. In discussing the possible influences of environmental agreements on OPEC, a range of present oil-economy models estimate that OPEC will lose from the Kyoto Protocol(see Barnett et al.(2004),Ghanem et al.(1999), McKibbin et al.(1999), Bernstein et al.(1999)), but none have linked these effects to the carbon tax in numerical modeling.

We develop a multi-region general equilibrium structure in which countries produce commodities of varying emissions intensities using substitutable fossil fuel based oil and non-oil inputs as in Dong & Whalley (2009). Unlike in conventional trade models in which there is a fixed endowment of factor inputs for each country, here we model a supply function for each country reflecting increasing extraction costs. We model the extraction cost function in constant elasticity form to yield a specification consistent with alternative values of the supply elasticity of oil. To our knowledge, this structure, while simple, is novel in numerical work.

We next turn to numerical simulation, and using a number of data sources construct a benchmark global equilibrium data set based on data for 2006. This covers production, consumption , and trade for five regions (China,EU,US,OPEC,ROW) .We calibrate our model to this data set using literature based estimates of key elasticities, with the exception of production function elasticities which we determine using data on oil prices and marginal cost and Lerner's pricing rule for monopoly producers.

Results show that a uniform carbon tax used by non-OPEC countries increases the oil-importing countries welfare and income, reduces OPEC's welfare and income, and transfers monopoly rents from OPEC to oil-importing countries. The higher the carbon tax, the more rent will be transferred. And carbon taxes also reduce global emissions, but the effect is small.

2. A Model of Carbon Tax and OPEC Monopoly Rent Transfers

We first present our carbon tax model in algebraic form. As we focused on OPEC, we make the strong assumption that oil is the only source of energy. There are five regions, $i = 1,\cdots 5$ China, EU, US, OPEC and ROW, there are two goods produced in each region, j=1,2. In production, good 1 has high oil cost intensity, and good 2 has low oil cost intensity. The model specifies two factors, *N* a non-oil input, which is immobile across countries, but mobile across sectors within a country, and *E* an oil input which is mobile across both countries and sectors.

On the production side, we consider a two sector (a high oil (emission) intensity good and a low oil (emission) intensity good), two factor (oil and non oil input) structure. We assume production is CES. The production function for each good in each country can be written as

$$Y_{ij} = \Phi_{ij}[a_{ij1}{}^{1/\sigma_s} E_{ij}^{\sigma_s - 1/\sigma_s} + a_{ij2}{}^{1/\sigma_s} N_{ij}^{\sigma_s - 1/\sigma_s}]^{\sigma_s/\sigma_s - 1} \quad i\text{=country, } j\text{=sector} \qquad (1)$$

where Y_{ij} is the output of good *j* produced in country *i*, and σ_s is the elasticity of substitution between the two inputs (assumed similar across countries). p_{iN} is the price of the non-oil input in country *i*, goods prices are P_{ij} .We assume that oil is mobile across countries, so that the producer price of oil in each country (the world price) is the same p_E . tc is the common carbon tax rate .The buyer's price of oil p_{EB} is

$$p_{EB} = p_E \cdot (1 + tc) \qquad (2)$$

First order conditions imply the following:

$$E_{ij} = Y_{ij}\Phi_{ij}^{-1} a_{ij1} p_{EB}^{-\sigma_s}[a_{ij1} p_{EB}^{1-\sigma_s} + a_{ij2} p_{iN}^{1-\sigma_s}]^{\sigma_s/1-\sigma_s} \qquad (3)$$

$$N_{ij} = Y_{ij}\Phi_{ij}^{-1} a_{ij2} p_{iN}^{-\sigma_s}[a_{ij1} p_{EB}^{1-\sigma_s} + a_{ij2} p_{iN}^{1-\sigma_s}]^{\sigma_s/1-\sigma_s} \qquad (4)$$

and the domestic composite price is

$$P_{ij} = \Phi_{ij}^{-1}[a_{ij1} p_{EB}^{1-\sigma_s} + a_{ij2} p_{iN}^{1-\sigma_s}]^{1/1-\sigma_s} \qquad (5)$$

Unlike traditional general equilibrium models which use a fixed endowment of oil, here, by introducing an extraction cost function for each country into the model, oil supply by country is now endogenously determined. The extraction cost function we use implies an increasing marginal cost of extraction and is written as

$$K_i = F_i(Q_i) = B_{i1} + B_{i2}Q_i^{B_{i3}} \tag{6}$$

where K_i is the extraction cost in country *i*, and Q_i is oil extraction in country i.

From the first-order conditions for the extraction cost function, we get

$$p_E = \frac{dK_i}{dQ_i} = \frac{dF_i(Q_i)}{dQ_i} = B_{i2}B_{i3}Q_i^{B_{i3}-1} \tag{7}$$

and the oil supply elasticity is

$$EQ_i = \frac{dK_i / K_i}{dQ_i / Q_i} = B_{i3} - 1 \tag{8}$$

Dividing the extraction cost function by the oil price, we can calculate the resources that are used in oil extraction.

$$R_i = \frac{K_i}{p_E} = \frac{B_{i1} + B_{i2}Q_i^{B_{i3}}}{p_E} \tag{9}$$

On the demand side of the model, the representative household utility function in each country is

$$U_i = U_i(RX_i, \Delta T) = [\gamma_{Hi}^{1/\sigma_d} H_i^{\sigma_d - 1/\sigma_d} + \gamma_{Li}^{1/\sigma_d} L_i^{\sigma_d - 1/\sigma_d}]^{\sigma_d/\sigma_d - 1} (\frac{C - \Delta T}{C})^{\beta} \tag{10}$$

This utility function follows Cai, Riezman & Whalley (2009). RX_i is composite consumption in country *i*, while ΔT is global temperature change. H_i is composite high emission goods consumption, L_i is composite low emission goods consumption, σ_d is the substitution elasticity between high and low emission goods, β reflects the assumed severity of damage from temperature change. In this specification, *C* can be thought of as the global temperature change at which all economic activity ceases (say, 20℃). In this formulation, as ΔT approaches *C*, utility goes to zero; and as ΔT goes to zero, there is no welfare impact of temperature change.

For the final good demand functions, RX_i is a two level nested CES function. Each region is assumed to maximize utility by first choosing among high and low oil (emission) intensity goods, and each region then chooses using among domestic goods and the other country goods at a second level.

$$RX_i = f(X_{i11}, X_{i21}, \cdots X_{i1r}, X_{i2r}) \tag{11}$$

Each of the five regions maximizes top level utility subject to a budget constraint. I_i is income in country i.

$$\sum_{ji'} P_{iji'} X_{iji'} = I_i \tag{12}$$

Income includes non-oil income, oil income, tariff revenue, carbon tax revenue and transfers from abroad (financing net goods import and net oil import).

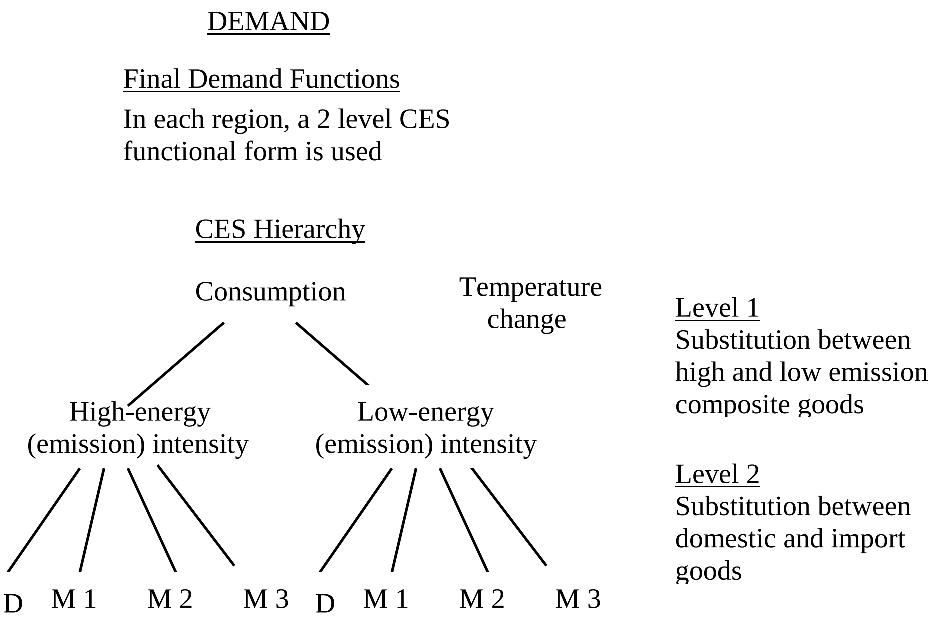
$$I_i = p_{iN} W_{iN} + [p_E Q_i - K_i] + R_i + RC_i + TR_i \tag{13}$$

For country i, p_{iN} is the price of non-oil input, W_{iN} is the non-oil endowment, K_i is the extraction cost of oil, and Q_i is oil extraction in country i. R_i is tariff revenue, RC_i is carbon tax revenue, and TR_i are exogenous transfers between countries (net goods import plus net oil import). These can be zero, but incorporating them allows calibration to unbalanced trade data.

Figure 1 shows the structure of the two level nested CES utility functions used. For each good *j* produced in country *i'*, we define the seller's price (net of tariff) as $p_{ji'}$, and allow each country *i* to impose tariffs at rate $t_{iji'}$ (country i's tariff on good j imported from country i') on each imported good. Tariffs are set to zero for exports. Internal (gross of tariff) prices for good *j* produced in country *i'* are thus

$$P_{iji'} = [1 + t_{iji'}] P_{ji'} \tag{14}$$

Figure 1 : Two Level Nested CES Utility Functions Used for Each Country



Temperature change in physical form is assumed to be a function of oil consumption, i.e.

$$\Delta T = g(\sum_i \sum_j E_{ij}) = a(\sum_i \sum_j E_{ij})^b + c \qquad (15)$$

In equilibrium, goods and factor markets clear. Goods market clearing implies:

$$\sum_i X_{iji'} = Y_{i'j} \quad i = 1, \cdots 5 \quad j = 1,2 \qquad (16)$$

Non-oil inputs are only mobile across sectors within regions and immobile across regions, so each region's non-oil input use equals its non-oil endowment. The non-oil factor clearing conditions are:

$$\sum_j N_{ij} = W_{iN} \quad i = 1, \cdots 5 \quad j = 1,2 \qquad (17)$$

Oil is mobile across countries and so global oil consumption equals global oil extraction. The oil clearing condition is:

$$\sum_i \sum_j E_{ij} = \sum_i Q_i \qquad (18)$$

3. Data and Parameterization

We build a model compatible benchmark general equilibrium data set which we use in calibration. Our base case include 2006 trade, production, and consumption data (as well as oil use) for a 2 good (energy /non energy intensive), 2 factor (oil inputs, other inputs) structure for 5 regions (China, US , EU, OPEC,ROW).

In Table 1-1 ,GDP data is from the World Bank's WDI database and OPEC Annual Statistics Bulletin 2007. The high-emission sector in each country is taken to be the manufacturing industry. The low-emission sector in each country is taken to be the service and agricultural sectors. For Table 1-2, trade data is taken from the UNCOMTRADE database, and F.o.b. export values as reported by exporting countries are used. In Table 1-3 , oil use and trade data for 2006 are calculated from IEA oil statistics. The unit of account used in the IEA statistics data is thousands of tonnes of oil equivalent, which we adjust to billion US dollars, (1 toe=7.33 barrel of oil equivalent, oil price (average)=$61.08/per barrel) .The extraction cost is calculated using the IEA energy balance table. In the data presented in Table 1-4 , adjustments are made to consumption so as to be compatible with GDP minus exports. There are also some small differences in goods classifications between the underlying consumption, production and tariff rate data. Table 1-5 gives energy consumption data from IEA statistics.

Table 1 Data Sources Used in Model Calibration

Table 1-1 2006 GDP by Sector by Region (Billion $)

	China		EU-27		US		OPEC		ROW	
	High	Low	High	Low	High	Low	High	Low	High	Low
GDP by sector	1279.23	1378.64	3852.48	10694.22	3006.63	10157.27	1169.39	1084.26	4249.39	11755.19
GDP	*2657.87*		*14546.7*		*13163.9*		*2253.65*		*16004.58*	

Source: World Bank's WDI database, OPEC Annual Statistics Bulletin2007.

Table 1-2 2006 Bilateral Trade Data (Billion $)

Export by (Billion $)		Import by China	EU-27	US	OPEC	ROW	World
China	High	0.00	159.05	139.22	32.20	364.00	694.47
	Low	0.00	85.42	64.58	8.80	115.66	274.46
	Total	*0.00*	*244.47*	*203.80*	*41.00*	*479.66*	*968.93*
EU-27	High	64.00	0.00	268.93	96.77	693.34	1123.04
	Low	15.29	0.00	65.82	24.60	230.71	336.42
	Total	*79.29*	*0.00*	*334.75*	*121.37*	*924.05*	*1459.46*
US	High	35.33	159.52	0.00	36.08	535.94	766.87
	Low	19.89	59.63	0.00	8.80	181.84	270.16
	Total	*55.22*	*219.15*	*0.00*	*44.88*	*717.78*	*1037.03*
OPEC	High	20.20	147.08	113.10	0.00	388.91	669.29
	Low	3.47	15.09	9.27	0.00	72.09	99.92
	Total	*23.67*	*162.17*	*122.37*	*0.00*	*461.00*	*769.21*
ROW	High	499.54	774.89	928.83	74.77	0.00	2278.03
	Low	133.74	297.04	329.24	90.86	0.00	850.88
	Total	*633.28*	*1071.93*	*1258.07*	*165.63*	*0.00*	*3128.91*
World	High	619.07	1240.54	1450.08	239.82	1982.19	5531.70
	Low	172.39	457.18	468.91	133.06	600.30	1831.84
	Total	*791.46*	*1697.72*	*1918.99*	*372.88*	*2582.49*	*7363.54*

Source: UNCOMTRADE database

Table 1-3 2006 Oil Balance Data (Billion $)

	Extrac-tion	Import	Export	Net Import	Extraction cost	Consumption	High emission sector input	Low Emission sector input
China	82.76	85.17	-9.70	75.47	22.09	136.14	76.27	59.87
Eu27	54.16	431.42	-160.86	270.56	35.28	289.44	205.12	84.33
US	142.29	321.18	-29.20	291.97	35.82	398.44	307.09	91.35
OPEC	782.97	35.92	-635.90	-599.98	39.71	143.27	103.03	40.23
ROW	741.96	589.48	-627.50	-38.02	112.57	591.37	398.40	192.97
World	1804.14	1463.17	-1463.17	0.00	245.47	1558.67	1089.92	468.75

Source: IEA oil statistics

Table 1-4 Consumption of Domestic Goods (2006) (Billion $)

	Consumption of Domestic Goods	
	High oil intensity goods	Low oil intensity goods
China	584.76	1104.18
Eu27	2729.44	10357.80
US	2239.76	9887.11
OPEC	500.10	984.34
ROW	1971.36	10904.31

Table 1-5 Energy Consumption (Billion US $)

Year	**China**	**EU-27**	**US**	**ROW**	**World**
2006	412.96	483.69	593.20	1446.90	2936.75
2036	80910.18	21510.37	30878.64	88533.37	221832.56
2056	612633.64	47336.00	76757.82	250518.18	987245.64

Source: International Energy Agency: *Key World Energy Statistics*, 2008.

As for elasticities, in the central case , model analyses elasticity parameters are used as follows: the consumption elasticity, that is the substitution elasticity between high and low emission goods in consumption is equal to 0.5, and the trade elasticity , The substitution elasticities between domestic and imported commodities follows the “rule of two”, that is the substitution elasticity between domestic and imported goods is equal to 2, as discussed in Hertel al. (2009). This rule was first proposed by Jomini et al.(1991) and later tested by Liu, Arndt,and Hertel(2002) in a back-casting exercise with a simplified version of the GTAP model.

For the production substitution elasticity, we assume values are the same in all countries and we use Lerner pricing by OPEC to calibrate them to the base data on the P-MC difference for oil extraction. We relate this difference to the implied oil demand elasticity, in non-OPEC countries as a point estimate at the benchmark equilibrium. Lerner’s pricing rule implies:

$$\frac{p_E - MC_E}{p_E} = \frac{1}{\varepsilon_E} \qquad (19)$$

where p_E is the price of oil, MC_E is the marginal cost of oil, and ε_E is the price elasticity of oil demand. Thus if the oil price is ,say $ 60/per barrel, and the marginal extraction cost is \$ 12, by equation (19), we get $\varepsilon_E = 1.25$. We obtain the production side substitution elasticity σ_s by iterative calculation of the arc estimate of the demand elasticity for oil facing OPEC in the model at the benchmark equilibrium. As shown in table 2 ,when $\sigma_s = 5.2$, the arc estimate of demand of oil produced in OPEC equals 1.25.

Using data for 2006,2036, and 2056 in table 1-5, and assuming the temperature change at these three points to be 0℃,2℃, and 5℃ respectively, we can solve for the values of parameters a,b,and c in equation (15) as

$$0 = a(2936.75 - 2936.75)^{\mathrm{b}} + c$$

$$2 = a(221832.56)^{\mathrm{b}} + c$$

$$5 = a(987245.64)^{\mathrm{b}} + c$$

Solving these equations for the parameters a,b,and c yields values of 0.0010, 0.6137 and 0. Substituting these values in the temperature equation yields

$$\Delta T = g(\sum_i \sum_j E_{ij}) = 0.001(\sum_i \sum_j E_{ij})^{0.6137} \tag{20}$$

Assuming a temperature change ΔT of 5℃ between 2006 and 2056 (consistent with Stern(2002)), Table 2 reports the calibrated preference parameters in equation (10) under alternative damage assumptions. As discussed in Cai et al.(2009), the share parameter β reflects the assumed severity of damage from temperature change. We assume 3% utility loss and $\beta = 0.1059$.

Table 2 also reports remaining parameter values in production, preferences and extraction cost functions generated by calibration. These are independent of the assumed utility damage due to temperature change.

Table 2 Calibrated Parameters

A. Production Elasticity

production elasticity	World oil demand: Base value	World oil demand: New value (1% increase of oil price)	Arc estimate at benchmark equilibrium of elasticity of oil demand	OPEC oil production/World oil production	Elasticity of world demand on OPEC oil
5.00	1558.6700	1484.9610	4.7290	25.43%	1.2028
5.20	*1558.6700*	*1482.0970*	*4.9127*	*25.43%*	***1.2495***
5.30	1558.6700	1480.6660	5.0045	25.43%	1.2729
5.50	1558.6700	1477.8090	5.1878	25.43%	1.3195

B. Assumed Changes in Preference Parameters

Assumed utility loss in BAU	1%	**3%**	5%	10%	15%	20%
Utility relative to no damage	0.99	**0.97**	0.95	0.9	0.85	0.8
β	0.0349	**0.1059**	0.1783	0.3662	0.5649	0.7757

C. Parameters in CES production functions

	China		**EU-27**		**US**		**OPEC**		**ROW**	
	high emission goods	low emission goods	high emission goods	low emission goods	high emission goods	low emission goods	high emission goods	low emission goods	high emission goods	low emission goods
technology coefficient	1.747566	1.704759	1.732102	1.519990	1.823222	1.506749	1.802201	1.684137	1.811027	1.584846
shares on oil	0.005717	0.004621	0.005300	0.001409	0.008197	0.001550	0.007424	0.004156	0.007739	0.002373
shares on non-oil	0.090174	0.101797	0.094239	0.177333	0.072058	0.170744	0.076837	0.107844	0.074810	0.142189

D. Parameters in Nested CES Utility functions

Shares of high and low energy (emission) composite goods

China		**EU-27**		**US**		**OPEC**		**ROW**	
high emission goods	low emission goods	high emission goods	low emission goods	high emission goods	low emission goods	high emission goods	low emission goods	high emission goods	low emission goods
0.628868	0.777512	0.262631	0.964896	0.244520	0.969644	0.475327	0.879809	0.232531	0.972589

Shares of consumption of high energy (emission) domestic and import goods

	China	**EU-27**	**US**	**OPEC**	**ROW**
China-H	0.124109	0.011915	0.010496	0.012533	0.021514
EU-H	0.016138	0.189772	0.020276	0.037665	0.04098
US-H	0.008909	0.01195	0.158553	0.014043	0.031677
OPEC-H	0.005094	0.011018	0.008527	0.163924	0.022986
ROW-H	0.125965	0.058049	0.070028	0.029102	0.103232

Shares of consumption of low energy (emission) domestic and import goods

China-L	0.322971	0.005331	0.00373	0.003729	0.005801
EU-L	0.005997	0.488794	0.003801	0.010425	0.011571
US-L	0.007801	0.003722	0.51301	0.003729	0.00912
OPEC-L	0.001361	0.000942	0.000535	0.33585	0.003616
ROW-L	0.052457	0.018538	0.019014	0.038506	0.436446

E. Parameters in Extraction functions

	China	**EU-27**	**US**	**OPEC**	**ROW**
Constant Parameter	-33.0833	-0.8267	-59.0400	-482.2700	-382.0700
Coefficient parameter	0.0733	0.0906	0.0559	0.0238	0.0245

4 . Model Experiments and Results for Carbon Tax and OPEC Monopoly Rent Transferring

We have used our calibrated model to simulate the impacts of using a joint carbon tax by non-OPEC countries on global emissions and country welfare. The results of these experiments show that a uniform carbon tax used by non-OPEC countries will increase the buyer's price of oil and decreasing the producer price of oil, and thus decrease non-OPEC countries' oil demand, and transfer OPEC's monopoly rent to non-OPEC countries. A jointly implemented carbon tax with supporting trigger price strategies can thus reduce the welfare of OPEC and increase the effect of the welfare of non-OPEC countries. Non-OPEC countries' income increases from two sources: one is OPEC rent transferring, the other is carbon tax revenue. Carbon tax can decrease global emissions, but the effect is small.

In Tables 3 — 7, we assume a uniform carbon tax rate adopted by non-OPEC countries (China, EU, US, ROW). By increasing the tax rate, we can analyze the effect of the carbon tax on oil price, oil demand, income, welfare and emissions.

Table 3 shows the impact of uniform carbon tax on the buyer's oil price. By increasing the carbon tax rate, the seller's price of oil will decrease and buyer's price of oil will increase. When the carbon tax rate is at 1%,3%,5%,10%,15% and 20%, the seller's price of oil will change -0.8745%, -2.5727%, -4.2061% , -8.0232%, -11.4900% and -14.6397% accordingly, and the buyers price in all countries will change by 0.1168%, 0.3501%, 0.5836%,1.1745%,1.7864% and 2.4323% accordingly.

Table 3 Impacts of Uniform Carbon Tax on Buyer's Oil Price (% Change Based on 2006 Data)

CARBON TAX	% Change in Oil Price					
	China	EU	US	OPEC	ROW	Total
1% uniform carbon tax	0.1168%	0.1168%	0.1168%	*-0.8745%*	0.1168%	0.1168%
3% uniform carbon tax	0.3501%	0.3501%	0.3501%	*-2.5727%*	0.3501%	0.3501%
5% uniform carbon tax	0.5836%	0.5836%	0.5836%	*-4.2061%*	0.5836%	0.5836%
10% uniform carbon tax	1.1745%	1.1745%	1.1745%	*-8.0232%*	1.1745%	1.1745%
15% uniform carbon tax	1.7864%	1.7864%	1.7864%	*-11.4900%*	1.7864%	1.7864%
20% uniform carbon tax	2.4323%	2.4323%	2.4323%	*-14.6397%*	2.4323%	2.4323%

Table 4 reports the consumption of oil in non-OPEC importing countries reducing with the increasing of carbon tax rate. When the carbon tax rate is 1%, the oil demand of China, EU, US and ROW decreases by 0.5683%, 0.5800%, 0.5555%, 0.5755%. When the carbon tax rate increases to 10%, the oil demand of China, EU, US and ROW decreases by 5.4613%, 5.6185%, 5.3800%, 5.5395%.

Table 4 Impacts of Uniform Carbon tax on Oil Demand
(% Change Based on 2006 Data)

CARBON TAX	% Change in Oil Demand					
	China	EU	US	OPEC	ROW	Total
1% uniform carbon tax	-0.5683%	-0.5800%	-0.5555%	4.2179%	-0.5755%	-0.1300%
3% uniform carbon tax	-1.6836%	-1.7228%	-1.6495%	13.0357%	-1.7063%	-0.3379%
5% uniform carbon tax	-2.7773%	-2.8478%	-2.7263%	22.3700%	-2.8160%	-0.4807%
10% uniform carbon tax	-5.4613%	-5.6185%	-5.3800%	48.0031%	-5.5395%	-0.5853%
15% uniform carbon tax	-8.1402%	-8.3878%	-8.0381%	76.9330%	-8.2541%	-0.3840%
20% uniform carbon tax	-10.8776%	-11.2118%	-10.7574%	109.0923%	-11.0208%	0.0634%

The results in Table 3 and Table 4 thus confirm the idea that taxation in an importing country implies a transfer of rents from producers to consumers. Since OPEC has high monopoly power in oil production, a jointly implemented carbon tax functions as an effective way to reduce OPEC's monopoly power.

Table 5 reports the influence of carbon taxes on OPEC and non-OPEC country's incomes. Non-OPEC countries increase their income due to rent transfers from OPEC and carbon tax revenue. When the carbon tax rate is 3%, the income of China, EU, US and ROW increases by 0.0937%, 0.0540%, 0.0663%, 0.0034%, OPEC's income falls by 1.0598%. When the carbon tax rate increases to 20%, the income of China, EU, US and ROW increases by 0.8187%, 0.3943%,0.5137%,0.2590%. OPEC's income falls by 5.3335%. For non-OPEC countries, the income increases are small.

Table 5 Impacts of Uniform Carbon Tax on Income

(% Change Based on 2006 Data)

CARBON TAX	**% Change in Income**					
	China	EU	US	OPEC	ROW	Total
1% uniform carbon tax	0.0279%	0.0171%	0.0206%	*-0.3664%*	-0.0019%	-0.0022%
3% uniform carbon tax	0.0937%	0.0540%	0.0663%	*-1.0598%*	0.0034%	0.0005%
5% uniform carbon tax	0.1683%	0.0932%	0.1158%	*-1.7044%*	0.0178%	0.0103%
10% uniform carbon tax	0.3778%	0.1954%	0.2483%	*-3.1282%*	0.0806%	0.0554%
15% uniform carbon tax	0.6002%	0.2974%	0.3835%	*-4.3241%*	0.1656%	0.1178%
20% uniform carbon tax	0.8187%	0.3943%	0.5137%	*-5.3335%*	0.2590%	0.1868%

In Table 6, we use Hicksian CV and EV measures capturing the effects of temperature change for welfare analysis. These are

$$CV_i = \frac{\Delta U_i}{(\frac{C_i - \Delta T_0}{C_i})^{\beta}} = \frac{U_i^1 - U_i^0}{(\frac{C_i - \Delta T_0}{C_i})^{\beta}} \tag{21}$$

$$EV_i = \frac{\Delta U_i}{(\frac{C_i - \Delta T_1}{C_i})^{\beta}} = \frac{U_i^1 - U_i^0}{(\frac{C_i - \Delta T_1}{C_i})^{\beta}} \tag{22}$$

Since the temperature change is small, $\Delta T_0 \approx \Delta T_1$, and CV and EV measures from equations (21) and (22) are similar. We only report the CV measure. Results show that non-OPEC countries improve welfare and OPEC loses welfare. When the carbon tax rate is 5%, CV measures for China, EU, US and ROW are 0.000043, 3.710793, 4.440146, 0.487235, CV of OPEC is -5.122175, When the carbon tax rate is 20%, CV measures for China, EU, US and ROW are 0.000216, 15.897682, 20.049688 , 10.130895. The CV of OPEC is -15.12791.

Table 6 Impacts of Uniform Carbon tax on welfare (CV)

CARBON TAX	**Change in Welfare by Region (CV)**					
	China	EU	US	OPEC	ROW	Total
1% uniform carbon tax	0.000007	0.672325	0.774374	*-1.115139*	-0.138067	0.286138
3% uniform carbon tax	0.000023	2.140034	2.520218	*-3.205549*	-0.022011	4.100982
5% uniform carbon tax	0.000043	3.710793	4.440146	*-5.122175*	0.487235	12.503942
10% uniform carbon tax	0.000098	7.841789	9.630654	*-9.238164*	2.924413	12.503942
15% uniform carbon tax	0.000158	11.981790	14.953226	*-12.526053*	6.339063	22.907469
20% uniform carbon tax	0.000216	15.897682	20.049688	*-15.127910*	10.130895	33.906084

Table 7 reports the effects of carbon tax on emissions. The global emissions decrease with an increasing carbon tax rate, but the effect is small. When the uniform carbon tax rate is 20%, global emissions decrease by 3.3599%. Across different regions, OPEC increases emissions since OPEC does not use a carbon tax, while non-OPEC countries decrease emissions due to reduced oil consumption.

Table7 Impacts of Uniform Carbon Tax on Emissions(Oil Use)

(% Change Based on 2006 Data)

CARBON TAX	% Change in Emissions					
	China	EU	US	OPEC	ROW	Total
1% uniform carbon tax	-0.5683%	-0.5800%	-0.5555%	*4.2179%*	-0.5756%	-0.2671%
3% uniform carbon tax	-1.6836%	-1.7229%	-1.6495%	*13.0357%*	-1.7063%	-0.7590%
5% uniform carbon tax	-2.7773%	-2.8478%	-2.7263%	*22.3700%*	-2.8160%	-1.1997%
10% uniform carbon tax	-5.4612%	-5.6185%	-5.3800%	*48.0031%*	-5.5395%	-2.1121%
15% uniform carbon tax	-8.1402%	-8.3878%	-8.0381%	*76.9330%*	-8.2541%	-2.8121%
20% uniform carbon tax	-10.8776%	-11.2118%	-10.7574%	*109.0923%*	-11.0208%	- 3.3599%

5. Concluding Remarks

We have used a multi-region general equilibrium model calibrated to 2006 benchmark data to evaluate the impacts of jointly imposed carbon taxes on OPEC and non-OPEC countries' oil consumption, income, emissions and welfare. Our results confirm the view that carbon taxes can have a third benefit for oil importing countries of transferring rents from OPEC to oil importing countries and reducing OPEC's monopoly power on oil market.

Results from model analysis also show that a uniform carbon tax by non-OPEC countries will increase the buyer's price of oil and decrease the seller's price of oil, thus decreasing non-OPEC countries' oil demand, and transferring OPEC's monopoly rent to non-OPEC countries. A carbon tax thus reduces the welfare of OPEC and increases the welfare of non-OPEC countries. Non-OPEC countries' income can increase from two sources: one is OPEC rent transfers; the other is from carbon tax revenue. A non-OPEC carbon tax can decrease global emissions, but the effect is small.

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