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CARBON MOTIVATED REGIONAL TRADE ARRANGEMENTS: ANALYTICS AND SIMULATIONS

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ABSTRACT

This paper presents both analytics and numerical simulation results relevant to proposals for carbon motivated regional trade agreements summarized in Dong & Whalley(2008). Unlike traditional regional trade agreements, by lowing tariffs on participant's low carbon emission goods and setting penalties on outsiders to force them to join such agreements , carbon motivated regional trade agreements reflect an effective merging of trade and climate change regimes, and are rising in profile as part of the post 2012 Copenhagen UNFCC negotiation. By adding country energy extraction cost functions, we develop a multi-region general equilibrium structure with endogenously determined energy supply. We calibrate our model to business as usual scenarios for the period 2006-2036. Our results show that carbon motivated regional agreements can reduce global emissions, but the effect is very small and even with penalty mechanisms used, the effects are still small. This supports the basic idea in our previous policy paper that trade policy is likely to be a relatively minor consideration in climate change containment.

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1. Introduction

This paper presents both analytics and numerical simulation results relevant to recent debate on carbon motivated regional trade agreements (see Chatham House (2007) and Dong & Whalley (2008)). Proposals which circulate include explicitly lowering or eliminating tariffs among parties to a regional agreement on low carbon intensive goods and products used in low carbon technologies,border adjustments on trade with parties outside the area based on differential emissions content of goods, and the use of trade sanctions against countries outside the area to enforce compliance with emissions reduction targets set for them. Such proposals reflect an effective merging of trade and climate change regimes, and are rising in profile as part of the post 2012 Copenhagen UNFCC negotiations (See Walsh & Whalley (2008), and Lockwood & Whalley(2008)). Here we discuss carbon motivated regional agreements in terms similar to customs union and regional trade agreements based literature (See Viner(1950)) .

We note that agreements with lower within-region barriers on low carbon intensive products need not reduce emissions globally if emissions intensities of production differ sharply within and inside the region. This reflects the differential impact of trade creation and trade diversion on emissions. We also note that unlike conventional customs union literature the welfare effects of a regional agreement now also include welfare impacts on climate change from emissions changes.

We use a multi-region general equilibrium structure in which countries produce commodities of varying emissions intensities using substitutable fossil fuel based energy and non-energy inputs. Commodities are differentiated by country of origin following Armington (1969). Preferences are defined over both consumption of goods and climate change, with lower utility from higher global temperature change.

Unlike in conventional trade models in which there is a fixed endowment of factor inputs for each country, here we model energy supply globally as integrated with a single global market and price, and there being a supply function for each country reflecting increasing extraction costs. We do not separately differentiate between fossil and non fossil fuels, but in a further model extension we could do so. We model the extraction cost function in constant elasticity form to yield a specification consistent with alternative values of the supply elasticity of energy. We then treat emissions in each country as fixed coefficient in energy use, and in this way incorporate endogeneity of emissions levels. Global emissions levels can thus rise or fall under any given regional trade agreement. This differs from other equilibrium structures, (see OECD(1993),Bhattacharyya(1996) and Wing(2004)) in which the energy endowment is fixed (perfectly inelastic supply).

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 each of a number of regions (US, EU, China, ROW) which we then project forward using 2004-2006 average growth rates for the period 2006-2036. In our static equilibrium model we thus treat the thirty year period 2006-2036 as a single period. The data set also contains estimates of energy use by sector and emissions for 2006 which are growth rate projected forward for period 2006-2036. We calibrate our model to this data set using literature based estimates of key elasticities.

Results from our analysis support the conjecture made verbally in our previous policy paper (see Dong & Whalley (2008)) that carbon motivated trade policies such as carbon free trade areas can only have a relatively small role in reducing carbon emissions. Carbon motivated regional agreements may increase world welfare, but the effects on participating countries may be negative or positive, when with penalties, the effect of carbon motivated trade policies on carbon emissions is still small. Though the carbon motivated regional agreements will have larger effects with emissions of high and low emissions intensities countries involved, the effects are still small.

2. Relevant Literature and Model Structure

2.1 *Literature Review*

Discussion of both the form and impact of carbon free trade agreements is related to the long studied customs union issue originally analyzed by Viner (1950). Viner, the initiator of subsequent customs union literature, pointed out that regional trade agreements do not necessarily result in gains to members, even though bilateral tariffs are eliminated by the agreement. He developed what later became known as the trade creation – trade diversion approach to regional trade agreements to help understand this ambiguity. Following Viner's work, for many years trade creating regional agreements were seen as good, and trade diverting regional agreements were seen as bad.

Viner's work was also the driving force behind later literature that subsequently sought to set out the conditions under which regional trade agreements would either improve or worsen welfare. This work was still based on trade creation—trade diversion considerations, but Meade (1955), Lipsey(1957) and others discovered that preference considerations also enter in trying to make such determinations. This was to lead to Lipsey and Lancaster's (1956) characterization of the general theory of the second best, confirmation that no general customs union results were possible. Dissatisfaction with the trade creation – trade diversion dichotomy resulted in Lipsey (1970), Kemp(1969), Riezman(1979) and others trying to develop other approaches that would yield clear propositions. The approach known as the terms of trade-volume of trade approach became popular, under which the impact of a regional trade agreement can be summarized by its effects on both terms of trade (prices) and trade volumes. Most traditional literature on regional trade agreements falls into the traditional Vinerian framework.

In Dong & Whalley(2008), we proposed three different forms of possible carbon motivated regional trade arrangements. One is regional trade agreements with varying types of trade preferences towards low carbon intensive products, low carbon new technologies and inputs to low carbon processes being used to stimulate trade (and hence consumption) in low carbon intensive products. In this way they are designed to contribute directly to emissions reduction through changed trade patterns. A second type focuses on the anti-competitive effects on domestic producers when significant joint emissions reduction commitments are made which others do not follow. Such commitments raise costs for domestic producers and whether there should be offsets for these relative cost effects compared to third country producers operating outside of such arrangements is an issue, as well as the form they should take. The perceived need for border tax adjustments had already arisen in Europe who saw themselves as going father and faster on emissions reductions than partner countries. A third type of arrangement could be where countries enter into free trade or other regional trade agreements and use joint and discriminatory carbon motivated trade barriers against third parties as a way of pressuring countries to join their joint environmental agreement. This form of trade arrangement is similar to that contained in the Montreal Protocol of 1987.

This paper follows Dong & Whalley (2008), and numerically evaluates the economic effects of type one and type three carbon free trade areas in that paper. In their simplest form, carbon free trade areas would involve free trade in low carbon containing products among countries jointly committing to significant emissions reductions or renewable commitments, and also with external trade barriers against third countries that do not follow. Discussion of both their form and impact is related to the long studied customs union issue originally analyzed by Viner(1950), but now there are also impacts of carbon pricing/reduction policies on emissions via endogenous energy supply. The paper focuses on two departures from Vinerian form, one includes climate change effects in utility, and the other changes traditional free trade areas and Customs Unions to carbon motivated free trade areas and Customs Unions. In carbon free trade agreements, traditional zero-tariffs on all goods changes to structural preferential trade policies setting high tariffs on high carbon intensive products and zero tariffs on low carbon intensive goods. We also consider a new form of carbon motivated Customs Unions of only setting zero tariffs on low carbon intensive goods.

We argue that agreements with lower within region barriers on low carbon intensive products need not reduce emissions globally if emissions intensities of production differ sharply within and outside the region. This reflects the differential impact of trade creation and trade diversion on emissions. We also note that unlike conventional customs union literature the welfare effects of a regional agreement also include welfare impacts on climate change from emissions changes.

2.2 *The Model*

We present our carbon free trade area model in algebraic form. In its simplest form, there are three regions, i=1,2,3,where regions 1 and 2 form a carbon free trade agreement, although in empirical implementation we can consider more regions. There are two goods, j=1,2, in production, good 1 has high energy intensity, and good 2 has low energy intensity. The model specifies two factors, *N* a non-energy input, which is immobile across countries, but mobile across sectors within a country, and *E* an energy input which is mobile across both countries and sectors.

On the production side, we consider a two sectors (a high emission good and a low emissions good), two factors (energy and non energy inputs) structure. We assume production is CES. The production function for each good in each country can be written as

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

where Y_{ij} is the output of good *j* produced in country *i*, p_E is the price of energy, σ_{ij} is the elasticity of substitution between the two inputs. We assume that energy is mobile across countries, so that the energy price in each country (the world price) is the same. p_{iN} is the price of the non-energy input in country *i*, goods prices are P_{ij} .

First order conditions imply the following:

$$E_{ij} = Y_{ij}\Phi_{ij}^{-1}a_{ij1}p_E^{-\sigma_{ij}}[a_{ij1}p_E^{1-\sigma_{ij}} + a_{ij2}p_{iN}^{1-\sigma_{ij}}]^{\sigma_{ij}/1-\sigma_{ij}} \qquad (2)$$

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

$$P_{ij} = \Phi_{ij}^{-1}[a_{ij1}p_E^{1-\sigma_{ij}} + a_{ij2}p_{iN}^{1-\sigma_{ij}}]^{1/1-\sigma_{ij}} \qquad (4)$$

Unlike traditional general equilibrium models which use a fixed endowment of energy, here, by introducing an extraction cost function for each country into the model, energy supply now is endogenously determined.

The extraction cost function can be written as

$$K_i = F_i(Q_i) = B_{i1} + B_{i2}Q_i^{B_{i3}} \tag{5}$$

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

We assume the energy market is perfectly competitive, and from the first-order conditions for the extraction cost function, we get

$$p_E = \frac{dK_i}{dQ_i} = \frac{dF_i(Q_i)}{dQ_i} = B_{i2}B_{i3}Q_i^{B_{i3}-1} \tag{6}$$

and the energy supply elasticity is

$$EQ_i = \frac{dK_i/K_i}{dQ_i/Q_i} = B_{i3} - 1 \tag{7}$$

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

$$R_i = \frac{K_i}{p_E} = \frac{B_{i1} + B_{i2}Q_i^{B_{i3}}}{p_E} \tag{8}$$

The utility function is

$$U_i = U_i(RX_i, \Delta T) = [\gamma_{Hi}^{1/\sigma_{1i}} H_i^{\sigma_{1i}-1/\sigma_{1i}} + \gamma_{Li}^{1/\sigma_{1i}} L_i^{\sigma_{1i}-1/\sigma_{1i}}]^{\sigma_{1i}/\sigma_{1i}-1}(\frac{C-\Delta T}{C})^{\beta} \tag{9}$$

This utility function follows Cai, Riezman & Whalley (2009). RX_i is composite consumption, ΔT is 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 case, as ΔT approaches C, utility goes to zero. In this form, 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 emission goods, and each region then chooses using among domestic goods and the other country goods at a second level.

$$RX_i = f(X_{i11}, X_{i21}, \cdots X_{i1r}, X_{i2r}) \quad (10)$$

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

$$\sum_{ji'} P_{iji'} X_{iji'} = I_i \quad (11)$$

income includes non-energy income, energy income, tariff revenue, and transfers from abroad (financing net goods import and net energy import).

$$I_i = p_{iN} W_{iN} + [p_E Q_i - K_i] + R_i + TR_i \quad (12)$$

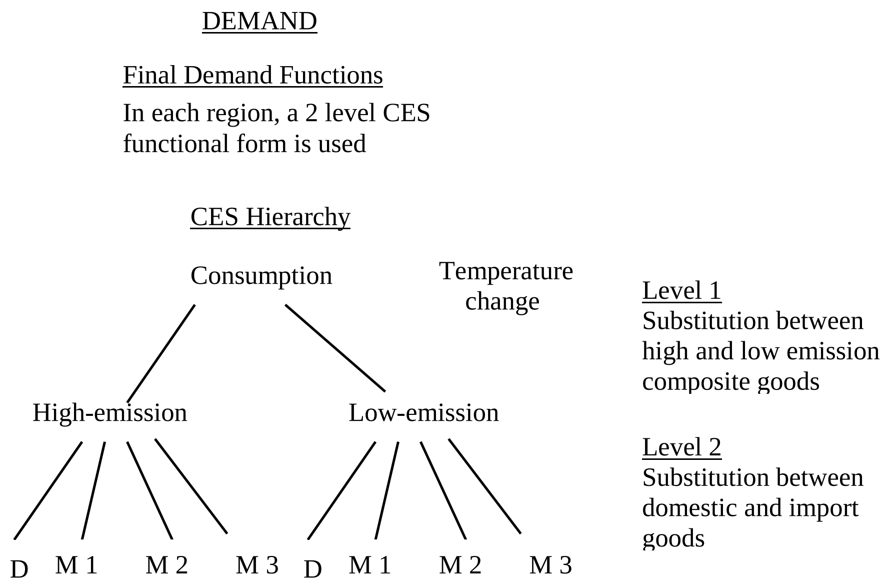
For country i, p_{iN} is the price of non-energy input, W_{iN} is the non-energy endowment, K_i is the extraction cost of energy, and Q_i is energy extraction in country i. R_i is tariff revenue, and TR_i are exogenous transfers between countries (net goods import plus net energy import). These can be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

Figure 1 shows the structure of two level nested CES utility functions used.

For each good *j* produced in country *i'*, we can 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

$$P_{iji'} = [1 + t_{iji'}] P_{ji'} \quad (13)$$

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



Temperature change in physical form is assumed to be a function of energy consumption, ie

$$\Delta T = g(\sum E_{ij}) = a(\sum E_{ij})^{b} + c \tag{14}$$

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

$$\sum_{i} X_{iji'} = Y_{i'j} \quad i = 1,2,3\,, \quad j = 1,2 \tag{15}$$

Non-energy is only mobile across sectors within regions and immobile across regions, so each region's non-energy consumption equals its non-energy endowment. The non-energy clearing condition is:

$$\sum_{j} N_{ij} = W_{iN} \quad i = 1,2,3 \tag{16}$$

Energy is mobile across countries and so global energy consumption equals global energy extraction. The energy clearing condition is:

$$\sum_{ij} E_{ij} = \sum_{i} Q_{i} \qquad i = 1,2,3 \tag{17}$$

3. Data and Parameterization

We build a model compatible benchmark general equilibrium data set which we use in calibration. Our base case assumes a single 30 year period, forward projecting a business as usual scenario for trade, production, and consumption data (as well as energy use) for a 2 good (energy / non energy intensive), 2 factor (energy inputs, other inputs) structure for 4 regions (China, US , EU, ROW). We forward project 2006 data using 2004-2006 average growth rates, for the period 2006-2036.

In Table 1-1 GDP data is from the World Bank's WDI database. The high-emission sector reflects manufacturing industry. The low-emission sector includes service and agricultural sectors. For Table 1-2, trade data is taken from the UNCOMTRADE database, F.o.b. export values as reported by exporting countries are used. Since data on EU's exports to China and US in 2006 were not available at the time of model execution, we use the import data of China and the US from the EU instead. Since China's growth rates is high relative to other regions ,to keep trade balance in the data, we use China's growth rate for China's imports and exports , while for other data , we use the import country's growth rate in our projections, tariff data is from the WTO Statistical Database.

In Table 1-3 , energy data for 2005 is calculated from IEA energy statistics. The unit of account of the IEA statistics data is thousand of tonnes of oil equivalent, which we adjust to billion US dollars, (1 toe=7.33 barrel of oil equivalent, oil price (average)=$ 50.64/per barrel) . In 2005, the energy balances for world were crude oil imports of 4476208 Ktoe, while exports were 4484919 Ktoe, comparable with world crude oil trade balance. The extraction cost is calculated using the IEA trade balance table.

In the data presented in Table 1-4 , adjustments are made to consumption by calculating 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 in Model Calibration

Table 1-1 2006-2036 GDP by Sector by Region (Billion $)

	China		EU-27		US		ROW	
	High	Low	High	Low	High	Low	High	Low
GDP by sector	250634.94	270111.98	171324.82	475585.94	156507.52	528727.91	331566.87	785626.32
GDP	520746.92		646910.76		685235.43		1117193.19	

Source: World Bank's WDI database

Table 1-2 2006-2036 Bilateral Trade Data (Billion $)

Exports by (Billion $)		**Imports by China**	**EU-27**	**US**	**ROW**	**World**
China	High	0.00	31162.09	27276.87	77626.04	136065.00
	Low	0.00	16736.03	12652.93	24385.00	53773.96
	Total	*0.00*	*47898.12*	*39929.80*	*102011.04*	*189838.96*
EU-27	High	12539.29	0.00	13998.92	48345.62	74883.83
	Low	2995.71	0.00	3426.20	15622.03	22043.94
	Total	*15535.00*	*0.00*	*17425.12*	*63967.65*	*96927.77*
US	High	6922.08	7094.06	0.00	35001.03	49017.17
	Low	3896.98	2651.82	0.00	11664.97	18213.77
	Total	*10819.06*	*9745.88*	*0.00*	*46666.00*	*67230.94*
ROW	High	101830.79	41001.21	54236.77	0.00	197068.77
	Low	26883.06	13880.83	17620.85	0.00	58384.74
	Total	*128713.85*	*54882.04*	*71857.62*	*0.00*	*255453.51*
World	High	121292.16	79257.36	95512.56	160972.69	457034.77
	Low	33775.75	33268.68	33699.98	51672.00	152416.41
	Total	*155067.91*	*112526.04*	*129212.54*	*212644.69*	*609451.18*

Source: UNCOMTRADE database

Table 1-3 2006-2036 Energy Balance Data (Billion $)

	Extrac-tion	**Import**	**Export**	**Net Import**	**Extraction cost**	**Consumption**	**High emission sector input**	**Low Emission sector input**
China	105558.07	13355.00	-6073.65	7281.34	-31929.23	80910.18	42907.78	38002.40
Eu27	6365.47	24024.08	-7869.24	16154.84	-1009.94	21510.37	11309.85	10200.52
US	21873.33	16281.39	-2082.20	14199.19	-5193.87	30878.64	18087.44	12791.21
ROW	137722.08	45302.26	-82937.63	-37635.37	-11553.34	88533.37	46889.71	41643.66
World	271518.94	98962.72	-98962.72	0.00	-49686.38	221832.57	119194.77	102637.79

Source: IEA energy statistics

Table 1-4 : Consumption of Domestic Goods (2006-2036) (Billion $)

	Consumption of domestic goods	
	High energy intensity goods	Low energy intensity goods
China	114569.94	216338.02
EU-27	96440.99	453542.00
US	107490.35	510514.14
ROW	134498.10	727241.58

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: for all countries the production elasticity is 0.5, the extraction / energy supply elasticity is 0.5, 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 ,that is the substitution elasticity between domestic and imported goods is equal to 2. The substitution elasticities between domestic and imported commodities follows the “rule of two”, 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. The model Global 2100 uses a capital and labour nest against energy with a substitution elasticity of 0.4 (see Manne and Richels, 1992), Kemfert(1998) studied the case of Germany, and the substitution elasticities in all sectors between composite of capital and labor , trading off against energy was 0.458. We thus use the setting of 0.5 as the substitution elasticity between energy and non-energy inputs.

Using the 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 (14) as

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

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

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

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

$$\Delta T = g(\sum E_{ij}) = 0.001(\sum E_{ij})^{0.6137} \tag{18}$$

Assuming a temperature change ΔT of 5℃ between 2006 and 2056 (consistent with Stern(2002)), Table 2 reports the calibrated preference parameters in equation (9) under alternative damage assumptions. If we assumed half temperature change, at these three points to be 0℃,1℃, and 2.5℃ respectively, we can solve for the values of parameters a,b,and c, 0.0005, 0.6137 and 0. If we double temperature change, temperature change at these three points will be 0℃,4℃, and 10℃ respectively, and the values of parameters a,b,and c are 0.0021 , 0.6137, and 0 .

The specification C can be thought of the global temperature change at which all economic activity ceases (say 20℃). In this case, as ΔT approaches C utility goes to zero. In this form , as ΔT goes to zero there is no welfare impact of temperature change. As discussed in Cai et al.(2009), the share parameter β reflects the assumed severity of damage from temperature change, which we later (in Table 7) calibrate to various damage estimates from business as usual global temperature change scenarios reported by Stern(2006) and Mendelson(2007).

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 under Alternative Damage Assumptions

A. Assumed Changes in Preference Parameters

Assumed Utility Loss	Utility Relative to No damage	β
1%	0.99	0.0349
1.5%	**0.985**	**0.0525**
3%	**0.97**	**0.1059**
5%	0.95	0.1783
6%	**0.94**	**0.2151**
10%	0.90	0.3662
15%	0.85	0.5649
20%	0.80	0.7757

B. Parameters in CES production functions

	China		**EU**		**US**		**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
technology coefficient	1.39621179	1.31890362	1.14065722	1.04381582	1.25695383	1.04955396	1.32072255	1.11159828
shares on energy	0.20228798	0.16157483	0.07050406	0.02191317	0.12956913	0.02478459	0.16252202	0.05588649
shares on non-energy	0.97932608	0.98686046	0.99751149	0.99975988	0.99157039	0.99969281	0.98670492	0.99843713

C. Parameters in Nested CES Utility functions

	China	**EU**	**US**	**ROW**
Shares of consumption of high emission domestic and import goods				
China-H	0.14174185	0.05360871	0.03921093	0.07263893
EU-H	0.01843119	0.15398406	0.02012367	0.04523964
US-H	0.01017459	0.01220404	0.14508505	0.03275238
ROW-H	0.14967854	0.07053513	0.0779662	0.11344204
Shares of consumption of low emission domestic and import goods				
China-L	0.34606345	0.02140224	0.01314736	0.01844225
EU-L	0.00642599	0.4385596	0.00356008	0.01181486
US-L	0.00835927	0.00339118	0.47659601	0.00882215
ROW-L	0.05766585	0.01775098	0.01830941	0.43768184

	China		**EU**		**US**		**ROW**	
Shares of high and low emission composite 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
	0.64095368	0.76757956	0.27094705	0.96259425	0.26848974	0.96328254	0.27433175	0.96163511

D. Parameters in Extraction functions

	China	EU	US	ROW
Constant Parameter	-38442.80	-3233.71	-9388.35	-80261.40
Coefficient parameter	0.00205193	0.00835591	0.00450766	0.00179642

4 . Model Experiments and Results for Carbon Motivated Regional Trade Agreements

We have used our calibrated model to simulate the impacts of carbon motivated regional trade agreements on emissions and welfare. Following Dong & Whalley (2008), we analyze the first type of carbon motivated regional agreement (lower tariffs on low carbon intensive goods) and the third types of carbon motivated regional agreements(added penalties on third parties). Results are presented in Table 3 to Table 8.

These experiments confirmed the conjectures in our previous policy paper (see Dong & Whalley (2008)), that while carbon motivated regional agreements can reduce global carbon emissions, the effect on carbon emissions is small. Carbon motivated regional agreements may increase world welfare, but the effects on participating countries may be negative or positive. When we consider third party penalties, the effects of carbon motivated trade policies on carbon emissions are still small. Even though carbon motivated regional agreements will have larger effects on emissions when high and low emissions countries are involved compared to more uniform emissions levels, the effects are still small.

In Tables 3,4,5, using central case model specifications, we analyze four groupings of regional trade agreements, these are EU-US, EU-China, US-China, and EU-US-China. In each group, there are two sub forms. One is carbon free trade agreements, which eliminates interior tariffs on low carbon intensive goods, and keep tariffs on high carbon intensive goods unchanged. The other is carbon motivated customs unions, besides within region tariff reductions as in carbon free trade agreements, we assume a common 5% external tariff on low carbon motivated goods. Totally we analyze eight kinds of carbon motivated regional trade agreements in our central case analyses.

Table 3 reports the impacts of carbon motivated trade arrangements on welfare and emissions. Most carbon motivated trade arrangements will reduce global emissions, but the effect is small. In Table 3-1, the global emissions are reduced in seven cases; the exception being in the US-China carbon CU case. The biggest reduction is from a EU-US-China carbon FTA, -0.0221% (very small change), and smallest reduction is from a EU-US carbon FTA, -0.0008%, Since China has much higher emissions intensity than the EU or the US, the carbon FTAs that involve China will have larger effects.

We can also compare carbon FTAs and carbon CUs. In case 1 and case 4, EU-US, EU-US-China, since China and ROW are respectively outside the agreement and both of these two regions have a higher emission intensity than the insiders (measured in average emissions intensity across sectors), carbon CUs has more impact than carbon FTAs in these two scenarios. In cases 2 and 3, EU-China, US-China, the outside countries have lower emissions levels than insiders (average level). In this case carbon FTAs have more impacts on emissions than a carbon CU. A carbon CU has a larger role than a carbon FTA in reducing carbon emissions when the outsider has higher emission intensity than insiders.

Table 3-1 also reports separate effects on country's emissions. The EU increases emissions in most cases, since EU's carbon intensity is low, and increased trade increases production in other member countries who have a relative higher carbon intensity. For China, participating in the carbon free trade areas will decrease China's carbon emissions, such that EU-China carbon FTA, US-China carbon FTA , EU-US-China FTA will decrease China's emissions 0.0227%, 0.0002%, 0.0202%. For US, in most cases, participating in carbon FTAs and CUs will reduce it's carbon emissions.

In Table 3-2, for welfare analysis, we use Hicksian CV and EV measures capturing the effects of temperature change.

$$CV_i = \frac{\Delta U_i}{(\frac{C_i - \Delta T_0}{C_i})^{\beta}} = \frac{U_i^1 - U_i^0}{(\frac{C_i - \Delta T_0}{C_i})^{\beta}} \qquad (19)$$

$$EV_i = \frac{\Delta U_i}{(\frac{C_i - \Delta T_1}{C_i})^{\beta}} = \frac{U_i^1 - U_i^0}{(\frac{C_i - \Delta T_1}{C_i})^{\beta}} \qquad (20)$$

In Table 3-2, since the temperature change is small, $\Delta T_0 \approx \Delta T_1$, and CV and EV measures from equations (19) and (20) are similar. We only focus on the CV measure. For the global economy, in most cases (except a US-China carbon FTA), carbon motivated regional trade agreements are welfare improving. And comparing carbon FTA and CU, in case 1, since the outsider has higher carbon emissions, the total welfare increase is small, for a EU-US FTA, when reducing the tariff on outsider's low carbon goods to a 5% CET , A EU-US CU however, seems to improve global welfare more. In cases 2,3 and 4, the high emission country China is involved in the carbon arrangement, so a carbon CU is more powerful than carbon FTAs in increasing global welfare. For insiders, in EU-US FTA/CU, EU-China FTA/CU , EU-US-China FTA/EU, the EU will benefit most from these arrangements, in US-China CU, China will benefit most. For outsiders, in all cases, outsiders increase welfare in carbon FTAs, but lose in a carbon CU.

Table 3-1 Impacts of Carbon Motivated Trade Agreements on Emissions(Energy Use) (% Change Based on 2006 Data)

	Carbon FTA/CU	% Change in Emissions				
		China	EU	US	Row	Total
1	EU-US FTA	0.0029%	0.0102%	-0.0266%	0.0013%	-0.0008%
	EU-US CU (5 % CET)	-0.0123%	0.1761%	-0.0019%	-0.0711%	-0.0162%
2	EU-China FTA	-0.0227%	0.1342%	0.0437%	-0.0715%	-0.0186%
	EU-China CU(5 % CET)	0.0174%	0.1576%	-0.0975%	-0.0509%	-0.0090%
3	US-China FTA	-0.0002%	0.0063%	-0.0069%	-0.0067%	-0.0027%
	US-China CU (5 % CET)	0.0311%	-0.0695%	-0.0627%	0.0268%	0.0103%
4	EU-US-China FTA	-0.0202%	0.1509%	0.0114%	-0.0771%	-0.0221%
	EU-US-China CU (5 % CET)	0.0108%	0.1591%	-0.0569%	-0.0695%	-0.0130%

Table 3-2 Impacts of Carbon Motivated Trade Agreements on Welfare (in billion $)

Carbon FTA	Change in Welfare by Region (CV)					Change in Welfare by Region (EV)				
	China	EU	US	Row	Total	China	EU	US	Row	Total
EU-US FTA	10.672797	151.197951	-178.789555	19.304016	2.385208	10.672797	151.197963	-178.789570	19.304018	2.385209
EU-US CU (5 % CET)	-952.283340	2299.904447	-18.192248	-656.740161	672.688698	-952.284389	2299.906981	-18.192268	-656.740884	672.689439
EU-China FTA	-1337.797145	1459.422417	25.368077	605.296458	752.289807	-1337.798767	1459.424187	25.368107	605.297192	752.290720
EU-China CU(5 % CET)	543.544092	2753.094287	-323.619967	-2816.767173	156.251240	543.544548	2753.096597	-323.620239	-2816.769536	156.251371
US-China FTA	-81.774228	9.803609	7.074769	127.446919	62.551069	-81.774246	9.803611	7.074771	127.446946	62.551082
US-China CU (5 % CET)	1716.633303	-108.648317	179.396058	-2375.405951	-588.024906	1716.632540	-108.648269	179.395979	-2375.404894	-588.024644
EU-US-China FTA	-1414.416407	1621.737205	-137.351419	751.945956	821.915336	-1414.418537	1621.739647	-137.351625	751.947088	821.916573
EU-US-China CU (5 % CET)	243.189927	2734.294852	63.773936	-2705.995800	335.262914	243.190199	2734.297920	63.774007	-2705.998836	335.263290

In Table 4, we compare the welfare effects of carbon based regional trade agreements and traditional trade agreements, also calibrating a non climate change traditional trade model to the same trade, production and consumption data for 2006-2036. This allows us to compare the welfare impacts of similar tariff arrangements with and without climate change considerations. There are four country cases where the sign change from a negative CV (in traditional carbon regional agreements) to a positive CV (in carbon based regional agreement). The four cases are: in EU-US FTA, the welfare of EU, and total welfare, in US-China CU, the welfare of US and in EU-US-China CU, the welfare of China. That suggests carbon motivated regional trade agreements increase welfare for participating countries over conventional regional agreements.

In Table 4, comparing impacts on total welfare, in most cases, carbon motivated regional trade agreements reduce welfare compared to traditional regional trade agreements. In the 6 cases(all except EU-US FTA/ CU) ,since these carbon regional trade agreements have no tariff preferences towards high energy intensive goods, which will reduce the consumption of such kind of goods, the negative consumption effect is bigger than the positive temperature effect, so the total welfare effect is negative.

In Table 4, we also consider the welfare change of individual countries, and for the ROW. All 8 cases show welfare reductions under a carbon regional trade agreements compared to traditional trade agreements which means that carbon motivated regional trade agreements offer more incentives for the outsiders to join environmental trade agreements. For China, only under a EU-US FTA/CU does China's welfare reduce under carbon free trade agreements. For EU, as an outsider the EU faces losses in US-China carbon regional trade agreements compared to traditional trade agreements. But when considering US , there is some change in EU-US FTA/EU cases where the US loses in carbon agreements compared to traditional agreements.

Table 4 Comparing Conventional CU / FTA Analysis and Carbon Based Regional Trade Agreement Analysis(billion $)

Carbon FTA/CU	Carbon Based Regional Agreement Analysis : Change in Welfare by Region (CV)					Conventional Regional Agreements Analysis : Change in Welfare by Region (EV)				
	China	**EU**	**US**	**Row**	**Total**	**China**	**EU**	**US**	**Row**	**Total**
EU-US FTA	10.672797	151.197951	-178.789555	19.304016	2.385208	63.895291	-24.256359	-171.007329	106.121569	-25.246827
EU-US CU (5 % CET)	-952.283340	2299.904447	-18.192248	-656.740161	672.688698	-897.757238	2122.934557	-11.926031	-568.811030	644.440258
EU-China FTA	-1337.797145	1459.422417	25.368077	605.296458	752.289807	-1583.533067	1216.959514	60.438650	1164.303098	858.168195
EU-China CU(5 % CET)	543.544092	2753.094287	-323.619967	-2816.767173	156.251240	294.330273	2497.693855	-287.134231	-2240.576825	264.313073
US-China FTA	-81.774228	9.803609	7.074769	127.446919	62.551069	-349.715881	51.949010	-51.645805	531.011861	181.599184
US-China CU (5 % CET)	1716.633303	-108.648317	179.396058	-2375.405951	-588.024906	1445.527652	-65.896454	113.499567	-1961.025906	-467.895142
EU-US-China FTA	-1414.416407	1621.737205	-137.351419	751.945956	821.915336	-1879.439131	1252.433868	-140.989771	1794.158006	1026.162972
EU-US-China CU (5 % CET)	243.189927	2734.294852	63.773936	-2705.995800	335.262914	-226.735896	2352.761394	52.656415	-1636.997994	541.683920

In Table 5 , we analyze the impacts of carbon based regional trade agreements on trade flows and production. In nearly all eight cases, carbon FTA/CU will increase insider's imports, except in the case of EU-China carbon FTA for China, and the EU-US-China FTA for China. For outsiders the results are that carbon FTAs will increase outsider's imports, but a carbon CU (5% CET) will reduce outsider's imports.

Table 5 also reports the impacts on production in nearly all cases. China, US, Row increase low energy intensive goods, production, and reduce high energy intensive goods production, except in an EU-US FTA(China production), a US-China CU (China ,ROW Production), a EU-China FTA(US production). As for the EU, except for US-China a FTA/CU increases low energy intensive goods production, and reduces high energy intensive goods production. In all other cases ,the EU reduces low energy intensive goods production and increases high energy intensive goods production. That means that high emission countries will tend to produce more low energy intensive goods, and less high energy intensive goods, no matter whether they are outsiders or insiders. For a low emission country (EU), when it is an outsider, it will tend to produce more low energy intensive goods, and less high energy intensive goods, and when it is an insider, vice versa. That means if carbon regional trade agreements are signed between high emission countries, it will be more forceful in reducing carbon emissions.

Table 5 Impacts of Carbon Based Regional Trade Agreements on Trade Flows and Production

	% Change in Value of Imports				% Change in Production							
					Emissions intensive good				Emissions non intensive good			
	China	**EU**	**US**	**Row**	**China**	**EU**	**US**	**Row**	**China**	**EU**	**US**	**Row**
EU-US FTA	0.0115%	0.7663%	0.1901%	0.0068%	0.0035%	0.0213%	-0.0612%	-0.0032%	-0.0023%	-0.0072%	0.0166%	0.0015%
EU-US CU (5 % CET)	-1.0611%	6.7985%	0.4708%	-0.2257%	-0.4318%	0.3886%	-0.0755%	-0.3010%	0.3970%	-0.1320%	0.0223%	0.1190%
EU-China FTA	-0.9654%	5.1045%	0.0170%	0.2108%	-0.5591%	0.2633%	0.0132%	-0.3120%	0.5120%	-0.0888%	-0.0013%	0.1236%
EU-China CU(5 % CET)	4.4944%	8.4233%	-0.1449%	-0.9729%	-0.0869%	0.3607%	-0.2599%	-0.2200%	0.0859%	-0.1228%	0.0713%	0.0871%
US-China FTA	0.5988%	0.0070%	1.0070%	0.0443%	-0.0633%	-0.0012%	-0.0282%	-0.0381%	0.0587%	0.0007%	0.0080%	0.0153%
US-China CU (5 % CET)	5.9092%	-0.0622%	1.2241%	-0.8219%	0.4138%	-0.1522%	-0.1029%	0.1165%	-0.3746%	0.0517%	0.0268%	-0.0461%
EU-US-China FTA	-0.3775%	5.8723%	1.2164%	0.2619%	-0.6206%	0.2837%	-0.0736%	-0.3539%	0.5699%	-0.0954%	0.0225%	0.1407%
EU-US-China CU (5 % CET)	4.3890%	8.6714%	1.4253%	-0.9342%	-0.2271%	0.3403%	-0.1924%	-0.2980%	0.2140%	-0.1154%	0.0537%	0.1179%

In Table 6-1, we report sensitivity results for elasticities and other key model parameters for carbon based regional trade agreements analysis. If we choose the case of a EU-US-China carbon FTA, decreasing trade elasticities increases the global emissions impact of the agreement. The outsider increases emissions, and for the insider, China emissions increases, while EU and US reduce emissions. Decreasing production elasticities, all insiders will reduce emissions, but for outsiders, the result is not clear. Reducing extraction elasticities, all regions increase emissions. With a combined reduction of trade elasticities, production elasticities and extractions elasticities together, total emissions increase, and outsiders still increase emissions, and for the insiders, EU and US emissions fall while the China increases emissions.

In Table 6-2, when considering welfare inputs, lower trade elasticities will increase all regions welfare impacts, and a fall in production elasticities increases the welfare of EU,US and ROW and decreases the welfare of the China and total welfare. Also a fall in extraction elasticities will increase the welfare of EU, US, Row, and decrease the welfare of the China and total welfare. With a combined reduction of trade elasticities, production elasticities and extractions elasticities together, all regions welfare impacts of trade agreements will increase.

Table 6-1 Sensitivity of Carbon Based Regional Trade Agreements Analysis to Elasticities and Other Key Model Parameters (% change based on 2005 data)

	EU-US-China FTA	% Change in emissions				
		China	EU	US	Row	Total
1.	Base Case (Table 3-1)					
2	1.5 trade elasticities in all regions	-0.0146%	0.1146%	0.0084%	-0.0405%	-0.0105%
3	Half trade elasticities in all regions	0.0133%	-0.0993%	-0.0105%	0.0357%	0.0092%
4	Double production substitution elasticities in all regions	0.0112%	0.0958%	0.1412%	-0.0721%	0.0065%
5	Half production substitution elasticities in all regions	-0.0114%	-0.0126%	-0.0108%	-0.0113%	-0.0114%
6	Double the extractions elasticities in all regions	-0.0081%	-0.0078%	-0.0080%	-0.0081%	-0.0081%
7	Half the extractions elasticities in all regions	0.0001%	0.0001%	0.0001%	0.0001%	0.0001%
8	2,4, and 6 together	-0.0115%	0.1222%	0.0142%	-0.0394%	-0.0074%
9	3,5,and 7 together	0.0061%	-0.1068%	-0.0172%	0.0286%	0.0020%

Table 6-2 Sensitivity of Carbon Based Regional Trade Agreements Analysis to Elasticities and Other Key Model Parameters (billion $)

	EU-US-China FTA	CV China	CV EU	CV US	CV Row	CV Total	EV China	EV EU	EV US	EV Row	EV Total
1	Base Case (Table 3-2)										
2	1.5 trade elasticities in all regions	-11884.33	-33674.22	-39881.21	-52711.38	-138151.13	-11884.33	-33674.24	-39881.23	-52711.41	-138151.22
3	Half trade elasticities in all regions	28332.00	81356.55	90683.11	130990.17	331361.84	28331.99	81356.51	90683.07	130990.10	331361.66
4	Double production substitution elasticities in all regions	-15.79	200.32	-1053.23	-327.36	-1196.06	-15.79	200.32	-1053.23	-327.36	-1196.06
5	Half production substitution elasticities in all regions	-8.29	4.24	1.41	0.51	-2.12	-8.29	4.24	1.41	0.51	-2.12
6	Double the extractions elasticities in all regions	0.39	-1.72	-1.31	-2.12	-4.76	0.39	-1.72	-1.31	-2.12	-4.76
7	Half the extractions elasticities in all regions	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	2,4, and 6 together	-11876.01	-33683.83	-39885.16	-52703.61	-138148.61	-11876.02	-33683.84	-39885.17	-52703.63	-138148.66
9	3,5,and 7 together	28327.44	81358.23	90683.47	130989.70	331358.85	28327.44	81358.23	90683.47	130989.69	331358.83

Table 7 Sensitivity of Results to Key Parameters in the Environmental Component of Modeling Structure (billion $)

		EU-US-China FTA (CV)					EU- China FTA(CV)				
		China	EU	US	Row	Total	China	EU	US	Row	Total
1	Base Case (Table 3-2)	473.88	997.74	1162.91	1549.24	4183.77	476.42	1003.10	1169.15	1557.56	4206.24
2	Halve damage estimated to calibrate preferences towards temperature change	-977.00	-2057.01	-2397.68	-3193.98	-8625.67	-966.35	-2034.60	-2371.56	-3159.18	-8531.70
3	Double damage estimated to calibrate preferences towards temperature change	481.65	1014.14	1181.90	1574.53	4252.22	484.28	1019.68	1188.36	1583.13	4275.44
4	Halve temperature change for BAU scenario	-1166.54	-104853.31	-2862.82	-3813.58	-112696.25	-1151.40	-103492.22	-2825.66	-3764.08	-111233.35
5	Double temperature change for BAU scenario	473.88	997.74	1162.91	1549.24	4183.77	476.42	1003.10	1169.15	1557.56	4206.24

Table 7 reports sensitivity analysis of key parameters in the environmental component of the modeling structure. We choose two cases, EU-US-China FTA and EU-China FTA, both cases show that if we increase damage cost estimates, the welfare impacts will increase. And also if we increase temperature change,the welfare impacts of agreements will increase with increasing temperature change.

In Table 8 ,we analyze the impacts of carbon based regional trade agreements on emissions and welfare with trade penalties on third parties. Results show that increasing penalties on outsiders effectively decreases the emissions of outsiders, but increase the emission of insiders, and also increase the world total emissions. The EU-US FTA involves zero tariff on low emission goods, increasing domestic production (and consumption) of high emission goods. Imports from China of high emission goods fall, and emissions rise in the EU and the US. Interestingly, there are peaks for the implied emissions reduction as a function of external penalty rates, suggesting an optimal external tariff in terms of maximizing emissions reduction.

Table 8 Impacts on Emissions of Carbon Based Regional Trade Agreements with Penalties (billion $)

		EU-US FTA % Change in Emissions				
		China	EU	US	Row	Total
1	FTA without penalty	0.0029%	0.0102%	-0.0266%	0.0013%	-0.0008%
2	15% external rate on high emission goods	-0.1525%	1.4337%	2.0618%	-1.0050%	-0.0352%
3	30% external rate on high emission goods	-0.3410%	3.0118%	4.3096%	-2.0372%	-0.0619%
4	50% external rate on high emission goods	-0.5672%	4.7040%	6.7504%	-3.0804%	-0.0772%
5	100% external rate on high emission goods	-1.0188%	7.6370%	11.0573%	-4.7278%	-0.0690%
6	150% external rate on high emission goods	-1.3469%	9.5141%	13.8655%	-5.6696%	-0.0385%
7	200% external rate on high emission goods	-1.5919%	10.8182%	15.8405%	-6.2688%	-0.0042%
8	15% external rate on all goods	-0.1325%	1.4400%	1.8748%	-0.9476%	-0.0299%
9	30% external rate on all goods	-0.2756%	2.8010%	3.8395%	-1.8232%	-0.0358%
10	50% external rate on all goods	-0.4518%	4.2468%	5.9622%	-2.7089%	-0.0342%
11	100% external rate on all goods	-0.8130%	6.7303%	9.6934%	-4.1116%	-0.0093%
12	150% external rate on all goods	-1.0810%	8.3110%	12.1237%	-4.9175%	0.0243%
13	200% external rate on all goods	-1.2836%	9.4075%	13.8343%	-5.4330%	0.0572%

5. Concluding Remarks

We build on an earlier policy piece by Dong & Whalley(2008) and develop a multi-region general equilibrium model calibrated to a single period data set reflecting a business as usual scenario between 2006 and 2036. We use this to evaluate the impacts of both carbon motivated free trade agreements and customs unions on trade, emissions and welfare. Our results confirm the widely held view that as a mechanism for reducing carbon emissions trade policy would seem to only offer quantitatively small and indirect effects, since it is economic growth more so than trade and its composition that seemingly fuels growing emissions.

Results from model analysis show that carbon motivated trade arrangements may reduce global carbon emissions. And as conjectured by Dong & Whalley(2008), the effect of such agreements on emissions are relatively small comparing carbon FTAs and carbon CU, carbon CUs seem more powerful than carbon FTAs in terms of emissions impacts when outsiders have higher emission intensities than insiders.

For welfare analysis , most carbon RTAs are welfare improving. When including high emission countries in the agreements, carbon based CUs are more effective than carbon FTAs. Comparing carbon RTAs to traditional RTAs, since carbon RTAs do not eliminate tariffs on high emission goods, the negative consumption effect is bigger than the positive temperature effects, so the total welfare effect is negative. Carbon RTAs also give a much bigger incentive than traditional RTAs for the outsider to join agreements. In most cases, carbon based RTAs will increase insider's imports, For outsiders , the impacts on imports are unclear: carbon based RTAs will increase the production of low energy intensive goods, and reduce the production of high energy intensive goods; Finally even with trade penalties on third parties there are still not large effects in terms of carbon emissions reductions

As the global debate on a new Post 2012 climate change regime moves forward to the 2009 Copenhagen UNFCCC negotiation, trade and climate issues will likely link prominently. These results seemingly support the general argument that as a way of addressing climate change, trade policy has only small impacts.

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