1. INTRODUCTION

The 1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) sets obligatory requirements for the so-called Annex-I countries with respect to their greenhouse gas emissions. These countries should, as a whole, cut their collective emissions of the six key greenhouse gases to 5.2 percent below the 1990 levels during the first commitment period (i.e., 2008-2012). The need for cost-effectiveness was emphasized in the UNFCCC Article 3.3 (UN, 1992) and is facilitated by the "flexible mechanisms" under Articles 6 (Joint Implementation, JI), 12 (Clean Development Mechanism, CDM), and 17 (International Emissions Trading, IET) of the Protocol (UN, 1997).

Under the flexible mechanisms, the reduction efforts are redistributed among the trading countries with differentiated costs. Consequently, the harmonization of marginal abatement costs are achieved, and the countries can meet the Kyoto targets cost effectively. The marginal costs of compliance with the abatement targets agreed in Kyoto crucially hinge on whether the use of the flexible mechanisms is restricted or not. In the case where the abatement is required on the basis of individual country, estimates of the marginal costs to meet the abatement targets vary from near zero to as high as US$1,200/tC.[1] In contrast, most studies allowing the use of the flexible mechanisms end up with estimates in the range between US$20/tC and US$150/tC (Weyant, 1999). Such different results reinforce the foundations of international cooperation in abating the emissions of greenhouse gases.

The Kyoto Protocol came into effect in early 2005, following the formal ratification of the Russian Federation. Starting from the year of 2008, the Russian Federation can sell its reductions in carbon emissions, normally referred to as hot air, under IET. The main reason for this reduction is the economic depression, mainly due to the collapse of the former Soviet Union (Victor *et al.*, 2001). Mastepanov *et al.* (2001) attributes 60-70 percent of the emission reductions in the energy sector during the last decade to economic downturn, 8-12 percent to initiation of institutional reforms in the energy sector, and the rest to wider use of natural gas and structural changes in the economy.

Nevertheless, large amounts of hot air may significantly decrease the environmental effectiveness of the Kyoto Protocol *vis-à-vis* strictly domestic abatement (Bohringer and Loschel, 2003). This concern has been confirmed by the research evidences which show that a great share of the effective abatement requirements can be covered by the hot air (Paltsev, 2000; Victor *et al.*, 2001). On the other hand, the dimension of the emission trading market also has an impact on the global economy. The Kyoto abatement targets represent a costly barrier of economic growth for the Annex-I countries, but the flexible mechanisms offer lower cost opportunities of meeting the Kyoto targets and thus reduce such a barrier. Including the hot air in IET represents a relaxation of the constraint on carbon emissions for the Annex-I countries as a whole, consequently leading to even lower economic losses.

Based on the above, the hot air trading has an important implication on the global environment and economy. How, and how much, then, will such a trading affect the reductions in carbon emissions, the equilibrium prices of the AAUs (Assigned Amount Units), and the compliance costs of the Annex-I countries? This question is of practical interest and deserves investigation since it has a significant influence on the environmental- and cost-

[1] US$/tC: US dollars per ton of carbon.

effectiveness of the Kyoto Protocol. It is therefore the goal of this paper to evaluate the quantitative effects of trading hot air under IET.

To achieve the goal of evaluating the quantitative effects of hot air trading, the model should be the one with the framework which (1) is global in coverage; (2) captures the interaction between the economy, the energy system, and the environment; (3) has an explicit treatment of energy substitution, physical energy use, and corresponding carbon emissions. For this reason, we follow the lead of Burniaux and Truong (2002), and employ a global, applied general equilibrium model with energy substitution. The model by Burniaux and Truong, namely, GTAP-E, is the energy-environmental version of Global Trade Analysis Project (GTAP) framework (Hertel and Tsigas, 1997), built upon the GTAP Version 5 database. Two scenarios are implemented with the GTAP-E model, including the Annex-I emissions trading with and without hot air. In both of the scenarios, the United States, Australia and the non Annex-I countries keep outside the Protocol and thus have no reductions in carbon emissions. Moreover, the CDM mechanism and the other greenhouse gases are not included. By exploring the differences in the numerical results of the two scenarios, we can show the quantitative effects of the hot air trading.

The remainder of this paper is organized as follows. Section 2 introduces the model and data sources, as well as regional and sectoral aggregation. In section 3, the simulation scenarios and the results are reported in turn. The concluding remarks are provided in the final section.

2. THE MODEL AND THE DATA AGGREGATION

The GTAP-E model is an extension of the GTAP model. Except for characterizing the economic activities as the GTAP model did, the GTAP-E model further incorporates the energy-economy-environment-trade linkages by modeling the key factor, energy substitution, in the linkages and by explicitly relating the carbon emissions to the volume of the physical energy use. The energy volume data in the GATP-E model are from the energy balances data bases of International Energy Agency (Burniaux *et al.*, 2002). Carbon emission coefficients for each kind of fuels are introduced to capture the proportional relationship between carbon emissions and per unit fuel use. The total carbon emission level for each country is computed by summing the products of sectoral and private households' physical energy use and the associated carbon emission coefficients. For more details about the GTAP and the GTAP-E models, the reader is referred to Hertel and Tsigas (1997) and Burniaux and Truong (2002), respectively.

To analyze the implications of trading hot air and its impact on the global economy, the data and the aggregation strategy we adopt in this paper is slightly different from that of the current GTAP-E model.[2] The GTAP Version 5.4 database containing 78 regions by 57 sectors is aggregated to a much higher level, 11 regions by 8 sectors. The 11 regions are the European Union, Japan, the Russian Federation, Eastern Europe & Rest of Former Soviet Union (EERFSU), the Rest of the Annex-I Countries (ROA-I), the Unites States, Net Energy Exporters, China, India, Australia, and the Rest of the World. The 8 sectors are agriculture,

[2] The current GTAP-E model is built upon the GTAP Version 5 database, and the base year is 1997. The GTAP Version 5.4 database has the same base year, but a more disaggregated regions and sectors. The main reason why we re-aggregate the database is due to the fact that Australia and the Russian Federation are not separated from the other Annex-I regions in the current GTAP-E model.

coal, crude oil, natural gas, refined oil products, electricity, energy intensive industries, and other industries and services.

3. Scenario Descriptions and Simulation Results

3.1 Scenario Descriptions

The scenarios in this paper are designed to illustrate the quantitative effects of the hot air trading. The percentage reductions of carbon emissions for the Annex-I countries/regions used here, as shown in Table 1, are taken from the GTAP-E model. They originate from OECD GREEN model (OECD, 1999). These emission constraints correspond to the reductions that the Annex-I countries are forecast to achieve in 2012 (i.e., the end of the first commitment period of the Protocol) relative to their associated emission levels in an unconstrained baseline scenario (see Table 1). The numbers with negative signs stand for the abatement obligations agreed in the Kyoto Protocol. The positive number of 12.87(%) for the Russian Federation means that it is allowed to have carbon emissions that is 12.87% higher than its baseline level (around 48 million tons of carbon). This is the so called hot air that may be traded under IET. In the scenario where the hot air is not traded, the percentage reductions of carbon emissions is set to equal 0, meaning that the Russia Federation is not required to abate the carbon emissions but can participate in IET. Given the fact that the United States, Australia, and non Annex-I countries keep outside the Protocol, on the other hand, these countries are not required to abate carbon emissions, and are not allowed to participate in IET. It is therefore that no emission reductions take place in these countries.

Table 1: Reductions of Carbon Emissions for the Annex-I Countries/Regions

Countries/Regions	Baseline Emissions (million tons of carbon)	Annex-I Trading with Hot Air (%)	Annex-I Trading without Hot Air (%)
The EU	911.16	-22.40	-22.40
Japan	337.22	-31.80	-31.80
Russia	372.53	12.87	0.00
EERFSU	404.51	0.00	0.00
ROA-I	173.08	-35.70	-35.70
Weighted Average	—	-14.79	-16.97

Source: The percent reductions of carbon emissions are taken from the GTAP-E Model (Burniaux and Truong, 2002).

3.2 Simulation Results

This subsection reports the quantitative results of the two simulation scenarios. We first discuss the marginal abatement costs of the Annex-I emissions trading. The emission changes relative to the baselines, and the compliance costs of the Annex-I countries are then presented in turn.

Marginal Costs of Abatement

Table 2 presents the simulation results for marginal abatement costs of the Annex-I emissions trading from our simulations and from other models. The marginal abatement costs are equalized across all of the trading countries at the equilibrium condition of IET, and equal the equilibrium price of the AAUs. Our result of marginal abatement cost for the Annex-I trading with hot air is US$49.20/tC. In the case where the hot air is not traded, the marginal abatement cost rises to US$59.81/tC. This is due to the fact that a large quantity of the AAUs is supplied in the case where the hot air is traded, consequently leading to a depression of the price of the AAUs. Such a depression of the price of the AAUs, however, might lead to an underestimation of the real cost to abate the carbon emissions.

Table 2: Simulation Results for Marginal Abatement Costs of Annex-I Trading

Models	Marginal Cost of Abatement (US$/tC)
GTAP-E	
Annex-I Trading with Hot Air	49.20
Annex-I Trading without Hot Air	59.81
SGM	76
MERGE	114
G-Cubed	37
POLES	112
GTEM	123
WorldScan	20
GREEN	67
AIM	65

Sources:
The simulation results of other models are taken from Baron and Lanza (2000), which is based on Van den Mensbrugghe (1998a). The original sources for the simulation results are SGM: Sands *et al.* (1998), MERGE: Manne and Richels (1998), G-Cubed: McKibbin *et al.* (1998), POLES: Capros (1998), GTEM: Tulpule *et al.* (1998), WorldScan: Bollen *et al.* (1998), GREEN: Van den Mensbrugghe (1998b), AIM: Kainuma *et al.* (1998).

Our results of the marginal abatement costs are somewhat below the average of the other models. This is mainly because the United States and Australia keep outside the Protocol in our simulation scenarios, which sharply decreases the demand for the AAUs and hence the equilibrium prices. As noted by Baron and Lanza (2000), such differences in simulation results may also arise from three other reasons, including (a) variations in business-as-usual projections of carbon emissions; (b) different assumptions on the availability and cost of carbon-saving technology; (c) more or less detailed treatment of end-use energy and corresponding prices and taxes.

Emissions Abatement and Trading

Table 3 reports the domestic emissions and abatement, as well as the trades of AAUs of the Annex-I countries/regions in the two scenarios. All of the values are in million tons of carbon (MtC). The countries/regions with positive values in the "AAU" columns are the buyers, and those with negative values are the sellers. Three major conclusions are drawn from the table.

First, from the table we see that the sum of the emissions for the Annex-I countries in the scenario with hot air (1,873.32 MtC) is higher than that in the scenario without hot air (1,825.45 MtC). In contrast, the sum of abatement in the scenario with hot air (325.18 MtC) is lower than that in the scenario without hot air (373.05 MtC). The difference in the sum of the emissions in the two scenarios is just equal to the difference in the sum of the abatement in the two scenarios (i.e., 1,873.32-1,825.45 = 373.05-325.18 = 47.87 MtC). The difference represents the hot air that the Russian Federation has. Including this hot air in IET implies a relaxation of the constraint on carbon emissions, and consequently leads to a higher level of the total emissions.

Table 3 Actual Emissions, Domestic Abatement, and Purchase of Allowances

Unit: million tons of carbon.

Countries/Regions	Annex-I Trading with Hot Air			Annex-I Trading without Hot Air		
	Emission	Abatement	AAU	Emission	Abatement	AAU
The EU	813.48	97.68	106.42	798.09	113.07	91.02
Japan	298.51	38.71	68.52	292.30	44.92	62.32
Russia	318.29	54.24	-102.18	309.01	63.52	-63.52
EERFSU	292.82	111.69	-111.69	279.56	124.95	-124.95
ROA-I	150.22	22.86	38.93	146.49	26.59	35.20
Sum	1,873.32	325.18	0.00	1,825.45	373.05	0.00

Source: Own calculations.

Second, the Russian Federation is the foremost supplier of the AAUs, no matter if the hot air is traded or not. The other major supplier is the Eastern Europe & Rest of Former Soviet Union. The AAU sales of the Russian Federation are 102.18 MtC in the scenario with hot air, and 63.52 MtC in the scenario without hot air, respectively. Both values are higher than that of the hot air it has. This result implies that the Russian Federation has lower abatement costs, as compared with the other Annex-I countries. Its participation in IET helps to reduce the compliance costs of the other Annex-I countries.

Finally, in the scenario where the hot air is traded, all countries/regions have higher levels of carbon emissions, or, equivalently, lower levels of domestic abatement. For all of the buyers, including the European Union, Japan, and the Rest of the Annex-I Countries, the AAU purchases are higher in such a scenario. This is because the price of the AAUs is lower when the hot air is traded. The buyers of AAUs thus have lower incentive to make domestic abatement.

Compliance Costs of the Annex-I Countries

Table 4 presents the GDP losses, trading expenditures, and compliance costs for the Annex-I countries/regions. All of the values are in millions of US dollars. The positive values in the "trading expenditure" columns correspond to the expenditures of AAU purchases, while the negative values correspond to the revenues of AAU sales. In the "compliance cost" columns, the positive values represent the costs of meeting the Kyoto targets, whereas the negative values are the gains, mainly resulting from the AAU sales.

The results in the table show that trading hot air leads to compliance cost savings for the Annex-I countries as a whole. In the scenario where the hot air is traded, the sum of the compliance costs is US$29,616 million. If the hot air is not traded, the sum rises to US$36,707 million, which is one-fourth greater than that in the scenario with hot air.

As for the buyers of the AAUs, including the European Union, Japan, and the Rest of the Annex-I Countries, the compliance costs in the scenario with hot air are all lower than those in the scenario without hot air. For each of these countries, the compliance cost in the scenario with hot air is around 85% of that in the scenario without hot air.

The results for the two sellers of the AAUs are somewhat different. In the scenario where the hot air is traded, the Russian Federation has a revenue of US$5,027 million from the AAU sales. Of the total revenue, approximately half is from the sales of the hot air (US$2,359 million), and the other half is from the sales of AAUs generated by domestic abatement (US$2,668 million). The associated GDP loss of the domestic abatement is US$3,370 million. Since the revenue from the AAU sales is greater than the GDP loss, the Russian Federation has a gain of US$1,657 million from participation in IET. As for Eastern Europe & the rest of the Former Soviet Union, the AAU sales to international trading system are all generated from domestic abatement. The associated GDP loss of domestic abatement is US$2,899 million, and the revenue from the AAU sales is US$5,495 million. Therefore it has a gain of US$2,595 million from participation in IET.

If the hot air is not traded, on the other hand, the AAU sales of the two suppliers are both generated from domestic abatement. The revenue from the sales of AAUs for the Russian Federation is US$3,799 million, and for Eastern Europe & the rest of the Former Soviet Union it is US$7,473 million. The associated GDP losses of the domestic abatement for these two suppliers are US$4,411 million and US$3,628 million, respectively. For the Russian Federation, the GDP loss of domestic abatement is higher than the revenue from the AAU sales, leading to a cost of US$612 million. In contrast, the Russian Eastern Europe & the rest of the Former Soviet Union has a gain of US$3,845 million. Accordingly, it might not be beneficial for the Russian Federation to participate in IET if the hot air is not allowed to trade.

Table 4 Compliance Costs of the Annex-I Counties

Unit: millions of US dollars.

Countries/ Regions	Annex-I Trading with Hot Air			Annex-I Trading without Hot Air		
	GDP Loss	Trading Expenditure	Compliance Cost	GDP Loss	Trading Expenditure	Compliance Cost
The EU	14,961	5,236	20,197	18,353	5,444	23,797
Japan	5,745	3,371	9,116	7,055	3,727	10,782
Russia	3,370	-5,027	-1,657	4,411	-3,799	612
EERFSU	2,899	-5,495	-2,595	3,628	-7,473	-3,845
ROA-I	2,641	1,915	4,557	3,259	2,106	5,364
Sum	29,616	0	29,616	36,707	0	36,707

Source: Own calculations.

4. CONCLUDING REMARKS

This paper has examined the quantitative effects of trading hot air within the Annex-I countries on global environment and economy. The insights which emerge from this paper are summarized as follows. First, trading hot air depresses the price of the AAUs but makes no real reductions in carbon emissions. Such depression of the price of the AAUs adds to the potential for lower cost of compliance with the Kyoto targets for the Annex-I countries. However, it not only leads to an underestimation of the real cost of abating carbon emissions but it also undermines the incentive to make the domestic abatement. Second, the costs of meeting the Kyoto targets for each of the Annex-I countries and for the Annex-I countries as a whole, are all smaller if the hot air is traded. For each of the Annex-I countries that has abatement obligation, the compliance cost in the scenario where the hot air is traded is around 85% of that in the scenario where the hot air is not traded. The sum of the compliance costs for the Annex-I countries in the scenario with hot air is 80% of that in the scenario without hot air.

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