Energy Studies Review Vol. 16, No.2, 2009

ANCILLARY BENEFITS OF CARBON MITIGATION: HOW DOES IT AFFECT COST EFFECTIVENESS OF THE ANNEX-1 EMISSIONS TRADING?

Tsung-Chen Lee

ABSTRACT

This paper explores how ancillary benefits of carbon mitigation may affect the cost effectiveness of Annex-1 emissions trading. We find that emissions trading could lead to cost-savings for both the Annex-1 countries as a whole and for the individual countries, as compared with the case of no-trading. The sum of the compliance costs is minimized under the cost-effective condition where marginal costs of domestic abatement are equalized across the Annex-1 countries. However, such a condition of cost effectiveness in emissions trading does not imply cost effectiveness in terms of the compliance of individual countries. The buyers of emission allowances, consisting of the European Union, the United States and Japan, could have even lower costs of compliance in the trading case where the ancillary benefits are taken into consideration. This result supports the intervention that takes account of the ancillary benefit in designing national carbon mitigation policies. To achieve the cost effectiveness in national carbon abatement, there should be regulatory interventions so that the price of carbon emission allowances can reflect the ancillary benefits.

Key Words:
carbon mitigation, ancillary benefits, international emissions trading, cost effectiveness

JEL Classification:
Q54, Q58

Tsung-Chen Lee, is with the Departmen. of Economics, National Taipei University. 151, University Rd., San Shia, Taipei 237, Taiwan. Tel: 886-2-86747131; Fax: 886-2-26739880; E-mail: tclee@mail.ntpu.edu.tw.

1. INTRODUCTION

International emissions trading (hereafter IET) is one of the flexible mechanisms proposed by the Kyoto Protocol which aims to lower the Annex-1 countries' costs of complying with given abatement targets. The cost-effectiveness of IET has been addressed in the relevant studies (e.g., Evans, 2003; Criqui *et al.*, 1999; Kainuma *et al.*, 1999; Weyant, 1999; Rose and Stevens, 1993). An important premise of these studies is that countries trade emissions efficiently. Under the condition where the marginal costs of domestic abatement are equalized across the Annex-1 countries, the sum of the compliance costs of individual countries will be minimized. Such unfettered international trade in emission allowances substantially reduces the economic costs of meeting the abatement targets. Nevertheless, it might also lower the environmental benefits of countries that purchase emission allowances, since purchasing emission allowances would lead to a fall in carbon abatement at home, which in turn reduces the ancillary benefits (such as the improved quality of local air) arising from domestic abatement.

Ancillary benefits of carbon abatement are generally referred to as the benefits derived from carbon abatement that are in addition to the reduction in the adverse impacts of global climate change. So far a number of studies on climate policy have discussed the ancillary benefits (e.g., IPCC, 2001; Burtraw and Toman, 1998; Ekins, 1996), and several have estimated the magnitude of the benefits (e.g., Barker and Rosendahl, 2000). The evidence from the recent literature also shows that the costs of carbon abatement can be offset by the ancillary benefits resulting from lower local air pollution (e.g., Dessus and O'Connor, 2003).

In the large literature on the economics of climate change, however, most determine the optimal geographic distribution of carbon abatement according to the market cost of carbon abatement, not accounting for the extent or value of the ancillary benefits. Yet little attention is paid to the implications of ancillary benefits on the equilibrium outcome of IET. An important exception is Lutter and Shogren (2002), which indicate that, in the presence of ancillary benefits, the unfettered price of carbon emission allowances observed in international markets might significantly exceed the incremental social cost of controlling carbon emissions. They identify a tariff on tradable emission allowances to account for the interdependence of climate policy and local air pollution, and justify market interventions in relation to emission allowances traded internationally.

In addition to justifying the interventions like Lutter and Shogren did, this paper examine how ancillary benefits of carbon mitigation can affect the cost effectiveness of Annex-1 emissions trading. Individual countries generally design their own climate policies from the perspective of own-cost minimization, rather than global-cost minimization. Despite of causing distortion and violating the trading efficiency in an IET market, intervention that takes account of local environmental benefits might be appealing to individual Annex-1 countries if it helps to lower the countries' real cost of compliance. Under the circumstance where the interventions are justified, the equilibrium trading outcome as well as the trading efficiency would be different from those in the cost-effective case, and neglecting the interventions would reach a biased prediction of trading outcomes. In addition, such an intervention in IET is validated for practicability, given the fact that the

Protocol itself does not provide an unambiguous definition regarding the individual Annex-1 countries' transaction levels, and that neither the Protocol nor WTO (World Trade Organization) provides specific measures in response to the interventions.

Accordingly, a theoretical model of IET and its numerical application to the Annex-1 emissions trading are developed to analyze the implications of ancillary benefits on IET. With the theoretical model, we first derive the equilibrium allowance prices and optimal emission levels in the scenario of considering ancillary benefits and that of global cost-effectiveness. It is shown that the equilibrium allowance price in the scenario of cost effectiveness is higher, since taking ancillary benefits into consideration leads to a fall in the aggregate demand for the emission allowances. High-benefit countries have lower emissions whereas low-benefit countries have higher emissions when considering ancillary benefits. The numerical results show that the allowance-buying countries, consisting of the European Union, the United States and Japan, could have even lower costs of compliance when considering the ancillary benefits. This result supports the interventions that take account of the ancillary benefits of domestic abatement in designing national carbon mitigation policies. To achieve the cost effectiveness in national carbon abatement, there should be regulatory interventions so that the price of carbon emission allowances can reflect the ancillary benefits.

The remainder of this paper is organized as follows. Section 2 develops the theoretical model of Annex-1 emissions trading. Section 3 presents the data and numerical analysis. The conclusions drawn from our findings and their implications for policy recommendations are provided in the final section.

2. THE MODEL

Consider a partial equilibrium model of IET among the Annex-1 countries. There are N countries, indexed by $i=1,..., N$. Let $\bar{b}_i$ be the BAU (business as usual) emissions of country i, i.e., the emission level that country i would generate in the course of its normal operations without any deliberate action on carbon abatement. Each country is required to be in compliance with the Kyoto agreement. Denote $\bar{w}_i$ the emission cap assigned to country i. The term $(\bar{b}_i - \bar{w}_i)$ hence represents the "Kyoto gap".

With IET, individual countries could comply with the emission caps by either domestic abatement or purchases (sales) of emission allowances. Let e_i be the actual emissions of country i, with $e_i \le \bar{b}_i$. Then the abatement target of the "Kyoto gap" could be expressed as $(\bar{b}_i - \bar{w}_i) = (\bar{b}_i - e_i) + (e_i - \bar{w}_i)$, where $(\bar{b}_i - e_i)$ and $(e_i - \bar{w}_i)$ are respectively the domestic abatement and purchases (sales) of emission allowances. The domestic abatement of country i is carried out at a cost given by

$$C_i(e_i) = (1/2)\,\alpha_i\,(\bar{b}_i - e_i)^2,\ i=1,..., N, \tag{1}$$

where $C_i(e_i)$ is the abatement cost associated with abatement level $(\overline{b}_i - e_i)$; and $\alpha_i > 0$ is the technological parameter. The domestic abatement cost is quadratic in the abatement level, implying that the marginal abatement cost is positive and increasing.

Domestic abatement of carbon emissions yields ancillary benefits such as the improved quality of local air. Based on Tol (1997), the ancillary benefits $A_i(\cdot)$ are assumed to be linear in the domestic abatement level:

$$A_i(e_i) = \gamma_i\,(\overline{b}_i - e_i)\,,\ i=1,\dots,N\,, \tag{2}$$

where $\gamma_i > 0$ represents the marginal ancillary benefits of domestic abatement for country i.

2.1 Optimality Conditions When Considering Ancillary Benefits

Given the above settings, the problem faced by country i is to minimize its net compliance cost (i.e., the net cost of domestic abatement plus trading expenditure) with respect to its domestic emissions e_i. That is,

$$\min_{e_i}\ \ [(1/2)\ \alpha_i\,(\overline{b}_i - e_i)^2 - \gamma_i(\overline{b}_i - e_i)] + p\,(e_i - \overline{w}_i)\,,\ i=1,\dots,N\,, \tag{3}$$

where p is the price of emission allowances. The associated first-order conditions for an interior solution are

$$\alpha_i\,(\overline{b}_i - e_i^*) - \gamma_i = p\,,\ i=1,\dots,N\,. \tag{4}$$

Equation (4) indicates that country i will adjust its emissions until the net marginal cost of domestic abatement ($\alpha_i\,(\overline{b}_i - e_i^*) - \gamma_i$) equals the marginal saving of abatement (p).

To derive the equilibrium allowance price, we first rearrange (4) as

$$e_i^* = (\alpha_i\,\overline{b}_i - \gamma_i - p)/\alpha_i\,,\ i=1,\dots,N\,. \tag{5}$$

Equation (5) shows the demand for emission allowances of country i. It implies that the individual country with higher BAU emissions or lower ancillary benefits of domestic abatement has a higher demand for allowances. A rise in the price of allowances instead leads to a fall in the demand for allowances. Substituting (5) into the market-clearing condition $\sum_{i=1}^{N} e_i^* = \sum_{i=1}^{N} \overline{w}_i$ gives the equilibrium allowance price

$$p^* = \frac{\sum_{i=1}^{N} [(\bar{b}_i - \bar{w}_i) - (\gamma_i / \alpha_i)]}{\sum_{i=1}^{N} (1/\alpha_i)} . \tag{6}$$

Based on (6), the equilibrium allowance price increases as the "Kyoto gap" $(\bar{b}_i - \bar{w}_i)$ increases, while decreases as the ancillary benefits γ_i become larger. A higher level of "Kyoto gap" could arise from: i) a higher level of $\bar{b}_i$ which increases the demand for allowances, and ii) a lower level of $\bar{w}_i$ which reduces the supply of allowances, and both of them result in a higher equilibrium price. On the other hand, the equilibrium allowance price is decreasing with rising ancillary benefits due to a lower demand for emission allowances.

2.2 Cost Effectiveness of the Annex-1 Emissions Trading

In the case where the ancillary benefits of domestic abatement are neglected, the optimal conditions of compliance cost minimization are

$$\alpha_i (\bar{b}_i - \hat{e}_i) = p , \; i = 1, \ldots, N . \tag{4'}$$

Equation (4') means that the marginal cost of domestic abatement for country i has to equal the allowance price, or equivalently, that the marginal costs of domestic abatement are equalized across the Annex-1 countries. This condition is generally referred to as the condition of cost-effectiveness for the Annex-1 emissions trading, as it is the condition under which the sum of the compliance costs of individual countries is minimized.

The demand for emission allowances could be obtained by rearranging (4') as

$$\hat{e}_i = (\alpha_i \bar{b}_i - p) / \alpha_i , \; i = 1, \ldots, N . \tag{5'}$$

A comparison between (5) and (5') shows that the demand for emission allowances would be higher if the ancillary benefits are neglected, ceteris paribus. Finally, substituting (5') into the market-clearing condition $\sum_{i=1}^{N} \hat{e}_i = \sum_{i=1}^{N} \bar{w}_i$ gives the associated equilibrium allowance price

$$\hat{p} = \frac{\sum_{i=1}^{N} (\bar{b}_i - \bar{w}_i)}{\sum_{i=1}^{N} (1/\alpha_i)} . \tag{6'}$$

2.3 A Comparison

In what follows, we provide a comparison between the equilibria of the above two scenarios. Note that "star (*)" and "hat (^)" respectively represent the scenario of considering ancillary benefits (hereafter AB) and the scenario of cost effectiveness (hereafter CE).

First, the difference in equilibrium allowance prices in the two scenarios can be derived by subtracting (6) from (6')

$$(\hat{p}-p^*)=\frac{\sum_{i=1}^{N}(\gamma_i/\alpha_i)}{\sum_{i=1}^{N}(1/\alpha_i)}>0. \tag{7}$$

Equation (7) indicates that $\hat{p}>p^*$, i.e., the equilibrium allowance price in the scenario of CE is higher. This result could be explained by the fact that taking ancillary benefits into consideration leads to a fall in the aggregate demand for the emission allowances.

Next turn to the difference between optimal emission levels, $\hat{e}_i$ and e_i^*. Subtracting (5) from (5') yields

$$\hat{e}_i-e_i^*=[-(\hat{p}-p^*)+\gamma_i]/\alpha_i. \tag{8}$$

As shown in (8), the relative magnitude of the emissions in the two scenarios is determined by the price effects ($-(\hat{p}-p^*)/\alpha_i$) and the domestic ancillary benefit effects (γ_i/α_i); and the former and the latter respectively capture the *aggregate* and *individual* impacts of ancillary benefits on the emission levels. The price effect is negative based on (7), since individual countries will have higher levels of emissions when facing a lower allowance price in the scenario of AB. In contrast, the domestic ancillary benefit effects are positive, because taking the ancillary benefits into consideration will lower the emissions. Combining the above two effects, we can not have an unambiguous sign of $(\hat{e}_i-e_i^*)$. Based on (8), we have

$$\hat{e}_i \underset{<}{>} e_i^* \quad \textbf{iff} \quad \gamma_i \underset{<}{>} \hat{p}-p^*. \tag{9}$$

Define countries with $\gamma_i>\hat{p}-p^*$ as high-benefit countries, and those with $\gamma_i<\hat{p}-p^*$ as low-benefit countries. Then following straightforwardly from (9), the actual emissions of high-benefit countries are lower whereas those of low-benefit countries are higher in the scenario of AB, as compared with the scenario of CE.

3. THE DATA AND NUMERICAL ANALYSIS

This section develops a numerical analysis of the Annex-1 emissions trading based on the theoretical model in Section 2. The numerical analysis is designed to illustrate how ancillary benefits of carbon mitigation could affect the equilibrium allowance prices, actual emissions, and (net) compliance costs of the Annex-1 countries. For simplicity and the significant status of the Annex-1 countries, the Annex-1 countries that we focus on here consist of the European Union, the United States, Japan, and Russia.

The data used in the numerical analysis are summarized in Table 1. The BAU emissions $\overline{b}_i$ and emission caps $\overline{w}_i$, originating from the OECD GREEN model (OECD, 1999), are taken from the GTAP-E model (Burniaux and Truong, 2002). The emission caps $\overline{w}_i$ correspond to the emission levels that Annex-1 countries are required to achieve in 2012 (i.e., the end of the first commitment period of the Protocol) relative to their corresponding emission levels in an unconstrained baseline scenario ($\overline{b}_i$). For all of the countries except for Russia, we have $\overline{b}_i > \overline{w}_i$. The values of $(\overline{b}_i - \overline{w}_i)$ represent the levels of abatement required by the Protocol. For Russia, we instead have $\overline{b}_i < \overline{w}_i$. The value of $(\overline{w}_i - \overline{b}_i)$ represents the hot air that could be sold in the international trading market. The main reason for the hot air is the economic disarray, which followed the collapse of the Soviet Union. The values of technological parameter α_i are estimated based on GTAP-E model, and those of ancillary benefits γ_i, arising from the reduction in conventional air pollution, are taken from the FUND (Climate Framework for Uncertainty, Negotiation and Distribution) model (Tol, 1997).

Table 1:
The Data Used in the Numerical Analysis

Countries/Regions	$\overline{b}_i$ (MtC) [a]	$\overline{w}_i$ (MtC) [a]	α_i	γ_i (\$/tC) [b]
European Union	911.16	707.06	0.64	11.18
United States	1499.78	965.86	0.18	15.00
Japan	337.22	229.98	1.58	4.02
Russia	372.53	420.47	0.97	9.46

Source: $\overline{b}_i$ and $\overline{w}_i$ are taken from the GTAP-E model. α_i is estimated based on the GTAP-E model. γ_i is taken from the FUND model (Tol, 1997).

[a]. MtC: million tons of carbon.

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

Table 2 summarizes the equilibrium allowance prices of the Annex-1 emissions trading from the present paper and from the other models. Our result for the equilibrium allowance price in the scenario of CE is $\hat{p}$ =91 ($/tC). This result is of medium value, as compared with those from the other models. The equilibrium allowance price in the scenario of AB is p^* =78 ($/tC), which is lower than that in the scenario of CE. The result is consistent with equation (7), since taking the ancillary benefits into consideration leads to a fall in the aggregate demand for the emission allowances and consequently depresses the equilibrium price.

Table 2:
Equilibrium Allowance Prices of the Annex-1 Emissions Trading[a]

Models	Allowance Price (US$ per ton Of Carbon)
This paper	
Scenario of Considering Ancillary Benefits	78
Scenario of Cost Effectiveness	91
SGM	76
MERGE	114
G-Cubed	37
POLES	112
GTEM	123
WorldScan	20
GREEN	67
AIM	65

a. The results of other models are taken from Baron and Lanze (2000), which is base on Van den Mensbrugghe (1998a). The original sources for the modeling 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)

The actual emissions, domestic abatement, and purchases of allowances for the Annex-1 countries/regions are reported in Table 3, where all of the values are measured by million tons of carbon (MtC). The countries/regions with positive values in the "allowance" column are the buyers of the emission allowances, while those with negative values are the sellers. Three major conclusions are drawn from the table. First, according to (9), the countries with $\gamma_i > \hat{p} - p^* = 13$ are high-benefit countries. Only the United States satisfies this condition. Due to the dominance of the ancillary benefit effects, the United States has a lower level of carbon emissions in the scenario of AB (983.60 MtC), as compared with that in the scenario of CE (995.39 MtC). Accordingly, it has a higher level of domestic abatement and a lower level of allowance purchase when considering ancillary benefits.

Second, the qualitative results for the low-benefit countries, consisting of the European Union, Japan, and Russia, are just the opposite. Owing to the dominance of price effects, their carbon emissions in the scenario of AB are higher, which implies lower levels of domestic abatement in the same scenario. As for the levels of allowance trading, the European Union and Japan have higher levels of allowance purchases while Russia has a lower level of allowance sale in the scenario of AB.

Third, Russia is the only supplier of the emission allowances in both scenarios. The values of its sales to the international market are higher than that of the hot air it has (i.e., $\overline{w}_i - \overline{b}_i = 420.47 - 372.53 = 47.94$ (MtC)), reflecting the fact that Russia has lower abatement costs vis-à-vis the other Annex-1 countries. Its participation adds to the potentials for lower cost of compliance of the other Annex-1 countries.

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

Countries/Regions	Scenario of Considering Ancillary Benefits		
	Emission	Abatement	Allowance
European Union	771.95	139.21	64.89
United States	983.60	516.18	17.74
Japan	285.36	51.86	55.38
Russia	282.46	90.07	-138.02

Countries/Regions	Scenario of Cost Effectiveness		
	Emission	Abatement	Allowance
European Union	769.30	141.86	62.24
United States	995.39	504.39	29.53
Japan	279.76	57.46	49.77
Russia	278.93	93.60	-141.54

Source: own calculations.
Note: Actual emissions, domestic abatement, and the purchase of allowances are measured in MtC (million tons of carbon).

Table 4:
Abatement Costs, Allowance Expenses, and Compliance Costs

	Scenario of Considering Ancillary Benefits		
Countries/Regions	Abatement Costs	Trading Expenditure	Compliance Costs
European Union	6,201.12	5,055.97	11,257.10
United States	23,979.71	1,382.34	25,362.05
Japan	2,124.34	4,314.79	6,439.12
Russia	3,935.01	-10,753.10	-6,818.09
Sum			36,240.18

	Scenario of Cost Effectiveness		
Countries/Regions	Abatement Costs	Trading Expenditure	Compliance Costs
European Union	6,439.84	5,650.74	12,090.58
United States	22,897.21	2,680.83	25,578.04
Japan	2,608.54	4,518.97	7,127.51
Russia	4,248.97	-12,850.53	-8,601.57
Sum			36,194.57

	Scenario of No Trading		
Countries/Regions	Abatement Costs	Trading Expenditure	Compliance Costs
European Union	13,330.16	-	13,330.16
United States	25,656.51	-	25,656.51
Japan	9,084.65	-	9,084.65
Russia	-	-	-
Sum			48,071.32

Source: own calculations
Note: Abatement costs, allowance expenses, and compliance costs are measured in US$ millions

The abatement costs, allowance-trading expenditure (or revenue), and compliance costs for the Annex-1 countries/regions are presented in Table 4, where all of the values are appraised by US$ millions. The conclusions drawn from the table are summarized as follows. First, the emissions trading could lead to cost savings for both the Annex-1 countries as a whole and for the individual countries, as compared with the case of no-trading. The sum of the compliance costs of individual countries is minimized under the cost-effective condition where the marginal costs of domestic abatement are equalized across Annex-1 countries (i.e., US$36,194.57 million in the scenario of CE).

Second, the above condition of cost effectiveness in emissions trading does not imply that the compliance costs of individual countries are minimized. The buyers of emission allowances, consisting of the European Union, the United States and Japan, could have even lower costs of compliance in the trading case where the ancillary benefits are considered. The cost of compliance of the European Union is US$11,257.10 million in the scenario of AB and US$12,090.58 million in the scenario of CE, where the former is 93.11% of the latter. The compliance costs of the United States in the two scenarios are US$25,362.05 million and US$25,578.04 million, respectively. The difference between them is insignificant. As for Japan, the compliance cost in the scenario of AB (US$6,439.12 million) is only 90.34% of that in the scenario of CE (US$7,127.51 million).

Table 5:
Compliance Costs, Ancillary Benefits, and Net Compliance Costs

	Scenario of Ancillary Benefits		
Countries/Regions	Compliance Costs	Ancillary Benefits	Net Costs
European Union	11,257.10	1,556.33	9,700.76
United States	25,362.05	7,742.69	17,619.36
Japan	6,439.12	208.46	6,230.66
Russia	-6,818.09	852.11	-7,670.19
Sum	36,240.18		25,880.59

	Scenario of Cost Effectiveness		
Countries/Regions	Compliance Costs	Ancillary Benefits	Net Costs
European Union	12,090.58	1,586.00	10,504.57
United States	25,578.04	7,565.91	18,012.13
Japan	7,127.51	231.00	6,896.51
Russia	-8,601.57	885.45	-9,487.01
Sum	36,194.57		25,926.20

	Scenario of No Trading		
Countries/Regions	Compliance Costs	Ancillary Benefits	Net Costs
European Union	13,330.16	2,281.84	11,048.32
United States	25,656.51	8,008.83	17,647.69
Japan	9,084.65	431.09	8,653.56
Russia	—	—	—
Sum	48,071.32		37,349.57

Source: own calculations.
Note: Compliance costs, ancillary benefits, and net compliance costs are measured in US$ millions.

Finally, intervention that takes account of the ancillary benefits would result in a redistribution of compliance costs. Due to a fall in the equilibrium allowance price in the scenario of AB, the only seller of emission allowances, Russia, has lower trading revenue. This explains the above results of lower compliance costs for the buyers.

Table 5 summarizes the compliance costs, ancillary benefits, and net compliance costs for the Annex-1 countries/regions. From the table we see that the sum of the compliance costs of the individual countries is minimized in the scenario of CE (US$36,194.57million) whereas that of net compliance costs is minimized in the scenario of AB (US$25,880.59 million). For the buyers of emission allowances, the compliance costs and net compliance costs are all lower in the scenario of AB, thus justifying the intervention that takes account of ancillary benefits in IET.

4. Concluding Remarks

The global climate pact came into effect in early 2005, following the formal ratification of the Russian Federation. Starting from 2008, the Annex-1 countries are able to trade emission allowances in the international market. While free international trade in emissions substantially reduces the economic costs of meeting the Kyoto targets, it might also lower the environmental benefits of own abatement for the countries that purchase emission allowances. Understanding the trade-offs between the cost-savings from international emissions trading and the ancillary benefits from domestic abatement is thus imperative, particularly for the design of a true cost-effective climate policy.

This paper has examined the implications of considering ancillary benefits on the compliance costs of the individual Annex-1 countries. The insights which emerge from this paper are summarized as follows. First, taking ancillary benefits into consideration leads to a fall in the aggregate demand for the emission allowances and consequently depresses the equilibrium price. The associated impacts on the levels of individual countries' carbon emissions are ambiguous, depending on the relative significance of countries' ancillary benefits and the price effects. High-benefit countries have lower emissions while low-benefit countries have higher emissions when considering ancillary benefits. Second, the cost effectiveness in emissions trading does not imply that the compliance costs of individual countries are minimized. The buyers of emission allowances (including the European Union, the United States and Japan) could have even lower costs of compliance in the trading case where the ancillary benefits are taken into consideration, even though the condition of cost effectiveness in emissions trading is violated.

The conclusion drawn from this paper reinforces the premise that the ancillary benefits of domestic abatement are of vital importance in designing national carbon mitigation policies, and suggests that domestic abatement and the use of flexible mechanisms should be coordinated carefully. It also justifies the regulatory interventions that take place in relation to allowances traded internationally, particularly for the allowance-buying countries with high abatement costs and/or ancillary benefits. To achieve the cost effectiveness in national carbon abatement, the interventions should be such that the price of emission allowances is able to reflect the ancillary benefits of domestic mitigation.

ACKNOWLEDGEMENTS

The author is grateful to the National Science Council of Taiwan for financial support. (NSC97-2410-H-305-014)

REFERENCES

Barker, T. and K.E. Rosendahl (2000), "Ancillary Benefits of GHG Mitigation in Europe: SO_2, NO_x, and PM-10 Reductions to Meet Kyoto Targets Using the E3ME Model and EXTERNE Valuations," in OECD, *op. cit.*, 413-451.

Baron, R. and A. Lanza (2000), "Kyoto Commitments: Macro and Micro Insights on Trading and the Clean Development Mechanism," *Integrated Assessment*, 1, 137-144.

Bollen, J., A. Gielen, and H. Timmer (1998), "Compliance with the Kyoto Protocol," in OECD (eds.), *Economic Modelling and Climate Change*, Workshop Report, Paris: Organization for Economic Co-operation and Development.

Burniaux, J.-M. and T.P. Truong (2002), "GTAP-E: An Energy-Environmental Version of the GTAP Model," GTAP Technical Paper, No.16.

Burtraw, D. and M. Toman (1998), "The Benefits of Reduced Air Pollutants in the U.S. from Greenhouse Gas Mitigation Policies," *Resources for the Future Discussion Paper*, 98-01-REV, Washington, D.C.: Resources for the Future.

Capros, P. (1998), "Economic and Energy System Implications of the European CO_2 Mitigation Strategy: Synthesis of Results from Model Based Analysis," in OECD (eds.), *Economic Modelling and Climate Change*, Workshop Report, Paris: Organization for Economic Co-operation and Development.

Criqui, P., S. Mima, and L. Viguier (1999), "Marginal Abatement Costs of CO_2 Emission Reductions, Geographical Flexibility and Concrete Ceilings: An Assessment Using the POLES Model", *Energy Policy*, 27, 585-601.

Dessus, S. and D. O'Connor (2003), "Climate Policy without Tears: CGE-Based Ancillary Benefits Estimates for Chile," *Environmental and Resource Economics*, 25, 287-317.

Ekins, P. (1996), "How Large a Carbon Tax is Justified by the Secondary Benefits of CO_2 Abatement?" *Resource and Energy Economics*, 18, 161-187.

Evans, M. (2003), "Emissions Trading in Transition Economies: the Link between International and Domestic Policy", *Energy Policy*, 31, 879–886.

IPCC (2001), *Summary for Policymakers, Climate Change 2001*: *Mitigation*, Paris: Intergovernmental Panel on Climate Change.

Kainuma, M., Y. Matsuoka, and T. Morita (1998), "Analysis of Post-Kyoto Scenarios: The AIM Model," in OECD (eds.), *Economic Modelling and Climate Change, Workshop Report*, Paris: Organization for Economic Co-operation and Development.

Kainuma, M., Y. Matsuoka, and T. Mortia (1999) Analysis of Post-Kyoto Scenarios: The Asian-Pacific Integrated Model, *The Energy Journal*, *Special Issue on the Cost of the Kyoto Protocol: A Multi-Model Evaluation*, 207-221.

Lutter, R. and J. Shogren (2002), "Tradable Permit Tariffs: How Local Air Pollution Affects Carbon Emissions Permit Trading," *Land Economics*, 78, 159-170.

Manne, A. and R. Richels (1998), "The Kyoto Protocol: A Cost-Effective Strategy for Meeting Environmental Objectives?" in OECD (eds.), *Economic Modelling and Climate Change*, Workshop Report, Paris: Organization for Economic Co-operation and Development.

McKibbin, W.J., R. Shackleton, and P.J. Wilcoxen (1998), "The Potential Effects of International Carbon Emissions Permit Trading Under the Kyoto Protocol," in OECD (eds.), *Economic Modelling and Climate Change*, Workshop Report, Paris: Organization for Economic Co-operation and Development.

OECD (1999), *Action Against Climate Change: The Kyoto Protocol and Beyond*, Paris: Organization for Economic Co-operation and Development.

Rose, A. and B. Stevens (1993) The Efficiency and Equity of Marketable Permits for CO_2 Emissions, *Resource and Energy Economics* 15, 117-146.

Sands, R.D., J.A. Edmonds, S.H. Kim, C.N. McCracken, and M.A. Wise (1998), "The Cost of Mitigating United States Carbon Emissions in the Post-2000 Period," in OECD (eds.), *Economic Modelling and Climate Change*, Workshop Report, Paris: Organization for Economic Co-operation and Development.

Tol, R. (1997), "On the Optimal Control of Carbon Dioxide Emissions: An Application of FUND," *Environmental Modeling and Assessment*, 2, 151-163.

Tulpule. V., S. Brown, J. Lim, C. Polidano, H. Pant, and B.S. Fisher (1998), "An Economic Assessment of the Kyoto Protocol Using the Global Trade and Environment Model," in OECD (eds.), *Economic Modelling and Climate Change*, Workshop Report, Paris: Organization for Economic Co-operation and Development.

Van den Mensbrugghe, D. (1998a), "Summary of Workshop on Economic Modelling and Climate Change," in OECD (eds.), *Economic Modelling and Climate Change*, Workshop Report, Paris: Organization for Economic Co-operation and Development.

Van den Mensbrugghe, D. (1998b), "A (Preliminary) Analysis of the Kyoto Protocol: Using the OECD GREEN Model," in OECD (eds.), *Economic Modelling and Climate Change*, Workshop Report, Paris: Organization for Economic Co-operation and Development.

Weyant, J. (1999), "The Cost of the Kyoto Protocol: A Multi-Model Evaluation," *The Energy Journal*, special issue.