Tsung-Chen Lee (Taiwan)

Industry export competitiveness and optimal quantitative strategies for international emissions trading

Abstract

This paper analyzes how quantitative strategies for international emissions trading (IET) could be used as an instrument to reduce countries' compliance costs and enhance export competitiveness. Using the cost-effective IET as a benchmark, the author shows that a green quantitative strategy of encouraging domestic abatement is optimal for permit-buying countries with relatively high demand for permits. In contrast, a brown quantitative strategy that discourages domestic abatement is optimal for permit-selling countries and permit-buying countries with relatively low demand. Finally, the country first setting quantitative strategy on IET could enjoy the first-mover advantage of reducing compliance costs and enhancing export competitiveness.

Keywords: export competitiveness, international emissions trading, quantitative strategy, cost-shifting strategy, strategic environmental policy.
JEL Classification: Q54, Q58.

Introduction

International emissions trading (hereafter IET) proposed in the Kyoto Protocol adds a new dimension to the practice of emissions trading scheme (ETS), which is an economic instrument to reduce pollutants in a cost effective manner. In the literature, there are several studies showing the cost effectiveness of ETS at national level (e.g., Chichilnisky and Heal, 1995) and international level (e.g., Evans, 2003; Criqui et al., 1999; Kainuma et al., 1999; Weyant, 1999). The extended practice of ETS to the international level signifies that countries' interaction in the international market could arise from, in addition to the competition in the commodity export market, the permit trading in the IET. Under the circumstance, countries' permit trading behavior directly affects the supply or demand condition and hence the equilibrium permit price as well as compliance costs, and indirectly influences countries' production decision, export competitiveness, and social welfare.

Even though violating the cost effectiveness of IET, self-interested countries may have incentive to trade permit strategically because through which they can transfer part of their compliance costs to others. This "cost-shifting policy", originating from the idea of the literature on strategic trade policy (STP)[1], is first proposed by Lee et al. (2013), who explore the extent to which the concept of STP can be applied in IET. Concerning the implication on export competitiveness, the cost-shifting strategies in IET could be also thought of as a strategic environmental policy, which is widely discussed in the literature on trade and the environment (e.g., Dean, 1992; Conrad, 1993; OECD, 1993; Barrett, 1994; Beghin et al., 1994; Jaffe et al., 1995; Thompson and Strohm, 1996; Ulph, 1996; Jayadevappa and Chhatre, 2000). Given the restriction on the use of trade instruments under free trade agreements such as World Trade Organization (WTO), strategic environmental policy appears as a feasible substitute to extract foreigners' rent.

Up to now, none of the studies have yet attempted to analyze the competitive implications of quantitative strategies in IET as a strategic environmental policy. This issue is important given the common concern for competitiveness in the design of climate policy and the megatrends in the wave of trade liberalization worldwide, hence stimulates our motivation to explore how strategic trading in IET could be used as a strategic environmental instrument to reduce countries' compliance costs and enhance export competitiveness.

Strategic trading in IET is plausible in the real world for at least two reasons. First, based on Article 17 of the Kyoto Protocol, IET shall be supplemental to domestic actions for the purpose of meeting quantified emission limitation and reduction commitments. However, this supplementarity principle does not provide a clear definition regarding the individual countries' transaction levels. As a consequence, differing interpretation on what extent the IET should be used arises (Zhang, 2001). One interpretation indicates that the domestic actions should be the main means of meeting the countries' abatement commitments, so that IET should be an addition to domestic actions. The other interpretation states that IET will be supplemental to whatever domestic actions are taken, and one country could use IET to meet its abatement commitments as much as it wishes. In other words, countries can freely choose the trading amount in IET to maximize their indi-

[1] The literature on STP usually focuses on government's trade policy which could affect firms' interactions in an international oligopolistic market. The central idea is the "strategic profit-shifting policy". Early contributors in this field include, among others, Brander and Spencer (1981, 1985), Spencer and Brander (1983), Dixit (1984), Brander (1986), Eaton and Grossman (1986), and etc.

Acknowledgements: This work is supported by the Ministry of Science and Technology of Taiwan (Project No.: NSC 99-2410-H-305-078).

vidual interests. Second, in the IET system, there is no supranational authority with the power to determine the transaction levels and/or to prevent individual governments to set strategic trading behavior. The strategic trading behavior in IET is also valid under the framework of WTO, because no associated measuring criterion is specified.

Specifically, this paper aims at examining the link between export competitiveness and the strategic trading in IET with binding exogenous target level of carbon emissions. We develop a two-stage sequential game with complete information to analyze the optimal quantitative strategies. Countries are assumed to be Cournot competitors in the international commodity market with free trade (e.g., Brander and Spencer, 1985) and price-takers in the ETS. Parallel to the literature on Porter hypothesis (e.g., Greaker, 2003), we define a green (brown) strategy as the one such that marginal cost of own abatement exceeds (falls short of) the international permit price. The optimal quantitative strategies and implications on export competitiveness are then explored under a second-best scenario given that the regulation on commodity trade is not allowed.

We show that the second-best quantitative strategies in IET depend on two effects, consisting of the direct effect on emissions trading and the indirect (spillover) effects on commodity export. Combining these two effects, a green strategy of promoting domestic abatement best serves the interest of a country's export industry when the industry has relatively high demand for permits. In contrast, a brown strategy of discouraging domestic abatement is optimal for permit-selling countries and permit-buying countries with relatively low demand. We also demonstrate that, in the case of unilateral regulation, the country adopting strategic trading behavior will be better-off. In sum, our result partially parallels what is found in the Porter hypothesis, indicating that countries with relatively high demand of permits, such as the European Union, would set stringent regulation in an IET system and come out in favor of a greener domestic abatement policy.

The remainder of this paper is organized as follows. Section 1 introduces the basic settings of the model. The equilibria without and with quantitative strategies are derived in Sections 2 and 3, respectively. The implications on export competitiveness are drawn in Section 4. Finally, the concluding remark is summarized in the final Section.

1. The basic settings

Assume a two-sector economy, with a numeraire sector and a homogeneous oligopoly sector. Consider a partial equilibrium model of the oligopoly sector. There are N ($N \geq 2$) Annex-1 countries, indexed by $i = 1, \ldots N$. The output level of country i is denoted as $q_i > 0$. All outputs in these countries are exported to a non Annex-1 region with the inverse demand $p = 1 - Q$, where $Q = \sum_{i=1}^{N} q_i$ is the aggregate output level. The production generates carbon emissions, and the emissions are proportional to output levels. Let $\theta_i > 0$ be the output-based emission factor (carbon emissions per unit of output) of country i. Country i's gross emission level is thus $\theta_i q_i$.

Among the N countries, there is an international agreement which sets legally binding restrictions on individual countries' carbon emissions, and allows these countries to comply with their respective caps by own abatement or permits trading in an IET market. The emission cap assigned to country i is $\overline{w}_i$ [1]. Country i could comply with $\overline{w}_i$ through making better use of technologies such as improvement of energy efficiency, carbon capture and storage, etc. Let e_i be the actual emission level of country i, where $0 \leq e_i \leq \theta_i q_i$. Country i's own abatement level equals $(\theta_i q_i - e_i)$ and the associated abatement costs $C_i(q_i, e_i) = \frac{\alpha_i}{2}(\theta_i q_i - e_i)^2$ are strictly convex, where $\alpha_i > 0$ is a technological parameter and increasing with falling abatement efficiency.

In the IET market, the non Annex-1 region plays no role because it has no obligation of carbon reductions. As for the Annex-1 countries, there is no specific restriction on their trading in the international agreement, so they can strategically choose the amount of permits trading. Denote country i's trading amount as t_i, where $t_i = e_i - \overline{w}_i; t_i > 0$ means the amount that country i purchases from the IET market, and $t_i < 0$ signifies the amount that country i sells to the IET market.

Based on the above setting, country i's social welfare S_i equals the revenue of commodity sales minus the cost of complying with emission cap $\overline{w}_i$, and the latter is composed of own abatement cost and permit trading expenditure or revenue. That is,

$$S_i(q_i, e_i) = pq_i - \left[\frac{\alpha_i}{2}\left(\theta_i q_i - e_i\right)^2 + r(e_i - \overline{w}_i)\right], i = 1, \ldots, N, \quad (1)$$

[1] The emission caps in an international agreement (e.g., Kyoto Protocol) are assigned for free. In practice, the allocation can be determined based on historic emissions (grandfathering), outputs, abatement performance, etc. In this paper, we assume that there is already an agreed allocation, and how this allocation is determined is beyond the scope of this paper.

where $r > 0$ is the permit price, and $r(e_i - \overline{w}_i) > (<) 0$ represents country i's permit trading expenditure (revenue).

In the following sections, we respectively solve the equilibria without and with quantitative strategies in the IET market. The competitiveness implications are then drawn by comparing the two equilibria.

2. Equilibrium without quantitative strategies

In the absence of quantitative strategies, each country i chooses optimal output level $\hat{q}_i$ and emission level $\hat{e}_i$ to maximize its social welfare, as denoted in (1). The associated first-order conditions for an interior solution are:

$$p - \hat{q}_i = [\alpha_i(\theta_i \hat{q}_i - \hat{e}_i)]\theta_i, \tag{2}$$

and

$$\alpha_i(\theta_i \hat{q}_i - \hat{e}_i) = r, i = 1, \ldots, N. \tag{3}$$

Equation (2) states that country i will adjust its output level until marginal revenue of commodity sales equals marginal cost of production (i.e., marginal abatement cost associated with producing one more unit of commodity). Equation (3) indicates that-country i's optimal emission level is determined at the condition under which marginal abatement cost equals permit price. This condition is generally referred to as the cost-effective condition of IET because all trading countries have the same marginal abatement cost and the sum of countries' compliance costs is minimized.

The equilibrium aggregate output $\hat{Q}$ and equilibrium output price $\hat{p}$ are derived using equations (2)-(3) and the inverse demand function $p = 1 - Q$, and are shown as follows:

$$\hat{Q} = \frac{N - \Theta r}{N + 1} \text{ and } \hat{p} = \frac{1 + \Theta r}{N + 1}, \tag{4}$$

where $\Theta = \sum_{i=1}^{N} \theta_i$. Country i's output level is $\hat{q}_i = \hat{p} - \theta_i r$ by (2)-(4). Substituting $\hat{q}_i = \hat{p} - \theta_i r$ (4) into (3) yields country i's demand for permits:

$$\hat{e}_i = \theta_i\left(\frac{1 + \Theta r}{N + 1} - \theta_i r\right) - \frac{r}{\alpha_i}, i = 1, \ldots, N. \tag{5}$$

Assume that the permit demand function is downward sloping, i.e., $\frac{\partial \hat{e}_i}{\partial r} < 0$. Thus the following assumption is made.

Assumption A1: $\mu_i = \theta_i\left(\theta_i - \frac{\Theta}{N + 1}\right) + \frac{1}{\alpha_i} > 0.$

Using (5) and the market-clearing condition of IET $\sum_{i=1}^{N} e_i = \sum_{i=1}^{N} \overline{w}_i$, we derive the equilibrium permit price as follows:

$$\hat{r} = \Gamma\left[\sum_{i=1}^{N}\left(\frac{\theta_i}{N + 1} - \overline{w}_i\right)\right], \tag{6}$$

where $\Gamma = \left(\sum_{i=1}^{N} \mu_i\right)^{-1} > 0$ given Assumption A1. In order to have a positive equilibrium permit price, we further make the following assumption.

Assumption A2: $\sum_{i=1}^{N}\left(\frac{\theta_i}{N + 1} - \overline{w}_i\right) > 0.$

At the equilibrium without quantitative strategies, the IET market operates in the cost effective way that minimizes the sum of countries' compliance costs for a given aggregate abatement target. This equilibrium will be used as the benchmark case for investigating the competitiveness implications of quantitative strategies in the following sections.

3. Optimal quantitative strategies in IET

This section develops a non-cooperative game to analyze individual countries' optimal quantitative strategies in IET. Strategic trading behavior in IET introduces shadow tariff (or subsidy) on emissions trading which would alter countries' demand for permits and market equilibrium. Countries recognize the ensuing impacts of strategic trading and take them into consideration in determining their optimal trading amounts. Accordingly, each country faces a two-stage optimization problem with an objective of maximizing social welfare. In the first stage, countries simultaneously choose their respective optimal quantitative strategies for IET, and, in the second stage, given the strategic trading amounts and the associated shadow tariff (or subsidy), they select their respective optimal outputs and emissions[1]. Then the equilibrium output price and permit price are respectively determined based on the inverse demand function for output and market-clearing condition of the IET.

To solve the subgame perfect equilibrium (hereafter SPE) of the game, we work backwards, starting from the second stage. In this stage, given the quan-

[1] The sequence of the game reflects the plausible situation in which quantitative strategies are made at the government levels, and the decisions for outputs and emissions are made at the firm levels.

titative strategy t_i, country i chooses optimal output q_i^* and emission e_i^* to maximize its social welfare

$$max_{(q_i,e_i)} S_i(q_i,e_i) = pq_i - [\frac{\alpha_i}{2}(\theta_i q_i - e_i)^2 + r(e_i - \overline{w}_i)], \quad (7)$$

$$\text{s.t. } t_i = e_i - \overline{w}_i, i = 1,\ldots,N. \quad (8)$$

The Lagrange function for the above problem is

$$\mathcal{L}_i(q_i,e_i,\lambda_i) = pq_i - \left[\frac{\alpha_i}{2}(\theta_i q_i - e_i)^2 + r(e_i - \overline{w}_i)\right] + \lambda_i[t_i - (e_i - \overline{w}_i)], \quad (9)$$

where λ_i is the Lagrange multiplier, which measures the effect of a small change in quantitative strategy t_i on country i's social welfare, and is referred to as the shadow tariff (or subsidy) of t_i.

The associated first-order conditions for an interior solution are:

$$p - q_i^* = [\alpha_i(\theta_i q_i^* - e_i^*)]\theta_i, \quad (10)$$

and

$$\alpha_i\left(\theta_i q_i^* - e_i^*\right) = r + \lambda_i, i = 1,\ldots,N. \quad (11)$$

Based on (11), the shadow tariff (or subsidy) of quantitative strategy t_i can be expressed as $\lambda_i = \alpha_i\left(\theta_i q_i^* - e_i^*\right) - r$, which is the difference between domestic marginal abatement cost and permit price. In the case of $\lambda_i > 0$, domestic abatement cost is greater than permit price, implying a shadow tariff imposed on the permit purchase or a shadow subsidy distributed to the permit sale. As a consequence, domestic abatement level increases. In contrast, $\lambda_i < 0$ means a shadow subsidy is distributed to the permit purchase or a shadow tariff is imposed on permit sale, consequently decreasing domestic abatement amount. Based on the above and the literature on Porter hypothesis (e.g., Greaker, 2003), the following definition is provided.

Definition D1. A green (brown) trading strategy is defined as the quantitative strategy for IET such that domestic marginal abatement cost exceeds (falls short of) the international permit price, and is a strategy of encouraging (discouraging) domestic abatement.

The equilibrium aggregate output Q^* and permit price p^* are given by

$$Q^* = \frac{N - \Theta r - \sum_{i=1}^{N}\theta_i\lambda_i}{N+1} \text{ and } p^* = \frac{1 + \Theta r + \sum_{i=1}^{N}\theta_i\lambda_i}{N+1} \quad (12)$$

Country i's optimal output level is $q_i^* = p^* - \theta_i(r + \lambda_i), i = 1,\ldots,N$ by (10)-(12). Substituting this equation of q_i^* and (12) into (11) yields country i's demand for permits:

$$e_i^* = \theta_i\left[\frac{1 + \Theta r + \sum_{j=1}^{N}\theta_j\lambda_j}{N+1} - \theta_i(r + \lambda_i)\right] - \frac{r + \lambda_i}{\alpha_i}, \quad (13)$$

which is also downward sloping given assumption A1, i.e., $\frac{\partial e_i^*}{\partial r} = -\mu_i < 0$. The associated equilibrium permit price is:

$$r^* = \hat{r} - \sum_{i=1}^{N}k_i\lambda_i, \quad (14)$$

where $k_i = \Gamma\mu_i, \sum_{i=1}^{N}k_i = 1$, and $0 < k_i < 1$.

So far we have obtained the relationships linking variables p^*, q_i^*, e_i^* and r^* to the shadow tariff (or subsidy) λ_i. Substituting (14) and $e_i^* = t_i + \overline{w}_i$ into (13), we can derive the optimal λ_i^*, which is a function of trading amounts (t_1, … t_N), i.e., $\lambda_i^* = \lambda_i^*\left(t_1, \ldots t_N\right)$. Assume that $\frac{\partial\lambda_i^*}{\partial t_i} < 0$ (i.e., a higher t_i means a larger purchase or a lower sale of allowances, and signifies a browner strategy). Using this assumption and equations (10)-(14), we derive the following results:

$$\frac{\partial e_i^*}{\partial t_i} > 0, \quad (15)$$

$$\frac{\partial r_i^*}{\partial t_i} > 0, \quad (16)$$

$$\frac{\partial q_i^*}{\partial t_i} > 0, \text{ and } \frac{\partial\left(\sum_{j\neq i}q_j^*\right)}{\partial t_i} < 0, \; i = 1,\ldots,N. \quad (17)$$

Proofs of (15)-(17) are in Appendix 1. Equations (15) and (16) state that if country i adopts a browner strategy (higher t_i), its optimal emission level and excess demand for permits will increase. Thus the equilibrium permit price increases, too. Equation (17) means that the country choosing a browner strategy can increase its output level, and, other things being equal, the aggregate output of its rivals' decreases.

Next, turn to the first stage of the game. Given $\left(q_i^*, e_i^*\right)_{i=1}^N$, p^*, and r^*, country i chooses t_i^* to maximize its social welfare. Given the assumption of $\frac{\partial \lambda_i^*}{\partial t_i} < 0,$ the optimal condition for shadow tariff (subsidy) can be expressed as follows:

$$\lambda_i^* = \Phi_i (e_i^* - \overline{w}_i) + \Omega_i q_i^*, i = 1, \ldots, N, \tag{18}$$

where $\Phi_i = \left(\frac{\partial r_i^* / \partial t_i}{\partial e_i^* / \partial t_i} \right) > 0$ and

$\Omega_i = \frac{\left[\partial \left(\sum_{j \neq i} q_j^* / \partial t_i \right) \right]}{\left(\partial e_i^* / \partial t_i \right)} < 0$ according to (15)-(17).

The optimal shadow tariff (subsidy) in (18) is a second-best strategy, and it is composed of two parts, consisting of a direct effect on emissions trading $\Phi_i \left(e_i^* - \overline{w}_i \right)$ and an indirect effect on commodity exports $\Omega_i q_i^*$.

Given $\Phi_i > 0,$ the direct effect on emission trading $\Phi_i \left(e_i^* - \overline{w}_i \right)$ is positive (negative) if and only if $e_i^* > (<) \overline{w}_i$. Therefore, when considering only the direct effect, a green strategy is optimal for permit-buying countries while a brown strategy is optimal for permit-selling countries. The explanation is provided as follows. In a perfectly competitive IET market without quantitative strategies, marginal abatement cost equals permit price by (3). Considering the ensuing impacts on permit price, individual countries would have incentive to adopt quantitative strategies such that the allowance price alters toward their respective desired direction. By doing so, they could transfer part of their respective compliance cost to others, i.e., referred to as the cost-shifting policies. Setting a green strategy is optimal for permit-buying countries because it decreases the excess demand for permits and hence the equilibrium permit prices. In contrast, it is optimal for permit-selling countries to select a brown policy to decrease their domestic abatement and excess supply of permits, and this will lead to a higher permit price. The above result is consistent with Lee et al. (2013), who suggest that discouraging permit trade (with a tax on permit trading) is optimal for price-taking countries as far as cost-shifting is concerned.

On the other hand, the indirect effect on commodity exports $\Omega_i q_i^*$ measures the spillover impact of the quantitative strategy t_i on commodity export. This effect is always negative, implying that a brown strategy is optimal if only the indirect effect is considered. This result is consistent with the common perception in the literature on trade and the environment which suggests that strict environmental regulation might shift the marginal cost upward and hence lowers profits and competitiveness. The above results are summarized as follows.

Proposition 1. The optimal permit-trading strategy hinges on two effects, consisting of the direct price effect on permit trading and indirect (spillover) effects on commodity export. If only the direct price effects are considered, the permit-selling countries should choose a brown strategy while the permit-buying countries should select a green strategy. In contrast, when considering only the indirect effect on commodity export, all countries should choose brown strategy.

Based on the above, the direct and indirect effects are both negative for permit-selling countries, hence $\lambda_i^* < 0$ (or equivalently, a brown policy) is optimal for these countries. In contrast, the optimal policies for permit-buying countries depend on the relative magnitude of the positive direct effect to the negative indirect effect. If the positive direct (negative indirect) effect dominates, a green (brown) strategy is optimal. In order to draw more intuitive insights regarding the optimal policy of a permit-buying country, equation (18) is rewritten as follows:

$$\lambda_i^* \overset{>}{\underset{<}{=}} 0 \text{ if and only if } I_i \overset{>}{\underset{<}{=}} \overline{I}_i,$$

$$\text{for country } i \text{ with } \left(e_i^* - \overline{w}_i \right) > 0, \tag{19}$$

where $I_i = \frac{(e_i^* - \overline{w}_i)}{\theta_i q_i} > 0$ is the permit-buying intensity (i.e., the ratio of permit purchase to the gross emission), and $\overline{I}_i = \frac{-\Omega_i}{\theta_i \Phi_i} > 0.$ Based on (19), the following definition is provided.

Definition D2. *A permit-buying country i has relatively high (low) demand for permits if and only if* $I_i > (<) \overline{I}_i$.

Given definitions D1-D2 and equation (19), permit-buying countries with relatively high demand for permits should adopt a green strategy, while those with relatively low demand for permits should choose a brown strategy. The above results are summarized as follows.

Proposition 2. A brown strategy is optimal for permit-selling countries and permit-buying countries with relatively low demand for emission permits. In contrast, a green strategy is optimal for permit-buying countries with relatively high demand for emission permits.

4. Implications on export competitiveness

This section is concerned with the competitiveness implications of quantitative strategies for IET. The emphasis is on whether and how the quantitative strategies affect the countries' social welfare.

First, compare the equilibria in the previous two sections. Based on equations (3) and (11), countries' quantitative strategies would violate the cost-effectiveness of ETS. Equation (14) indicates that the aggregate impact of quantitative strategies on the equilibrium permit price is ambiguous because countries might adopt green or brown strategies. Accordingly, individual countries' optimal permit trading amounts and domestic abatement levels could be higher or lower at the equilibrium with quantitative strategies, as compared to the benchmark case (i.e., the cost-effective equilibrium). Thus individual countries may or may not benefit from strategic trading in the case of multilateral quantitative strategies. This result and implication are summarized as follows.

Proposition 3. Countries' quantitative strategies would violate the cost-effectiveness of IET. Countries may or may not gain from adopting quantitative strategies in the case of multilateral quantitative strategies.

In the literature and in practice, strategic "cost-shifting" trading behavior in IET is widely neglected. Therefore, our next focus is on a plausible circumstance of unilateral quantitative strategy (i.e., a circumstance where only one country has the far-seeing intelligence to act strategically in the IET, while others behave based on the cost-effective condition in equation (3), as suggested by the general literature). Without loss of generality, assume that country 1 sets quantitative strategy while other countries do not. The associated equilibrium is provided as follows.

Corollary 1. The equilibrium of unilateral quantitative strategy is given by:

$$\tilde{\lambda}_1 = \Phi_1\left(\tilde{e}_1 - \overline{w}_1\right) + \Omega_1\tilde{q}_1;$$

$$\tilde{Q} = \frac{N - \Theta\tilde{r} - \theta_1\tilde{\lambda}_1}{N+1} \text{ and } \tilde{p} = \frac{1 + \Theta\tilde{r} + \theta_1\tilde{\lambda}_1}{N+1};$$

$$\tilde{q}_1 = \tilde{p} - \theta_1\left(\tilde{r} + \tilde{\lambda}_1\right) \text{ and } \tilde{q}_i = \tilde{p} - \theta_i\tilde{r} \text{ for } i = 2, \ldots N;$$

$$\tilde{e}_1 = \theta_1\left[\tilde{p} - \theta_1(\tilde{r} + \tilde{\lambda}_1)\right] - \frac{\tilde{r} + \tilde{\lambda}_1}{\alpha_1} \text{ and } \tilde{e}_i = \theta_i\left[\tilde{p} - \theta_i\tilde{r}\right] - \frac{\tilde{r}}{\alpha_i}$$

for $i = 2, \ldots N$; and

$$\tilde{r} = \hat{r} - k_1\tilde{\lambda}_1.$$

Compared to the equilibrium without quantitative strategies in Section 2, country 1's social welfare is higher at the equilibrium of unilateral quantitative strategy, i.e., $\tilde{S}_1 > \hat{S}_1$, and the proof is in Appendix 2. In other words, the country takes the first step to set the unilateral quantitative strategy can enjoy the first-mover advantage of making the price toward its desired direction and shifting its compliance costs to others. As a result, the country's production cost is lower and its exports become more competitive. This result is summarized as follows.

Proposition 4. The country with far-seeing intelligence of acting strategically in IET would enjoy the first-mover advantage of enhancing export competitiveness.

Conclusion

This paper investigates the optimal quantitative strategies on the IET market and the associated competitiveness implications. We show that the optimal permit trading strategy depends on two effects, consisting of the direct effect on emissions trading and the indirect (spillover) effects on commodity export. The direct effect captures the impact of strategic trading on permit price. Allowance-buying countries can select a green strategy to reduce the excess demand and lower the permit price, while allowance-selling countries can choose a brown strategy to reduce the excess supply and enhance the permit price. On the other hand, when considering only the indirect effect on commodity export, all countries should choose a brown strategy. Combining the direct and indirect effects, we show that a brown strategy is optimal for permit-selling countries and permit-buying countries with relatively low demand for permits, while those with relatively high demand should adopt a green strategy. Finally, the country taking the lead in setting quantitative strategy in IET will enjoy the first-mover advantage of reducing compliance costs and enhancing competitiveness.

This paper presumes a perfectly competitive ETS, which can be relaxed in the future. In other words, one can assume that some countries have market power, and explore how market structures affect the results. On the other hand, an empirical estimation of the impacts of quantitative strategies on the export competitiveness deserves future research attention. In particular, reliable estimates on countries' abatement costs and comprehensive simulations could make such an analysis applicable to practical policy design.

References

1. Barrett, S. (1994). Strategic Environmental Policy and International Trade, *Journal of Public Economics*, 54, pp. 325-338.
2. Brander, J. (1986). Rationales for Strategic Trade and Industrial Policy, In: Krugman P. (eds.) Strategic Trade Policy and the New International Economics, MIT Press, Cambridge, pp. 23-46.
3. Brander, J. and B. Spencer (1981). Tax and the Extraction of Foreign Monopoly Rent under Potential Entry, *Canadian Journal of Economics*, 14, pp. 371-389.
4. Brander, J. and B. Spencer (1985). Export Subsidies and International Market Share Rivalry, *Journal of International Economics*, 18, pp. 83-100.
5. Beghin, J., D. Roland-Holst and D. van der Mensbrugghe (1994). A Survey of the Trade and Environment Nexus: Global Dimensions, OECD Economic Studies, 23, pp. 161-192.
6. Chichilnisky, G. and Heal, G. (1995). Markets for Tradable CO_2 Emission Quotas: Principles and Practice, OECD Working Papers. Paris: Organization for Economic Co-operation and Development.
7. Conrad, K. (1993), Taxes and Subsidies for Pollution-Intensive Industries, *Journal of Environmental Economics and Management*, 25, pp. 121-135.
8. 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, pp. 585-601.
9. Dean, J.M. (1992). Trade and the Environment: A Survey of the Literature, Working Papers – Policy Research: Background Paper for the World Development Report. Washington, D.C.: Word Bank.
10. Dixit, A. (1984). International Trade Policy for Oligopolisitc Industries, *The Economic Journal*, 94 (supplement), pp. 1-16.
11. Eaton, J. and G. Grossman (1986). Optimal Trade and Industrial Policy under Oligopoly, *Quarterly Journal of Economics*, 101 (2), pp. 383-406.
12. Evans, M. (2003). Emissions Trading in Transition Economies: The Link between International and Domestic Policy, *Energy Policy*, 31, pp. 879-886.
13. Greaker, M. (2003). Strategic Environmental Policy; Eco-Dumping or a Green Strategy? *Journal of Environmental Economics and Management*, 45, pp. 692-707.
14. Jaffe, B.A., S.R. Peterson, P.R. Portney and R.N. Stavins (1995). Environmental Regulation and the Competitiveness of US Manufacturing: What Does the Evidence Tell Us? *Journal of Economic Literature*, 33 (1), pp. 132-164.
15. Jayadevappa, R. and S. Chhatre (2000). International Trade and Environmental Quality: A Survey, *Ecological Economics*, 32, pp. 175-194.
16. 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, pp. 207-221.
17. Lee, T.C., H.C. Chen and S.M. Liu (2013). Optimal Strategic Regulations in International Emissions Trading Under Imperfect Competition, *Environmental Economics and Policy Studies*, 15, pp. 39-57.
18. OECD (1993). Environmental Policies and Industrial Competitiveness. Paris: Organization for Economic Co-operation and Development.
19. Spencer, B. and J. Brander (1983). International R&D Rivalry and Industrial Strategy, *Review of Economic Studies*, 50, pp. 707-722.
20. Thompson, P. and L.A. Strohm (1996). Trade and Environmental Quality: A Review of the Evidence, *Journal of Environment and Development*, 5 (4), pp. 363-388.
21. Ulph, A. (1996). Environmental Policy and International Trade When Governments and Producers Act Strategically, *Journal of Environmental Economics and Management*, 30, pp. 265-281.
22. Weyant, J. (Ed.) (1999). The Cost of the Kyoto Protocol: A Multi-Model Evaluation, *The Energy Journal*, special issue.
23. Zhang, Z.X. (2001). An Assessment of the EU Proposal for Ceilings on the Use of Kyoto Flexibility Mechanisms, *Ecological Economics*, 37, pp. 53-69.

Appendix 1

Proof of Equation (15):

$$\frac{\partial e_i^*}{\partial \lambda_i}=\left[\theta_i\left(\frac{\theta_i}{N+1}-\theta_i\right)-\frac{1}{\alpha_i}\right]+\mu_i k_i=\left[\theta_i\left(\frac{\Theta-\sum_{j\neq i}\theta_j}{N+1}-\theta_i\right)-\frac{1}{\alpha_i}\right]+\mu_i k_i=\mu_i\left(k_i-1\right)-\theta_i\left[\left(\frac{\sum_{j\neq i}\theta_j}{N+1}\right)\right]<0 \text{ given } \mu_i>0 \text{ and } 1+k_i>0.$$

Using Chain rule, we have $\dfrac{\partial e_i^*}{\partial t_i}=\left(\dfrac{\partial e_i^*}{\partial \lambda_i}\right)\left(\dfrac{\partial \lambda_i^*}{\partial t_i}\right)>0.$

Proof of Equation (16):

$$\frac{\partial r^*}{\partial t_i}=\left(\frac{\partial r^*}{\partial \lambda_i}\right)\left(\frac{\partial \lambda_i^*}{\partial t_i}\right)=-k_i\left(\frac{\partial \lambda_i^*}{\partial t_i}\right)>0.$$

Proof of Equation (17):

By (10) and (11), we have $q_i^* = p^* - \theta_i(r^* + \lambda_i)$. Differentiating this equation with respect to λ_i yields

$$\frac{\partial q_i^*}{\partial \lambda_i} = \frac{1}{N+1}\left(-\Theta k_i + \theta_i\right) + \theta_i(k_i - 1) = \left(\frac{N\theta_i}{N+1}\right)(k_i - 1) + \left(\frac{\sum_{j\neq i}\theta_j}{N+1}\right)(-k_i) < 0, \text{ given } 0 < k_i < 1.$$

Using Chain rule, we have $\frac{\partial q_i^*}{\partial t_i} = \left(\frac{\partial q_i^*}{\partial \lambda_i}\right)\left(\frac{\partial \lambda_i^*}{\partial t_i}\right) > 0.$

Because equation (12) indicates that $\frac{\partial Q_i^*}{\partial \lambda_i} = \frac{\Theta k_i - \theta_i}{N+1}$, we have

$$\frac{\partial\left(\sum_{j\neq i} q_j^*\right)}{\partial \lambda_i} = \frac{\partial Q^*}{\partial \lambda_i} - \frac{\partial q_i^*}{\partial \lambda_i} = \left(\frac{N-1}{N+1}\right)\theta_i\left(1 - k_i\right) + \left(\frac{2\sum_{j\neq i}\theta_j}{N+1}\right)(k_i) > 0.$$

Using Chain rule, we have $\frac{\partial\left(\sum_{j\neq i} q_j^*\right)}{\partial t_i} = \left(\frac{\partial\left(\sum_{j\neq i} q_j^*\right)}{\partial \lambda_i}\right)\left(\frac{\partial \lambda_i^*}{\partial t_i}\right) < 0.$

Appendix 2

Proof of Proposition 4:

Denote $A = \tilde{q}_1 - \hat{q}_1$, $B = \tilde{p} - \hat{p}$, $F = \tilde{r} - \hat{r}$, and $K = \tilde{e}_1 - \hat{e}_1$. Then we have

$$\tilde{S}_1 - \hat{S}_1 = A\hat{q}_1 + B\tilde{q}_1 - \frac{\left(F + \lambda_1\right)^2}{2\alpha_1} - F(\tilde{e}_1 - \overline{w}_1). \tag{a1}$$

From Corollary 1, $\left(\tilde{e}_1 - \overline{w}_1\right) = \frac{\tilde{\lambda}_1 - \Omega_1\tilde{q}_1}{\Phi_1}$. Substituting this equation into (a1) and rearranging yields

$$\tilde{S}_1 - \hat{S}_1 = -W\left(\tilde{\lambda}_1\right)^2, \tag{a2}$$

where $W = \left(\frac{-\Theta k_1 + \theta_1}{N+1} - \theta_1\left(1 - k_1\right)\right)^2 + \frac{(1-k_1)^2}{2\alpha_1} - \frac{k_1}{\Phi_1} < 0.$

Therefore, from (a2) we have $\tilde{S}_1 - \hat{S}_1 > 0$, or, equivalently, $\tilde{S}_1 > \hat{S}_1$.