行政院國家科學委員會專題研究計畫　成果報告

可交易排放權證制度下之寡占廠商污染防治誘因

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The Pollution Control Incentive for Oligopolists under the Tradeable Permit System

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一、中文摘要

關鍵詞：可交易排放權證、排放稅、污染防治誘因、寡占

可交易排放權證是一種環境管制的經濟工具，它賦予污染者排放的權利。可交易排放權證係用來解決污染交易市場不存在所引起的市場失靈，並藉由創造市場的方式形成污染權的市場價格，進而使污染成本內部化。該制度目前已廣為OECD國家等所採用。台灣至今仍未實施可交易排放權證制度，因此政策實施前的理論研究與評估便十分重要。

1970年代的相關理論文獻多顯示：可交易排放權證可以達到有效率的均衡結果。然而近10年的實證與理論文獻卻陸續顯示：可交易排放權證經常導致缺乏效率的結果。對此，既存文獻所檢討的原因有：交易成本太高、同時限制總和與個別污染者排放量、執法成本較其他管制工具下更高、不利於獨立研發授權者的環保創新誘因等。

環境管制工具的政策及研究主軸，早已由命令與控制（command and control）移轉至經濟工具（economic instruments），常見的環保經濟工具有：產品稅、排放稅、補貼、財產權、可交易排放權證、押金、執法誘因、環保標章、志

願性環保計劃等。在不同的外在環境下，每一種經濟工具的環境與經濟效果不同，而導致所對應的經濟效率也不同。而分析與比較各種環保經濟工具的效果與效率，實乃學術與政策上的重大議題（Baumol and Oates 1988、Ebert 1996、Jung, Krutilla and Boyd 1996、OECD 1994）。

污染外部性的發生原因之一，係因為交易市場不存在，這可藉創造市場（market creation）的方式解決（Coase 1960、葉俊榮 1993、Rosen 1999、Cooter and Ulen 2000）。若資源的分配採「環境優勢原則」，則可以建立環境財產權，賦予財產權人排他使用權利，透過財產權人與污染者（環境使用者）間的協商，以形成環境的價格，並使得污染成本內部化。根據著名的Coase定理，「在交易成本為零下，只要財產權確立（無論誰擁有財產權），則市場機制自動達成Pareto最適的資源配置。」若資源的分配採「污染優勢原則」，則可以提供污染者排放的權利（right-to-emit）。政府一開始可以透過指派或拍賣等方式將排放權證移轉給民間，但只要排放權證是可以轉讓的，則市場機制將決定排放權證的價格，而使得污染者必須負擔持有排放權證的機會成本，亦可使污染成本內部化。而本研究將以可交易排放權證的經濟與環境效果為重點。

台灣至今仍未實施可交易排放權證制度，因此政策實施前的理論研究與評估便十分重要，以使得一旦實施此政策時的法規政策等能更為完備。1970年代初期的理論文獻（例如：Montgomery 1972等），由於忽略交易成本等因素，因而得到與Coase定理一致的結論，而認為無論起始的污染權證配置為何，可轉讓排放權證市場都可達到有效率的均衡結果。然而，隨者OECD國家等逐漸累積實施可交易排放權證的資料後，這樣的說法卻逐漸受到實證與理論文章的否定：

Atkinson and Tietenberg（1990）利用美國聖路易地區27個最大空氣點污染源的排放資料，利用線性規劃的方法檢驗這些污染源的成本有效性。他們的實證結果卻發現：可交易排放權證制度並不具備成本有效性，而其成本節省效果有限。他們認為，可交易排放權證市場失靈的原因為交易過程中的成本很高。這是因為廠商必須兩兩個別（bilateral）、依序（sequential）協商，而無法同時多邊協商。此外，個別

排放者的污染物內容也不盡相同，大幅增加了協商成本。即使達成交易，買賣雙方都必須同時改變空氣品質，調整成本很高。從線性規劃的角度而言，可交易排放權證同時限制了個別及總和排放量，限制增加的結果使得均衡解偏離最適解更多。

繼Atkinson and Tietenberg（1990）的前驅研究之後，近10年的後續文獻多半認為可交易排放權證未必能達到有效率的均衡結果。除了交易成本太高外，他們提出的理由還有：可交易排放權證降低獨立環保創新（兼授權）者的研發誘因（Laffont and Tirole 1996），可交易排放權證市場為不完全的（Hagem 1998），針對個別廠商的監督與執法成本太高（Starlund and Dhanda 1999），廠商與政府間對污染防治成本的資訊不對稱問題（Yates and Cronshaw 2001）、污染量事前為隨機的、廠商無法事前準確計算排放量配額（Hannessy and Roosen 1999）等。其中Laffont and Tirole（1996）之大作，直接啟發了本研究計劃之動機：

Laffont and Tirole（1996）建立一個理論模型，其中有單一環境創新者、*N*個污染性廠商。環保創新者本身並不進行生產與銷售最終財，而廠商並不進行環保創新。環保創新者將其污染防治技術以有償方式授權給廠商，而政府則訂定排放權證價格。排放權證提供了廠商另一種選擇，使後者得以減少污染防治水準而仍然合法。排放權證數量的增加使得環境創新者的研發受益減少，而使得廠商污染防治量下降，反而不利於環保。他們也討論了環保創新者將其污染防治技術以有償方式授權給政府，再由政府技術移轉給廠商的情形。此外，他們還證明：政府於事前就採購此環保創新所需支付的權利金較低。

然而，現代廠商在研發與創新行為上扮演的角色，甚至遠超過獨立研發者，因此Laffont and Tirole（1996）的獨立研發者模型無法直接應用於分析廠商間的環保創新競爭上。現存的環境研發與污染防治競爭文獻，例如：Carraro and Siniscalco (1992, 1997)、Chiou and Hu（2001）、Damania（1996）、Katsoulacos and Xepapadeas（1995, 1996a, b）、Katsoulacos, Y. (1997)等，多直接考慮廠商同時選擇產量與污染防治量，並討論廠商間環保創新競爭之經濟與環境效果。值得注意的是，這些文獻普遍指出：廠商的污染防治行為，處了具有影響自身利潤的「利潤效果」外，還有影響競爭對手產量的「策略效

果」。廠商可以藉由第一階段中的污染防治行為，間接影響第二階段產量競爭或合作的結果。

此外，廠商可以藉由減少產量等策略以節省污染稅等成本，而不從事污染防治工作，使得環境政策失靈。然而，在經濟發展已無法走回頭路的今天，人類必須藉由環保研發以在生產規模擴大的同時、降低污染排放量。此外，地球的資源有限，如何藉由環保研發以提高包含環境因素在內的生產效率，亦是永續發展上的重大議題。因此，上述文獻特別強調：應設計能提供廠商從事污染防治誘因的環境政策。

本研究以排放稅作為對照比較用的環境管制工具，並驗證排放稅下雙占廠商的污染防治誘因。並且比較分別使用及並用兩種管制工具下的經濟與環境效果。本研究建立一個理論模型，討論可交易排放權證下寡占廠商的污染防治誘因。（本研究之理論模型及其求解，煩請參見英文摘要。）

本文一開始先從獨占模型出發，此獨占者可以內生性地選擇產量及污染防治量。理論模型求解結果顯示：給定相同的總排放量下，排放稅與可轉讓排放權證帶來相同的均衡污染防治水準與產量。

雙占模型中則有兩家廠商，皆於生產過程中產生污染。兩者具備相同的生產成本與污染防治成本，皆可從事污染防治與購買排放權證。

本文理論模型證明：給定相同的總排放量下，在排放權證制度下雙占廠商污染防治的誘因較低、而隱性產量勾結的誘因較高，因而降低社會剩餘。換言之，若廠商可從事污染防治，則在寡占市場結構下可交易排放權證劣於排放稅。

本文理論發現與 Atkinson and Tietenberg（1990）、Laffont and Tirole 1996、Hagem （1998）、Starlund and Dhanda （1999）、Yates and Cronshaw （2001）、Hannessy and Roosen （1999）的理論或實證研究發現，可交易排放權證經常無法達到有效率結果的結論一致。如此一來，就現實生活中常見的寡占市場結構而言，可交易排放權證並不能取代排放稅。相反的，在寡占市場結構下，排放稅優於可交易排放權證。

二、English Abstract

Keywords: tradeable permit, emission tax, pollution abatement incentives, oligopoly

I. Introduction

The tradeable permit is an economic instrument for environmental protection. It renders the right-to-emit to the polluters. The tradeable permit is designed to solve the market failure caused by the non-existence of a pollution market. It also forms the price of rights-to-pollute by market creation, making pollution cost be internalized. Many OECD countries already have tradeable permits systems. Taiwan still has not implemented such a system and hence the theoretical assessment before policy implementation is extremely important.

Most related theoretical literature in the 1970s showed that tradeable permits could achieve efficient equilibrium outcomes. However, many empirical and theoretical articles in the past ten years have shown that tradeable permits often result in inefficient equilibrium outcomes. The possible reasons for such inefficiencies are as follows: higher transaction cost, simultaneous restriction of the total and individual emissions, higher enforcement cost, adverse effects on an independent environmental innovator and licensor's innovation incentives, etc.

In this research, we establish a theoretical model, in order to discuss the pollution abatement incentives of oligopolists under a tradeable permit system.

The benchmark model starts with a case of monopoly. The monopolist can endogenously choose its output quantity and pollution abatement effort. In a monopolistic market, if the targeted total emission quantities are the same ($\hat{E} = E^*$), then the equilibrium pollution abatement level and output quantities are the same under an emission tax and an emission quota.

There are two polluting firms in the duopolistic model, with the same production and pollution abatement costs. Both firms are able to choose from pollution abatement and purchasing tradeable permits. We want to prove the following propositions: The firm with higher production efficiency can strategically purchase more permits, reducing its pollution abatement incentives. The firm with lower production efficiency may have a lower per output emission level.

The emission tax will be used for comparison with the tradeable permit. Pollution abatement incentives of the duopolists under the emission tax will be examined. We also intend to prove the following proposition: Te tradeable permit is not always superior to the emission tax, if firms are able to engage in pollution abatement. We will then compare the economic and environmental effects of these two instruments.

II. The Monopoly Case under the Emission Tax and the Emission Quota

2.1 A Monopoly under the Emission Tax

To compare with the case of a duopoly, we start with the case of an environmentally innovating monopoly. The inverse demand function of the market is

$$P = a - bQ, \qquad (1)$$

where P is the market price; Q is the quantity produced by the monopolist. To focus pollution abatement R&D decision without losing generality, we assume that the marginal production cost of the firm is zero. There are two stages in this model: In the first stage, the monopolist chooses its pollution abatement in pollution abatement r to lower its own emission per unit of output. Following D'Aspremont and Jacquemin (1988) and Katsoulacos and Xepapadeas (1996a), we assume a quardratic pollution abatement R&D cost function:

$$R(r) = \frac{R}{2} r^2, \qquad (2)$$

where $R > 0$. To simply the calculation, we assume that the fixed marginal cost of production is zero.[1] Therefore, in stage one, the monopolist's profit maximization

[1] This assumption will not affect the qualitative discussion.

problem is

$$\underset{Q,r}{Max} \quad \pi^* = (a - bQ)q - t(\bar{e} - r)q - \frac{R}{2}r^2, \qquad (3)$$

where t is the emission tax. In the second stage, the monopolist's profit maximizing quantity is

$$Q(r) = \frac{a - t(\bar{e} - r)}{2b}. \qquad (4)$$

After we substitute Equation (4) into Equation (3), the monopolist's maximization problem in the first stage becomes

$$\underset{r}{Max} \quad \pi^*(Q(r), r) =$$

$$\frac{a^2 - t^2(\bar{e} - r)^2}{4b} - t(\bar{e} - r)\frac{a - t(\bar{e} - r)}{2b} - \frac{R}{2}r^2. \qquad (5)$$

The second order conditions for the monopolist's profit maximization is $2bR - t^2 > 0$. Solving the monopolist's profit maximization problem under an emission tax, we obtain the pollution abatement level $r^* = \frac{t(a - t\bar{e})}{2bR - t^2}$, the output quantity $Q^* = \frac{R(a - t\bar{e})}{2bR - t^2}$, emission level $E^* = \bar{e} - r^* = \frac{2bR\bar{e} - at}{2bR - t^2}$. Note that if the emission tax is zero ($t = 0$), then $Q^* = \frac{a}{2b}$ and $r^* = 0$. That is, the monopolist has no incentive to undertake pollution abatement if there is no government regulation.

[Lemma 1] $\frac{dr^*}{dt}|_{t=0} > 0$, $\frac{dr^*}{dt} \gtrless 0$; $\frac{dQ^*}{dt}|_{t=0} < 0$, $\frac{dQ^*}{dt} \gtrless 0$.

[Proof] $\frac{dr^*}{dt} = \frac{2at^2 - 4bRt\bar{e} + 2abR}{(2bR - t^2)^2} \gtrless 0$, $\frac{dr^*}{dt}|_{t=0} = \frac{2}{2bR} > 0$;

$$\frac{dQ^*}{dt} = \frac{R(2at - t\bar{e} - 2bR\bar{e})}{(2bR - t^2)^2} \gtrless 0,$$

$\frac{dQ^*}{dt}|_{t=0} = -\frac{\bar{e}}{2b} < 0$.

Lemma 1 tells that if the emission tax rate is low enough, an increase in emission tax rate induces the monopoly to increase pollution abatement R&D and decrease output quantity. However, the government can no longer promote emission abatement R&D through raising the emission tax rate if the tax rate is high enough.

2.2 A Monopoly under the Emission Quota

The government can also induce pollution abatement by setting an emission quota ($\bar{E}$). To compare with an emission tax, we assume that the targeted emission is the same under the two instruments, that is $\bar{E}$

= E^*. Therefore, the monopolist's profit maximization problem becomes

$$\underset{Q,r}{Max} \quad \hat{\pi} = (a - bQ)Q - \frac{R}{2}r^2 - \omega\overline{E}$$

$$\text{s.t.} \quad (\overline{e} - r)Q = \overline{E}\,, \tag{6}$$

where ω is the price of one unit emission quota. According to the constraint (Equation (6)), Q and r must be simultaneously determined when $\overline{E}$ is given. Therefore, we are able to solve Q and r simultaneously as if it is a one-stage game. Solving the monopolist's profit maximization problem under the emission quota, we obtain the pollution abatement level $\hat{r} = \dfrac{t(a - t\overline{e})}{2bR - t^2}$, output quantity $\hat{Q} = \dfrac{R(a - t\overline{e})}{2bR - t^2}$, and emission level $\hat{E} = \overline{e} - \hat{r} = \dfrac{2bR\overline{e} - at}{2bR - t^2}$.

[Proposition 1] *In a monopolistic market, if the targeted total emission quantities are the same (*$\hat{E} = E^*$*), then the equilibrium pollution abatement level and output quantities are the same under an emission tax and an emission quota.*

Proposition 1 shows that under a monopolistic market structure, the government can induce the same environmental and economic results by either an emission tax or an emission quota. However, in Section III we are going to show that an emission tax and an emission quota with the same targeted emission amount have different environmental and economic impacts.

III. A Duopoly under the Emission Tax and Quota

The aim of this article is to focus on the duopolistic pollution abatement; therefore, the monopoly case in Section I is a benchmark to illustrate the effect of market structure on the implementation of environmental instruments. In this section, we will analyze the duopoly case and compare the results to the monopoly case.

3.1 A Duopoly under the Emission Tax

In a duoplistic competition, there are two firms which are indexed by 1, 2, respectively. The two firms produce homogeneous goods. The inverse demand function of the market is

$$P = a - bQ, \qquad (1')$$

where P is the market price; $Q = q_1 + q_2$; q_1, q_2 are the quantities produced by firms 1 and 2, respectively. The marginal production cost of the two firms is zero. There are two stages in this game: In the first stage, the two firms choose their pollution abatement in pollution abatement r_i, i = 1, 2, to lower its own emission per unit of output. The pollution abatement R&D functions are identical:

$$R_i(r_i) = \frac{R}{2} r_i^2,\ i = 1, 2, \qquad (2')$$

where $R > 0$.. In the second stage, the two firms choose their output quantities simultaneously. Therefore the profit functions of the two firms are, respectively,

$$\pi_i^{**} = (a - bQ)q_i - t(\bar{e} - r_i)q_i - \frac{R}{2} r_i^2,$$

$$i = 1, 2, j = 1, 2, i \neq j. \qquad (7)$$

We apply the solution concept of subgame-perfect Nash equilibrium (SPNE) to solve this game (Osborne and Rubinstein (1994)). In the second stage, firm i's best response in quantity is

$$q_i^{**} = \frac{1}{3b}\left[a - t\bar{e} + 2tr_i - tr_j\right],$$

$$i = 1, 2, j = 1, 2, i \neq j. \qquad (8)$$

It is clearly shown by Equation (7) that there is a strategic effect of the abatement levels on output quantities. Therefore, in the first stage firm i's profit maximization problem becomes

$$\underset{r_i}{Max}\ \pi_i^{**}(q_1(r_1, r_2), q_2(r_1, r_2), r_i),\ i = 1, 2. \qquad (9)$$

By the property of symmetry, the first order condition for both firms' profit maximization is

$$\frac{4}{3} tq - Rr = 0\,, \qquad (10)$$

where q denotes the equilibrium output of each firm. Solving firms 1 and 2's maximization problem simultaneously, we obtain the SPNE pollution abatement level $r_1^{**} = r_2^{**} = r^{**} = \dfrac{4t(a - t\bar{e})}{9bR - 4t^2}$, the SPNE output quantities $q_1^{**} = q_2^{**} = q^{**} =$

$\frac{3R(a-t\bar{e})}{9bR-4t^2}$, and the SPNE total emission amount E^{**} = $Q^{**}(\bar{e} - r^*)$ = $\frac{6R(a-t\bar{e})[9bR\bar{e}-4at]}{[9bR-4t^2]^2}$.

3.2 A Duopoly under the Emission Quota

Instead, the government can also induce pollution abatement by setting a total emission quota ($\bar{E}$) which is sold to the two duopolists with the price ω. We assume that the two firms split the quota (permits) equally, that is, each firm has the emission quota share $\frac{\bar{E}}{2}$. We denote the SPNE duopolistic pollution abatement, output, total emission levels under an emission quota by $\hat{\hat{r}}$, $\hat{\hat{q}}$, $\hat{\hat{E}}$, respectively. Therefore, firm i's profit maximization problem becomes

$$\max_{q_i, r_i} \quad \hat{\hat{\pi}}_i = (a-bQ)Q - \frac{R}{2}r_i^2 - \frac{\omega}{2}\bar{E} \qquad (11)$$

$$\text{s.t.} \quad (\bar{e} - r_i)q_i \le \frac{\bar{E}}{2}, \; i = 1, 2. \qquad (12)$$

If $\bar{E} < \frac{2a\bar{e}}{3b}$, then $q_i = \frac{\bar{E}}{2(\bar{e}-r_i)}$. If $\bar{E} > \frac{2a\bar{e}}{3b}$, then $\hat{\hat{r}}_1 = \hat{\hat{r}}_2 = \hat{\hat{r}} = 0$. That is, the total emission associated with two firms' profit maximization is strictly less than the total quota. Therefore, the emission quota is then a non-binding (ineffective) constraint. We assume that $\bar{E} < \frac{2a\bar{e}}{3b}$ for the emission quota constraint (Equation (12)) to be binding at the solution. Therefore, the best responses in pollution abatement are

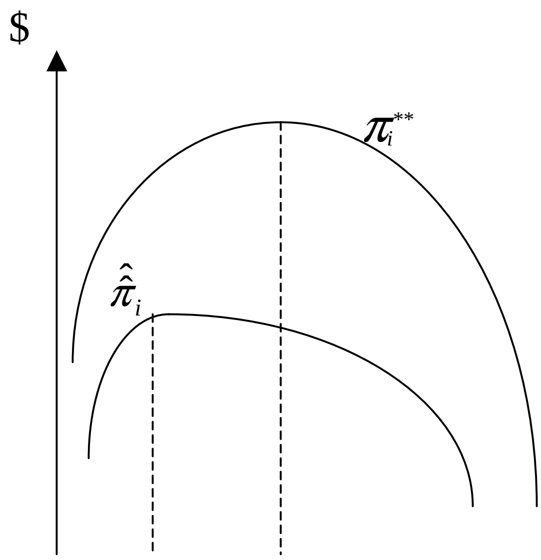
$$\hat{\hat{r}}_i = \bar{e} - \frac{\bar{E}}{2q_i}, \quad i \neq j, i = 1, 2. \qquad (13)$$

Thus, firm i's profit maximization problem becomes

$$\max_{q_i} \quad \hat{\hat{\pi}}_i = (a-bQ)q_i - \frac{R}{2}\left(\bar{e} - \frac{\bar{E}}{2q_i}\left(\frac{1}{q_i}\right)\right)^2, \quad i = 1, 2. \qquad (14)$$

And by symmetry, the associated first order condition becomes

$$\frac{\partial \hat{\hat{\pi}}}{\partial q} = a - 3bq - R\bar{E}\left(\bar{e} - \frac{\bar{E}}{2q}\right)\frac{1}{2q^2} = 0. \qquad (15)$$



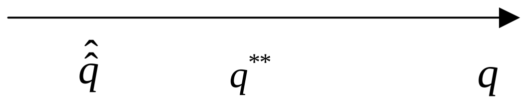


Figure 1: The Profit Functions of a Symmetric Duopolist under the Emission Tax and Quota

[Proposition 2] *Under a duopolistic market structure, if the targeted total emission quantities are the same, that is, if* $\hat{\hat{E}} = E^{**}$, *then the pollution abatement levels and output quantity under an emission quota are both lower than an emission tax.*

[Proof] By Equation (10), $\frac{2(2-\beta)}{3}tq^{**} - Rr^{**} = 0$ must hold. Along with Equation (15), we obtain

$$\frac{\partial \hat{\hat{\pi}}}{\partial q_i}\Big|_{q_i = q^{**}} = -\left[\bar{e} - r^{**}\right]\left(-\frac{1}{3}t\right) < 0 \qquad .$$

Therefore, the duopolists' profit functions in output quantity under an emission tax and an emission quota, respectively, are as depicted in Figure 1. Thus, we must have $\hat{\hat{q}} < q^{**}$ which implies $\hat{\hat{Q}} < Q^{**}$. Therefore, $\bar{e} - \hat{\hat{r}} > \bar{e} - r^{**}$ which implies $\hat{\hat{r}} < r^{**}$.

Proposition 2 tells us that an emission tax should be more desirable to an emission quota under a duopolistic competition in regard with consumer surplus and pollution abatement level. This is because the implicit collusion effect between the oligopolists under an emission quota is larger than that under an emission tax.

However, Proposition 1 says that with the same targeted emission amount, an emission tax and an emission quota have the same economic and environmental effects for a monopolistic market structure.

IV. Concluding Remarks

From Propositions 1 and 2, it is clearly shown that the environmental and economic effects of an environmental instrument crucially depend on the market structure (Katsoulacos and Xepapadeas (1996b)). For a duopoly, an emission tax is superior to an emission quota with respect to emission abatement and consumer surplus.

Our theoretical findings are consistent with many theoretical and empirical papers, for example, Atkinson and Tietenberg (1990), Laffont and Tirole (1996), Hagem （1998）, Starlund and Dhanda (1999), Yates and Cronshaw (2001), Hannessy and Roosen (1999), etc. They also find that tradeable permits may not achieve an efficient market equilibrium.

Since an oligopoly is often seen in the real life, an emission tax is hence superior to an tradeable permit system with respect to pollution abatement and the social surplus. A tradeable permit system thus cannot replace the emission tax. An emission tax still more preferable for a market of oligopoly.

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