On the efficiency of competitive markets for input quotas: The case of emission permit trading

Eftichios Sophocles Sartzetakis

University College of the Cariboo

Abstract. It is typical for economists and policy makers alike to presume that competitive markets allocate input licenses efficiently. This paper demonstrates that competition in the licenses market cannot assure efficiency when the product market is oligopolistic. We develop a model to provide the conditions under which a bureaucratic mechanism is welfare superior to a marketable input licenses system. Price taking behaviour in the licenses market ensures transfer of licenses to the less efficient firm which becomes more aggressive in the product market. A higher than the welfare maximizing number of licenses are traded. When the input and final output technologies are positively correlated, competitive license trading may result in lower output and welfare.

Keywords:. competitive trading of input quotas, oligopolistic product markets, economic efficiency.

Address all correspondence to Eftichios S. Sartzetakis at Department of Economics, School of Business, University College of the Cariboo, 900 McGill Road, PO Box 3010, Kamloops, BC, Canada V2C 5N3; Tel: (250) 371-5754; Fax: (250) 371-5675; email: **esartzetakis@cariboo.bc.ca.**

I. Introduction

Economists typically take as given that competitive markets allocate licenses efficiently, that is, to the user with the highest value. It has been shown, however, that competitive trading of licenses does not necessarily yield social welfare maximization, and that in some cases a bureaucratic mechanism could be welfare superior. Borenstein (1988) demonstrates that lumpiness of operating licences and the transfer of production to inefficient entrants due to product market imperfections, inhibits the ability of competitive markets to efficiently allocate operating licences. Spencer (1997) finds that a bureaucratic scheme that prohibits resale of quotas for imported capital equipment could dominate a tradeable quota system by supporting an "infant" domestic capital equipment industry. Malueg (1990) points to the possibility that an emission permit trading program may reduce social welfare when the product market is not perfectly competitive. Despite these results, the belief that competitive markets for licenses will guide firms to welfare maximizing decisions remains widely held among economists.

This paper examines the efficiency of competitive trading of licenses restricting the use of an input or resource. Our goal is to provide the conditions under which a bureaucratic mechanism is welfare superior to competitive trading of licenses, and to reveal the intuition underlining this result. Our analysis abstracts from entry decisions and issues related to lumpiness of licenses, and focuses on the interactions between a competitive market for input licenses and an oligopolistic product market. The paper is motivated by the environmental policy makers' problem of choosing between a bureaucratic mechanism and a tradeable emission permits system to control pollution. The increasing importance of environmental regulation and the widespread acceptance of tradeable emission permits systems among policy makers, warrant the focus of our paper. We consider the environmental policy makers' problem of choosing the welfare-maximizing policy instrument in a second-best environment, that is, without the ability to change firms' contact in the product market.

In order to derive meaningful general conditions for the welfare comparison of policy instruments, we separate production from abatement technologies. Abatement costs depend on the level of production and the number of emission licenses available to firms, establishing the link between emission licenses and output decisions. We show that the conditions for the welfare comparison can be stated in terms of firms' differences in abatement and production technologies.

If the more efficient in abatement firms are less efficient in production, competitive trading of emission permits is welfare superior to a bureaucratic mechanism. If, however, firms' technological efficiencies in production and abatement are positively correlated,[1] prohibiting trade of emission permits could dominate competitive trading of emission permits. Under the latter assumption about firms' technologies, another, and perhaps more interesting, result is that competitive trading of emission permits could yield a reduction in industry's output relative to a bureaucratic mechanism. Our results are certainly not calls for limiting the interest over tradeable emission permit programs or other licenses trading programs. They are, however, reasons for considering careful design of these programs in order to improve their efficiency.

To understand the intuition behind these results we focus on the role of the product market through which the gains of competitive trading of emission permits are realized. Price taking behaviour in the emission permit market guarantees that emission permits flow from the low to the high abatement cost firms. Industry's marginal cost of abatement decreases, which assures welfare maximization when the product market is perfectly competitive. However, when the product market is oligopolistic, profits are not necessarily positively correlated with either industry's output or welfare. If rival firms behave à la Cournot, acquisition of emission permits increases the aggressiveness of the less efficient firms while the more efficient firms react by decreasing production to preserve a high price.[2] The reduction of the efficient firms' output decreases their marginal cost of abatement yielding a further release of emission permits to the less efficient firm. This latter transfer of emission permits does not occur in price-taking markets. Thus, the number of emission permits traded could exceed the welfare-maximizing number. When the efficiency differences among firms are more prominent in production rather than abatement, industry's output may decrease. A reduction in welfare could come from two sources: an output reduction, or when the excess transfer of emission permits effect on profits outweighs the effect of increased output on consumer surplus.

The presentation of these results within a general model is undertaken in Section III, following

1 If the age of capital is considered, it is reasonable to expect that production and abatement technologies are positively correlated. Newly acquired capital is more productive, less polluting and more likely to be associated with newer, more productive abatement equipment.

2 In this paper we examine a non-cooperative game. Fershtman and de Zeeuw (1996) and van Long and Soubeyran (1977) for example, have pointed to the possibility that trading of emissions permits may facilitate cooperation among oligopolists by allowing credible commitments that bypass antitrust regulation.

the specification of the model in Section II. In order to illustrate the mechanics of the trading of emission permits we proceed in Section IV to employ a simple example that allows closed form solutions to be derived. We also present the results of some simulations providing a visual illustration as well as some idea of the relative magnitude of the effects of emission permit trading. Section V concludes the paper.

II. The model

Assume a two sector economy; the first is a competitive numeraire sector, the other is a differentiated duopoly. Production generates a negative externality, emission E of a pollutant. Consumer preferences are given by a utility function that is separable in the numeraire good and in emission,

$$U = u(q^1, q^2) + m - V(E) , \tag{1}$$

where m is expenditure on a competitively supplied numeraire good and q^i is the output of firm i in the differentiated sector.[3] To avoid unnecessary repetitions, hereafter, $i, j = 1, 2$ and $i \neq j$.

Each duopolist has cost of production $C^i(q^i)$, with strictly positive marginal cost of production, $c^i > 0$. The amount of pollution emitted by each firm e^i, is an increasing function of its output level, $e^i = H^i(q^i)$ with $H^i(0) = 0$, $h^i = \partial H^i / \partial q^i \geq 0$. Firms can reduce emissions by either reducing output or controlling emissions by engaging in abatement. Total abatement Z^i, is increasing in both output and abatement per unit of output z^i, i.e. $Z^i(q^i, z^i)$, with $Z^i_q > 0$, and $Z^i_z > 0$. Cost of abatement $A^i(Z^i(q, z^i))$ is a strictly increasing function of total abatement efforts, $a^i(Z^i(q, z^i)) = \partial A^i / \partial Z^i > 0$.

We consider two forms of regulatory intervention policy makers could use to limit firms' emission. The first is a bureaucratic mechanism in the form of licensing firm-specific emission quota, and the other is a tradeable emission quota (permits) system. It is reasonable to exclude the possibility that the welfare maximizing distribution of emission quota can be implemented, because of information and/or political constraints. Denoting by $\bar{e}_i$ firm i's emission quota, the aggregate emission quota for the oligopolistic sector is $\sum_{i=1}^{2} \bar{e}_i = \bar{E}$.

Let $\partial u / \partial q^i = p^i(q^1, q^2)$ be firm i's inverse demand, and $R^i(q^1, q^2) = p^i q^i$ the total revenue. We assume that q^1 and q^2 are strategic substitutes, that is, $R^i_j < 0$ and $R^i_{ij} < 0$. Each firm in the

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3 Thus, marginal utility of income is constant and equal to one.

oligopolistic sector sets output on the assumption that the other firm holds its output fixed, arriving at a Cournot-Nash equilibrium. In the case of emission permits trading we assume that although firms interact strategically in the output market, they are price takers in the emission permits market. Thus, we rule out strategic interaction between the output and the emission permit market. Output and abatement per unit of output are determined simultaneously.

III.A. Non-tradeable emission quota

Under the bureaucratic mechanism, the regulator allocates $\bar{e}_i$ non-tradeable emission quota licenses to firm i. Firm *i* chooses output and abatement per unit of output in order to maximize profits subject to the emission constraint, $H^i(q^i) - Z^i(q^i, z^i) = \bar{e}_i$,

$$\max_{q^i, z^i} \quad \pi^i(q^i, q^j, z^i, \bar{e}_i) = R^i(q^i, q^j) - C^i(q^i) - A^i(Z^i(q^i, z^i)) \\ subject\ to \quad H^i(q^i) - Z^i(q^i, z^i) = \bar{e}_i \ . \tag{2}$$

The first order conditions yield firm i's output reaction function,[4]

$$\pi_i^i = R_i^i(q^1, q^2) - c^i(q^i) - a^i(Z^i(q^i; \bar{e}_i))h^i(q^i) = 0 \ . \tag{3}$$

Firm *i*'s Cournot-Nash equilibrium output is a function of firms' production and abatement technologies as well as their emission quota,

$$q^i = \phi^i(\bar{e}_1, \bar{e}_2) \ . \tag{4}$$

Assume that there is a reallocation of emission quota from firm 1 to firm 2. We are interested in deriving the output effect of this reallocation. Total differentiation of the first order conditions, equation (3), with respect to outputs q^1, q^2, and emission quota $\bar{e}_1, \bar{e}_2$ yields,

$$\pi_{11}^1 dq^1 + \pi_{12}^1 dq^2 = -a_1^1 Z_{\bar{e}}^1 h^i \ d\bar{e} \ , \qquad \pi_{21}^2 dq^1 + \pi_{22}^2 dq^2 = a_2^2 Z_{\bar{e}}^2 h^2 \ d\bar{e} \ ; \tag{5}$$

where $d\bar{e} = d\bar{e}_2 = -d\bar{e}_1$, reflects the assumption of a constant aggregate emission quota. The solution of the above system yields,

4 Appendix 1 provides some details of the calculations leading to (3).

$$\phi^1_{\bar{e}} \equiv \frac{dq^1}{d\bar{e}} = -\frac{\pi^2_{22} a_1^1 Z^1_{\bar{e}} h^1 + \pi^1_{12} a_2^2 Z^2_{\bar{e}} h^2}{\Omega}, \quad \phi^2_{\bar{e}} \equiv \frac{dq^2}{d\bar{e}} = \frac{\pi^1_{11} a_2^2 Z^2_{\bar{e}} h^2 + \pi^2_{21} a_1^1 Z^1_{\bar{e}} h^1}{\Omega}. \tag{6}$$

Since $\pi^i_{ii}<0$, $\pi^i_{ij}=R^i_{ij}<0$, $h^i>0$ and $a_i^i Z^i_{\bar{e}}<0$, both numerators are positive, and given that $S>0$,[5] it follows that, $\phi^1_{\bar{e}}<0$ and $\phi^2_{\bar{e}}>0$. Thus, if the allocation of emission quota is slanted in favour of firm 2, its output increases, while of firm 1's output decreases.

An increase in one firm's emission quota, lowers its required abatement per unit of output, which lowers its marginal cost, shifts its reaction function outward, and increases its output and market share, holding the other firm's emission quota constant.[6] Since the aggregate emission quota is assumed fixed, any increase in one firm's emission quota implies an equal reduction in the other firm's quota. Thus, the increase in output and market share of the firm whose emission quota increases, is augmented. The market share of the firm that receives the emission quota transfer increases more when firms act as Cournot rivals compared to the case that firms are price takers. The firm whose share of emission quota decreases, reacts to its rival's increased output by reducing its own output, allowing its rival to become more aggressive. Figure 1 illustrates the above discussion. The equilibrium moves from point A to B as firm 2's emission quota increases while firm 1's decreases. Thus, under the bureaucratic mechanism market shares depend on the allocation of emission quota, given firms' relative efficiency in production and abatement.

The aggregate output effect of the reallocation of emission quota depends on the production and abatement cost structure of the industry. Summing up the two expressions in (6) yields the aggregate output effect,

$$Q_{\bar{e}} \equiv \phi^1_{\bar{e}} + \phi^2_{\bar{e}} = \frac{\left(\pi^1_{11} - \pi^1_{12}\right) a_2^2 Z^2_{\bar{e}} h^2 - \left(\pi^2_{22} - \pi^2_{21}\right) a_1^1 Z^1_{\bar{e}} h^1}{\Omega}. \tag{7}$$

Using (3) note that, $\pi^i_{ii} = 2p_i^i + q^i p^i_{ii} - c_i^i - a_i^i Z_q^i h^i - a^i h_i^i$ and $\pi^i_{ij} = p_j^i + q^i p^i_{ij}$. Thus, $\pi^i_{ii} - \pi^i_{ij} = 2p_i^i - p_j^i + q^i\left(p^i_{ii} - p^i_{ij}\right) - c_i^i - a_i^i Z_q^i h^i - a^i h_i^i$. For homogeneous goods, the requirement for $\pi^i_{ii} - \pi^i_{ij} \leq 0$ reduces to $p' - \left(c_i^i + a_i^i Z_q^i h^i + a^i h_i^i\right) \leq 0$, that is, the output effect on price has to be stronger (more negative) than on marginal costs. Since $a^i>0$, $a_i^i Z_q^i \geq 0$, $h^i>0$ and $h_i^i \geq 0$, a

5 In Appendix 1 we provide the definition of S and we discuss the meaning and importance of these conditions.

6 Total differentiation of (3) with respect to q^i i=1,2 yields the slope of firm i's reaction function, which is negative given the second order conditions and strategic substitutability, $dq^i/dq^j = -R^i_{ij}/\pi^i_{ii}<0$.

necessary and sufficient condition for $\pi^i_{ii} - \pi^i_{ij} \leq 0$ is that the slope of the marginal production cost is non-negative, $c_i^{\prime i} \geq 0$. Under this condition, both terms on the numerator of (7) are positive and given that S>0, the sign of the aggregate output effect depends on the magnitude of these terms. Without specifying firms' technological differences, the aggregate output effect is ambiguous.[7]

III.B. Competitive trading of emission quota

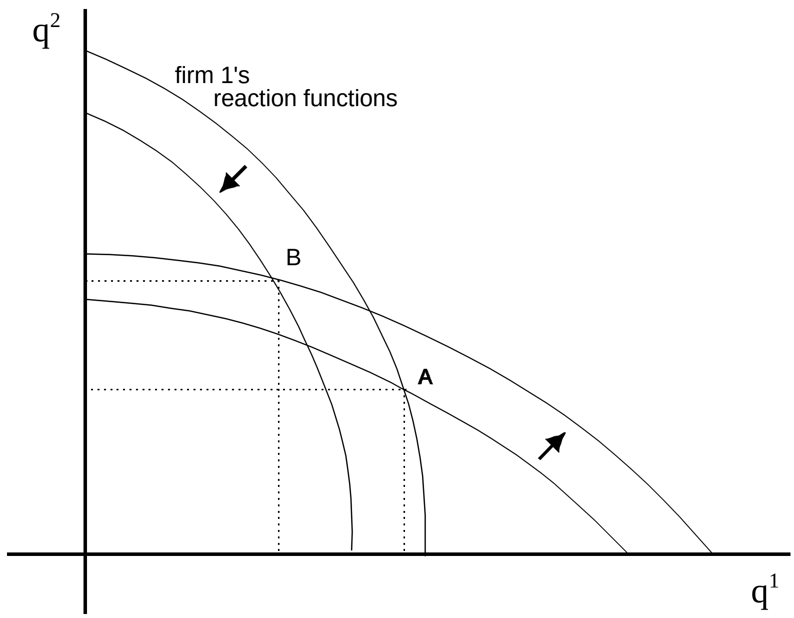

Figure 1.
Market share effects of emissions ceilings reallocation

Under the tradeable emission permits system the regulator issues permits, each allowing emission of one unit of pollutant, and distributes them free of charge to the polluting sources. A total of $\bar{e}$ emission permits are distributed to the firms in the differentiated sector, each receiving $\bar{e}_i$.[8]

7 In the absence of technological differences, a reallocation of emission quota leaves aggregate output unaffected, while increasing the market share of the firm whose emission quota increases.

8 The initial emission permits allocation as well as the total amount of allowable emission are the same as under the bureaucratic mechanism.

After the initial distribution, firms trade emission permits. Firm *i*'s net demand for emission permits is $ND^i = H^i(q^i) - Z^i(q^i, z^i) - \bar{e}_i$. Firm *i*'s net demand for emission permits is solved for z^i as a function of its output and its holdings of emission permits after trading, $\epsilon^i = ND^i + \bar{e}_i$. Substituting z^i into firm *i*'s cost of abatement yields $Z^i(q^i; \epsilon^i)$ and thus, firm *i*'s abatement cost is $A^i(Z^i(q^i; \epsilon^i))$. Firm *i* chooses output and emission permits in order to maximize profits,

$$\max_{q^i, \epsilon^i} \quad \pi^i(q^1, q^2, \epsilon^i) = R^i(q^1, q^2) - C^i(q^i) - A^i(Z^i(q^i; \epsilon^i)) - P^\varepsilon ND^i, \tag{8}$$

where P^ε is the competitive emission permits price.[9] At the equilibrium, firms' marginal costs of abatement are equalized, and thus, industry's abatement costs are minimized. Competitive trading of emission permits achieves the cost-effective distribution of abatement efforts.

The first order conditions yield firm i's output reaction function as function of its emission permits holdings at the equilibrium, $R_i^i(q^1, q^2) - c^i(q^i) - a^i(Z^i(q^i; \epsilon^i))h^i(q^i) = 0$. The solution of firms' reaction functions yields the Cournot-Nash equilibrium outputs as functions of firms' holdings of emission permits at the equilibrium,

$$q^i = \phi^i(\epsilon^i, \epsilon^j). \tag{9}$$

Hereafter we assume that firm 2 is less efficient in abatement than firm 1. Therefore, firm 2 is a net buyer of emission permits and engages in less abatement effort relative to the non-trading equilibrium. At the trading equilibrium, firms' market shares depend solely on production cost differences because marginal costs of abatement are equalized.

The change in firms' emission permit holdings after trading is determined endogenously and thus, simple comparative static analysis cannot be used to compare the bureaucratic mechanism with trading of emission permits. The two equilibria are compared using mean value theorem analysis. For the relevant version of the mean value theorem and the proofs of propositions see Appendix 2. Proposition 1 compares firms' market shares and industry's output under the two regulatory regimes.

Proposition 1. (i) Trading of emission permits results in output reallocation towards the less efficient

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9 P^ε is derived from the solution of the permit market clearing condition $\sum_{i=1}^{2} ND^i = 0$.

in abatement firm. (ii) Industry's output increases as a result of trading emission permits, iff $a_2^2 Z_\epsilon^2 h^2 / a_1^1 Z_\epsilon^1 h^1 > \left(\pi_{22}^2 - \pi_{21}^2\right) / \left(\pi_{11}^1 - \pi_{12}^1\right)$. (iii) Assuming homogeneous goods, industry's output increases iff, $p^{/} < 0$, $c_i^{\,i} \geq 0$ and $a_2^2 Z_\epsilon^2 h^2 / a_1^1 Z_\epsilon^1 h^1 \geq \left(c_2^2 + a_2^2 Z_q^2 h^2 + a^2 h_2^2\right) / \left(c_1^1 + a_1^1 Z_q^1 h^1 + a^1 h_1^1\right)$.

Trading of emission permits affects firms' marginal cost of abatement and as a consequence their output decisions. Proposition 1.(ii) requires that the ratio of changes in firm 2 over firm 1's marginal cost of abatement due to emission permits trading should be greater than the ratio of changes in firm 2 over firm 1's marginal profits resulting from the reallocation of market shares. The case of homogeneous goods with downward sloping demand and convex production costs allows for a clear exposition of the intuition. Proposition 1.(iii) requires that the effect of emission permits trading on firms' marginal abatement cost is stronger than the effect of the resulting output changes on marginal costs. The reductions in industry's abatement costs due to reallocation of abatement efforts from firm 2 to firm 1 should not be outweighed by increases in industry's total production costs due to firm 2's gains in market share. Both conditions require that the positive effect of emission permits trading on abatement costs dominates any adverse effects from the resulting output reallocation.

Although the market shares reallocation effect is well understood (see for example Malueg (1990)), the possibility that industry's output might decrease as a result of emission permits trading has, to the best of our knowledge, never been raised before. The literature unanimously assumes that emission permits trading yields an increase in industry's output as long as firms are price takers in the emission permits market. This is attributed to the fact that the interaction between production decisions and permits trading have not been fully developed in previous works. Neglecting the effect that emission permits trading has on production costs, and given that industry's abatement costs decrease (for a given level of output), one is led to assume that industry's output necessarily increases. Under the general model employed in the present paper, additional conditions must be satisfied for the output effect of emission permits trading to be positive. These conditions establish the appropriate connections between the effects of emission permits trading on production and abatement costs. In Section IV we illustrate some situations in which these conditions are violated.

Within the partial equilibrium framework of our analysis we examine the effect of emission permits trading on welfare, defined as the sum of consumer and producer surplus

$$W\left(e^{i},e^{j}\right)=u\left(q^{i},q^{j}\right)-\sum_{i=1}^{2} C^{i}\left(q^{i}\right)-\sum_{i=1}^{2} A^{i}\left(Z^{i}\left(q^{i};e^{i}\right)\right), \tag{10}$$

where $q^{i}=\phi^{i}\left(e^{i},e^{j}\right)$ and e^{i} is firm *i*'s level of allowable emission, which under the bureaucratic mechanism is fixed at $\bar{e}_{i}$ and under emission permits trading is $\epsilon^{i}=\bar{e}_{i}+ND^{i}$. Differentiating (10) with respect to the change in firms' allowable emission due to emission permits trading, yields,[10]

$$\frac{\partial W}{\partial e}=\left(p^{i}-c^{i}-a^{i}Z_{q}^{i}\right)\phi_{e}^{i}+\left(p^{j}-c^{j}-a^{j}Z_{q}^{j}\right)\phi_{e}^{j}-a^{i}Z_{e}^{i}-a^{j}Z_{e}^{j}, \tag{11}$$

where $\phi_{e}^{i}=\phi_{e^{i}}^{i}+\phi_{e^{j}}^{i}$ is the total effect of emission permits trading on firm i's output, given in (6), and $Z_{e}^{i}=Z_{e^{i}}^{i}+Z_{e^{j}}^{i}$ is the total effect of emission permits trading on firm i's abatement efforts. For homogeneous products, expression (11) reduces to

$$\frac{\partial W}{\partial e}=pQ_{e}-\left(c^{i}+a^{i}Z_{q}^{i}\right)\phi_{e}^{i}-\left(c^{j}+a^{j}Z_{q}^{j}\right)\phi_{e}^{j}-a^{i}Z_{e}^{i}-a^{j}Z_{e}^{j}, \tag{12}$$

where Q_{e} is given in (11). Proposition 2 compares welfare under the two regulatory regimes.

Proposition 2. Assuming homogeneous goods, emission permits trading yields higher welfare relative to a bureaucratic mechanism, iff $pQ_{e}>\left(c^{i}\phi_{e}^{i}+c^{j}\phi_{e}^{j}\right)+\left(a^{i}Z_{q}^{i}\phi_{e}^{i}+a^{j}Z_{q}^{j}\phi_{e}^{j}+a^{i}Z_{e}^{i}+a^{j}Z_{e}^{j}\right)$.

The condition in Proposition 2 could be violated in a variety of situations. For example, recall that the output of the less efficient in abatement firm 2 increases as a result of emission permits trading, $\phi_{D}^{2}>0$, while the output of firm 1 decreases, $\phi_{D}^{1}<0$. If firm 2 is also less efficient in production, that is, $c^{2}>c^{1}$, then $c^{2}\phi_{e}^{2}+c^{1}\phi_{e}^{1}>0$. Assume further that industry's output increases as a result of emission permits trading. Since $p>c^{i}$ and $Q_{e}=\sum\phi_{e}^{i}$, then $pQ_{e}>c^{i}\phi_{e}^{i}+c^{j}\phi_{e}^{j}$ and thus, it is the effect of emission permits trading on industry's abatement costs that determines the sign of the welfare effect. If the output reallocation effect is large, the increase in industry's output is small while the increase in industry's abatement costs could be substantial and therefore, the value of the right hand side could exceed the value of the left hand side. If the benefits from the more efficient allocation of abatement efforts are mainly absorbed in redistributing output and profits to the less

10 Assuming that the aggregate emission quota remains the same under both regulatory systems, the effect of emissions on welfare is identical under both regulatory systems.

efficient firm rather than increasing industry's output, emission permits trading is clearly welfare inferior to the bureaucratic mechanism.

The intuition underlying results of this nature is easier understood in the context of the second best problem. On the one hand, oligopolistic behaviour in the product market yields a higher market share for the less efficient firm relative to the cost-minimizing allocation of production. On the other hand, bureaucratic mechanisms of allocating emission quota yield inefficient distributions of abatement efforts, that is, the firm with the less efficient abatement technology engages in more than the efficient abatement effort.[11] Allowing firms to transfer emission quota through a competitive market, corrects the abatement misallocation problem but could aggravate the production misallocation problem. Removing only one distortion could adversely affect both output and welfare. Emission permits trading aggravates the output misallocation problem when firms' technological efficiency in production and abatement are positively correlated. Price taking behaviour in the emission permits market assures that the less efficient in abatement firm acquires emission permits, reducing industry's marginal abatement cost (for given output), but increasing industry's production costs. If firms' technological differences are more prominent in production rather than abatement, industry's output may decrease. Furthermore, welfare may decrease even if industry's output increases as long as the increase in output is achieved by aggravating the output missalocation problem.

IV. Example

In this Section, we examine a simple example of the economy described in Section II with the following characteristics: utility is quadratic $u(Q) = aQ - (1/2)bQ^2$, yielding a linear demand function $p = a - bQ$; both firms have common, constant rate of emission ρ, that is, $e^i = H^i = \rho q^i$; constant marginal cost of production c^i; and quadratic cost of abatement $A^i = e_i (Z^i)^2$, where $Z^i = z^i q^i$. Under these specifications firm i's and industry's output under the bureaucratic mechanism that prohibits trading of emission quota are

$$q^{ic} = \frac{a - 2c^i + c^j - \rho(2\lambda^i - \lambda^j)}{2b}, \quad Q^c = \frac{2a - c^i - c^j - \rho(\lambda^i + \lambda^j)}{3b}, \tag{13}$$

11 This result is independent of the initial allocation of emission quota.

where the superscript *c* indicates equilibrium values under the bureaucratic mechanism and λ^i is firms *i*'s shadow value of emission quota, which at the equilibrium equals firm *i*'s marginal cost of abatement.

Using the same demand and technological specifications, we derive firm *i*'s and industry's output under trading of emission permits

$$q^{it} = \frac{a - 2c^i + c^j - \rho P^{\varepsilon}}{3b}, \quad Q^t = \frac{2a - c^i - c^j - 2\rho P^{\varepsilon}}{3b}, \tag{14}$$

where the superscript *t* indicates emission permits trading equilibrium values. The equilibrium price of emission permits lies between firms' evaluation of emission quota before trade, that is, $\lambda^1 < P^{\varepsilon} < \lambda^2$. Under the specifications of our example, the permit price can be expressed as a weighted sum of firms' shadow values of their emission quotas under command and control

$$P^{\varepsilon} = \frac{e_j\left(3b + 2e_i\rho^2\right)\lambda^i + e_i\left(3b + 2e_j\rho^2\right)\lambda^j}{3b\left(e_i + e_j\right) + 4e_ie_j\rho^2}. \tag{15}$$

The relationship between firms' evaluation of emission quota in the two regulatory equilibria facilitates output comparison. From equations (13), (14) and (15) we derive

$$q^{it} - q^{ic} = \frac{\rho\left[b\left(e_i + 2e_j\right) + 2e_ie_j\rho^2\right]\left(\lambda^i - \lambda^j\right)}{b\left[3b\left(e_i + e_j\right) + 4e_ie_j\rho^2\right]}, \quad Q^t - Q^c = \rho\left(e_i - e_j\right)\left(\lambda^i - \lambda^j\right). \tag{16}$$

Trading of emission permits increases the output of the firm with the higher evaluation of its emission quota, that is, the higher marginal cost of abatement at the bureaucratic equilibrium. Industry's output increases as a result of permits trading if $e_i > e_j \Rightarrow \lambda^i > \lambda^j$. Thus, allowing trading of emission quota yields an increase in industry's output if and only if the less efficient in abatement firm, that is firm 2 $\left(e_2 > e_1\right)$, has the higher marginal cost of abatement at the bureaucratic equilibrium $\lambda^2 > \lambda^1$. The difference of firms' shadow value of emission quota is,

$$\lambda^i - \lambda^j = \frac{3b^2\left(e_i - e_j\right)\left(\rho\hat{Q} - \bar{e}\right) - \left[3b\left(e_i + e_j\right) + 4e_ie_j\rho^2\right]\left[\rho\left(c^i - c^j\right) + b\left(\bar{e}_i - \bar{e}_j\right)\right]}{\Psi}, \tag{17}$$

where $\Psi = 3b^2 + 4\rho^2\left[e_ie_j\rho^2 + b\left(e_i + e_j\right)\right]$, and $\hat{Q}$ denotes the Cournot-Nash output in the absence of any restriction in emission. Industry's emission quota cannot exceed unregulated emission, that is, $\rho\hat{Q} > \bar{e}$. Thus, firm 2 has higher evaluation of emission quota at the equilibrium, that is $\lambda^2 > \lambda^1$, if it is not less efficient than firm 1 in production $c^2 \leq c^1$, and does not receive a higher share of emission quotas $\overline{e}_2 \leq \overline{e}_1$. Result 1 is a specialized version of Proposition1.

Result 1. Assuming linear demand, constant marginal cost of production, constant emission rate per unit of output and quadratic abatement costs, a bureaucratic mechanism yields higher output iff $e_i > e_j$ and $3b^2(e_i - e_j)(\rho\hat{Q} - \overline{e}) < \left[3b(e_i + e_j) + 4e_i e_j \rho^2\right]\left[\rho(c^i - c^j) + b(\overline{e}_i - \overline{e}_j)\right]$.

The possibility that the bureaucratic mechanism dominates competitive trading of emission permits is higher, the more restrictive is the aggregate quota, that is, the smaller the value of $\rho\hat{Q} - \overline{e}$. It is also worth noticing that a bureaucratic mechanism allocating emission quota according to firms' unregulated level of emissions, that is $\overline{e}_i = \xi\rho\hat{q}^i$,[12] assures that $c^i > c^j \Rightarrow \overline{e}_i < \overline{e}_j$. Therefore, such an allocation of emission quota, makes the second term in the numerator of (17) smaller and thus, it weakens the possibility that a positive correlation in firms' abatement and production efficiency will result in the dominance of the bureaucratic mechanism.

To provide a graphical illustration of Result 1 we present simulations of the model. The initial values of parameters are chosen so as to satisfy all nonegativity and other necessary conditions.[13] Figure 2 illustrates the difference in industry's output between the two regulatory regimes (z axis) as a function of firms' difference in abatement (denoted as $\Delta e = e_2 - e_1$ on the y axis) and production technology (denoted as $\Delta c = c^2 - c^1$ on the x axis). To facilitate clear exposition of the results, we focus on the region in which firm 2 is less efficient in both abatement and production, that is, when production and abatement technologies are positively correlated. At $\Delta e = 0$ and $\Delta c = 0$ firms have the same abatement and production technologies and as Δe and Δc increase, firm 1 becomes more efficient in both abatement and production. To improve presentation, Figure 2 includes the plane corresponding to zero difference in output, which is presented in solid black colour. Figure 2 illustrates that the difference in industry's output is negative $Q^t - Q^c < 0$, for a range of parameter values in the area in which firm 2's inefficiency is much more prominent in production rather than in abatement.

12 Where $\xi<1$, is the rate by which the government wishes to decrease emissions.

13 The initial values of the parameters used for the simulations are: a=1,500; b=0.20; c^1=200; e_1=0.10; ρ=0.60; and ξ=0.40. Figures 2, 3 and 4 present simulations for the following range of values: $200 \leq c^2 \leq 500$ and $0.10 \leq e_2 \leq 0.70$.

As noted above the initial distribution of emission quota affects the range of parameters within which the bureaucratic mechanism results in higher output. In the case presented in Figure 2, the allocation of emission quota is inversely related to firms' marginal cost of production. When Δc is

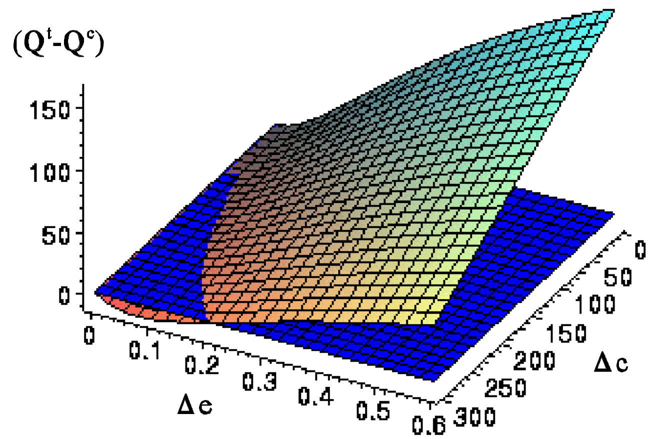

Figure 2
Difference in industry s output

large, firm 2's share of emission quota is very small and its marginal abatement cost very high, and thus its output very low at the bureaucratic equilibrium. When trade of emission permits is allowed, acquisition of additional emission permits leads to a rapid expansion of firm 2's output, which is faster than the reduction in firm 1's output. However, if emission quotas are allocated equiproportionally, transfer of quotas would not have the same effect. In the latter case there is an increase in the range of parameters for which the bureaucratic regulation results in higher output. Thus, the initial distribution of emission quotas determines the range of parameter values for which a bureaucratic mechanism yields higher output than emission permits trading.

We now proceed with the discussion of the welfare effect of emission permits trading. Under the demand and technology specifications of this section, the welfare difference between the two regulatory regimes is

$$W^t - W^c = (1/2)\left(p^t + p^c\right)\left(Q^t - Q^c\right) - c^i\left(q^{it} - q^{ic}\right) - c^j\left(q^{jt} - q^{jc}\right) - \sum_{i=1}^{2}\left(A^{it} - A^{ic}\right), \qquad (18)$$

where p^t and p^c denote output prices under the two regulatory regimes. Welfare increases as a result of emission permits trading when industry's output increases and the resulting increase in consumer surplus[14] exceeds industry's costs incurred in achieving this increase. Substituting the equilibrium values in (18) and making the appropriate simplifications, the welfare difference is

$$W^t - W^c = \left[\Delta\lambda^2\left(\omega_2 \Delta e + \omega_3\right) + \Delta\lambda\left(\omega_4 \Delta e - \omega_5 \Delta c\right)\right] / \omega_1 \quad , \tag{19}$$

where $\Delta\lambda = \lambda^i - \lambda^j$ and ω_i, $i=1,5$ are all positive parameters.[15] Not surprisingly, the same parameters that determine the sign of industry's output difference, are present in expression (19) albeit in one order higher. Result 2, which is a special version of Proposition 2, summarizes the conditions resulting from expression (19).

Result 2. Assuming linear demand, constant marginal cost of production, constant emission rate per unit of output and quadratic abatement costs, a bureaucratic mechanism yields higher welfare iff $\Delta\lambda\left[\left(\omega_2 \Delta\lambda + \omega_4\right)\Delta e + \omega_3 \Delta\lambda - \omega_5 \Delta c\right] < 0$.

Although the possibility that output and welfare decrease as a result of emission permits trading arises in the same region, it is not at all necessary that welfare decreases when output decreases. Figure 3 presents the simulations of the welfare difference. Welfare increases when industry's output decreases, while it decreases for a range of parameters that yield an increase in industry's output (compare Figure 2 to 3).[16] This result is explained with the aid of Figure 4 that reports the difference in industry's abatement costs, $\sum_{i=1}^{2}\left(A^{it} - A^{ic}\right)$.

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14 The first term in (18) corresponds to the area under the linear demand $p^t\left(Q^t - Q^c\right) + (1/2)\left(p^c - p^t\right)\left(Q^t - Q^c\right)$.

15 The values are: $\omega_1 = 36 b e_i e_j x^2$, $\omega_2 = 3b\left[27b^2 e_j\left(e_i + 2e_j\right) + 2e_i e_j \rho^2\left[3b\left(3e_i + 5e_j\right) - 2e_i e_j \rho^2\right]\right]$, $\omega_3 = 18 b e_j^2\left[4 e_i^3 \rho^4 + 9b^2 e_j + 6b\left(e_i + e_j\right) e_i \rho^2\right]$, $\omega_4 = 12 b e_i e_j \rho x\left(a - c_i - \rho\lambda_i\right)$, $\omega_5 = 4 e_i e_j \rho x\left[2\left(2x + e_i e_j \rho^2\right) + 3 b e_j\right]$ and $x = 3b\left(e_i + e_j\right) + 4 e_i e_j \rho^2$. Detailed calculations leading to (19) are available by the author upon request.

16 Welfare increases as a result of emission permits trading, when the more efficient in abatement firm is less efficient in production. This case is not shown in Figure 3.

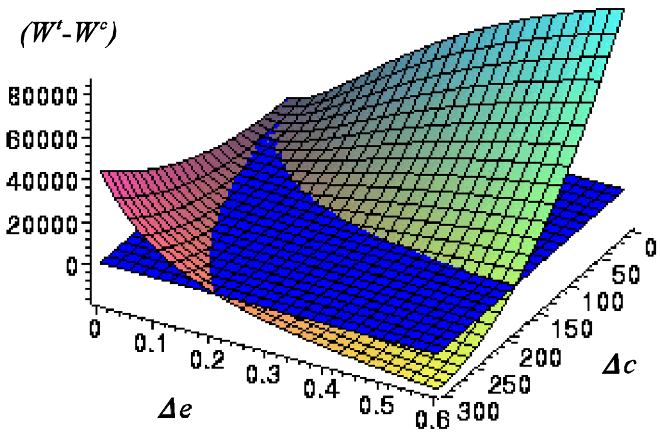

Figure 3
Welfare difference

Industry's abatement costs increase with industry's output. However, the rate of change in industry's abatement costs is greater than the rate of change in industry's output around the curve tracing zero values in the respective surfaces. As output starts increasing, industry's abatement costs are rising fast enough to accelerate the decrease in industry's profits to a level higher than the rate of increase in consumer surplus. After a point, the increase in industry's abatement costs smoothens, inducing a similar effect on the decrease in industry's profits and thus, welfare increases.

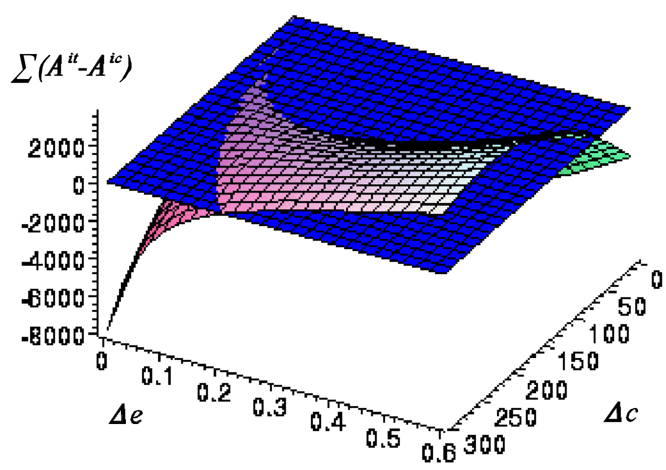

Figure 4
Difference in industry s abatement costs

VI. Conclusions

We have demonstrated that competitive markets cannot assure the efficient allocation of emission permits. We have also showed that a bureaucratic mechanism can be welfare superior to competitive trading of emission permits in a number of situations. Furthermore, we have proved that a bureaucratic mechanism could yield higher output relative to competitive emission permits trading. In deriving these results we focussed on clarifying the intuition behind the excess-trading bias resulting from oligopolistic behaviour in the product market.

Our results should be seen as cautioning policy makers not to presume that competitive trading of licenses assures social efficiency. Our result should not be perceived as arguments against the use of marketable quota licenses. As the simulations in Section IV indicate, allowing trade of emission permits generates, in the majority of situations, great output and welfare gains. However, policy makers should be aware of the potential problems so as to reserve some flexibility for their response when welfare decreasing situations arise. One possible direction of policy makers' response is to restrict the amount of trades based on firms' production efficiency. Clearly, this solution requires a great deal of information and could have a great cost in forgone welfare-maximizing trades in case of error. That is why we believe that more effort, both theoretical and empirical, should be devoted in evaluating modifications to the unrestricted trading, taking into account the characteristics of the environment in which the market for quota licenses operates.

Our analysis is close in spirit to Malueg (1990). In his paper, Malueg presumes that trading of emission permits always increases industry's output and explores the possibility that welfare might decrease as a result of emission permits trading. Our paper provides clear proofs supporting Malueg's intuition. Furthermore, our analysis provides a simple, yet thorough, exposition of the workings of emissions permits trading through the product market, by separating abatement from production costs. The specific example along with the simulations provide evidence of the likelihood that welfare might be adversely affected by competitive trading.

Although our analysis builds around emission permits, the general formal model we use admits several interpretations, and thus, our results have broader consequences for public policy since they apply to a wide range of government licencing. Consider for example the case that a government uses quotas to restrict imports of a factor used as an intermediate input in a domestic oligopolistic industry.

Import quotas are imposed to support domestic production of this factor that is undertaken by subsidiaries of the final product oligopolists, which exhibit technological differences. Competitive trading of import quotas will result in transferring quotas towards the less efficient firms. Assuming Cournot reactions in the final product market, firms with higher opportunity cost of quotas will acquire more than the welfare-maximizing number of quotas. If less efficient oligopolists are associated with less efficient subsidiaries, the possibility arises that competitive trading of import quotas is welfare inferior to a bureaucratic allocation of input quotas.

Appendix 1

For positive values of output and abatement per unit of output, the first order conditions of the constrained profit maximization problem in (2) are,

$$\pi_i^i \equiv R_i^i(q^i, q^j) - c^i(q^i) - a^i Z_q^i - \lambda^i h^i + \lambda^i Z_q^i = 0\,, \qquad \text{(A.1.1)}$$

$$-a^i Z_z^i + \lambda^i Z_z^i = 0 \Rightarrow \lambda^i = a^i\,, \qquad \text{(A.1.2)}$$

along with the regulatory constraint that is binding assuming $\lambda^i > 0$. Where λ^i, the Lagrange multiplier of the constrained maximization problem, should be seen as the shadow value of firm i's emission quota, which at the equilibrium equals firm *i*'s marginal cost of abatement. The second order conditions with respect to output require, $\pi_{ii}^i < 0$. We also assume that own effects of output on marginal profit exceed cross effects,

$$\Omega \equiv \left(R_{11}^1 - c_1^1 - a_1^1 Z_q^1 h^1 - a^1 h_q^1\right)\left(R_{22}^2 - c_2^2 - a_2^2 Z_q^2 h^2 - a^2 h_q^2\right) - R_{12}^1 R_{21}^2 > 0\,. \qquad \text{(A.1.3)}$$

This assumption is related to conditions for uniqueness of the equilibrium and to reaction function stability. To avoid complicating the presentation unnecessarily, we consider situations in which the values of the parameters yield unique and stable equilibria.[17]

The regulatory constraint is solved for firm *i*'s abatement per unit of output z^i as a function of q^i and $\bar{e}_i$,

$$z^i = g(q^i, \bar{e}_i)\,. \qquad \text{(A.1.4)}$$

The required abatement per unit of output is decreasing in the level of emission quota $\bar{e}_i$ and is increasing in output q^i, i.e. $z_{\bar{e}}^i < 0$ and $z_q^i > 0$. Total abatement is also decreasing in the level of allowable emissions, $Z_{\bar{e}}^i < 0$. Substituting $Z^i(q\,;\bar{e}_i)$ into firm *i*'s total and marginal abatement cost, yields $A^i(Z^i(q\,;\bar{e}_i))$ and $a^i(Z^i(q\,;\bar{e}_i))$. Thus, assuming that the slope of the marginal cost of abatement is positive $a_i^i > 0$, an increase in firm i's allowable emissions yields a decrease in marginal abatement cost, $a_i^i Z_{\bar{e}}^i < 0$.

17 For sufficient conditions for the existence, uniqueness and stability of Cournot equilibrium see Friedman (1977), Nishimura and Friedman (1981) and Gaudet and Salant (1991).

Substituting λ^i from (A.1.2) and z^i from (A.1.4) into (A.1.1), firm *i*'s output reaction function is expressed as a function of firm *i*'s emission quota,

$$\pi_i^i = R_i^i(q^1, q^2) - c^i(q^i) - a^i(Z^i(q^i; \bar{e}_i))h^i(q^i) = 0\ . \qquad (A.1.5)$$

Appendix 2

Mean value theorem [18]

Let $f(e)$ be a continuously differentiable real-valued function defined on a convex subset of Euclidean *n*-space. Let e^c and e^t be two vectors in this subset. Then, there exists a point e^* such that,

$$\Delta f \equiv f(e^t) - f(e^c) = \nabla f(e^*) \cdot (e^t - e^c), \qquad (A.2.1)$$

where *Lf(e*)* is the gradient of *f* evaluated at e^*, and $e^*=e^c+2(e^t-e^c)$ for some *20(0,1)*. The two vectors we are interested in are firms' holdings of emission quotas at the bureaucratic and the emission permits trading equilibria, i.e. $e^c = (\bar{e}_1, \bar{e}_2)$ and $e^t = (\bar{e}_1 + ND^1, \bar{e}_2 + ND^2)$. The difference in emission quota for firm i is $\Delta e_i = e_i^t - e_i^c = ND^i$. Competition in the permits market requires $\sum_{i=1}^2 ND^i = 0$ and thus, $ND^2 = -ND^1$. It follows that $\Delta e = \Delta e_2 = -\Delta e_1$. Assuming that firm 2 is less efficient in abatement than firm 1, implies that the effect on cost and marginal cost of abatement due to the change in permit holdings is stronger for firm 2 than firm 1, between e^c and e^t, i.e. $a^2 Z_e^2 < a^1 Z_e^1$ and $a_2^2 Z_e^2 < a_1^1 Z_e^1$. Thus, firm 2 will be a net buyer of emission permits, $ND^2 > 0$ and firm 1 will be a net seller of emission permits, $ND^1 < 0$.[19]

Proof of Proposition 1.

(i) Applying (A.2.1) to $q^i = \phi^i(e^1, e^2)$ yields

$$\Delta q^i = \phi_1^i \Delta e_1 + \phi_2^i \Delta e_2\ , \qquad (A.2.2)$$

where ϕ_1^i and ϕ_2^i are evaluated at some point between the vectors of emission quotas holdings under

18 We adopt the version of the theorem from Brander and Spencer (1983), p. 233.

19 Firm 2 buys emission permits for as long as the cost reduction generated by the additional emission permits exceeds the permit price.

the two regulatory regimes, e^c and e^t. Then, $\Delta q^i = \phi_e^i \Delta e$, where ϕ_e^i is the total change in firm *i*'s output resulting from changes in both firms' emission quotas due to emission permits trading. The value of ϕ_e^i is given in (6). Assuming that firm 2 is less efficient in abatement relatively to firm 1, it follows that firm 2's market share increases, while firm 1's decreases as a result of emission permits trading.

(ii) Applying (A.2.1) to industry's output $Q = \sum_{i=1}^{2} \phi^i(e^1, e^2)$ yields

$$\Delta Q = Q_1 \Delta e_1 + Q_2 \Delta e_2 \ , \tag{A.2.3}$$

where Q_1 and Q_2 are evaluated at some point between the vectors of emission quotas holdings under the two regulatory regimes, e^c and e^t. Then, $\Delta Q = Q_e \Delta e$, where Q_e is the total change in industry's output resulting from changes in both firms' emissions quotas due to emission permits trading. The value of Q_e is given by (7). The sufficient condition in Proposition 1.(ii), $(\pi_{11}^1 - \pi_{12}^1) a_2^2 Z_e^2 h^2 > (\pi_{22}^2 - \pi_{21}^2) a_1^1 Z_e^1 h^1 \Rightarrow Q_e > 0$ is derived directly from expression (7). Substituting for the differences in parentheses yields, $(2p_1^1 - p_2^1 + q^1(p_{11}^1 - p_{12}^1) - c_1^1 - a_1^1 Z_q^1 h^1 - a^1 h_1^1) a_2^2 Z_e^2 h^2 >$ $(2p_2^2 - p_1^2 + q^2(p_{22}^2 - p_{21}^2) - c_2^2 - a_2^2 Z_q^2 h^2 - a^2 h_2^2) a_1^1 Z_e^1 h^1$.

(iii) For homogeneous goods, the above condition simplifies to $p'(a_2^2 Z_e^2 h^2 - a_1^1 Z_e^1 h^1) - (c^1 + a_1^1 Z_q^1 h^1 + a^1 h_1^1) a_2^2 Z_e^2 h^2 + (c^2 + a_2^2 Z_q^2 h^2 + a^2 h_2^2) a_1^1 Z_e^1 h^1 > 0$. Since we evaluate Q_e at some point e^* prior to the completion of emission permits trading, the effect of emission permits trading on marginal cost of abatement is stronger for firm 2 than firm 1, that is, $a_2^2 Z_e^2 < a_1^1 Z_e^1$. Assuming that firm 2's rate of emission is not lower than firm 1's $h^2 \geq h^1$, yields $a_2^2 Z_e^2 h^2 - a_1^1 Z_e^1 h^1 < 0$. Assuming that $p' < 0$, the first term is positive and thus, it suffices that $(c_2^2 + a_2^2 Z_q^2 h^2 + a^2 h_2^2) a_1^1 Z_e^1 \geq (c_1^1 + a_1^1 Z_q^1 h^1 + a^1 h_1^1) a_2^2 Z_e^2$. Assuming further that marginal cost of production is nondecreasing, a sufficient condition for $Q_e > 0$, is $a_2^2 Z_e^2 h^2 / a_1^1 Z_e^1 h^1 \geq (c_2^2 + a_2^2 Z_q^2 h^2 + a^2 h_2^2) / (c_1^1 + a_1^1 Z_q^1 h^1 + a^1 h_1^1)$. **Q.E.D.**

Proof of Proposition 2.

Applying (A.2.1) to welfare $W(e^1, e^2)$ yields

$$\Delta W = W_1 \Delta e_1 + W_2 \Delta e_2 \ , \tag{A.2.4}$$

where W_1 and W_2 are evaluated at some point between the vectors of emission quotas holdings under the two regulatory regimes, e^c and e^t. Then, $\Delta W = W_e \Delta e$, where $W_e = \partial W / \partial e$ is the total change in welfare resulting from emission permits trading. W_e is evaluated at some point $e^* = e^c + \theta(e^t - e^c)$, for some $\theta \in (0,1)$. Thus, welfare increases as a result of emission permits trading, if $W_e(e^*) > 0$. The value of W_e is given in (18). Expression (18) yields the sufficient condition in Proposition 2, that is, $pQ_e > (c^i + a^i Z_q^i)\phi_e^i + (c^j + a^j Z_q^j)\phi_e^j$. (**Q.E.D.**

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