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**EMISSION PERMIT TRADING AND
MARKET STRUCTURE**

by

Eftichios Sofokles Sartzetakis

B.A.(Honours) Univ. of Macedonia, M.A. Univ. of Saskatchewan

A thesis submitted to the Faculty of Graduate Studies
and Research in partial fulfilment of the
requirements for the degree of
Doctor of Philosophy
in the
Department of Economics

CARLETON UNIVERSITY

Ottawa, Ontario

June, 1993

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submitted by

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in partial fulfilment of the requirements

for the degree of

Doctor of Philosophy

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Carleton University
3 June 1993

ABSTRACT

This thesis examines the effect of the interaction of permit and product market power on the efficiency of tradeable emission permit regulation under a variety of oligopolistic environments in the product market. When one of the regulated firms has market power in the permit market, it either seeks to minimize the cost of compliance with the regulation or it seeks to raise its rivals' costs. In the first case the firm with power in the permit market underbuys permits while in the second case it overbuys permits. The behaviour of the firm with market power in the permit market depends on the product market structure.

In Chapter II the base model is developed assuming Cournot behaviour in the product market and the auctioning of emission permits. A command and control system is compared to the tradeable permit system both when the permit market is competitive and when a firm has the power to set the permit price. Under perfect competition, a tradeable emission permit system is more efficient than command and control. When one of the firms is a permit price setter command and control may be more efficient than a tradeable permit system.

In Chapter III two of the assumptions of the basic model are relaxed and the sensitivity of the results on these assumptions is tested. The magnitude of the results in Chapter II is sensitive on the assumptions about the production technology and the number of firms in the industry. Qualitatively though, the results continue to hold.

In Chapter IV the case in which emissions are initially distributed free of charge is explored under the assumption of Cournot behaviour in the product market. The two systems of initial permit allocation are compared. Under perfect competition the efficiency of a tradeable permit system is independent of the initial permit allocation. If one firm has price setting power in the permit market, a tradeable permit system is more efficient under auctioning than under grandfathering for low degrees of product differentiation and less efficient for high degrees of product differentiation. The possibility that a firm might find entry unattractive is greater under grandfathering than under auctioning.

In Chapters V and VI a number of models assuming that one of the firms has a dominant position in the product market are examined. In all models a competitive tradeable permit market is more efficient than command and control. In the case of price setting behaviour in the permit market the results differ from the Cournot case. The behaviour of the permit price setter firm depends on its pre-regulation product market share.

Στοὺς γονεῖς μου Σοφοκλῆ καὶ Μαρία

Προσῆκον δὴ τὸ μᾶθημα ἂν εἴη, ὧ Γλαῦκων, νομοθετῆσαι, καὶ πείθειν τοὺς μέλλοντας ἐν τῇ πόλει τῶν μεγίστων μεθέξειν ἐπὶ λογιστικὴν ἵεναι καὶ ἀνθ'ἀπτεσθαι αὐτῆς μὴ ἰδιωτικῶς, ἀλλ' ἕως ἂν ἐπὶ θεῶν τῆς τῶν ἀριθμῶν φύσεως ἀφίκωνται τῇ νοήσει αὐτῇ, οὐκ ὦνῆς οὐδὲ πρᾶσεως χάριν ὥς ἐμπόρους ἢ καπῆλους μελετῶντας, ἀλλ' ἕνεκα πολέμου τε καὶ αὐτῆς τῆς ψυχῆς ῥασιῶννης μεταστροφῆς ἀπὸ γενέσεως ἐκ' ἀλήθειαν τε καὶ οὐσίαν.

Πλάτωνος Πολιτεία Z, 525, 12-19

Then this is a kind of knowledge which legislation may fitly prescribe; and we must endeavour to persuade those who are to be the principal men of our State to go and learn arithmetic, not as amateurs, but they must carry on the study until they see the nature of numbers with the mind only; nor again, like merchants or retail-traders, with a view of buying or selling, but for the sake of their military use, and of the soul herself; and because this will be the easiest way for her to pass from becoming to truth and being.

Plato's The Republic VII, 525, 12-19
Translated into English by B. Jowett
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ACKNOWLEDGEMENTS

I would like to express my appreciation to many people who helped me during my studies at Carleton University and contributed to the completion of this thesis, each in their own way.

I am grateful to my supervisor Professor Donald McFetridge for his advise and guidance during all stages of this thesis. His patience and understanding were essential for the completion of this thesis. Working with Don on the thesis and on a number of other projects has broadened my understanding of economics and especially of its applied aspects.

I owe a great deal to Professor Thomas Ross whose encouragement in the early stages was "thesis saving" and his advice and comments in later stages crucial for the development of the thesis. I would like to thank Professor Keith Acheson for his advice, encouragement and comments during numerous discussions. Many thanks are due to Professor Stephen Ferris not only for his comments and advice on the thesis but also for creating an inspiring academic environment.

My development as an economist and most importantly as a thinking person has been aided from the discussions with Steven, Keith, Tom and Don.

I would also like to thank all the members of the Joint Ph.D. Program from whose teaching I benefited and especially those whose seminar comments helped in the development of the thesis: these include, Zhigi Chen, Chantale Lacasse, Stylianos Perrakis and John McManus.

I also wish to extend my thanks to Judy Poole, Ginette Harte, Shirley Beaton, Edie Landau, Lalita Figueredo, Charlotte Burba, Alex Howard and Norma Shickle for providing an excellent "supporting" environment.

I would like to recognize the contribution of my parents Sofokles and Maria whose moral support was invaluable. I would also like to express my appreciation to my friend and wife Erato Kostopoulou for her love, encouragement and understanding especially during our transition to parenthood. To my daughter Maria many thanks for waiting for me to become a father again.

My friends Gregory Kalivas, Chris Carabatsos, Laurie Few and Thodoros Topaloglou deserve a special note of thanks for their warm friendship.

Financial Assistance received from Carleton University during my time as a graduate student and also from the Dewan Chand and Rathe Devi Marwah Memorial Scholarship was greatly appreciated.

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CHAPTER 1

INTRODUCTION

From its beginning as a radical issue in the early sixties the concern over the environment has become the major economic problem of the nineties. The problem of environmental degradation is that of over-exploitation of the assimilative capacity of the environment.

In order to construct an environmental policy to address the problem, it is essential to properly identify the source of the problem. For an economist, environmental problems are externalities--instances when the market prices of goods and services fail to include the environmental damage associated with their production and/or consumption--reflecting instances of incomplete or missing markets. A large body of literature exists on the theory of externalities and its applications to environmental problems.¹ The theory of externalities suggests that the proper policy should provide the economic agents with adequate incentives to undertake the right amount of the externality creating activity. This can be done either by price based instruments--charges (usually referred to as Pigouvian taxes) or subsidies--or by quantity-based instruments, such as a system of tradeable emission permits. A "Pigouvian tax" (subsidy) is a charge (payment) per unit of emissions (emissions reduction) levied on polluting firms. To obtain the efficient reduction in emissions it is set equal to the marginal social damage. With tradeable emission permits the regulator operates through direct control of emission quantity. It issues emission permits equal to the efficient quantity of emissions. Under ideal conditions, clear specification of property rights, perfect knowledge and perfect competition, a price

¹See Baumol and Oates(1988) for an extensive survey. Helm and Pearce(1991) also analyze the environmental problem in the concept of externalities.

mechanism is equivalent to a quantity mechanism in that they both achieve efficiency.²

However, this theoretical symmetry between price and quantity (policy) instruments cannot be extended to actual policies. Considerations such as that of imperfect information in which case the calculation of the efficient tax is troublesome or that of market imperfections or transaction costs in which case the efficient solution is not achieved with tradeable permits complicate the policy choice problem.³

Emission charges are mainly used in Europe and Japan, though more commonly employed to control water pollution than air pollution.⁴ In France and the Netherlands the charges are designed to raise revenue to fund improvements of water quality. In Germany charges are used in combination with standards in order to improve water quality, while in Sweden and Greece charges are used in combination with subsidies to provide incentives for the use of cars with catalytic converters. Carbon taxes are used in Finland, the Netherlands, Norway and Sweden. These are charges on the use of an input and not on emissions. In none of these cases, however, are charges intended primarily to resolve the externality problem. They are used instead in order to raise funds to finance projects of water or air quality improvement.

In the United States there is little experience with emission charges.⁵ One example is the imposition of a tax on the use of CFCs. This tax is imposed on input use and it is used to complement existing regulations. In Canada some examples of input (not emission) charges are the tax on leaded gasoline and the excise taxes on

²For the formal proofs see Tietenberg(1985), Spulber(1985) and Pezzey(1992). There is a debate over the equivalence between subsidies and charges -see Baumal and Oates(1988), Cropper and Oates(1991) and Pezzey(1992)-- which on the theoretical level concerns the assumption about the availability of subsidies to new entrants.

³See Tietenberg(1991) and Cropper and Oates(1992) for an extensive discussion on the choice between price vs quantity instruments.

⁴See Brown and Johnson(1984), Brown and Bressers(1986), Bressers(1988), Tietenberg(1992) and (1991), and Hahn(1989).

⁵For a review of the environmental policies used in the United States see Burtraw and Portney(1991).

motive fuels. User charges for the use of municipal water services and waste collection and disposal can be thought of as an example of emission charges along with provincial taxes on the use of specific goods such as lead and batteries and tires.⁶

Tradeable emission permits programs are in use in the United States. The most important of these programs is the Environmental Protection Agency's (EPA) Emission Trading Program for the regulation of air quality.⁷ According to this program, the regulator, the EPA, sets both the individual and the aggregate ceiling on emissions of a particular air pollutant and allows the emission sources (firms) to choose their emission control techniques as long as they do not exceed the aggregate ceiling. Firms that reduce their emission beyond the required individual ceiling get certification of excess control in the form of an emission reduction credit from the regulator. These permits then can be banked or used in a bubble, offset or netting programs.⁸

Other programs of the same nature as the Emission Trading Program are the Wisconsin System of Tradeable Discharge Permits for the Management of Air Quality, the Lead Trading Program and a program for the trading of rights in phosphorous discharges into the Dillon Reservoir in Colorado.⁹

In addition, a new program created under the 1990 amendments of the Clean Air Act of 1970, addresses the acid rain problem by substantially reducing emissions of sulphur dioxide (SO₂) and nitrogen oxide (NO_x). Although similar to the ETP, this program differs from the others in the following ways. First, under the Clean Air Act the regulator issues emission allowances (permits), each of which gives the right to emit one ton of pollutant, equal to each year's targeted ceiling for emissions. The

⁶See Canada(1992a), "Economic Instruments for Environmental Protection".

⁷For a detailed examination of the ETP see Tietenberg(1989). Hahn and Hester(1989b) provide an assessment of the program.

⁸For a description of these programs see Tietenberg(1985).

⁹For a review of the programs see Cropper and Oates(1992).

number of permits issued is decreased each year to achieve the ultimate target. Second, these permits are then allocated on an annual basis to the polluting sources based on an average of their prior emissions. There are provisions under which a small portion of permits may be withheld and auctioned off periodically in order to accommodate the needs of small, high-emitting sources. After the initial allocation of permits, sources are free to trade permits. Third, for the first time, the nation as a whole is considered as one market.¹⁰

Despite the growing support for incorporating appropriate economic incentives in policy in the United States and recently in Canada,¹¹ the most widely used approach remains the traditional system of command and control regulations. As is noted in Cropper and Oates(1992), there are several ways of defining the command and control approach. These can be divided into two categories,¹² according to whether the regulator allows any flexibility in the form of compliance: those that specify the procedures used by the individual sources to meet the policy standard and those that specify the policy standard for each individual source, but allow them to choose the form of compliance.¹³

There are some practical reasons for the broad use of command and control systems. First, there is considerable hostility within the environmentalist community towards approaches of economic incentives¹⁴ and especially towards tradeable emission permit systems that seem to create rights to pollute. Second, there are types of pollution that are difficult to reduce by market-based approaches. Third, the

¹⁰For an detailed description of this program see Canada(1992b). Also Hausker(1992) describes this program and offers a discussion of how auctions could enhance the market for permits.

¹¹See Canada(1992a), "Economic Instruments for Environmental Protection".

¹²Helfand(1991) examines a broader range of command and control definitions.

¹³For a discussion of the differences between these two alternative definitions of command and control see Besanko(1987).

¹⁴See for example Kelman(1981).

broader institutional framework in a country influences the decisions of the regulator.¹⁵

On the theoretical level, however, the advantages of market-based approaches over command and control are apparent. The virtue of a tradeable emission permits system is that, by allowing abatement effort to vary according to abatement costs, it minimizes the aggregate cost of compliance.¹⁶ Theory predicts significant cost savings from the replacement of command and control by a tradeable permits system.¹⁷

The evidence from the Emission Trading Program shows, however, that these expectations have not been entirely fulfilled.¹⁸ Although a certain number of transactions occurred, the majority being internal, and substantial cost savings were realized, the predicted cost savings were not fully realized.

This shortfall has been attributed to a number of factors.¹⁹ One is the reluctance of the government to establish an active market for emission permits. An extensive and complicated set of procedures for external trades, for most types of pollutants²⁰ increased the cost of transactions substantially. The complicated administrative environment also increased the uncertainty among the potential traders. Atkinson and Tietenberg attribute some significant proportion of this shortfall to the nature of the process by which emission permits are traded.²¹

¹⁵For example, UK places considerable emphasis on command and control techniques reflecting its administrative institutional history; see Helm(1991).

¹⁶This is well known. See, for example, Tietenberg(1992).

¹⁷See Tietenberg(1985), Chapter 3 and Tietenberg(1991) for a review of studies estimating excess costs savings relatively to command and control for various cases.

¹⁸See Hahn and Hester(1989a) and (1989b) for an assessment of the existing tradeable permit programs.

¹⁹See Tietenberg (1991) for an extensive discussion on the subject.

²⁰Trades of uniformly mixed pollutants require smaller administrative costs, and that is why they constitute the majority of trades.

²¹See Atkinson and Tietenberg(1991).

Another concern is with imperfections in permit markets resulting from small numbers. The consequences of monopsony in permit markets have been analyzed in Hahn(1984) and Tietenberg(1985) among others. These authors found that monopsonized permit markets may be less efficient than command and control. Although acknowledged, the issue of monopsony in the permit markets received very little attention. This may be a consequence of the view expressed by some that market power in the permit market is unlikely to have much effect.²²

THE ISSUE ADDRESSED IN THE THESIS

The existence of monopsony power in the permit market reduces the potential cost savings from tradeable permits. This issue deserves more attention than it has received. Another problem of potential importance, the effect of the interaction of permit and product market power on the efficiency of tradeable permit systems has also been neglected.

This neglect has not been total. Tietenberg(1985) acknowledges the possibility that firms might attempt to use their power in the permit market to reduce competitive pressures in the product market. Two types of behaviour by a firm with power in the permit market are suggested: "...whereas the price-setting firm (monopsonist) acquires fewer permits than normal, the predatory firm acquires more". [Tietenberg (1985), p.138] Tietenberg's analysis of predatory behaviour is limited to cases in which it is very expensive for the predator and thus unlikely occur.

Other authors, such as Burrows(1981), Farber and Martin(1986) and Malueg(1990) hint at the possible combined effects of permit and product market power but do not provide a full analysis. Copeland(1990) investigates the effect of market structure on the efficiency of a tax regime. The model employed by Copeland has many similarities to the one used in this thesis. A paper by Misiolek and Elder(1987) is the first and only one that examines the case of firms seeking to reduce the competitive pressure in the product market by using their power in the permit

²²See for example Tietenberg(1985).

market to raise their rivals' costs. They do not explicitly model the emission permit market. Instead they apply the results of existing analyses of raising rivals' costs to the case of permit markets.

This study provides a detailed analysis using power in the permit market to raise rivals' costs given a variety of oligopolistic structures in the product market. The joint effects of product and permit market power on the efficiency of tradeable permits relative to command and control are analyzed in detail. Table 1 presents the different cases examined in the thesis.

Table 1. The different models developed in the thesis

			product market structure			
ERA	PIA	PMS	Cournot	Stack.Q	Stack.P	D.firm
CAC			Ch. II			
TEP	auct.	compet.	Ch. II	Ch. V	Ch. V	
		power	Ch. II	Ch. V*	Ch. V	
	grandf.	compet.	Ch. IV			Ch. VI
		power	Ch. IV			Ch. VI

*Both the case that the leader and the case that the follower is the permit price setter are examined.

where the following abbreviations are used: Environmental Regulation Approach (ERA), Permits' Initial Allocation (PIA), Permit Market Structure (PMS), Command and Control (CAC), Tradeable Emission Permit system (TEP), Stackelberg in Quantities model (Stack.Q), Stackelberg in Prices model (Stack.P), Dominant firm model (D.firm), auctioning (auct.), grandfathering (grandf.), competition (compet.) and price setting power (power).

This study reaches a number of conclusions regarding the efficiency of a tradeable emission permit system relative to a command and control system. It also expands the framework of the raising rivals' costs theory by considering cases other than the one in which the rivals are price takers in both the product and the permit market.²³

²³The raising rivals' costs theory is focused on the case of the dominant firm model. Salop and Scheffman(1987) suggest that research should be directed in examining other oligopoly markets.

STRUCTURE OF THE THESIS

The thesis is structured as follows: In Chapter II the base model is developed assuming Cournot behaviour in the product market and the auctioning of emission permits. A command and control system is compared to the tradeable permit system both when the permit market is competitive and when a firm has the power to set the permit price. In Chapter III two of the assumptions of the basic model are relaxed and the sensitivity of the results derived in Chapter II on these assumptions is tested. In Chapter IV the case in which emission permits are initially distributed free of charge (grandfathering of permits) is explored under the assumption of Cournot behaviour in the product market. The two systems of initial permit allocation are then compared to each other. In Chapter V the cases of Stackelberg leadership in quantities and in prices are examined. Chapter VI relates the results derived in the previous chapters to the existing literature.

CHAPTER II
COMPARISON BETWEEN MARKET BASED AND SOURCE
SPECIFIC ENVIRONMENTAL REGULATION
IN A COURNOT MODEL

INTRODUCTION

Chapter II develops an analytical framework to compare the cost of achieving a given reduction in emissions by the traditional command and control approach to the costs of a system of tradeable permits. The cost of reducing emissions is defined to include the cost of acquiring and operating the abatement technology as well as any losses in consumer and producer surplus due to resulting reductions in output. The relative costs of tradeable permits and command and control are compared in a model assuming differentiated Cournot duopoly in the product market, under the respective assumptions of price taking and price setting behaviour in the permits market.

The analysis reveals that welfare is always higher with a competitive market for emission permits than under command and control. If the permit market is not competitive welfare may be lower with tradeable permits than under command and control. The firm with the monopsony power in the permit market may have an incentive either to reduce the price of permits by underbuying--doing more abatement--or to increase the price of permits by overbuying--doing less abatement--thereby increasing its rival's costs. The degree of product market differentiation determines the effect of the exercise of price setting power on the price of permits.

The model employed in the paper also generates conclusions regarding the effects of various emissions control regimes on product market structure. It is shown that command and control generally results in a greater degree of inequality in market shares for a given reduction in aggregate emissions than would a competitive permit market.

SECTION I. PRE-REGULATION EQUILIBRIUM

Assume a two-sector economy; the first a competitive numeraire sector; the second a differentiated duopoly. Assume that consumers preferences are given by a utility function which is separable and linear in the numeraire good.

$$U = y + u(q_1, q_2)$$

Furthermore, assume that the utility of the differentiated sector, is quadratic and strictly concave,

$$u(q_1, q_2) = a_1 q_1 + a_2 q_2 - \frac{(b_1 q_1^2 + 2\delta q_1 q_2 + b_2 q_2^2)}{2}$$

where a_i and b_i are assumed to be positive, $i = 1, 2$, $b_1 b_2 - \delta^2 > 0$, and $a_i b_j - a_j \delta > 0$ for $i \neq j$, $i = 1, 2$. Under these assumptions the following set of linear inverse demand functions can be derived. For simplicity, symmetry ($a_1 = a_2$ and $b_1 = b_2$) is assumed.

$$P_i = a - b q_i - \delta q_j, \quad i = 1, 2$$

If the two firms have the same constant marginal cost of production, c , under Cournot conjectures, each firm's profit maximizing output is:

$$\hat{q}_i = \frac{(a - c)}{(2b + \delta)}, \quad i = 1, 2$$

When $\delta = 0$, the goods are independent and the model gives the monopoly solution for each separate good, $q_i = (a - c)/2b$, $i = 1, 2$. At the other extreme, if $\delta = b$, the goods become perfect substitutes and the solution collapses to the homogeneous Cournot result, $q_i = (a - c)/3b$, $i = 1, 2$.

Production of the differentiated product is assumed to create emissions. It is assumed that a single uniformly mixed, fund pollutant is emitted.²⁴ In contrast to stock pollutants, fund pollutants can be assimilated by the environment over time so

²⁴For a complete classification of pollutants see Tietenberg(1992).

the link between present emissions and future damage can be ignored. Furthermore, with uniformly mixed pollutants the damage caused is relatively insensitive to where the emissions are injected into the atmosphere. Therefore, the policy can focus on controlling the total emissions. Moreover, as noted in the introduction, the experience with tradeable permit systems shows that the majority of external trades involve uniformly mixed pollutants. It is assumed that each firm creates ρ units of emission per unit of output. The output of both firms can be measured in comparable units. The total emissions of the two firms is then:

$$E = \rho(\hat{q}_1 + \hat{q}_2) = \rho \frac{2(a-c)}{2b+\delta} \quad (1)$$

The emissions are called pollution because they are assumed to impose costs on the outside sector. Reducing pollution is costly in that it requires either a reduction in output and/or emissions per unit of output (abatement). It is assumed that in the absence of regulatory intervention, the polluting firms will do neither. Private transactions between the polluting firms and those suffering damage are assumed to be prohibitively costly.

Two forms of regulatory intervention are compared. The first is source-specific regulation, traditionally called "command and control". There are many alternative definitions of command and control. The definition adopted in this thesis is that aggregate emissions are reduced by requiring all polluters to reduce their total emission in the same proportion.

Alternatively, command and control could take the form of specifying a percentage reduction in emissions per unit of output. By specifying emission standards on the total emission level instead of a per unit of output basis, makes the level of abatement per unit of output a choice variable for the firm. Consequently, a cost minimizing solution is obtained.²⁵ The two alternative specifications of command and control are equally efficient only if government has complete

²⁵Besanko(1987) compares these two alternative definitions of command and control on the basis of minimizing compliance costs and on the basis of welfare maximization.

information about firms' abatement costs. But in such a case command and control would result in first best solution and no comparison of different systems would be necessary. Here, it is assumed that the government has incomplete information about firms' cost structure.

The second form of emissions control analyzed is the distribution of tradeable emission permits which allow the same aggregate level of emissions as was assumed under command and control.

SECTION II. COMMAND AND CONTROL

Assume that the government wishes to reduce emissions by a fraction $(1 - \psi)$. Under a command and control regime, each firm must reduce its emissions by the same fraction. Therefore, profit maximization is constrained by the following condition:

$$pq_i - \alpha_i q_i = \psi p \hat{q}_i, \quad i = 1, 2 \quad (2)$$

where: α_i is abatement per unit of output for firm i , ψ is the allowable fraction of emissions²⁶ and $\hat{q}_i$ is the pre-regulation output level of firm i .

It is assumed that the introduction of the ceiling on emissions is not anticipated. Thus, firms do not manipulate pre-regulation output, $\hat{q}_i$.

Reducing the level of emissions is costly. The cost of abatement is assumed to be a quadratic function²⁷. In addition, marginal abatement costs are assumed to differ across firms²⁸. The total cost of abatement for firm i is then:

²⁶For the purposes of this paper the level of allowable emissions for the industry is treated as a constant, $\bar{E} = \psi E$, where E is given by equation (1).

²⁷This abatement cost function implies a total cost function, $TC_i(q_i, \alpha_i)$, such that $TC_q > 0$, $TC_{qq} > 0$, $TC_{\alpha} > 0$, $TC_{\alpha\alpha} > 0$, where TC_{α} is the marginal cost of abatement per unit of output.

²⁸If they do not, the command and control approach yields the efficient allocation of abatement effort between firms.

$$CA_i = d_i \alpha_i q_i + e \alpha_i^2 q_i^2, \quad i = 1, 2 \quad (3)$$

Each firm chooses its level of output and abatement per unit of output by maximizing profits subject to the emissions constraint described by equation (2). That is, the Lagrange maximization problem for firm i is:

$$\max_{\alpha_i, q_i} \mathcal{L}_i = TR_i - TC_i + \lambda_i (\psi \rho \hat{q}_i - \rho q_i + \alpha_i q_i), \quad i = 1, 2, \quad \text{where: } TC = cq_i + CA_i$$

The first order conditions are:

$$\frac{\partial \mathcal{L}_i}{\partial q_i} = 0 \Rightarrow q_i = \frac{a - c - d_i \alpha_i - \lambda_i (\rho - \alpha_i)}{2(b + e \alpha_i^2)} - \frac{\delta}{2(b + e \alpha_i^2)} q_j, \quad i \neq j, \quad i, j = 1, 2 \quad (4)$$

$$\frac{\partial \mathcal{L}_i}{\partial \alpha_i} = 0 \Rightarrow \lambda_i = d_i + 2e \alpha_i q_i, \quad i = 1, 2 \quad (5)$$

$$\frac{\partial \mathcal{L}_i}{\partial \lambda_i} = 0 \Rightarrow A_i = \alpha_i q_i = \rho q_i - \psi \rho \hat{q}_i, \quad i = 1, 2 \quad (6)$$

Optimization implies that each firm reduces output to the point where the marginal loss in profit on output foregone is equal to the abatement cost of reducing emissions by an additional unit. The left hand side of equation (5) is the shadow price of the per unit reduction in emissions, λ_i , i.e. the loss in the level of profits evaluated at the optimum, caused by a marginal reduction in emissions ($\partial(\Pi_i^*)/\partial \bar{E}_i = \lambda_i$, where $\bar{E}_i = \psi \rho \hat{q}_i$, $i = 1, 2$). By the envelope theorem for models with one constraint: $\partial(\Pi_i^*)/\partial \bar{E}_i = \partial \mathcal{L}_i / \partial \bar{E}_i$. [See Silberberg, pp.170-71]. The right hand side of equation (5) is the marginal cost of abatement. This result is also obtained by Borrows(1981) and used by Farber and Martin(1986).

Substituting equation (5) into equations (4) and (6), firm i 's reaction function, and the Lagrange multiplier are derived:

$$q_i = \frac{a-c-\lambda_i \rho}{2b} - \frac{\delta}{2b} q_j, \quad \text{for } i \neq j, \quad i, j = 1, 2 \quad (7)$$

$$\lambda_i = 2e\rho q_i + d_i - 2e\rho \psi \hat{q}_i, \quad i = 1, 2 \quad (8)$$

Equation (7), for $i = 1, 2$, is solved for firm i 's output under command and control as a function of the Lagrange multipliers. To simplify the analytical solution, results are expressed as functions of firms' pre-regulation level of output.

$$q_i^c = \hat{q}_i - \rho \frac{2b\lambda_i - \delta\lambda_j}{\Phi\Psi}, \quad i \neq j, \quad i, j = 1, 2 \quad (9)$$

$$\text{where: } \Phi = 2b - \delta, \quad \Psi = 2b + \delta$$

The sum of the two firms' output is then:

$$q_1^c + q_2^c = \hat{q}_1 + \hat{q}_2 - \frac{\rho}{\Psi} (\lambda_1 + \lambda_2) \quad (10)$$

Solving equations (7), (5) and (8), for $i = 1, 2$, simultaneously, yields the equilibrium values of both firms' choice variables and the Lagrange multipliers. Firm i 's Lagrange multiplier is²⁹:

$$\lambda_i = \frac{\Psi(\Phi + 2e\rho^2)2e(\rho\hat{q}_i - \bar{E}_i) + (\Psi\Phi + 4be\rho^2)d_i + 2\delta e\rho^2 d_j}{(\Phi + 2e\rho^2)(\Psi + 2e\rho^2)}, \quad i \neq j \quad (11)$$

The firm with the lower intercept of the marginal cost of abatement has the smaller Lagrange multiplier that is, if $d_1 < d_2$, then $\lambda_1 < \lambda_2$. Thus, according to equation

²⁹For later reference note that the average of the two firms' Lagrange multipliers which in equilibrium, equals the average of the respective marginal costs of abatement of the two firms is:

$$\frac{\lambda_1 + \lambda_2}{2} = \frac{\Psi[2e\rho(\hat{q}_1 + \hat{q}_2) + (d_1 + d_2) - 2e\bar{E}]}{2(\Psi + 2e\rho^2)} \quad (12)$$

(9), the low abatement cost firm reduces its output by a relatively smaller amount than the firm with the high intercept of the marginal cost of abatement, that is $q_1^c > q_2^c$. Substituting equation (8) into (5), firm i 's abatement level is expressed as: $A_i = q(q_i - \psi \hat{q}_i)$. Therefore, the low abatement cost firm engages in higher volume of abatement relative to the high abatement cost firm, $A_1^c > A_2^c$.

In the homogeneous Cournot case ($\delta = b$), the impact of command and control on the product market is to reduce total output as well as the market share of the firm with the higher marginal cost of abatement. That is, $\partial Q^c / \partial \psi > 0$ (where $Q^c = q_1^c + q_2^c$) and $\partial^2 s_i^c / \partial \psi \partial d_i > 0$ (where $s_i = q_i^c / Q^c$, $i = 1, 2$).

Equivalent results obtain in the differentiated Cournot case ($0 < \delta < b$). In this case $\partial q_i^c / \partial \psi > 0$, $i = 1, 2$ and $\partial / \partial d_i [(1/q_1^c) (\partial q_i^c / \partial \psi)] > 0$, $i = 1, 2$. The firm with the higher marginal abatement cost experiences a greater proportional decline in output.

In conclusion, under command and control both firms have to reduce their emissions by the same percentage. In order to comply with the environmental regulation each firm can either reduce emissions by reducing output or engage in costly abatement. The firm with the higher marginal cost of abatement engages in a relatively lower level of abatement and reduces its output by a relatively larger amount which results in a reduction in its product market share. The firm with the higher abatement cost thus relies more on output reduction and less on abatement per unit of output to meet its emissions target than does the lower abatement cost firm. The interesting result here is that allowing firms to respond to emissions ceilings by adjusting both output and abatement adjustments, instead of adjusting only output, results in a more efficient allocation of abatement effort between firms. The high cost firm reduces its share of oligopoly profit in return for lower abatement cost. The social benefit of this action exceeds its private benefit.

SECTION III. TRANSFERABLE EMISSION PERMITS

A transferable emission permits system is assumed to take the following form. All sources are required to own emission permits in order to emit. Each permit specifies an amount of allowable emissions, assumed to be one unit, and is freely

transferable. The number of permits issued by the regulator is the maximum allowable units of emissions. In order to obtain meaningful comparison between the command and control and tradeable permit systems it is assumed that the government sets the same target level of emissions under each system. Thus, the supply of emission permits, $\bar{E}$, is:

$$\bar{E} = \psi\rho(\hat{q}_1 + \hat{q}_2) \quad (13)$$

The government can either auction the emission permits initially or it can distribute them free of charge to the firms. The first case is examined in this Chapter and the second is examined in Chapter IV.

With the introduction of tradeable emission permits, another market, the emission permits market is added to the model. This market may be either perfectly or imperfectly competitive. Two cases are analyzed, that of a perfectly competitive permit market and that of a permit market in which one of the firms sets the price of permits. These cases are compared both to each other and to the command and control system.

1. Perfectly competitive market for permits

Suppose that government auctions $\bar{E}$ permits to pollute. Under the assumption that each firm treats the price of permits, P^e , as parametric, the equilibrium price of permits is then the price at which the aggregate demand for permits equals the supply, $\bar{E}$, issued by the regulatory authority.

Each firm requires a number of permits equal to the level of emissions implied by its level of output and level of abatement per unit of output. Therefore, each firm's demand for permits is:

$$E_i^d = (\rho - \alpha_i)q_i, \quad i = 1, 2 \quad (14)$$

The optimal values of the choice variables for firm i , the level of output and the level of abatement per unit of output, are found by solving the following profit maximization problem:

$$\max_{\alpha_i, q_i} \Pi_i = TR_i - TC_i, \text{ where: } TC_i = cq_i + CA_i + P^e E_i^d, \quad i = 1, 2$$

The first order conditions are:

$$\frac{\partial \Pi_i}{\partial q_i} = 0 \Rightarrow q_i = \frac{a - c - d_i \alpha_i - P^e (\rho - \alpha_i)}{2(b + e \alpha_i^2)} - \frac{\delta}{2(b + e \alpha_i^2)} q_j, \quad i \neq j, \quad i = 1, 2 \quad (15)$$

$$\frac{\partial \Pi_i}{\partial \alpha_i} = 0 \Rightarrow P^e = d_i + 2e \alpha_i q_i, \quad i = 1, 2 \quad (16)$$

Optimization in this case implies that each firm buys permits until the marginal cost of an extra permit, P^e , is equal to its marginal abatement cost.

The first order conditions are solved simultaneously for firm i 's reaction function:

$$q_i = \frac{a - c - P^e \rho}{2b} - \frac{\delta}{2b} q_j, \quad i \neq j, \quad i, j = 1, 2 \quad (17)$$

Equation (17), for $i = 1, 2$, is solved for firm i 's output under the competitive permit market as a function of the permit price:

$$q_i^e = \hat{q}_i - \frac{\rho}{\Psi} P^e, \quad i = 1, 2 \quad (18)$$

In equilibrium the marginal abatement costs of both firms are the same and equal to the price of permits. Although they have different abatement technologies, each firm produces the same level of output. While each firm reduces its output by the same percentage, the firm with the lower marginal cost of abatement does more abatement per unit of output (if $d_1 < d_2$, then $\alpha_1^e > \alpha_2^e$) and thus reduces its emissions by a greater amount ($A_1^e > A_2^e$). Since the respective marginal costs of abatement are equalized at P^e this distribution of abatement effort is efficient.

The sum of the two firms' output is:

$$q_1^e + q_2^e = \hat{q}_1 + \hat{q}_2 - \frac{\rho}{\Psi} 2P^e \quad (19)$$

The equilibrium value of the permit price is derived by setting the total demand for permits equal to the supply, $\bar{E}$:

$$P^e = \frac{\Psi [2e\rho(\hat{q}_1 + \hat{q}_2) + (d_1 + d_2) - 2e\bar{E}]}{2(\Psi + 2e\rho^2)} \quad (20)$$

The permit price, given by equation (20), is equal to the average of the Lagrange multipliers, equation (12) in footnote 9:

$$P^e = \frac{\lambda_1 + \lambda_2}{2} \quad (21)$$

The permit price and the Lagrange multipliers are equal to each firm's marginal cost of abatement at the corresponding equilibrium. Thus, as equation (21) indicates, when the market for permits is competitive, the command and control and tradeable permit systems yield the same average marginal cost of abatement in equilibrium. The two regimes result in the same total volume of output. That is, $q_1^c + q_2^c = q_1^e + q_2^e$, in equations (10) and (19). This result is a consequence of the assumption that the firms' marginal abatement cost functions have the same slope³⁰.

Figure 1 illustrates this result. Marginal abatement cost in dollars is measured on the vertical axis. Firm 1's marginal cost of abatement is measured from the left axis ($d_1 + 2e\alpha_1 q_1$), while firm 2's marginal abatement cost is measured from the right axis ($d_2 + 2e\alpha_2 q_2$). The total amount of abatement in units of emission is measured on the horizontal axis. The optimal allocation of abatement among the two firms

³⁰If $e_1 \neq e_2$, the competitive permit price is a weighted sum of the Lagrange multipliers with the weights being e_1 and e_2 .

$$P^e = \frac{e_1 \lambda_1 + e_2 \lambda_2}{e_1 + e_2} \quad (22)$$

occurs at the intersection of the two firms' marginal cost of abatement schedules or point E in Figure 1.

Under command and control, both firms are required to reduce their emissions by the same percentage. Since they cannot trade emissions rights, however, the firm with the lower cost of abatement moves to a point such as C_1 on its marginal cost of abatement schedule while the firm with the higher cost of abatement moves to a point such as C_2 on its marginal cost of abatement schedule.

Figure 1. Cost effectiveness of tradeable permits

As was suggested in Section I, allowing firms to respond to the emissions ceiling by adjusting both output and abatement per unit of output, is a more efficient form of command and control than requiring equal percentage reductions in emission per unit of output. This would require an equal reduction in emissions for both firms, putting them at points D_1 and D_2 respectively in Figure 1. As can be seen from Figure 1, the deadweight loss from equal percentage reduction in emission per unit of output exceeds the deadweight loss from equal percentage reduction in emission.

The industry's level of abatement under command and control can be expressed as: $A_1 + A_2 = [(\lambda_1 e_2 + \lambda_2 e_1) - d_1 e_2 - d_2 e_1] / 2e_1 e_2$. Under tradeable permits, the industry's abatement is: $A_1 + A_2 = [P^e(e_1 + e_2) - d_1 e_2 - d_2 e_1] / 2e_1 e_2$. These two are equal by equation (22). This makes it possible to present each firm's optimal choices under each regime in the same diagram.

If $e_1 = e_2$, the triangle $C_1 C_2 E$ is isosceles and thus its height from E bisects $C_1 C_2$. Thus, the competitive permit price is equal to the average of the Lagrange multipliers and total output is the same under both command and control and under the competitive permit market. If $e_1 \neq e_2$, P^e is equal to a weighted average of the Lagrange multipliers. Total abatement is the same but total output differs between command and control and tradeable permits. These are the results shown in equations (21) and (22).

The introduction of tradeable emission permits, with $\psi < 1$, reduces the optimal level of output for each firm compared to the no regulation ($\psi = 1$) case by equation (18). The respective market shares of firms 1 and 2, whether defined in value or quantity terms--with value shares being appropriate in the differentiated product case--remain unaffected.

The first order conditions are used in order to compare the equilibrium values of the choice variables between command and control and tradeable permits. From equations (9) and (18), for $i = 1$, the difference in output between command and control and tradeable permits as a function of the corresponding difference in marginal abatement cost is derived using the relationship in equation (21):

$$q_1^c - q_1^e = \frac{\rho}{\Phi} (P^e - \lambda_1) \quad (23)$$

From equations (5) and (16), for $i = 1$, the difference in abatement between the two regulatory regimes is derived as a function of the corresponding difference in the marginal abatement cost:

$$A_1^e - A_1^c = \frac{1}{2e} (P^e - \lambda_1) \quad (24)$$

The difference in firm 1's marginal cost of abatement between command and control and tradeable permits, is derived from equations (11) for $i = 1$ and (20):

$$P^e - \lambda_1 = \frac{\Phi(d_2 - d_1)}{2(\Phi + 2e\rho^2)} \quad (25)$$

Equation (25) indicates that the lower abatement cost firm operates at a higher point in its marginal cost of abatement function in the tradeable permits equilibrium than in the command and control equilibrium.

Assume that firm 1 is the lower abatement cost firm ($d_1 < d_2$). According to equations (23) and (24), firm 1 increases its abatement and reduces its output relative to command and control. When the right to emit becomes tradeable, the firm with the lower abatement cost finds it profitable to abate³¹ more and buy fewer permits. By doing more abatement this firm increases its marginal cost of abatement--since the cost of abatement is quadratic--and thus decreases its output, equation (23).

In conclusion, with tradeable permits, the firm with the lower marginal cost of abatement does more abatement than the high abatement cost firm. Since total abatement is the same under both regimes, the total cost of abatement is lower under tradeable permits.

2. Power in the market for permits

Assume that both firms compete as Cournot oligopolists in the product market but one of these firms, firm 1, is a price setter in the permit market. The price setter operates along the other firm's marginal cost of abatement schedule. That is, the

³¹By increasing abatement per unit of output. This can be demonstrated as follows. Since $P^e - \lambda_1^c > 0$ for $d_1 < d_2$, then $q_1^e < q_1^c$ and $A_1^e > A_1^c$ from equations (26) and (27) respectively. Thus, $A_1^e/q_1^e > A_1^c/q_1^c$, which by the definition of total abatement implies that, $\alpha_1^e > \alpha_1^c$.

price setter chooses abatement and output given a fixed supply of permits and the knowledge of the price taker's permit purchases at any given price of permits.³²

The assignment of permit market power is arbitrary since the two firms have the same marginal cost of production and the same emission prior to regulation.³³

The symmetry assumption is carried over to the monopsony case because it keeps the analytical solution simple and facilitates comparison of the various cases examined. Furthermore, assuming equal marginal production costs and emissions per unit of output shows that the only asymmetry--in addition to the one of different marginal cost of abatement--needed to generate the results of this Section is a behavioral one. In what follows it is proven that under Cournot behaviour in the product market a firm that has price setting power in the permit market can expand its power into the product market, regardless of its size in the product and/or the permit market. The qualitative results of this section continue to hold if one of the firms is a bigger polluter.

This case is modelled as a two stage game. In the first stage the price setter chooses a profit maximizing offer price for emission permits. In the second stage the two firms make their profit maximizing output and abatement per unit of output decisions given the permit price determined in the first stage.

The second stage problem is solved first. Each firm decides its optimal level of output and abatement per unit of output given the permit price determined in the first stage and Cournot conjectures.

In making its optimal choice of output and abatement per unit of output, the price setter takes into consideration the effect that its permit price choice will have on its choice variables. In other words, in setting the permit price the price setter is constrained by the permit market clearing condition. Thus, the price setter's maximization problem is:

³²Hahn (1984) models the case that market power exist in the permit price in a similar way. The analysis in this paper differs from Hahn's in that Hahn is not considering the linkage between the product and the output market.

³³For some evidence on the existence of significant power in the permit markets, see O'Neil W. (1983), O'Neil W. et al. (1983), Lyon R. (1986) and David M. et al. (1980).

$$\max_{\alpha_1, q_1} \mathcal{L}_1 = \Pi_1 + \lambda^\mu (\bar{E} - E_1^d - E_2^d), \quad \text{where: } \Pi_1 = p_1 q_1 - c q_1 - C A_1 - P^\mu E_1^d$$

The first order conditions are:

$$\frac{\partial \mathcal{L}_1}{\partial q_1} = \frac{\partial \Pi_1}{\partial q_1} - \lambda^\mu \frac{\partial E_1^d}{\partial q_1} = 0 \Rightarrow q_1 = \frac{a - c - d_1 \alpha_1 - (P^\mu + \lambda^\mu)(\rho - \alpha_1)}{2(b + e \alpha_1^2)} - \frac{\delta}{2(b + e \alpha_1^2)} q_2 \quad (26)$$

$$\frac{\partial \mathcal{L}_1}{\partial \alpha_1} = \frac{\partial \Pi_1}{\partial \alpha_1} - \lambda^\mu \frac{\partial E_1^d}{\partial \alpha_1} = \frac{\partial \Pi_1}{\partial \alpha_1} + \lambda^\mu q_1 = 0 \Rightarrow P^\mu + \lambda^\mu = d_1 + 2e \alpha_1 q_1 \quad (27)$$

$$\frac{\partial \mathcal{L}_1}{\partial \lambda^\mu} = 0 \Rightarrow \bar{E} = \rho(q_1 + q_2) - A_1 - A_2 \quad (28)$$

Optimization implies that the price setter buys permits to the point where the marginal cost of an extra permit, $P^\mu + \lambda^\mu$, is equal to its marginal abatement cost. The price setter's marginal cost of an extra permit differs from the permit price, by the value of the Lagrange multiplier³⁴.

Substituting equation (27) into (26), the reaction function of the price setter is derived as a function of the permit price and the Lagrange multiplier:

$$q_1 = \frac{a - c - (P^\mu + \lambda^\mu)\rho}{2b} - \frac{\delta}{2b} q_2 \quad (29)$$

The reaction function and the abatement per unit of output for the price taker (firm 2) are given by equations (17) and (16) respectively, for $i = 2$, where the price of permits is denoted now by P^μ . Solving equations (17) and (29) simultaneously, the

³⁴Notice that the Lagrange multiplier of this problem has a different meaning from the Lagrange multipliers that were derived in the command and control case. Here, $\lambda^\mu = \partial(\Pi_1^*)/\partial \bar{E}$, where $\bar{E} = \psi\rho(\hat{q}_1 + \hat{q}_2)$, which means that the monopsonist is dealing with the total supply of permits.

output of firm 1 and 2 as functions of the permit price, P^* , and the Lagrange multiplier, λ^* are derived:

$$q_1^* = \hat{q}_1 - \rho \frac{\Phi P^* + 2b\lambda^*}{\Phi \Psi} \quad (30)$$

$$q_2^* = \hat{q}_2 - \rho \frac{\Phi P^* - \delta\lambda^*}{\Phi \Psi} \quad (31)$$

Summing equations (30) and (31), the level of total output is derived:

$$q_1^* + q_2^* = \frac{2 \left[a - c - \left(P^* + \frac{\lambda^*}{2} \right) \rho \right]}{\Psi} \quad (32)$$

Substituting equation (32) and the values for A_1 and A_2 from equations (27) and (16) respectively into equation (28), the value of the Lagrange multiplier is derived as a function of the permit price:

$$\lambda^* = \frac{\Psi \left[2e\rho(\hat{q}_1 + \hat{q}_2) + (d_1 + d_2) - 2e\bar{E} \right]}{\Psi + 2e\rho^2} - 2P^*, \text{ from equation (20): } \lambda^* = 2(P^e - P^*) \quad (33)$$

The average marginal cost of reducing emissions is the same under price setting as under competition³⁵. Under competition the cost of reducing emissions by a unit is the same for both firms, P^e . Under monopsony this cost is equal to the price of permits, P^* , for the price taker and to $P^* + \lambda^*$ for the monopsonist.

Substituting the value of the Lagrange multiplier from equation (33) into equation (32) yields:

³⁵Similarly to the result in equation (21), this result is also contingent upon the assumption that the slope of the marginal cost of abatement is the same between firms.

$$q_1^\mu + q_2^\mu = \frac{2(a - c - \rho P^e)}{\Phi} = q_1^e + q_2^e = q_1^c + q_2^c \quad (34)$$

Under the assumption that the slopes of the marginal abatement cost functions are the same, total output depends only on the mandated level of emissions, $\bar{E}$. It does not matter whether $\bar{E}$ is achieved by command and control or transferable permits. Nor does it matter whether there is monopsony power in the permit market.

Turning now to the first stage problem, the price setter chooses the profit maximizing permit price taking into account the price taker's output reaction to the permit price chosen³⁶.

$$\max_{P^\mu} \Pi_1 = \Pi_1(q_1(P^\mu), q_2(P^\mu), \alpha_1(P^\mu), P^\mu)$$

Using the following: the first order conditions of the second stage profit maximization problem, equations (26) and (27), which give: $\partial \Pi_1 / \partial q_1 = \lambda^\mu(\rho - \alpha_1)$ and $\partial \Pi_1 / \partial \alpha_1 = -\lambda^\mu q_1$; the structure of Π_1 which gives: $\partial \Pi_1 / \partial q_2 = -\delta q_1$ and $\partial \Pi_1 / \partial P^\mu = -E_1^d$; and the identity, $A_1 = \alpha_1 q_1$ from which: $\partial A_1 / \partial P^\mu = \alpha_1 \partial q_1 / \partial P^\mu + q_1 \partial \alpha_1 / \partial P^\mu$, the first order condition of the first stage profit maximization problem is derived:

$$\frac{\partial \Pi_1}{\partial P^\mu} = 0 \Rightarrow -\delta \frac{\partial q_2}{\partial P^\mu} q_1 - E_1^d + \lambda^\mu \rho \frac{\partial q_1}{\partial P^\mu} - \lambda^\mu \frac{\partial A_1}{\partial P^\mu} = -\delta \frac{\partial q_2}{\partial P^\mu} q_1 - E_1^d - \lambda^\mu \frac{\partial E_1^d}{\partial P^\mu} = 0 \quad (35)$$

In this form the components of the permit price decision rule can be identified. The change in the permit price setter's profits due to an increase in permit price has three

³⁶Substituting the value of the Lagrange multiplier from equation (35) into equations (31) and (32) the reaction function of the monopsonist and its abatement per unit of output are derived as functions of the permit price, $\alpha_1(P^\mu)$. Then the reaction functions of the two firms can be solved simultaneously for the output level of the two firms as function of the permit price only, $q_1(P^\mu)$, $q_2(P^\mu)$.

components: 1) the increase in the price setter's cost of permits, E_1^d , 2) the increase in the price setter's revenue due to the increase in the product price--resulting from the decrease in the rival's output responding to the higher permit price-- $\delta \partial q_2 / \partial P^m q_1$, 3) the increment in the demand for permits evaluated at λ^m , the value of which is derived using the first order conditions of the second stage profit maximization problem, $\lambda^m \partial A_1 / \partial P^m$ and $\lambda^m \rho \partial q_1 / \partial P^m$. The price setter raises the permit price above the competitive level if the effect of raising rival's costs on profit dominates the effect on its own costs.

Making the appropriate substitutions, equation (36) yields the following relationship between the Lagrange multiplier and the permit price:

$$\lambda^m = \frac{\Phi \Psi [4e\rho(b-\delta)\hat{q}_1 + \Phi d_1] - \Phi [\Phi \Psi + 4(b-\delta)e\rho^2] P^m}{2\Phi^2 \Psi + [2\Phi \Psi + 8b(b-\delta)]e\rho^2} \quad (36)$$

Equations (33) and (36) are solved for the equilibrium level of permit price and the Lagrange multiplier. The permit price is:

$$P^m = \frac{Y [2e\rho(\hat{q}_1 + \hat{q}_2) + (d_1 + d_2) - 2e\bar{E}] - \Phi (\Psi + 2e\rho^2) [4e\rho(b-\delta)\hat{q}_1 + \Phi d_1]}{(\Psi + 2e\rho^2) [3\Phi^2 + 4(3b-2\delta)e\rho^2]} \quad (37)$$

$$\text{where: } Y = 2\Phi^2 \Psi + [\Phi \Psi + 4b(b-\delta)]2e\rho^2$$

The price setter's choice of price is higher the lower its pre-regulation level of output and the better is its abatement technology.

From equations (20) and (37), the difference between the competitive and price setting permit prices is derived:

$$P^\mu - P^\varepsilon = \frac{\Phi[\Phi\Psi + 4(b-\delta)e\rho^2][2e\rho(\hat{q}_1 + \hat{q}_2) + (d_1 + d_2) - 2e\bar{E}]}{2(\Psi + 2e\rho^2)[3\Phi^2 + 4(3b - 2\delta)e\rho^2]} - \frac{\Phi[4e\rho(b-\delta)\hat{q}_1 + \Phi d_1]}{3\Phi^2 + 4(3b - 2\delta)e\rho^2} \quad (38)$$

Expression (38) is continuous in δ and in the case of perfect substitutability, $\delta = b$, it takes the following positive value:

$$P^\mu - P^\varepsilon = \frac{b(P^\varepsilon - d_1)}{3b + 4e\rho^2}, \text{ using eq. (16), } P^\mu - P^\varepsilon = \frac{2be}{3b + 4e\rho^2} A_1^\varepsilon > 0 \quad (39)$$

In the case of zero substitutability, $\delta = 0$, it takes the following negative value:

$$P^\mu - P^\varepsilon = -\frac{2be\bar{E} + b(d_1 - d_2)}{6(b + e\rho^2)} < 0 \quad (40)$$

When the goods produced by the two firms are close substitutes, the price setter's benefit from increasing its rival's cost dominates its loss from higher cost of permits and thus it sets a permit price above the competitive level.³⁷ As the degree of substitutability decreases so does the gain from increasing its rival's cost and the price setter's optimal permit price declines. By the second theorem of continuity³⁸ there is a degree of substitutability, δ^* , at which the competitive and the monopsony permit prices are the same.

At δ^* the monopsonist's benefit from raising its rival's cost in the product

³⁷This result also holds in some of the cases in which one of the firms dominates the product market as it is proven in Chapter II. The same result is also derived in Misiolek and Elder(1989). Their work is discussed in Chapter IV.

³⁸Which states that if a function $y = f(x)$ is continuous on the interval $[a, b]$ and it takes on values of different signs at the end points of this interval, then between the points a and b there will be one point $x = c$ at which the function becomes zero: $f(c) = 0$, $a < c < b$.

market is just offset by the higher price of permits paid. For degrees of substitutability below δ^* , the traditional³⁹ monopsony effect dominates the raising rival's cost effect and $P^\mu < P^c$. As long as the second firm has positive marginal abatement costs, however, the monopsonist can not drive the price of permits to zero.

The difference between the output level of the price setter and the price taker as a function of the difference in the permit price under monopsony and under competition, $P^\mu - P^c$, is derived from equations (30) and (31).

$$q_1^\mu - q_2^\mu = -\frac{\rho\lambda^\mu}{2b - \delta} = \frac{2\rho(P^\mu - P^c)}{2b - \delta} \quad (41)$$

Expression (41) demonstrates that the difference between the output level of the price setter and the price taker is continuous in δ , for $0 \leq \delta \leq b$. It takes the following positive value in the case of perfect substitutability:

$$q_1^\mu - q_2^\mu = \frac{2\rho(P^c - d_1)}{3b + 4e\rho^2} > 0 \quad (42)$$

If the goods produced by firm 1 and 2 are independent in demand, the difference between the monopsonist's and the price taker's output is:

$$q_1^\mu - q_2^\mu = -\frac{2e\rho\bar{E} + \rho(d_1 - d_2)}{6(b + e\rho^2)} < 0 \quad (43)$$

Recall that, prior to the imposition of a ceiling on emissions ($\psi = 1$) the output levels of firm 1 and 2 were the same ($\hat{q}_1 = \hat{q}_2$). Therefore, expression (42)

³⁹ See T.H. Tietenberg (1988), Chapter 15, pp.349-353, and R.W. Hahn (1984).

implies that in the case of perfect substitutability the permit price setter increases its share in the product market. The increase in the price setter's product market share is bigger the better its abatement technology is. The permit price setter uses its power in the permit market in order to increase its share of the product market.

Expression (43) implies that in the case of zero substitutability the permit price setter's output declines by a greater amount than the price taker's. In the case of zero substitutability, however, it is not meaningful to interpret this as a decrease in market share. The price setter incurs all the cost of decreasing the permit price--increased abatement costs--while the price taker benefits without any cost. However, since there is no link between the product markets, the benefit realized by the price taker has no effect on the price setter. The latter simply minimizes its cost of permits.

From equations (27) and (16) the difference in firm 1's abatement between price setting behaviour and competition as a function of the difference in the permit price, $P^u - P^c$, can be derived. It can then be shown that under perfect substitutability, the price setter's level of abatement is lower than the price taker's. That is, if $\delta = b$, then $A_1^u < A_2^u$. Under zero substitutability the price setter engages in more abatement than the price taker. That is, if $\delta = 0$, then $A_1^u > A_2^u$.

Figure 2 treats the same set of data as Figure 1 except that the price setter's marginal cost of permits curve --MPC in the diagram-- is added. The marginal permit cost is the sum of the permit price and the Lagrange multiplier. Since firm 2 is a permit price taker, the permit price is equal to its marginal cost of abatement in equilibrium. In equilibrium, the price setter sets its marginal abatement cost equal to

In order to compare the optimal values of the choice variables under monopsony and competition and under monopsony and command and control respectively, the first order conditions are used.

First, from equations (30) and (18) firm 1's output difference between monopsony and competition in the permits market is derived by first substituting the value of the Lagrange multiplier, λ^μ , from equation (34) into (30):

$$q_1^\mu - q_1^\varepsilon = \frac{\rho}{\Phi} (P^\mu - P^\varepsilon) \quad (44)$$

From equations (28) and (16), the difference in firm 1's abatement between competition and monopsony is derived:

$$A_1^\varepsilon - A_1^\mu = \frac{1}{2e} (P^\varepsilon - P^\mu - \lambda^\mu) = \frac{1}{2e} (P^\mu - P^\varepsilon) \quad (45)$$

In the case of perfect substitutability, ($\delta = b$), the permit price is higher under monopsony than competition, according to equation (38). Thus, $q_1^\mu > q_1^\varepsilon$ and $A_1^\mu < A_1^\varepsilon$, according to equations (44) and (45), respectively. These inequalities imply that $A_1^\varepsilon/q_1^\varepsilon > A_1^\mu/q_1^\mu$ or $\alpha_1^\varepsilon > \alpha_1^\mu$. The price setter does less abatement per unit of output than in the case when there is competition. This decrease is large enough to outweigh the output increases, accounting for an overall reduction in abatement per unit of output compared to the competitive case.

In the zero substitutability case ($\delta = 0$), the permit price is higher under competition than under monopoly, equation (40). Thus, $q_1^\mu < q_1^\varepsilon$ and $A_1^\varepsilon < A_1^\mu$, from equations (44) and (45), respectively. These inequalities imply that

$A_1^c/q_1^c < A_1^m/q_1^m$ or $\alpha_1^c < \alpha_1^m$. The price setter does more abatement per unit of output than when there is competition in the permit market. This increase outweighs the output decrease, resulting in a net increase in abatement per unit of output.

Second, the output difference between monopsony and command and control is derived using equations (30) and (9):

$$q_1^m - q_1^c = \frac{\rho}{\Phi} \left[-(P^c - \lambda_1) + (P^m - P^c) \right] = \frac{\rho}{\Phi} \left[\lambda_1 - (P^m + \lambda^m) \right] \quad (46)$$

The abatement difference between monopsony and command and control is derived using equations (28) and (5).

$$A_1^c - A_1^m = \frac{1}{2e} \left[-(P^c - \lambda_1) + (P^m - P^c) \right] = \frac{1}{2e} \left[\lambda_1^c - (P^m + \lambda^m) \right] \quad (47)$$

The first form of equations (46) and (47) shows the change in output and abatement in two steps. The first step is an output decrease, assuming $d_1 < d_2$, as the regulatory regime changes from command and control to tradeable permits. The second is an output increase when $\delta = b$, (decrease when $\delta = 0$) in the case that firm 1 sets the price in the permit market. The output increase (decrease) in the perfect substitutability (zero substitutability) case is larger (smaller) if the monopsonist has the higher marginal cost of abatement, $d_1 > d_2$.

The second form of equations (46) and (47) shows the output and abatement difference between monopsony and command and control as a function of the difference in the respective marginal costs of controlling emissions.

In the case of perfect substitutability, $\delta = b$, comparison of equation (25) and

(39) reveals that $P^\mu - P^c > P^c - \lambda_1^c$. Thus, $q_1^\mu > q_1^c$ and $A_1^c > A_1^\mu$, according to equations (46) and (47) respectively. These relationships imply that $\alpha_1^c > \alpha_1^\mu$.

Under perfect substitutability, the price setter reduces its abatement per unit of output not only below the efficient level, α_1^e , but also below the command and control level, $\alpha_1^\mu < \alpha_1^c < \alpha_1^e$. Therefore, the price setting case is the least efficient of all cases, from the point of view of minimizing abatement cost, since the low marginal cost of abatement firm, $d_1 < d_2$, engages in the lowest level of abatement per unit of output.

In the case of zero substitutability, $P^\mu - P^c < 0$ and $P^c - \lambda_1^c > 0$, which implies that $(P^\mu - P^c) - (P^c - \lambda_1^c) < 0$. Thus $q_1^\mu < q_1^c$ and $A_1^c < A_1^\mu$ according to equations (46) and (47), respectively. These relationships imply that $\alpha_1^c < \alpha_1^\mu$. Thus, the monopsonist does more abatement per unit of output than in any other case, $\alpha_1^c < \alpha_1^e < \alpha_1^\mu$. Although this case is more efficient from the point of view of minimizing abatement cost, its welfare implications require further investigation. The welfare implications of each case are examined separately in the next Section.

SECTION IV. WELFARE ANALYSIS

Total welfare in this economy is the sum of consumers surplus and the profits of firms 1 and 2. If the economy's endowment is m and y is the output of the numeraire sector, the budget constraint of the economy is:

$$y = m - p_1 q_1 - p_2 q_2 \quad (48)$$

where p_1 and p_2 are the prices of q_1 and q_2 respectively.

Substituting y from equation (48) into the utility function described in the first

section of the paper, yields consumers' surplus which is:

$$U^* = m - p_1^* q_1^* - p_2^* q_2^* + u^*(q_1^*, q_2^*) \quad (49)$$

where the superscript star, *, denotes equilibrium values.

The sum of the profits of the two firms in the differentiated product sector is the total profit of the economy since y is produced under competitive conditions.

Therefore, total producers' surplus of the economy is:

$$\Pi_1^* + \Pi_2^* = p_1^* q_1^* + p_2^* q_2^* - TC_1^* - TC_2^* \quad (50)$$

Substituting the sum of the two firms total revenue into equation (49), the total welfare of the economy is:

$$W^* = U^* + \sum_{i=1}^2 \Pi_i^* = m - \sum_{i=1}^2 TC_i^* + u^*(q_1^*, q_2^*) \quad (51)$$

Keeping the economy's endowment fixed, across different regulatory regimes, the change in welfare resulting from a given policy change is⁴⁰:

$$\Delta W = \Delta u(q_1, q_2) - \Delta \sum_{i=1}^2 TC_i = \Delta u(q_1, q_2) - \Delta TCA \quad (52)$$

In what follows, the welfare effects of the two regulatory regimes (command and control and tradeable permits) under two different permit market structures, namely price-taking and price-setting, are examined.

⁴⁰Since--under the assumption of equal slopes of marginal cost of abatement between firms--total output is independent of the regulatory regime as well as of the permit market structure and both firms have the same marginal cost of production, total production cost does not change, so that: $\Delta \sum TC_i = \Delta \sum CA_i = \Delta TCA$, for $i = 1, 2$. Furthermore, it is assumed that the cost of permits is a transfer to the government and does not affect economy's total welfare.

1. Command and control vs competitive emission permits market

At the equilibrium, the difference in the utility of the differentiated products between command and control and competitive permits market is:

$$u(q_1^c, q_2^c) - u(q_1^e, q_2^e) = - \frac{\rho^2(b-\delta)(d_2-d_1)^2}{4(\Phi + 2e\rho^2)^2} \quad (53)$$

The difference in the aggregate cost of abatement, TCA, is:

$$\Delta TCA = TCA^c - TCA^e = \frac{\Phi^2(d_1-d_2)^2}{8e(\Phi + 2e\rho^2)^2} \quad (54)$$

The welfare difference between the two regulatory regimes is derived by summing equations (53) and (54):

$$W^c - W^e = - \frac{[2e\rho^2(b-\delta) + \Phi^2](d_1-d_2)^2}{8e(\Phi + 2e\rho^2)} \leq 0 \quad (55)$$

which implies that:

$$\begin{aligned} \text{if } d_1 \neq d_2, \text{ then: } W^c < W^e, \quad \forall 0 \leq \delta \leq b \\ \text{if } d_1 = d_2, \text{ then: } W^c = W^e, \quad \forall 0 \leq \delta \leq b \end{aligned} \quad (56)$$

Welfare is higher under a competitive market for tradeable permits than under command and control. The welfare difference increases with the difference in marginal abatement costs. It also increases with the degree of product differentiation. Figure 3 illustrates the welfare difference as function of the degree of product differentiation. On the horizontal axis the degree of product differentiation is

measured, $\delta \in [0, b]$. On the vertical axis the welfare difference, $W^e - W^c$, is measured in dollars. At point B the welfare difference is: $b(2b + 3e\rho^2)(d_1 - d_2)^2 / 8e(b + e\rho^2)^2 > 0$. At point A the welfare difference is: $b^2(d_1 - d_2)^2 / 8e(b + 2e\rho^2)^2$.

Figure 3. Auctioning with competition vs command and control

Part of the welfare advantage of tradeable permits is due to the decrease in emission control cost resulting from the efficient allocation of abatement effort under tradeable permits. The other part is due to the effect of the reduction in abatement costs on the output market. Consumers' welfare is higher under tradeable permits than under command and control, except when goods 1 and 2 are perfect substitutes. In the latter case the total welfare increase is equal to the decrease in total abatement cost. For any other degree of product differentiation, however, the total welfare improvement over command and control is larger than the decrease in total abatement cost.

2. Command and control vs monopsonistic emission permits market

The difference in the utility of the differentiated products between command and control and tradeable permit systems with price setting in the permit market, is derived using the equilibrium values of the choice variables in the two cases.

$$u^c - u^\mu = \frac{\rho^2(b - \delta)}{\Phi^2} [\lambda_1^c \lambda_2^c - P^\mu(P^\mu + \lambda^\mu)] \quad (57)$$

The difference in total abatement cost is:

$$TCA^c - TCA^\mu = \frac{1}{2e} [\lambda_1^c \lambda_2^c - P^\mu(P^\mu + \lambda^\mu)] \quad (58)$$

The total welfare change is:

$$W^c - W^\mu = \frac{[2e\rho^2(b - \delta) + \Phi^2]}{2e\Phi^2} [\lambda_1^c \lambda_2^c - P^\mu(P^\mu + \lambda^\mu)] \quad (59)$$

The sign of the total welfare change depends on the difference between the respective products of the two firms' marginal costs of abatement under command and control and under tradeable permits, with price setting power in the permit market. The sign of the difference between the products of two pairs of numbers with the same sum is determined by the sign of the difference between the absolute values of the differences between the members of each pair⁴¹. Recall that, under the assumption of equal slopes of the marginal cost of abatement functions, the sum of

⁴¹If, $a + b = c + d$ then $ab > cd$ iff $|a - b| < |c - d|$. The proof is as follows. Taking the square of both sides of the equation and rearranging yields: $4(ab - cd) = c^2 + d^2 - 2cd - a^2 - b^2 + 2ab$. Then, $ab > cd$ if and only if, $c^2 + d^2 - 2cd > a^2 + b^2 - 2ab$, which can be written as: $(c - d)^2 > (a - b)^2$, or $|c - d| > |a - b|$.

marginal abatement cost across firms is the same under command and control, competitive and monopsonized permits markets respectively. That is,

$\lambda_1^c + \lambda_2^c = \lambda^\mu + P^\mu + P^\mu = 2P^\mu$. Therefore, the following statement is true:

$$\lambda_1^c \lambda_2^c > (P^\mu + \lambda^\mu)P^\mu \text{ iff } |\lambda_1^c - \lambda_2^c| < |\lambda^\mu| \quad (60)$$

which leads to the following condition for the sign of the welfare change:

$$W^c > W^\mu \text{ iff } |\lambda_1^c - \lambda_2^c| < |\lambda^\mu| \quad (61)$$

The interesting result here is that the difference in the welfare does not depend on whether the monopsonist is the low or high abatement cost firm. The welfare difference between the command and control and tradeable permit systems, with price setting power in the permit market, is greater the smaller is the difference between the two firms' marginal cost of abatement and the greater is the difference between the permit price prevailing under price setting behaviour and under perfect competition⁴². Thus the welfare difference depends on the degree of product differentiation.

Figure 4 illustrates the welfare difference, $W^c - W^\mu$, as a function of the degree of product differentiation. In the extreme cases of perfect substitutability and zero substitutability, the welfare of the economy is smaller under a monopsonized permit market than under command and control. As the degree of substitutability approaches the critical value δ^* at which the price setter chooses the competitive

⁴²Recall that $\lambda^\mu = 2(P^\mu - P^*)$.

permit price, a price setting permit market yields higher welfare than command and control provided that marginal abatement costs differ.

Figure 4. Auctioning with price setting vs command and control

In conclusion, for any degree of product differentiation and for any difference in the abatement cost between the two firms, the decrease in society's welfare due to the costs of environmental regulation is always smaller under regulations based on a competitive emission permit market than under source-specific regulation (command and control). When one firm is a permits price setter, it may have an incentive to increase the price of permits by overbuying permits, thereby increasing its rival's costs. The price setter's behaviour depends on the degree of product differentiation. If the two products are close substitutes, the price setter increases the permit price above the competitive level. As the degree of product differentiation increases, the price setter reduces the permit price below the competitive level. At the extremes of

perfect and zero substitutability, welfare is lower with price setting in the permits market than under command and control. For the range of product differentiation for which the price setter chooses a permit price close to the competitive level, welfare is greater with price setting in the permits market than under command and control.

CHAPTER III
SENSITIVITY OF THE RESULTS TO THE ASSUMPTIONS
ABOUT THE PRODUCTION TECHNOLOGY AND THE
NUMBER OF FIRMS IN THE PERMIT MARKET

INTRODUCTION

The primary objective of Chapter II is to compare the respective welfare effects of emissions reduction by means of source specific regulation (command and control) and market based regulation (tradeable permits). In order to accomplish this objective some simplifying assumptions concerning the production technology and the number of firms in the differentiated product sector of the economy were made. It turns out that, under these assumptions, a market for emission permits accomplishes a given reduction in emissions with a smaller decrease in welfare than command and control regulation if the permit market is perfectly competitive. If there is a price setter in the emission permit market however, the emissions target may be achieved more efficiently by command and control regulation. In this case, the welfare loss due to the distortion in the permit market exceeds the welfare loss resulting from the misallocation of abatement effort under command and control. This occurs when the product market is characterized by either very close or very weak substitutability.

In the present Chapter the sensitivity of these results to the assumptions of constant marginal cost of production and of only two firms in the differentiated product sector of the economy is explored.

SECTION I. PRODUCTION TECHNOLOGY

In Chapter I it is assumed that firms have the same, constant marginal cost of production. This assumption is made because it facilitates closed form solution for welfare under different environmental regimes. In this Section the sensitivity of the results derived in Chapter I to the assumption of constant marginal cost of production is examined.

Since the derivation of the closed form solution for welfare is cumbersome in the case of increasing marginal cost, no direct welfare comparison between command

and control and tradeable permits system is undertaken. The analysis focuses on the difference between the permit price under price taking and price setting respectively in the permit market. The analysis is confined to the case of perfect substitutability in the product market.

1. Pre-regulation equilibrium

The following, by now familiar, set of assumptions is employed: Cournot conjectures in the product market; linear demand; increasing marginal cost of abatement; and emissions a linear function of the firm's output level. The only difference from Chapter I is that the production cost function is assumed to be quadratic. For simplicity it is assumed that the slope of the marginal cost of production is the same for both firms while the intercept differ.

Under these assumptions, each firm's pre-regulation level of output is:

$$\hat{q}_i = \frac{Ma - 2(b+k)c_i + bc_j}{MN}, \quad i \neq j, \quad i, j = 1, 2 \quad (62)$$

$$\text{where: } M = b + 2k, \quad N = 3b + 2k$$

where k is the slope of both firms' marginal cost of production.

If both firms emit ρ units of pollution per unit of output, the aggregate level of emissions is:

$$E = \rho \hat{Q} = \rho \frac{2a - c_1 - c_2}{N} \quad (63)$$

where $\hat{Q} = \hat{q}_1 + \hat{q}_2$, is the industry's pre-regulation level of output.

Assume that the government decides to reduce emissions by a fraction $(1 - \psi)$. The government can achieve its target by implementing either command and control regulation or tradeable emission permits.

2. Command and Control

Under command and control, as defined in the thesis, each firm is required to reduce emission by the same fraction, $(1 - \psi)$. Then, each firm's constrained profit maximization problem is:

$$\max_{\alpha_i, q_i} \mathcal{P}_i = TR_i - TC_i + \lambda_i(\psi \rho \hat{q}_i - \rho q_i + \alpha_i q_i), \quad i = 1, 2$$

The first order conditions with respect to the choice variables and the Lagrange multiplier are solved for the firm i 's reaction function, its abatement level and the Lagrange multiplier.

$$q_i = \frac{a - c_i - \rho \lambda_i}{2(b + k)} - \frac{b}{2(b + k)} q_j, \quad i \neq j, \quad i, j = 1, 2 \quad (64)$$

$$\lambda_i = d_i + 2e\alpha_i q_i, \quad i = 1, 2 \quad (65)$$

$$\lambda_i = 2e\rho q_i + d_i - 2e\rho \psi \hat{q}_i, \quad i = 1, 2 \quad (66)$$

The optimization condition for abatement does not change as the production cost changes; equation (65) is the same as equation (5).

Solving the system of equation (64) for firm i 's output level as a function of the Lagrange multipliers yields the system:

$$q_i = \hat{q}_i - \rho \frac{2(b+k)\lambda_i - b\lambda_j}{MN}, \quad i \neq j, \quad i, j = 1, 2 \quad (67)$$

The sum of the two firms' output is then:

$$q_1 + q_2 = \hat{q}_1 + \hat{q}_2 - \rho \frac{\lambda_1 + \lambda_2}{N} \quad (68)$$

Summing equations (66) and substituting equation (68) into the result yields the sum of the Lagrange multipliers:

$$\lambda_1 + \lambda_2 = \frac{N[2e\rho(\hat{q}_1 + \hat{q}_2) + d_1 + d_2 - 2e\bar{E}]}{N + 2e\rho^2} \quad (69)$$

As in the case of constant marginal costs of production, each firm complies with the regulation by either reducing output or engaging in abatement. The firm with the lower abatement cost engages in more abatement and reduces its output by a relatively smaller amount. In doing so, it gains in product market share relative to the pre-regulation situation.

3. Tradeable Emission Permit System

Under the tradeable emission permit system, a number of permits are issued and sold at auction. Each permit specifies one unit of allowable emissions. The total supply of permits is $\bar{E} = \psi E$, where E is given by equation (63). All sources are required to own permits in order to emit.

i. Perfectly competitive market for permits

If both firms are price takers in the permit market, each firm's profit maximization problem is:

$$\max_{q_i, \alpha_i} \Pi_i = (a - bq_i - bq_j)q_i - (c_i + \kappa q_i)q_i - d_i \alpha q_i - e \alpha_i^2 q_i^2 - P^m E_i^d$$

The simultaneous solution of the two first order conditions yields the firm i 's output reaction function and abatement level.

$$q_i = \frac{a - c_i - \rho P^e}{2(b + \kappa)} - \frac{b}{2(b + \kappa)} q_j, \quad i \neq j, \quad i, j = 1, 2 \quad (70)$$

$$P^e = d_i + 2e \alpha q_i, \quad i = 1, 2 \quad (71)$$

Substituting the optimal values of both firms' choice variables, equations (70) and (71), into the permit market clearing condition yields the equilibrium permit price:

$$P^* = \frac{N[2e\rho\hat{Q} + (d_1 + d_2) - 2e\bar{E}]}{2(N + 2e\rho^2)} \quad (72)$$

Under the assumption that the slopes of the marginal abatement cost functions are the same, the competitive permit price, equation (72), is equal to the average of the Lagrange multipliers under command and control, equation (69). Thus, as in the case of constant marginal costs of production, the total volume of output is the same under command and control and under tradeable permits.

As was the case in Chapter I, the firm with the lower cost of abatement does more abatement and reduces more output than under command and control. The reverse is true for the firm with the higher cost of abatement.

ii. Power in the market for permits

For the reasons explained in Chapter I, the situation in which one of the two firms is assumed to have price setting power in the permit market, is modeled as a two stage game. In the first stage the permit price setter chooses the permit price that maximizes profit. In the second both firms choose output and abatement taking the permit price as given.

The second stage problem is solved first. In the second stage both firms make their optimal decisions given the permit price setter's choice of permit price.

The permit price setter, firm 1, maximizes its profits subject to the constraint that it has to buy the residual supply of permits at the price that it chooses in the first stage. The permit price setter's constrained profit maximization problem is:

$$\max_{q_1, \alpha_1} \mathcal{L}_1 = (a - bq_1 - bq_2)q_1 - (c_1 + \kappa q_1)q_1 - d_1\alpha_1 q_1 - e\alpha_1^2 q_1^2 - P^m E_1^d + \lambda^m (\bar{E} - E_1^d - E_2^d)$$

The first order conditions with respect to the choice variables are solved for the price setter's reaction function and demand for permits.

$$q_1 = \frac{a - c_1 - \rho(P^m + \lambda^m)}{2(b + \kappa)} - \frac{b}{2(b + \kappa)} q_2 \quad (73)$$

$$P^m + \lambda^m = d_1 + 2e\alpha_1 q_1 \quad (74)$$

The permit price taker's optimal decisions do not change from the case of competition since it still behaves as a price taker in the permit market. Its output reaction function and its permit market optimal condition are given by equations (70) and (71).

Solving equations (70) and (73) simultaneously yields the output level of both firms as a function of the permit price and the Lagrange multiplier.

$$q_1 = \hat{q}_1 - \rho \frac{MP^m + 2(b + k)\lambda^m}{MN} \quad (75)$$

$$q_2 = \hat{q}_2 - \rho \frac{MP^m - b\lambda^m}{MN} \quad (76)$$

The first order condition of the permit price setter's Lagrange function with respect to the Lagrange multiplier is the permit market constraint. Substituting the output and abatement levels of both firms, equations (75), (76), (74) and (71), into the permit market clearing condition yields the following relationship between the Lagrange multiplier and the permit price.

$$\lambda^m = \frac{N[2e\rho\hat{Q} + (d_1 + d_2) - 2e\bar{E}]}{N + 2e\rho^2} - 2P^m, \text{ from equation (72): } \lambda^m = 2(P^e - P^m) \quad (77)$$

Substituting equation (77) into equations (75) and (76) and summing yields:

$$Q^m = \frac{2(a - c_1 - c_2 - \rho P^e)}{N} = Q^e = Q^c \quad (78)$$

Under the assumption that the slopes of the marginal abatement cost functions are the same, the industry's output is the same under competition and under price setting

behaviour. Furthermore, the industry's output is the same under tradeable permits and command and control. Both these results were also obtained under the assumption of constant marginal production costs.

The first stage profit maximization problem of the permit price setter is:

$$\max_{P^m} \Pi_1 = \Pi_1(q_1(P^m), q_2(P^m), A_1(P^m), P^m)$$

Using the first order conditions of the second stage profit maximization problem of the permit price setter, the first order condition of the above profit maximization problem takes the following form:

$$\frac{\partial \Pi_1}{\partial P^m} = 0 \Rightarrow -\delta \frac{\partial q_2}{\partial P^m} q_1 - E_1^d + \lambda^m \rho \frac{\partial q_1}{\partial P^m} - \lambda^m \frac{\partial A_1}{\partial P^m} = 0 \quad (79)$$

Equation (79) gives the permit price setter's decision rule. The terms in (79) and their interpretation are the same as those in equation (35), although their values are different.

Making the appropriate substitutions, equation (79) yields the following relationship between the Lagrange multiplier and the permit price:

$$\lambda^m = \frac{MN[4ke\rho\hat{q}_1 + (b+2k)d_1] - M[MN + 4ke\rho^2]P^m}{2M^2N + [MN + 4k(b+k)]2e\rho^2} \quad (80)$$

Equations (77) and (80) are solved for the equilibrium value of the Lagrange multiplier and the permit price. The latter is:

$$P^m = \frac{\Omega[2e\rho\hat{Q} + (d_1 + d_2) - 2e\bar{E}] - M(N + 2e\rho^2)(4ke\rho\hat{q}_1 + Md_1)}{(N + 2e\rho^2)[3M^2 + 4(b+3k)e\rho^2]} \quad (81)$$

$$\Omega = 2M^2N + [MN + 4k(b+k)]2e\rho^2$$

Equation (81) is similar to equation (37), with perfect substitutability. Comparison of (81) and (37) shows that, the permit price is lower when the marginal

cost of production is increasing, P^m , than when is constant, P^c . Both equations imply that the permit price setter's pre-regulation level of output has a negative effect on the permit price. The magnitude of this effect though, is different between the two case. This is because the absolute value of the marginal change in the price taker's output due to a change in P^m , $\partial q_2 / \partial P^m$, is smaller in the case of increasing marginal production cost than in the case of constant marginal production cost, $|\partial q_2 / \partial P^m| < |\partial q_2 / \partial P^c|$. Thus, the permit price setter's benefit from raising its rival's cost--as shown in equations (36) and (79)--is smaller when the marginal cost of production is increasing. This leads the permit price setter to choose a lower permit price than when the marginal cost of production is constant.

The permit price difference between competition and price setting behaviour in the permit market is derived using equations (72) and (81):

$$P^m - P^c = \frac{M(MN + 4ke\rho^2)[2e\rho\hat{Q} + (d_1 + d_2) - 2e\bar{E}]}{2(N + 2e\rho^2)[3M^2 + 4(b + 3k)e\rho^2]} - \frac{M(4ke\rho\hat{q}_1 + Md_1)}{3M^2 + 4(b + 3k)e\rho^2} \quad (82)$$

Equation (82) is similar to equation (38) and collapses to equation (39) for $k = 0$. In contrast to equation (39), the sign of equation (82) is not always positive. Under perfect substitutability the permit price setter does not necessarily choose a permit price above the competitive level. In order to specify the sign of the permit price difference, an alternative form of (82) is used. Substituting $\bar{E} = \psi\rho\hat{Q}$ into equation (82) and rearranging yields:

$$P^m - P^c = \frac{2e\rho M \left[N(b - 2k) - 4ke\rho^2 \right] \hat{q}_1 - (MN + 4ke\rho^2) (\psi\hat{Q} - \hat{q}_2)}{2(N + 2e\rho^2)[3M^2 + 4(b + 3k)e\rho^2]} + \frac{M \left[(MN + 4ke\rho^2)d_2 - [MN + 4(b + k)e\rho^2]d_1 \right]}{2(N + 2e\rho^2)[3M^2 + 4(b + 3k)e\rho^2]} \quad (83)$$

The sign of the above expression depends: first, on the slope of the demand relative to the slope of the marginal cost of production; second, on the permit price

setter's pre-regulation share in the product market; third, on its abatement efficiency relative to its rival; and fourth, on the allowable level of emissions. The price setter chooses a permit price closer to the competitive level, $(P^m - P^r) \rightarrow 0$, or even below the competitive level, if the demand is much steeper⁴³ than the marginal production cost function, $b \rightarrow 2\kappa$, provided that pre-regulation market share is bigger than its rival's and it is not more efficient in abatement. More precisely, P^r is unambiguously greater than P^m under the following conditions: 1) $b < 2\kappa$, 2) $\psi > \hat{q}_2/\hat{Q}$, 3) $d_1 > d_2$. These conditions are sufficient but not necessary. In Section II of Chapter III, it is shown that the condition concerning the product market share is sufficient even if the condition concerning the slopes of the demand and production cost does not hold.

To summarize, the permit price setter is more likely to choose a permit price above the competitive level: the smaller is its market share in the pre-regulation equilibrium, the more efficient is its abatement relative to its rival, the more inelastic its market demand, the lower is the level of allowable emissions, and the less steeply sloped is the marginal production cost function. Intuitively, the cost to the permit price setter of raising its rival's cost is larger the greater is its pre-regulation share in the product market. This is because the larger is the permit price setter's product market share, the more permits it uses and thus the greater is its inframarginal cost of raising the permit price. The more inefficient is the rival in abatement the larger is the effect of an increase in the price on the rival's market share. The more inelastic the demand (the greater is b) the greater is the increase in product price resulting from the decrease in the permit price taker's output due to a permit price increase. The less steep the slope of the marginal cost of production, the bigger is the significance of the permit market relatively to the output market, and thus the bigger the effect of a high permit price on output decisions.

The above analysis indicates that the results derived in Chapter I are sensitive to the assumption made about the slope of the marginal production cost function. By

⁴³Recall that b is the slope of the indirect demand function. The smaller b is the bigger is the slope of the direct demand.

assuming a more general production cost function, other influences on the price setter's choice of permit price, are revealed. These are: the permit price setter's pre-regulation product market share, the slope of the market demand function, and the importance of emission control cost relative to the production cost.

The qualitative results derived in Chapter I continue to hold. There are however, cases, depending now on more parameters than just the degree of product differentiation, in which a given reduction in emissions is accomplished more efficiently with command and control regulation than with tradeable permits.

SECTION II. NUMBER OF FIRMS IN THE INDUSTRY

In Chapter I it is assumed that only two firms operate in the differentiated product sector of the economy. In this Section the sensitivity of the results derived in Chapter I to the number of firms in the industry is examined.

1. Pre-regulation equilibrium

The following, by now familiar, set of assumptions is employed: Cournot conjectures in the product market; linear demand; increasing marginal cost of abatement; constant and identical marginal production costs functions; and emissions proportional to output. The only difference from Chapter I is that the number of firms in the industry is assumed to be n . The inverse demand functions are:

$$P_i = a - bq_i - \delta \sum_{j=1}^n q_j, \quad i \neq j, \quad i, j = 1 \dots n \quad (84)$$

Under the above assumptions, each firm's pre-regulation level of output is:

$$\hat{q}_i = \frac{a - c}{2b + \delta(n - 1)}, \quad i = 1 \dots n \quad (85)$$

Assuming that all firms emit ρ units of pollution per unit of output, the aggregate level of emissions is:

$$E = \rho \sum_{i=1}^n \hat{q}_i = \rho \frac{n(a-c)}{2b + \delta(n-1)} \quad (86)$$

Assume that the government decides to reduce emission by a fraction $(1 - \psi)$. It can do this by implementing either a command and control system or a tradeable permits system.

2. Command and control

Under this system, each firm is required to reduce emissions by the same fraction. As in Section II of Chapter I, each firm maximizes profit subject to the emission control constraint. Each firm's constrained profit maximization problem takes the following form:

$$\max_{\alpha_i, q_i} \mathcal{L}_i = TR_i - TC_i + \lambda_i(\psi \rho \hat{q}_i - \rho q_i + \alpha_i q_i), \quad i = 1 \dots n$$

The first order conditions with respect to the choice variables and the Lagrange multiplier are solved for the firm i 's reaction function, its abatement level and the Lagrange multiplier.

$$q_i = \frac{a-c-\lambda_i \rho}{2b} - \frac{\delta}{2b} \sum_{j=1}^n q_j, \quad i \neq j, \quad i, j = 1 \dots n \quad (87)$$

$$\lambda_i = d_i + 2e\alpha_i q_i, \quad i = 1 \dots n \quad (88)$$

$$\lambda_i = 2e\rho q_i + d_i - 2e\rho\psi \hat{q}_i, \quad i = 1 \dots n \quad (89)$$

As in the case of two firms, each firm reduces output to the point where the marginal loss in profit, the shadow price of the per unit reduction in emissions, is equal to the marginal cost of abatement.

The system of n equations resulting from equation (87), for $i = 1 \dots n$, is solved for firm i 's output level as a function of the Lagrange multipliers.

$$q_i = \hat{q}_i - \rho \frac{[2b + \delta(n-2)]\lambda_i - \delta \sum_{j=1}^n \lambda_j}{\Phi O}, \quad i \neq j, \quad i, j = 1, n \quad (90)$$

where: $O = 2b + \delta(n-1)$

Summing up equation (90) for $i = 1 \dots n$, the aggregate level of output is:

$$\sum_{i=1}^n q_i = \sum_{i=1}^n \hat{q}_i - \rho \frac{\sum_{i=1}^n \lambda_i}{O} \quad (91)$$

Summing up equation (89) for $i = 1 \dots n$, and using equation (91), the sum of the Lagrange multipliers is derived:

$$\sum_{i=1}^n \lambda_i = \frac{O \left[2e\rho \sum_{i=1}^n \hat{q}_i + \sum_{i=1}^n d_i - 2e\bar{E} \right]}{O + 2e\rho^2} \quad (92)$$

As in the case of two firms, each firm complies with the regulation by either reducing output or engaging in abatement. The firms with the lower abatement costs engage in more abatement and reduce their output by a relatively smaller amount than the firms with the higher abatement costs. In doing so, they gain in product market share.

3. Tradeable emission permit system

Under the tradeable emission permit system, a number of permits are issued and sold at auction. All sources are required to own permits in order to emit. Each permit specifies one unit of allowable emissions. The total supply of permits is $\bar{E} = \psi E$, where E is given by equation (86). Each firm's demand for permits, E_i^d , is given by equation (14).

i. Perfectly competitive market for permits

When all n firms are price takers in the permit market, each firm's profit maximization problem is:

$$\max_{q_i, \alpha_i} \Pi_i = \left[a - bq_i - \delta \sum_{j=1}^n q_j \right] q_i - c_i q_i - d_i \alpha_i q_i - e \alpha_i^2 q_i^2 - P^m E_i^d, \quad i \neq j, \quad i, j = 1 \dots n$$

The simultaneous solution of the two first order conditions yields firm i 's output reaction function and the optimization condition for emission control.

$$q_i = \frac{a - c_i - \rho P^e}{2b} - \frac{\delta}{2b} \sum_{j=1}^n q_j, \quad i \neq j, \quad i, j = 1 \dots n \quad (93)$$

$$P^e = d_i + 2e\alpha_i q_i, \quad i = 1 \dots n \quad (94)$$

Substituting the optimal values of all firms' choice variables, equations (93) and (94) for $i = 1, 2$, into the permit market clearing condition yields the equilibrium level of the permit price:

$$P^e = \frac{O \left[2e\rho \sum_{i=1}^n \hat{q}_i + \sum_{i=1}^n d_i - 2e\bar{E} \right]}{n(O + 2e\rho^2)} \quad (95)$$

Under the assumption of equal slopes of marginal abatement cost between firms, the competitive permit price, equation (95), is equal to the average of the Lagrange multipliers under command and control, equation (92). Thus, as in the case of two firms, the total volume of output is the same under command and control and under tradeable permits. As in Chapter I, the firms with relatively low abatement cost do more abatement and reduce more output than under command and control.

ii. Power in the market for permits

Assume that one of the firms, firm i , is a permit price setter in the permit market. It chooses a permit price at which it buys the residual supply of permits after

all other firms make their permit purchases.

This case is modeled as a two stage game. In the first stage the permit price setter chooses its profit maximizing permit price. In the second stage all firms take the permit price as given and choose their profit maximizing level of output and abatement.

The second stage is solved first. The permit price setter's profit maximization is constrained by the permit market clearing condition. Its maximization problem is:

$$\max_{\alpha_i, q_i} \mathcal{L}_i = TR_i - TC_i + \lambda^m \left[\bar{E} - E_i^d - \sum_{j=1}^n E_j^d \right], \quad i \neq j$$

The first order conditions with respect to the choice variables are solved for the permit price setter's reaction function and its abatement level as functions of the Lagrange multiplier and the permit price.

$$q_i = \frac{a - c - \rho(P^m + \lambda^m)}{2b} - \frac{\delta}{2b} \sum_{j=1}^n q_j, \quad j \neq i, \quad j = 1 \dots n \quad (96)$$

$$P^m + \lambda^m = d_i + 2e\alpha q_i \quad (97)$$

The reaction function and the abatement per unit of output for the price takers are given by equations (93) and (94), where the permit price is denoted now by P^m .

Solving the system of equations (96) and (93) for $j = 1 \dots n$ and $j \neq i$, the output of the permit price setter and the permit price takers is derived.

$$q_i = \hat{q}_i - \rho \frac{\Phi P^m + [2b + \delta(n-2)]\lambda^m}{\Phi O} \quad (98)$$

$$q_j = \hat{q}_j - \rho \frac{\Phi P^m - \delta\lambda^m}{\Phi O}, \quad i \neq j, \quad j = 1 \dots n \quad (99)$$

Summing equations (98) and (99) for $j = 1 \dots n$ and $j \neq i$, the aggregate level of output is derived.

$$\sum_{i=1}^n q_i = \sum_{i=1}^n \hat{q}_i - \rho \frac{nP^m + \lambda^m}{0} \quad (100)$$

Substituting the aggregate output, equation (100), and the aggregate abatement level derived from equations (97) and (94) for $j = 1 \dots n$ and $j \neq i$, into the permit market clearing condition, the following relationship between the Lagrange multiplier and the permit price is derived:

$$\lambda^m = \frac{0 \left[2e\rho \sum_{i=1}^n \hat{q}_i + \sum_{i=1}^n d_i - 2e\bar{E} \right]}{0 + 2e\rho^2} - nP^m = n(P' - P^m) \quad (101)$$

Under the assumption that the slopes of the marginal cost of abatement function are the same for all firms, the sum of all firms' marginal evaluation of emissions reduction is the same under price setting and under price taking in the permit market. Recall that equation (95) implies that the aggregate marginal evaluation of emissions reduction is also the same under competitive tradeable permit market as it is under command and control. Thus, as in the case with the two firms, the aggregate marginal evaluation of emissions reduction is independent of the method of regulation and of the structure of the permit market as long as the slope of the marginal abatement cost is the same for all firms. This also implies that aggregate output in the differentiated sector remains unchanged.

In the first stage, the permit price setter chooses the profit maximizing permit price knowing the price takers' output reaction to its choice of permit price.

$$\max_{P^m} \Pi_i = \Pi_i(q_i(P^m), q_j(P^m), A_i(P^m), P^m), \quad j \neq i, \quad j = 1 \dots n$$

Using the first order conditions of the permit price setter's second stage constrained profit maximization problem, the first order condition of this profit maximization problem can be written as follows:

$$\frac{\partial \Pi_i}{\partial P^m} = 0 \Rightarrow -\delta \sum_{j=1}^n \frac{\partial q_j}{\partial P^m} q_j - E_i^d + \lambda^m \rho \frac{\partial q_i}{\partial P^m} - \lambda^m \frac{\partial A_i}{\partial P^m} = 0, \quad j \neq i, j = 1 \dots n \quad (102)$$

Equation (102) is similar to equation (35) and its interpretation is also the same, although the value of each term is different from that of equation (35).

Making the appropriate substitutions, equation (102) yields the following relationship between the Lagrange multiplier and the permit price:

$$\lambda^m = \frac{\Phi O [2e\rho(2b - \delta n)\hat{q}_i + \Phi d_i] - \Phi [\Phi O + (2b - \delta n)2e\rho^2] P^m}{n\Phi^2 O + [(n-1)\Phi O + \Sigma(2b - \delta n)]2e\rho^2} \quad (103)$$

$$\text{where: } \Sigma = 2b + \delta(n-2)$$

Equation (103) collapses to equation (36) for $n = 2$. Equations (101) and (103) are solved for the equilibrium level of permit price and the Lagrange multiplier. The permit price is:

$$P^m = O \frac{\Pi \left[2e\rho \sum_{j=1}^n \hat{q}_j + \sum_{j=1}^n d_j - 2e\bar{E} \right] - \Phi (O + 2e\rho^2) [2e\rho(2b - \delta n)\hat{q}_i + \Phi d_i]}{(O + 2e\rho^2) [(n^2 - 1)\Phi^2 O + [n(n-1)\Phi O + (2b - \delta n)(n\Sigma - \Phi)]2e\rho^2]} \quad (104)$$

$$\text{where: } \Pi = n\Phi^2 O + [(n-1)\Phi O + (2b - \delta n)\Sigma]2e\rho^2$$

From equations (104) and (95) the difference between the permit price setter's choice of permit price and the competitive permit price is derived:

$$P^m - P^c = \frac{\Phi O [\Phi O + (2b - \delta n)2e\rho^2] \left[2e\rho \sum_{j=1}^n \hat{q}_j + \sum_{j=1}^n d_j - 2e\bar{E} \right]}{n(O + 2e\rho^2) [(n^2 - 1)\Phi^2 O + [n(n-1)\Phi O + (2b - \delta n)(n\Sigma - O)]2e\rho^2]} \quad (105)$$

$$\frac{-\Phi O [2e\rho(2b - \delta n)\hat{q}_i + \Phi d_i]}{[(n^2 - 1)\Phi^2 O + [n(n-1)\Phi O + (2b - \delta n)(n\Sigma - O)]2e\rho^2]}$$

Equation (105) collapses to equation (38) for $n = 2$. The sign of (105) is ambiguous. As in the case of two firms, it depends on the degree of product differentiation. For a range of degrees of product differentiation, $[b, \delta^*]$, the permit price setter chooses a permit price above the competitive level, $P^m > P^c$, while for a range, $[\delta^*, 0]$, it chooses a permit price below the competitive level, $P^m < P^c$. The critical value of δ , δ^* , now depends on the number of firms in the permit market as well as the other parameters of the model.

The magnitude of the difference between the price setting and price taking permit price depends on the number of firms in the permit market. In order to explore the sensitivity of the permit price difference to the number of firms in the permit market, the extreme cases of perfect and zero substitutability are examined.

Under perfect substitutability, the competitive permit price and the permit price setter's choice of permit price are derived from equations (95) and (104) after making the appropriate substitutions.

$$P^c = \frac{2e\rho(1-\psi)n(a-c) + b(n+1)\sum_{j=1}^n d_j}{n[b(n+1) + 2e\rho^2]} \quad (106)$$

$$P^m = \frac{\left[\frac{b(n+1)n + (2n-1)2e\rho^2}{(n^2-1)[b(n+1) + 2e\rho^2]} \left[2e\rho(1-\psi)n(a-c) + b(n+1)\sum_{j=1}^n d_j \right] - \frac{[-2e\rho(n-2)(a-c) + b(n+1)d_i]}{(n^2-1)[b(n+1) + 4e\rho^2]} \right]}{(n^2-1)[b(n+1) + 2e\rho^2]} \quad (107)$$

In the case of perfect substitutability, the permit price setter's choice of permit price is above the competitive level. As the number of firms in the industry increases, however, both the competitive permit price and the price chosen by the permit price setter decrease. The permit price setter's choice of permit price approaches the competitive permit price asymptotically. Figure 5 illustrate this result.

Intuitively, as the number of firms increases, output and thus emissions per firm decrease. This implies that each firm engages in less abatement. Each firm operates on a lower point on its marginal abatement cost function. In the limit, the marginal cost of abatement and thus the price of permits converges on the average intercept of the abatement cost functions, $\sum d_i/n$.

Alternatively, these results can be explained in the context of Figure 2. As the number of firms in the industry increase, the horizontal aggregation of all price takers' marginal abatement cost functions and thus the price setter's marginal cost of permits function becomes flatter. This implies that, as the number of firms tends to

Figure 5. Permit price with n firm and $\delta = b$

infinity, the competitive permit price, which is now determined by the intersection of the aggregate marginal abatement cost of the $(n - 1)$ firms with the marginal abatement cost of the price setter, tends towards the lowest intercept of the $(n - 1)$ firms' marginal cost of abatement functions.

Under zero substitutability, the permit price under competition and under price setting behaviour are derived from equations (95) and (104).

$$P^* = \frac{e\rho(1-\psi)n(a-c) + b \sum_{j=1}^n d_j}{n(b + e\rho^2)} \quad (108)$$

$$P^m = \frac{(n^2 - 1)e\rho(a-c) - n^2\psi e\rho(a-c) + nb \sum_{j=1}^n d_j - bd_1}{(n^2 - 1)(b + e\rho^2)} \quad (109)$$

In the case of zero substitutability, the permit price setter acts as a monopsonist in the permit market choosing a permit price below the competitive level. As the number of firms in the permit market increases, total emissions increase and the supply of permits increases proportionately. Since all firms participate in different product markets, each firm's output and emissions do not change. Thus, the demand for and supply of permits increase proportionately leaving the competitive permit price unchanged. Since marginal production cost is assumed constant and identical across firms, any change in the competitive permit price must be due to differences in abatement technology. In Figure 6 it is assumed for simplicity that firms have similar abatement technologies. That is, the difference in the intercepts of their marginal abatement cost functions is small. Thus, the competitive permit price does not change as the number of firms in the permit market increases. The permit price setter's choice of permit price increases as the number of firms increases, approaching the competitive price asymptotically.

As the number of firms in the permit market increases, the relative size of the permit price setter in the permit market and thus its power in the permit market decreases. As the number of firms in the permit market increases, the elasticity of the residual supply of permits increases and the degree of monopsony power decreases.

In conclusion, as the number of firms in the permit market increases, the inefficiency of tradeable emission permit regulation resulting from the existence of permit price setting power decreases for any degree of product differentiation. As the

number of firms tends to infinity, this inefficiency is completely eliminated. However, it should be noted that this does not necessarily imply an improvement over command and control. In the case of perfect substitutability, as the number of firms

Figure 6. Permit price with n firms and $\delta = 0$

in the industry increases, each firm's actual volume of emissions declines, as does its share in total emissions. Thus, each firm engages in less abatement and the inefficiency of command and control, which is the result of the missallocation of abatement effort among firms, declines. In the limit, each firm does a very small amount of abatement and both the inefficiency due to the price setting power in the permit market and the inefficiency of command and control vanish.

In the case of zero substitutability, the inefficiency of command and control does not diminish as the number of firms in the permit market increases because each firm's actual level of emissions and abatement do not decline. The inefficiency of command and control can actually increase if the additional firms have substantially different abatement technologies.

CHAPTER IV

GRANDFATHERING OF EMISSION PERMITS

INTRODUCTION

The analysis in Chapters II and III assumes that the regulator initially allocates emission permits through an auction. Permits could also be distributed to emitting firms free of charge (grandfathering of permits). After the initial distribution, firms can trade permits freely. In Chapter IV the case of grandfathered permits is modeled. Its solution is compared to the case in which permits are auctioned.

In order to compare the two systems of permit allocation, a common structure for the product market is used. As in Chapter II, it is assumed that firms behave as Cournot rivals in the product market. Furthermore, the assumptions regarding the economy, demand and the production and abatement technologies made in Chapter II are also employed here.

Chapter IV is structured as follows: Section I examines the extent to which government's choice of the initial allocation of permits affects the permit price both under price taking and price setting in the permit market; Section II examines the possibility that permits can be used as a barrier to entry in the product market.

SECTION I. GRANDFATHERING vs AUCTIONING

Since all the assumptions made in Chapter II are employed in this Chapter, the pre-regulation equilibrium is the same as described in Section I of Chapter II. The aggregate level of emissions, E , is given by equation (1). The government decides to reduce emissions by a fraction $(1 - \psi)$ by implementing a system of tradeable emission permits. Suppose that the government distributes $\bar{E}$ permits (given by equation (13)) free of charge in proportion to each firm's pre-regulation level of emissions. Each firm receives an endowment of permits $\bar{E}_i$, such that:

$$\bar{E}_i = \psi \rho \hat{q}_i, \quad \text{with:} \quad \sum_{i=1}^2 \bar{E}_i = \psi \rho \sum_{i=1}^2 \hat{q}_i = \bar{E}, \quad i = 1, 2 \quad (110)$$

After the initial allocation of permits trade is allowed. Under the assumptions

that both firms have identical, constant marginal production costs and the same rate of pollution, ρ , both firms receive the same number of permits. The firm with the better abatement technology abates more and sells its excess of permits to the other firm. The net demand (supply) of permits of the firm with the higher(lower)marginal abatement cost is:

$$NE_i^d = E_i^d - \bar{E}_i = (\rho - \alpha_i)q_i - \bar{E}_i, \quad \text{with: } \sum_{i=1}^2 NE_i^d = 0 \quad \text{in equilibrium} \quad (111)$$

Two cases are examined. First, both firms are assumed to be price takers in the permit market. Second, one of the two firms is assumed to have price setting power in the permit market.

1. Perfectly competitive market for permits

In the case of price taking behaviour in the permit market, grandfathering does not change the solution derived in Chapter II. Firm i derives the optimal values of its choice variables, q_i and α_i , from the following profit maximization problem:

$$\max_{\alpha_i, q_i} \Pi_i = (a - bq_i - \delta q_j)q_i - cq_i - d_i \alpha_i q_i - e(\alpha_i q_i)^2 - P^e NE_i^d$$

In the case that the permits are auctioned each firm has a demand for permits. When the permits are grandfathered, one firm is a net supplier and the other a net demander of permits. Thus, the specification of each firm's profit function appears to be different than that described in Chapter II. Notice however, that the net demand for permits is equal to each firm's total demand for permits, E_i^d , minus its permits endowment, $\bar{E}_i$. Since the permits endowment is fixed, it does not affect the firm's marginal decision when both firms are price takers.

The first order conditions of the above profit maximization problem are:

$$\frac{\partial \Pi_i}{\partial q_i} = 0 \Rightarrow q_i = \frac{a - c - d_i \alpha_i - P^e(\rho - \alpha_i)}{2(b + e\alpha_i^2)} - \frac{\delta}{2(b + e\alpha_i^2)} q_j, \quad i \neq j, \quad i = 1, 2 \quad (112)$$

$$\frac{\partial \Pi_i}{\partial \alpha_i} = 0 \Rightarrow P^* = d_i + 2e\alpha_i q_i, \quad i = 1, 2 \quad (11?)$$

The above first order conditions are identical with equations (15) and (16) which are derived under the assumption that the regulatory authority auctions the permits. Since both firms are price takers in the permit market and the endowment of each firm is fixed, the optimal choices of the firm are the same as when permits are auctioned.

The equilibrium level of the permit price under grandfathering, P^* , is equal to the permit price under auctioning, P^e . Furthermore, the equilibrium permit price under grandfathering is independent of the initial distribution of permits. Excluding corner solutions such as the case of exit from the industry, as long as both the buyer and the seller of permits do not have any power in the permit market, the equilibrium permit price will be given by equation (20). This continues to hold in the extreme case that all permits are grandfathered to one of the firms. Under perfect competition in the permit market, grandfathering simply decreases the regulator's permit revenue and increases the profits of the two firms according to the initial permit distribution.

2. Power in the market for permits

Price setting power in the permit market is modelled in the same way as in the previous two Chapters. One of the two firms is assumed to be able to influence the permit price through its permits purchases or sales. In the case of duopoly the assignment of the power in the permit market is arbitrary. In order to facilitate comparison with the case analyzed in Chapter II, it is assumed that only one of the two firms can influence the permit price while the other acts as a permit price taker.

Each firm is allocated permits in proportion to its pre-regulation level of emissions, equation (110). When the net supplier (buyer) of permits, the low (high) abatement cost firm, has the power in the permit market, it is expected, to act as a monopolist (monopsonist). Since the permit price choice of either the monopsonist or the monopolist takes product market effects into account, however, their behaviour is

the same. As in Chapter II, it is assumed that the firm with the lower abatement cost (the net supplier under competition) has the power in the permit market.

For reasons given in Chapter II, the case of price setting power in the permits market is modeled as a two stage game. In the first stage, the price setter chooses its profit maximizing permit price. In the second stage, the two firms make their profit maximizing output and abatement per unit of output decisions taking the permit price determined in the first stage as given.

The second stage problem is solved first. In the second stage both firms are price takers in the permit market. For reasons given in the case of perfect competition in the permit market, the solution of each firm's profit maximization problem in the second stage is the same as when the permits are auctioned. Notice that the price setter's constraint (permit market clearing) in the case of grandfathering which is that the sum of both firms net demand for permits should be zero, could also be written as the price setter's constraint that permit demand should equal permit supply in the case of auctioning.⁴⁴ Therefore, each firm's level of output and abatement will be functions of the permit price as described by equations (30), (31), (27) and (16), where the price of permits is now P^m .

Substituting the values of the choice variables into the permit market clearing condition, yields the relationship between the Lagrange multiplier and the permit price given by equation (33), where the Lagrange multiplier is now denoted by λ^m .

In the first stage the price setter chooses the profit maximizing permit price taking into account the price taker's output reaction to its choice of permit price:

$$\max_{P^m} \Pi_1 = (a - bq_1 - \delta q_2)q_1 - cq_1 - d_1\alpha_1q_1 - e\alpha_1^2q_1^2 - P^m NE_1^d$$

Using the first order conditions of the permit price setter's profit maximization

⁴⁴Using equation (111), the permit market clearing condition under grandfathering is written as follows:

$$\sum_{i=1}^2 NE_i^d = 0 \Rightarrow \sum_{i=1}^2 E_i^d - \sum_{i=1}^2 \bar{E}_i = 0 \Rightarrow \sum_{i=1}^2 E_i^d = \bar{E}, \quad i = 1, 2$$

which is the permit market clearing condition under auctioning.

problem in the second stage, equations (26) and (27), the first order condition of the above profit maximization problem takes the following form:

$$\frac{\partial \Pi_1}{\partial P^m} = 0 \Rightarrow -\delta \frac{\partial q_2}{\partial P^m} q_1 - NE_i^d + \lambda^m \rho \frac{\partial q_1}{\partial P^m} - \lambda^m \frac{\partial A_1}{\partial P^m} = 0 \quad (114)$$

Equation (114) is similar to equation (36). The first term indicates the raising rival's cost effect on the permit price setter's profits and is the same in the cases of auctioning and grandfathering. The second term indicates the increase in the permit price setter's cost of permits due to an increase in permit price and is different between the case of auctioning and grandfathering. Under auctioning, this term is equal to the permit price setter's demand for permits, while under grandfathering it is equal to the permit price setter's demand for permits net of its permit endowment. The last two terms differ between auctioning and grandfathering in that the Lagrange multiplier is different between the two cases, $\lambda^u \neq \lambda^m$.

Making the appropriate substitutions into equation (114), yields the following relationship between the Lagrange multiplier and the permit price:

$$\lambda^m = \frac{\Phi \Psi [4e\rho(b-\delta)\hat{q}_1 + \Phi d_1 - 2e\Phi \bar{E}_1] - \Phi [\Phi \Psi + 4(b-\delta)e\rho^2] P^m}{2\Phi^2 \Psi + [2\Phi \Psi + 8b(b-\delta)]e\rho^2} \quad (115)$$

Equations (33) and (115) are solved for the equilibrium values of the Lagrange multiplier and the permit price. The latter is:

$$P^m = \frac{Y [2e\rho(\hat{q}_1 + \hat{q}_2) + (d_1 + d_2) - 2e\bar{E}] - \Phi (\Psi + 2e\rho^2) [4e\rho(b-\delta)\hat{q}_1 + \Phi d_1 - 2e\Phi \bar{E}_1]}{(\Psi + 2e\rho^2) [3\Phi^2 + 4(3b-2\delta)e\rho^2]} \quad (116)$$

From equations (116) and (20), the difference between the price setter's choice of permit price and the competitive permit price is derived:

$$P^m - P^e = \frac{\Phi[\Phi\Psi + 4(b-\delta)e\rho^2] \left[2e\rho \sum_{i=1}^2 \hat{q}_i + \sum_{i=1}^2 d_i - 2e\bar{E} \right]}{2(\Psi + 2e\rho^2)[3\Phi^2 + 4(3b-2\delta)e\rho^2]} - \frac{\Phi[4e\rho(b-\delta)\hat{q}_1 + d_1 - 2e\bar{E}_1]}{3\Phi^2 + 4(3b-2\delta)e\rho^2} \quad (117)$$

The difference between the price setter's choice of permit price under grandfathering, equation (116), and under auctioning, equation (37), is:

$$P^m - P^a = \frac{2e\Phi^2\bar{E}_1}{3\Phi^2 + 4(3b-2\delta)e\rho^2} \geq 0, \text{ for } \bar{E}_1 \geq 0 \quad (118)$$

A firm with power in the permit market chooses a higher permit price when permits are initially grandfathered than when permits are auctioned as long as it has a positive endowment of permits. The permit price difference is an increasing function of the price setter's initial endowment of permits and independent of whether the permit price setter is the low or high abatement cost firm.

In order to intuitively explain why the permit price setter chooses a higher permit price under grandfathering than under auctioning, the case of perfect and zero substitutability are examined separately.

Under perfect substitutability, $\delta = b$, the value of the permit price difference between competition and price setting in the case of grandfathering is derived using equation (117):

$$P^m - P^e = \frac{b(P^e - d_1)}{3b + 4e\rho^2} + \frac{2be\bar{E}_1}{3b + 4e\rho^2} = \frac{2eb(A_1^e + \bar{E}_1)}{3b + 4e\rho^2} \quad (119)$$

Under grandfathering, the permit price difference between price setting and competitive behaviour in the permit market, equation (119), is greater than the permit price difference under auctioning, equation (39). The difference between the two expressions is proportional to the price setter's endowment of permits. Therefore, in the case of perfect substitutability: $P^m > P^a > P^e = P^c$.

The most interesting implication of the above result is that under grandfathering, a firm with the power in the permit market chooses a permit price,

P^m , higher than the one that it would have chosen under auctioning, P^a , regardless of whether it is a net supplier or buyer of permits under perfect competition.

This behaviour can easily be explained in the case that the firm with power in the permit market is the low abatement cost firm (net seller under competition). It might be argued that a net seller chooses a high permit price in order to increase its permit revenue, i.e. act as a pure monopolist in the permit market. A firm that is a net seller of permits when it is a permit price taker does not remain a seller however, when it is a price setter in the permit market. Under perfect substitutability, the price setter's net demand for permits is⁴⁵:

$$NE_1^d = \frac{6bep(b + 2ep^2)\hat{q}_1 + (3b^2 + 4e^2p^4 + 6bep^2)(2e\bar{E}_2 - d_2) - b(3b + 4ep^2)(2e\bar{E}_1 - d_1)}{2e(3b + 2ep^2)(3b + 4ep^2)} \quad (120)$$

The above expression is positive as long as the price taker in the permit market has a significant initial endowment of permits. Therefore both the low and the high abatement cost firm are net permit buyers when they have the power to set the permit price. Neither acts so as to minimize permit costs. Instead, each uses its power in the permit market in order to increase its share of the product market.

In order to accomplish this, the low abatement cost firm offers a high permit price in order to induce its rival to sell permits. In doing so the permit price setter increases its permit costs but at the same time it forces its rival to engage in more abatement which raises its rival's marginal cost. Similarly, if the high abatement cost firm is the permit price setter, it demands a greater amount of permits than it would demand under competition.

⁴⁵Substituting the value of permit price, P^m , into equation (115) the Lagrange multiplier is derived. Substituting the permit price and the Lagrange multiplier into the expressions for output and abatement from the second stage, the optimal levels of output and abatement for both firms are derived. The net permit demand is then derived substituting these values for output and abatement into: $NE_i^d = \rho q_i - A_i - \bar{E}_i$.

In both the above cases the product market share of the price setter increases relative to the case of the competitive permit market as well as to the case of price setting under auctioning of permits, $q_i^m/Q > q_i^c/Q > q_i^a/Q$.⁴⁶

In the case of zero substitutability, $\delta = 0$, the difference between the permit price chosen by the price setter and the permit price prevailing under competition in the permit market is derived using equations (117):

$$P^m - P^c = \frac{b(d_2 - d_1)}{6(b + e\rho^2)} > 0, \text{ for } d_2 > d_1 \quad (121)$$

Recall that under the assumptions of permit auctioning and zero substitutability in the product market, the price setter acts as a pure monopsonist choosing a permit price below the competitive level, equation (40). However, in the case of grandfathering the sign of the permit price difference depends on the price setter's abatement technology relative to the abatement technology of the permit price taker.

If the price setter has the better abatement technology, it chooses a permit price above the competitive level: $P^m > P^c = P^e > P^a$. In this case the price setter is a net seller of permits and acts as a pure monopolist in the permit market. The value of the permit price depends on the relative markup that it can charge in the two markets (i.e. the relative demand elasticities).

If the permit price setter is the high abatement cost firm it chooses a permit price below the competitive level but still above the level that it would choose under auctioning: $P^e > P^m > P^a$. The price setter is a net demander of permits and acts as a pure monopsonist of permits choosing a permit price below the competitive level. Note that even in this case $P^m > P^a$ reflecting the fact that the supply of permits that the price setter is facing under grandfathering, $\bar{E}_2$, is smaller than the supply of permits under auctioning, $\bar{E}$, by the amount of its own endowment of permits, $\bar{E}_1$.

⁴⁶Under the assumption of equal slopes of the marginal abatement cost between firms, industry's output is independent of whether the permits are auctioned or grandfathered, $Q^m = Q^a$ and $Q^e = Q^c$. Then from equation (34) it can be concluded that: $Q^m = Q^a = Q^e = Q^c = Q^s = Q$.

3. Welfare analysis

If the permit market is competitive, welfare under a tradeable permit system is the same regardless of whether permits are initially auctioned, W^e , or grandfathered, W^g , and in both cases it is higher than under command and control, $W^e = W^g \geq W^c$.

This result contrasts with Malueg's proposition that: "...social welfare may fall with the introduction of emission credits trading, even if the market for emission credits is competitive and there are no transaction or administrative costs associated with the trading program." [Malueg(1990), p. 66] Malueg gives an example of a case with two firms in which the introduction of tradeable permits results in an increase in the product market share of the less efficient firm. [Malueg(1990) Appendix B] This is incorrect. In his example the industry's output differs between command and control and tradeable permits. Malueg derives the permit price from the condition that total emissions are the same between command and control and tradeable permits, rather than from the permit market clearing condition. The price he derives does not clear the permit market. With many firms Malueg's proposition cannot be shown to be impossible but appears to be highly unlikely.

If the permit market is not competitive the conclusion reached under auctioning that welfare might be higher under a source specific system than under a non competitive market based system, is strengthened in some cases. In order to support this argument first recall that equation (61) suggests that the magnitude of the welfare difference, for a given difference between the two firms' marginal cost of abatement, depends on the absolute value of the difference between the competitive and the non-competitive permit price λ^m . Then, in the case of perfect substitutability, for example, the absolute value of the price setter's shadow price of permits is higher under grandfathering than under auctioning, $|\lambda^m| > |\lambda^g|$.⁴⁷

Turn now to a detailed examination of the welfare. Since the welfare of the economy under different systems depends on the shadow values of emission reduction

⁴⁷ Under perfect substitutability $P^m > P^g > P^c = P^e$ for either the case that the low or the high abatement cost firm is the permit price setter. Therefore, $|P^c - P^m| > |P^e - P^g|$. Recall that $\lambda^i = 2(P^e - P^i)$, $i = m, g$, which proves the above proposition.

under each system, and these depends on the degree of product differentiation, the two extreme cases of perfect and zero substitutability are examined separately.

Under perfect substitutability, $b = \delta$, welfare will be higher if permits are auctioned rather than grandfathered and in both cases welfare is lower than under command and control. As the degree of product differentiation decreases, $\delta < b$, both P^u and P^m decrease and welfare differences under both the case of auctioning and the case of grandfathering, $W^c - W^u$, and, $W^c - W^m$, also decrease, for a given difference in abatement costs.

Recall that under permit auctioning, there is a certain degree of product differentiation, δ^* , for which $P^u = P^c$ in which case $W^u > W^c$ for a range of values of δ close to δ^* . For values of δ beyond this range and towards zero, the pure monopsonistic (cost minimizing) incentive dominates the behaviour of the price setter who decreases the permit price well below the competitive level. With zero substitutability the inefficiency due to monopsony in the permit market outweighs the inefficiency of no trade inherent in any source specific system, $W^u < W^c$.

Under grandfathering when the price setter is the low abatement cost firm, its choice of permit price decreases as rivalry in the product market weakens, $\delta \rightarrow 0$, although it never drops below the competitive level. The price setter's choice of permit price reaches its minimum level under zero substitutability, $\delta = 0$. In this case using equation (11)⁴⁸ and equation (121), the following relationship is derived:

$$\left| \frac{b(d_2 - d_1)}{3(b + e\rho^2)} \right| < \left| \frac{b(d_1 - d_2)}{(b + e\rho^2)} \right| \Rightarrow |2(P^c - P^m)| < |\lambda_1^c - \lambda_2^c| \Rightarrow W^m > W^c, \text{ for } \delta = 0 \quad (122)$$

When the raising rival's cost effect is very small--for values of δ close to zero--the only distortion in the permit market is the pure monopoly effect. This effect

⁴⁸From equation (11), for $i = 1, 2$, the difference between the two firms' shadow values of emission reduction under command and control is derived under zero substitutability, $\delta = 0$:

$$\lambda_1^c - \lambda_2^c = \frac{b(d_1 - d_2)}{(b + e\rho^2)}$$

creates an inefficiency in the permit market which is smaller than the inefficiency of command and control. Thus, welfare is lower under command and control than under the tradeable permit system.

Under grandfathering, when the permit price setter is the high abatement cost firm, the permit price that it chooses decreases with the degree of product differentiation. As in the case of auctioning, there is a certain degree of product differentiation, $\delta^{**} \neq \delta^*$, for which $P^m = P^c$. For a range of values of δ close to δ^{**} , $W^m > W^c$. Moreover, in the case of grandfathering this range includes the case of zero substitutability⁴⁹.

Figure 7 illustrates the above results. Welfare is measured on the vertical

Figure 7. Grandfathering and auctioning with price setting vs command and control

axis. On the horizontal axis the degree of product differentiation is measured, with $\delta \in [0, b]$. The solid curve represents the welfare difference under grandfathering,

⁴⁹In this case $P^m - P^c < 0$, but the absolute value of this difference is again smaller than the absolute value of the difference between the firms' shadow value of emission under command and control which implies that $W^m > W^c$ when $\delta = 0$.

$W^c - W^m$, when the permit price setter is the high abatement cost firm, $d_1 > d_2$, while the dotted line shows the welfare difference when the permit price setter is the low abatement cost firm, $d_1 < d_2$. The third curve is the welfare difference under auctioning, $W^c - W^a$.

It should be noted that the shapes of all three curves are only suggestive. The foregoing analysis suggests first, that when the permit price setter is the high abatement cost firm, the welfare difference under auctioning and under grandfathering takes the same value, denoted in the Figure by point A, for the degree of product differentiation, δ^* , and, δ^{**} , respectively. The reason is that, for these degrees of product differentiation, the following holds: $P^a(\delta^*) - P^g(\delta^*) = P^m(\delta^{**}) - P^g(\delta^{**}) = 0$. Second, when the permit price setter is the low abatement cost firm, point B lies above point A because, under grandfathering, the price setter always chooses a permit price above the competitive level. In the case of grandfathering the efficiency is never attained. Third, the inefficiency of permit price setting power under perfect substitutability is greater under grandfathering than under auctioning. This implies that point D lies below points E and F in Figure 7. Fourth, the degree of product differentiation at which the permit price setter chooses the competitive price is closer to perfect substitutability under auctioning than under grandfathering. This implies that point δ^* lies closer to the b axis than point δ^{**} . The actual values of all points in Figure 7 depend on the parameters of the model.

In summary, under perfect substitutability, when one of the firms has price setting power in the permit market, pro-rata grandfathering of permits results in greater inefficiency than when permits are auctioned. Both are worse than command and control. With zero substitutability, pro-rata grandfathering of permits results in greater welfare than under auctioning and command and control.

Note with respect to the initial distribution of permits, that under perfect competition, the initial distribution of permits does not affect the equilibrium permit price. It only affects the distribution of profits and has no welfare consequences. In the case of price setting however, the initial distribution of permits affects the price setter's optimal permit price. If the price setter is grandfathered with more permits

than the price taker, its optimal permit price is higher and thus distorts the allocation of abatement effort even more. This implies a decrease in welfare relative to price taking and command and control.

SECTION II. ENTRY UNDER GRANDFATHERING

In Section I it is shown that the only difference between auctioning and grandfathering arises in the case that price setting power exists in the permit market. In this case, welfare under grandfathering may be higher or lower than welfare under auctioning depending on the degree of product differentiation. This result is due to the effect of different initial allocation of permits on the price setter's optimal price.

Another possible difference between auctioning and grandfathering is the effect of permit price setting behaviour on entry. This Section establishes that in the case that power in the permit market exists, the permit price setter's choice of permit price under grandfathering of permits may be high enough to make the entry of an additional firm unprofitable, while under auctioning of permits the same firm would enter the market since the permit price setter's choice of permit price under auctioning is lower than in the case of grandfathering.

In order to illustrate the above proposition the following situation is considered: Assume a market of a homogeneous product that is served by two firms behaving as Cournot rivals. Production in this industry results in the proportional emission of a single uniformly mixed pollutant. The government decides to reduce emissions by implementing a transferable emission permit system. According to this system, the government issues each period a number of emission permits equal to the maximum allowable level of emission which is assumed to be a fraction, $(1 - \psi)$ of aggregate pre-regulation emissions. The permits are grandfathered every period to the two firms according to their pre-regulation level of emissions. One of the firms is assumed to set the price in the permit market. Recall that under perfect substitutability, the permit price setter behaves as a permit buyer regardless of whether it is the low or the high abatement cost firm. Thus, the permit price setter announces a permit price at which it will buy the price taker's net supply of permits.

Equilibrium is reached when aggregate net demand is zero. Assuming that the policy target and the allocation process of permits remain the same every period--the same amount of permits are distributed to the two firms in the same proportion every period--the equilibrium does not change over time.

Assume that at some point, a third firm assesses the profitability of entering the market. It is assumed that its production cost structure is such that, in the absence of the permit system it would enter the market. If a permit system of the type described above is in place, the third firm has to be a permit buyer offering at least the price setter's choice of permit price, since all permits are grandfathered to the incumbent firms. Alternatively it has to comply with the requirements of the regulation by engaging in abatement and buying no permits. In order to concentrate in the difference between auctioning and grandfathering it is assumed that the potential entrant's abatement cost structure is such that if it does not buy permits it does not enter the market.

The potential for entry when the same number of permits are auctioned in the beginning of each period is also examined. It has been shown that, the only difference between the two situations is in the permit price chosen by the permit price setter. The results of these two exercises are then compared.

Closed form solutions for each firm's choice variables in these models can be derived. However, because of the size of the expression for the value of the entrant's profit, the conditions under which entry is unprofitable are difficult to derive. Thus, only closed form solutions for the firm's choice variables are derived and then the model is simulated to obtain the value of each firm's profits. By using simulations it is demonstrated that when one of the incumbent firms has price setting power in the permit market, there are cases under which grandfathering of permits results in entry deterrence, while auctioning results in accommodation of entry.

In order to discuss entry and exit from the product market it is assumed that firms have fixed costs. As it is noted above, the analysis is confined to the case of perfect substitutability since in this case the permit price setter's choice of permit price is higher than when the products are differentiated and thus the possibility that

the potential entrant decides not to enter the market is also higher. Since simulations have to be used because of the complexity of the analytical solutions, the more general assumption of increasing marginal production cost is employed.

With the addition of the increasing marginal production cost assumption, the assumptions of the present Section are the same as those of Section I of Chapter II. Thus, under auctioning, the pre-entry solution of the model when only two firms share the market is identical to that of Section I of Chapter II.⁵⁰ In the case of grandfathering the solution changes in the way described in the previous Chapter.

Consider now the case that a third firm examines the profitability of entering the market. It is assumed that firm 1 is a price setter and firm 2 is a price taker in the permit market. Firm 3 considers entering the market as a permit price taker. If it makes positive profits by being a permit buyer, it enters the market; if it makes negative profits, it does not enter.

The profit maximization problem of the potential entrant--firm 3--is the same as that of the incumbent permit price taker--firm 2--except in that firm 3 has a zero endowment of permits. However, since both firm 2 and 3 are permit price takers the value of the permit endowment does not influence the optimal choice of output and abatement. Each of the two permit price taking firms solves the following profit maximization problem:

$$\max_{q_i, \alpha_i} \Pi_i = [a - b(q_1 - q_i - q_j)]q_i - (c_i + \kappa q_i)q_i - d_i \alpha_i q_i - e \alpha_i^2 q_i^2 - P^m N E_i^d - F_i, \quad i, j = 2, 3$$

The simultaneous solution of the two first order conditions yields firm i 's output reaction function and demand for permits.

$$q_i = \frac{a - c_i - \rho P^m}{2(b + \kappa)} - \frac{b}{2(b + \kappa)}(q_1 + q_j), \quad i, j = 2, 3 \quad (123)$$

⁵⁰The addition of fixed costs influences only the value of each firm's profits and not its choice variables.

$$P^m = d_i + 2e\alpha_i q_i, \quad i = 2, 3 \quad (124)$$

The Lagrange function of the price setter's constrained profit maximization problem is:

$$\max_{q_i, \alpha_i} \mathcal{L}_1 = TR_1 - TC_1 + \lambda^m (\bar{E} - E_1^d - E_2^d - E_3^d)$$

The first order conditions with respect to the choice variables are solved for the price setter's reaction function and demand for permits.

$$q_i = \frac{a - c_i - \rho(P^m + \lambda^m)}{2(b + \kappa)} - \frac{b}{2(b + \kappa)}(q_2 + q_3) \quad (125)$$

$$P^m + \lambda^m = d_i + 2e\alpha_i q_i \quad (126)$$

Solving equations (125) and (123) for $i = 2, 3$ simultaneously, yields all three firms' output level as functions of the permit price and the Lagrange multiplier.

$$q_i = \hat{q}_i - \rho \frac{2bP^m + N\lambda^m}{2KM} \quad (127)$$

$$\text{where: } K = 2b + k$$

$$q_i = \hat{q}_i - \rho \frac{2(b + k)P^m - b\lambda^m}{2MK}, \quad i = 2, 3 \quad (128)$$

where $\hat{q}_i = [Ma - Nc_i + b(c_2 + c_3)]/2KM$, is each of the three firms' pre-regulation level of output.

The first order condition with respect to the Lagrange multiplier gives the permit market constraint. Substituting the output and abatement level of all three firms into the permit market constraint, the following relationship between the Lagrange multiplier and the permit price is derived.

$$\lambda^m = \frac{K \left[2e\rho \sum_{i=1}^3 \hat{q}_i + \sum_{i=1}^3 d_i - 2e\bar{E} \right]}{K + 2e\rho^2} - 3P^m \quad (129)$$

Equation (129) is a combination of the results derived in Sections I and II of Chapter II. Although not derived here, the results of Chapter II suggest that the first term on the right hand side of equation (129) is three times the competitive permit price. Under the assumption of equal slopes of the marginal abatement cost among firms, the Lagrange multiplier is proportional to the permit price difference and thus industry's output is independent of the permit market structure.

The first stage profit maximization problem of the permit price setter is:

$$\max_{P^m} \Pi_1 = \Pi_1(q_1(P^m), q_2(P^m), q_3(P^m), A_1(P^m), P^m)$$

Using the first order conditions of the permit price setter's profit maximization problem in the second stage, the first order condition of the above profit maximization problem takes the following form:

$$\frac{\partial \Pi_1}{\partial P^m} = 0 \Rightarrow -b \left[\frac{\partial q_2}{\partial P^m} + \frac{\partial q_3}{\partial P^m} \right] q_1 - NE_i^d + \lambda^m \rho \frac{\partial q_1}{\partial P^m} - \lambda^m \frac{\partial A_1}{\partial P^m} = 0 \quad (130)$$

Equation (130) is similar to equation (102) and its interpretation is also the same. The value of each term though, is different.

Making the appropriate substitutions into equation (130), yields the following relationship between the Lagrange multiplier and the permit price:

$$\lambda^m = \frac{MK \left[2e\rho(2k-b)\hat{q}_1 + Md_1 - 2eM\bar{E}_1 \right] - M \left[MK + 2(2k-b)2e\rho^2 \right] P^m}{3M^2K + [2MK + 2N(2k-b)]2e\rho^2} \quad (131)$$

Equations (129) and (131) are solved for the equilibrium values of the Lagrange multiplier and the permit price. The latter is:

$$P^m = K \frac{D \left[2e\rho \sum_{i=1}^3 \hat{q}_i + \sum_{i=1}^3 d_i - 2e\bar{E} \right] - M(K + 2e\rho^2) [2e\rho(2b - k)\hat{q}_1 + Md_1 - 2eM\bar{E}_1]}{(K + 2e\rho^2) [8M^2K + [6MK + 2(2b - k)(8b + 4k)]2e\rho^2]} \quad (132)$$

$$\text{where: } D = 3M^2K + [2MK + 2(2b - k)(3b + 2k)]2e\rho^2$$

Using the solution for the permit price prevailing under price setting behaviour in the permit market, equation (132), the choice variables and thus the profits of all three firms are derived. As stated above, analytical solutions for each firm's profits are difficult to obtain. Instead, the model is simulated and it is shown that, for the set of values of the parameters used in the simulation, the entrant decides not to enter the market at the permit price chosen by the permit price setter.

For the simulation purposes the following set of values for the parameters of the model is employed.

$$a = 1500, b = 0.20, c_1 = 10, c_2 = 350, c_3 = 450, \kappa = 0.07$$

$$d_1 = 100, d_2 = 250, d_3 = 300, e = 0.28, \rho = 0.60, \psi = 0.60$$

$$F_1 = 8,000, F_2 = 10,000, F_3 = 12,000$$

Some important characteristics of the above set of values are, first, both the abatement and the production technology of the permit price taker incumbent firm and the potential entrant are similar. Actually, for the entry to be unprofitable under grandfathering, the technological difference is not necessary.

Second, the cost parameters and the rate of emissions per unit of output are chosen such that, in this industry, the cost of environmental regulation is a significant part of total cost. This assumption ensures that the potential entrant cannot profitably rely totally on abatement in order to comply with the regulation.

Third, the price setter is assumed to have the better production technology. This implies that the price setter has the larger pre-regulation product market share. This assumption is made in order to demonstrate the result concerning the permit

price chosen by the permit price setter when production cost is assumed quadratic, equation (83) in Section I of Chapter II. Recall that under the assumptions of increasing marginal cost of production, homogeneous product and auctioning of permits, the permit price setter chooses a permit price below the competitive level under certain conditions. The most important condition is that the permit price taker's pre-regulation product market share is smaller than the allowable rate of emission. This condition is satisfied by the values chosen for the simulation, while the condition concerning the slope of the demand and the production cost function, $b < 2\kappa$, is not satisfied.

The competitive permit price (not shown in Table 1 and 2) when only two firms share the product market is $P^c = 326.2$. It is the same for both the case of auctioning and grandfathering of emission permits. Table 1 shows the permit price chosen by the permit price setter under auctioning, $P^a = 313.1$, which is indeed below the competitive level. Table 2 shows the permit price chosen by the permit price setter under grandfathering, $P^m = 417.8$, which is above the competitive level. This outcome verifies the result in the preceding Section, according to which the permit price setter chooses a higher permit price under grandfathering than under auctioning.

Table 2 and Table 3 present the values of the firms' choice variables and profits when permits are grandfathered and when permits are auctioned respectively.

It should be noted that the results concerning the case of three firms are not in accordance to the theoretical results derived earlier. For example, both under auctioning and under grandfathering, the permit price when there are three firms is higher than when there are only two firms, in contrast to the result of Section II of Chapter II. This anomaly is due to the fact that the number of permits available in the market does not increase even if firm 3 enters the market. Thus, permit supply stays constant while the demand increases resulting in an increase in the permit price.

Table 2.

Auctioning of emission permits

	2 firms no regulation	2 firms power	3 firms no regulation	3 firms power
output	2,283.8	1,998.2	2,073.2	2,033.9
F1 abatement	0	425.1	0	252.13
profit	1,408,230	1,139,325	1,160,521	1,302,257
output	1,283.8	1,040.8	1,073.2	764.4
F2 abatement	0	114.1	0	257.02
profit	444,987.2	286,125.5	310,984.3	166,268.9
output	0	0	779.1	470.3
F3 abatement	0	0	0	167.7
profit	0	0	163,888.6	55,598.2
P*	0	313.1	0	393.93
Q	3,567.6	3,039.1	3,925.5	3,268.7
$\Sigma \Pi_i$	1,853,217	1,425,450	1,635,394	1,218,767.4
C.Surplus	1,272,753	923,558.9	1,540,980	1,068,431.3

Table 3.

Grandfathering of emission permits

	2 firms no regulation	2 firms power	3 firms no regulation	3 firms power
output	2,283.8	2,181.6	2,073.2	2,184.7
F1 abatement	0	239.4	0	99.5
profit	1,408,230	1,440,105	1,160,521	1,302,257
output	1,283.8	857.4	1,073.2	689.1
F2 abatement	0	299.7	0	333.3
profit	444,987.2	406,719.9	310,984.3	351,097
output	0	0	779.1	394.9
F3 abatement	0	0	0	244.1
profit	0	0	163,888.6	0
P ^m	0	417.8	0	436.65
Q	3,567.6	3,039.1	3,925.5	3,268.7
$\Sigma \Pi_i$	1,853,217	1,846,825	1,635,394	1,729,136.8
C.Surplus	1,272,753	923,558.9	1,540,980	1,068,431.3

Table 2 and 3 show that under grandfathering, the entrant makes zero profits and exits the market while under auctioning entry is possible. Thus, it is demonstrated that entry that would be accommodated under auctioning of permits is deterred when permits are grandfathered.

An alternative system of distributing permits that would not result in entry deterrence can be designed. Under this system the government grandfathers only a portion of the total amount of permits each period and auctions the rest of the permits. By doing so the government moderates the strategic behaviour of the price setter and allows for entry. The necessary amount of permits holdback that would secure accommodation of entry can be calculated in each case.

Another important issue is the effect of entry on welfare. Table 1 and 2 indicate that total welfare --the sum of aggregate profits and consumer surplus, and of permit revenue in the case of auctioning-- increases slightly when entry occurs, both with and without regulation. However, this is not always the case. Therefore, the government's decision of whether to withhold permits in order to make entry possible might also take into account that there can be situations in which there is too much entry and facilitating more does not increase welfare.⁵¹

⁵¹See Dixit and Stiglitz(1977) and Spence(1976).

CHAPTER V

EMISSION PERMITS TRADING

UNDER LEADERSHIP IN THE OUTPUT MARKET

INTRODUCTION

The analysis in all previous Chapters assumed Cournot behaviour in the product market. In this Chapter the product market is assumed to be characterized by quantity and price leadership respectively. The permit market is characterized by price taking and price setting behaviour respectively. This yields four cases in all. These four cases are then compared with the Cournot results obtained in Chapter II and, indirectly, with command and control.

SECTION I. STACKELBERG LEADERSHIP IN QUANTITIES

The assumptions made in Chapter II regarding the economy, the demand structure and the production and abatement technologies are employed throughout this Chapter. One of the two firms in the differentiated duopoly sector of the economy, is assumed to behave as a Stackelberg leader in quantities. Assuming that both firms have the same, constant marginal cost of production, each firm's output level before regulation is:

$$\hat{q}_L = \frac{\Phi(a-c)}{2X}, \quad \hat{q}_F = \frac{(2X - \delta\Phi)(a-c)}{4bX}$$

$$\text{where: } X = 2b^2 - \delta^2$$

where $\hat{q}_L$ and $\hat{q}_F$ are the leader's and the follower's output respectively.

Assuming that each firm emits ρ units of pollution per unit of output, aggregate emissions are:

$$E = \rho(\hat{q}_L + \hat{q}_F) = \rho \frac{(2X + \Phi^2)(a-c)}{4bX} \quad (133)$$

Assume that the government decides to reduce emission by a fraction $(1 - \psi)$ by implementing a system of tradeable emission permits. $\bar{E} = \psi E$ emission permits

are issued and auctioned off. Each permit specifies one unit of allowable emissions. All sources are required to own permits in order to emit.

In what follows, the case of price setting power in the permit market is examined and compared to the benchmark case of perfect competition in the permit market. The latter is developed first.

1. Perfectly competitive market for permits

Under the assumption of price taking behaviour, the permit price, P^e , is treated by firms as parametric. Each firm's demand for permits is given by equation (14). The equilibrium permit price is determined by setting demand equal to supply. In order to determine the total demand for permits, the two firms' choice variables are calculated by solving their respective profit maximization problems.

The follower in the product market takes both the output of the leader and the permit price as given. Its behaviour is exactly the same as that of a Cournot rival described in Chapter I. Therefore, its reaction function and its level of abatement per unit of output as functions of the permit price are given by equations (17) and (16).

The leader chooses its profit maximizing level of output and abatement per unit of output, taking into account the follower's reaction to its choice of output. Its profit maximization problem is:

$$\max_{q_L, \alpha_L} \Pi_L = (a - bq_L - \delta q_F)q_L - cq_L - d_L \alpha_L q_L - e \alpha_L^2 q_L^2 - P^e(\rho - \alpha_L)q_L$$

The first order conditions are solved for the leader's output as function of the permit price and its decision rule in the permit market.

$$q_L = \hat{q}_L - \frac{\Phi \rho}{2X} P^e \quad (134)$$

$$P^e = d_L + 2e\alpha_L q_L \quad (135)$$

Substituting the leader's output from equation (134) into the follower's reaction function, equation (17), the follower's output as a function of the permit price is derived.

$$q_F = \hat{q}_F - \frac{(2X - \delta\Phi)\rho}{4bX} P^e \quad (136)$$

The equilibrium value of the permit price is derived by setting the total demand for permits equal to the supply.

$$P^e = \frac{2bX[2e\rho(\hat{q}_L + \hat{q}_F) + (d_L + d_F) - 2e\bar{E}]}{4bX + \Xi e\rho^2} \quad (137)$$

$$\text{where: } \Xi = 2X + \Phi^2$$

The competitive permit price is equal to each firm's marginal cost of abatement in equilibrium, as equations (16) and (135) indicate.

2. Power in the market for permits

In order to understand the way that a firm exercises its power in the permit market changes depending on its position in the product market, both the case that the leader and the case that the follower has price setting power in the permit market are considered.

i. The leader is the permit price setter

Since the Stackelberg leader-permit price setter can credibly commit in both the quantity that it will produce and the amount of permits that it will buy, the situation is modeled as a one stage game.

The follower acts as a quantity taker in the output market and a price taker in the permit market. Therefore, its profit maximization problem is the same as that of

the Cournot rivals defined in Chapter I. Its reaction function and its level of abatement are given by equations (17) and (16).

The optimal values of the leader's choice variables are derived from the solution of its profit maximization problem. In making its optimal choices the leader is subjected to the permit market constraint. Effectively, the leader/permit price setter maximizes its profits subject to the follower/permit price taker's output reaction function and demand for permits, since the supply of permits is fixed. That is, the price setter's maximization problem is:

$$\max_{q_L, \alpha_L, P^\mu} \mathcal{L}_L = TR_L - TC_L + \lambda_L^\mu (\bar{E} - E_L^d - E_F^d), \text{ where } TC_L = cq_L + CA_L + P^\mu E_L^d$$

The first order conditions with respect to output and abatement per unit of output are solved for the leader's output as function of the permit price and the Lagrange multiplier and its decision rule in the permit market:

$$q_L = \hat{q}_L - \frac{\Phi \rho}{2X} (P^\mu + \lambda_L^\mu) \quad (138)$$

$$P^\mu + \lambda_L^\mu = d_L + 2e\alpha_L q_L \quad (139)$$

Substituting the leader's level of output from equation (138) into the follower's reaction function, the follower's level of output as a function of the permit price level and the Lagrange multiplier is derived.

$$q_F = \hat{q}_F - \frac{(2X - \delta\Phi)\rho P^\mu - \delta\Phi\rho\lambda_L^\mu}{4bX} \quad (140)$$

The first order condition of the leader's profit maximization problem with respect to the Lagrange multiplier states that the permit market constraint holds as an equality. The first order condition with respect to the permit price is:

$$\frac{\partial \mathcal{L}}{\partial P^\mu} = 0 \Rightarrow -\delta \frac{\partial q_F}{\partial P^\mu} q_L - E_L^d - \lambda_L^\mu \frac{\partial q_F}{\partial P^\mu} + \lambda_L^\mu \frac{\partial A_F}{\partial P^\mu} = 0 \quad (141)$$

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The above expression is similar to equation (36). The economic meaning of the first two terms in equation (141) is the same as that described for the first two terms in equation (36). Note, however, that the last two terms are different. When the permit price setter is also a leader in the product market, it determines all its choice variables simultaneously (one stage game). In this case the change in the leader's output and abatement resulting from a permit price change is not captured directly. The change in the leader's profit due to these changes is given in equation (141) as a function of the changes in the follower's choice of output and abatement. The permit market price setting decision mechanism is similar regardless of whether the permit price setter is a quantity leader or a quantity follower in the product market. However, the value of each term differs between the two cases. This implies that the permit price chosen by a quantity follower is different than the one chosen by a quantity leader.

Substituting the leader's and follower's level of output, equations (138) and (140), and level of abatement, equations (139) and (16), into both the permit market clearing condition and equation (141), yields two equations in two unknowns; the Lagrange multiplier and the permit price.

$$\lambda_L^\mu = \frac{2bX[2e\rho(\hat{q}_L + \hat{q}_F) + (d_L + d_F) - 2e\bar{E}] - TP^\mu}{\Lambda} = \frac{T}{\Lambda}(P^e - P^\mu) \quad (142)$$

$$\text{where: } T = 4bX + 2e\rho^2, \quad \Lambda = 2bX + \Phi^2 e\rho^2$$

$$\lambda_{L'}^\mu = \frac{2X(\Phi e\rho\hat{q}_L + bd_{L'}) - \Lambda P^\mu}{T} \quad (143)$$

Note that equation (142) relates the two firms' marginal costs of abatement in the case of the competitive permit market-- P^e for both firms--and in the case that the leader sets the permit price-- P^μ for the price taker and $P^\mu + \lambda_L^\mu$ for the price setter. Equation (142) is similar to equation (33). In the Cournot case the Lagrange multiplier is double the difference between the price taking and the price setting permit price. This is because under Stackelberg leadership, the effect of price setting

on the leader's and follower's output is different than in Cournot. Aggregate output under Cournot behaviour is the same under price taking and price setting behaviour in the permit market. The same is not true in the case that the product market is characterized by Stackelberg leadership.

The system of equations (142) and (143) is then solved for the leader's choice of permit price and the Lagrange multiplier. The permit price is:

$$P^\mu = \frac{bT[2e\rho(\hat{q}_L + \hat{q}_F) + (d_L + d_F) - 2e\bar{E}] - \Lambda(\Phi e\rho\hat{q}_L + bd_L)}{(b + e\rho^2)[3bX + (X + \Phi^2)e\rho^2]} \quad (144)$$

Comparing equation (144) to equation (37) reveals the similarities between the leader's and the follower's permit price setting decision mechanism noted above. In both cases the permit price setter sets a higher price the lower its pre-regulation product market share and the better its abatement technology.

The difference between the leader's choice of permit price and the competitive permit price is derived using equations (142) and (137).

$$P^\mu - P^\varepsilon = \frac{2X\Lambda[b\Lambda[2e\rho(\hat{q}_L + \hat{q}_F) - 2e\bar{E}] - T(\Phi e\rho\hat{q}_L + bd_L)]}{T(T^2 - \Lambda^2)} \quad (145)$$

The sign of the above expression can be either positive or negative depending on the values of the parameters. The sign of the permit price difference is considered in the cases of perfect and zero substitutability.

In the case of perfect substitutability equation (145) becomes:

$$P^\mu - P^\varepsilon = \frac{b(2b + e\rho^2)^2[2e\rho(\hat{q}_L + \hat{q}_F) + (d_L + d_F) - 2e\bar{E}]}{2(b + e\rho^2)(3b + 2e\rho^2)(4b + 3e\rho^2)} - \frac{b(2b + e\rho^2)(e\rho\hat{q}_L + d_L)}{2(b + e\rho^2)(3b + 2e\rho^2)} \quad (146)$$

The sign of the above expression depends both on relative abatement costs and pre-regulation product market shares. After rearranging terms and substituting the value of $\bar{E} = \psi\rho(\hat{q}_L + \hat{q}_F)$ in equation (146), the numerator of this equation takes the following form:

$$e\rho[2(2b + e\rho^2)(1 - \psi) - (4b + 3e\rho^2)\hat{\zeta}_L](\hat{q}_L + \hat{q}_F) + (2b + e\rho^2)d_F - 2(b + e\rho^2)d_L \quad (147)$$

where: $\hat{\zeta}_L = \frac{\hat{q}_L}{(\hat{q}_L + \hat{q}_F)}$ *is the leader's pre-regulation share in the product market*

The magnitude of the first term in expression (147) is larger than the last two terms. Therefore, the sign of the first term is the sign of expression (147) as a whole. Thus, the sign of expression (147) depends on the relative magnitude of the fraction by which the government wishes to reduce emissions and the price setter's pre-regulation product market share. If the following inequality holds,

$$(1 - \psi) < \frac{4b + 3e\rho^2}{4b + 2e\rho^2} \hat{\zeta}_L \quad (148)$$

then, the price setter chooses a permit price lower than the competitive permit price.

Note that, under perfect substitutability and constant and equal marginal cost of production, the pre-regulation product market share of the leader is $\hat{\zeta}_L = 2/3$. Therefore, only in the case of environmental regulations requiring more than a 2/3 reduction in emissions does the leader/permit price setter raises the permit price above the competitive level. This occurs because the number of permits available is very small and firms are engaging in high levels of abatement. Then, according to equation (141): 1) the cost to the leader/price setter from raising the permit price is smaller since it holds a smaller number of permits, 2) the benefit is larger because it increases the follower/permit price taker's cost much more because both are operating further along their marginal abatement cost functions. In the case of zero substitutability, the permit price setter does not exercise product market leadership and acts as a monopsonist in the permit market setting a permit price below the competitive. The expression for the permit price difference is the same as in the case of the Cournot model, equation (40).

In summary, the behaviour of a quantity leader/permit price setter is different from that of a Cournot duopolist/permit price setter, except in the case of zero

substitutability. While a Cournot duopolist that has the power to set the permit price raises the permit price above the competitive level, a Stackelberg leader in output decreases the permit price below the competitive level except some extreme cases.

This difference in behaviour can be explained by noticing the following two points. First, the Stackelberg leader has a larger share of a larger market than the Cournot duopolist. With a competitive permit market, the Stackelberg leader buys more permits than a Cournot duopolist. Thus, the inframarginal cost of an increase in the permit price is higher for a Stackelberg leader than for a Cournot duopolist. In terms of the equations (141) and (35) this means that $E_L^d > E_I^d$.

Second, the raising rival's cost effect is different under Stackelberg leadership than under Cournot duopoly. Consider the case of perfect substitutability as an example. Because of the assumed production cost symmetry, with Cournot behaviour in the product market, the permit price setter's output increases by the same amount as its rival's output decreases leaving the industry's output and price unchanged. Therefore, with Cournot behaviour, the price setter's marginal revenue doesn't change when it sets a higher than the competitive permit price. In the Stackelberg game, however, the follower's output decreases by a smaller amount than the increase in the leader's output when the leader sets a higher than the competitive permit price. This implies that total output increases and price of the product falls as a result of a permit price increase. Therefore, the price setter's marginal revenue decreases.

In conclusion, the Stackelberg leader that is also a permit price setter finds that if it sets a permit price above the competitive level, the increase in its costs outweighs its gains from raising rival's costs except in some extreme cases. Thus, although it realizes the effect that the permit price has in the output market, the leader/permit price setter, sets a permit price lower than the competitive price. This decreases the follower's compliance costs and improves its product market share. It should be emphasized, that the leader does not act myopically. The permit price that it sets, although lower than the competitive price, is higher than the one that the leader/permit price setter would choose if it were to ignore the linkage between the permit and the product market outcomes.

Part ii. The follower is the permit price setter

The case in which the follower can set the permit price is modelled as a two stage game since the follower is a quantity taker in the product market. In the first stage the price setter chooses a profit maximizing permit price. In the second stage the two firms make their profit maximizing output and abatement per unit of output decisions given the permit price determined in the first stage.

The second stage problem is solved first. Each firm decides its optimal level of output and abatement per unit of output. In making its optimal choice of output and abatement per unit of output, the follower/permit price setter is constrained by the fact that it has to absorb the residual supply of permits. The follower/permit price setter's constrained profit maximization problem is:

$$\max_{q_F, \alpha_F} \mathcal{L} = TR_F - TC_F + \lambda_F^{\mu} (\bar{E} - E_L^d - E_F^d), \quad \text{where: } TC_F = cq_F + CA_F + P^{\mu} E_F^d$$

The follower/permit price setter's constrained profit maximization problem in the second stage is the same as the Cournot duopolist/permit price setter. Therefore, the first order conditions of the above constrained profit maximization problem are given by equations (26), (27) and (28).

The leader/permit price taker maximizes its profits subject to the follower's output reaction function, equation (29).

$$\max_{q_L, \alpha_L} \Pi_L = (a - bq_L - \delta q_F)q_L - cq_L - d_L \alpha_L q_L - e \alpha_L^2 q_L^2 - P^{\mu} (\rho - \alpha_L) q_L$$

The first order conditions are solved for the leader/permit price taker's output as a function of the permit price, P^{μ} , and the Lagrange multiplier, λ_F^{μ} , and the leader/permit price taker's optimization condition in the permit market:

$$q_L = \hat{q}_L - \frac{\Phi \rho P^{\mu} - \delta \rho \lambda_F^{\mu}}{2X} \quad (149)$$

Substituting equation (149) into (29) yields the follower/permit price setter's output as a function of the permit price and the Lagrange multiplier:

$$P^\mu = d_L + 2e\alpha_L q_L \quad (150)$$

$$q_F = \hat{q}_F - \frac{(2X - \delta\Phi)\rho P^\mu + \Phi\Psi\rho\lambda_F^\mu}{4bX} \quad (151)$$

Substituting the leader's and the follower's output and abatement levels given by equations (149), (150), (151) and (27), into the permit market equilibrium condition, equation (28), yields:

$$\lambda_F^\mu = \frac{2bX[2e\rho(\hat{q}_L + \hat{q}_F) + (d_L + d_F) - 2e\bar{E}] - TP^\mu}{\Gamma} = \frac{T}{\Gamma}(P^\varepsilon - P^\mu) \quad (152)$$

$$\text{where: } \Gamma = 2bX + (\Phi\Psi - 2b\delta)e\rho^2$$

Equation (152) is similar to equations (143) and (33). It gives the relationship between marginal abatement costs of the two firms under different permit market structures.

In the first stage the follower/permit price setter chooses the profit maximizing permit price taking into account the price taker's output reaction to the permit price chosen.

$$\max_{P^\mu} \Pi_F = \Pi_F(q_F(P^\mu), q_L(P^\mu), A_F(P^\mu), P^\mu)$$

Using the first order conditions of the follower/permit price setter's profit maximization problem in the second stage, the first order condition of the above profit maximization problem yields:

$$\frac{\partial \Pi_F}{\partial P^\mu} = 0 \Rightarrow -\delta \frac{\partial q_L}{\partial P^\mu} q_F - E_F^d + \lambda_F^\mu \rho \frac{\partial q_F}{\partial P^\mu} - \lambda_F^\mu \frac{\partial A_F}{\partial P^\mu} = 0 \quad (153)$$

Equation (153) is similar to equations (35) and (141). Note that because the permit price setter is a quantity taker, equation (153) is more closely associated to equation (35) than to equation (141). However, the value of each term in equation (153) is different from both the other cases.

Making the appropriate substitutions, equation (153) yields the following relationship between the Lagrange multiplier and the permit price:

$$\lambda_F^\mu = \frac{2bX(2e\rho B\hat{q}_F + \Gamma d_F) - [2bX\Gamma + (2X - \delta\Phi)Be\rho^2]P^\mu}{2bX(\Gamma + 2bX) + [2bX(X + 2b(3b + 2\delta) + 4be\rho^2) + \Phi\Psi B]e\rho^2} \quad (154)$$

where: $B = b(2X - \delta\Psi) + (\Phi\Psi - 4b\delta)e\rho^2$

Equation (154) is solved simultaneously with equation (152) to yield the price setter's profit maximizing choice of permit price and the Lagrange multiplier. The optimal permit price is:

$$P^\mu = \frac{2bX \left[Z[2e\rho(\hat{q}_L + \hat{q}_F) + (d_L + d_F) - 2e\bar{E}] - \Gamma(2Be\rho\hat{q}_F + \Gamma d_F) \right]}{ZT - \Delta\Gamma} \quad (155)$$

where: $Z = 2bX(\Gamma + 2bX) + [2bX(X + 2b(3b + 2\delta) + 4be\rho^2) + \Phi\Psi B]e\rho^2$
and $\Delta = 2bX\Gamma + (2X - \delta\Phi)Be\rho^2$

The difference between the follower/permit price setter's choice of permit price and the competitive permit price is derived using equations (155) and (137).

$$P^\mu - P^e = \frac{2bX\Gamma \left[\Delta[2e\rho(\hat{q}_L + \hat{q}_F) + (d_L + d_F) - 2e\bar{E}] - T(2Be\rho\hat{q}_F + \Gamma d_F) \right]}{(ZT - \Delta\Gamma)T} \quad (156)$$

The sign of the denominator in equation (86) is positive. The sign of the numerator in equation (156) depends on the degree of product differentiation. In the case of perfect substitutability, $B = -b_2(b + e\rho^2) < 0$, which implies that $P^\mu > P^e$. In the case of zero substitutability the follower/permit price setter acts as a permit cost minimizer its choice of permit price is below the competitive permit price level, $P^\mu < P^e$. The expression for the permit price difference between price setting and competition is the same as in the case of the Cournot model, equation (40).

In summary, when the goods produced by the two firms are close substitutes, the follower/permit price setter increases the price of emission permits above the

competitive level thereby increasing its rival's costs. In this way, the follower/permit price setter increases its share in the product market. As the degree of substitutability decreases so does the gain from increasing rival's costs and the price setter's profit maximizing permit price declines. By the second theorem of continuity there is a degree of product differentiation, δ^* , at which the competitive and the monopsony permit price are the same. This result is qualitatively the same as the one found under Cournot rivalry in Chapter I.

SECTION II. PRICE LEADERSHIP GAME

In this Section it is assumed that firms choose prices rather than quantities in the product market. All other assumptions remain the same. In order to solve for the optimal prices, direct demands are used. The direct demands resulting from the consumer's utility maximization problem laid out in Section I of Chapter II are:

$$q_i = \theta - \beta p_i + \gamma p_j, \quad \text{for } i \neq j, \quad i, j = 1, 2$$

$$\text{where: } \theta = \frac{ab - a\delta}{b^2 - \delta^2}, \quad \beta = \frac{b}{b^2 - \delta^2}, \quad \gamma = \frac{\delta}{b^2 - \delta^2} \quad (157)$$

The demand for good i is downward sloping and increases (decreases) with increases in the price of the competitor if the goods are substitutes, $\delta > 0$, (complements, $\delta < 0$). When δ is positive and approaches the value of b the market approaches a homogeneous one. When $\delta = b$, the utility function is not strictly concave, $b^2 - \delta^2 = 0$, and the demands are not defined.

Assume that one of the two firms in the differentiated duopoly acts as a price leader. Each firm's level of output before regulation is:

$$\hat{q}_L = \frac{(b - \delta) \Psi (a - c)}{4b(b^2 - \delta^2)}, \quad \hat{q}_F = \frac{(b - \delta)(4b^2 + 2b\delta - \delta^2)(a - c)}{4X(b^2 - \delta^2)} \quad (158)$$

Suppose that the rate of emissions per unit of output is ρ . Then, aggregate emissions are:

$$E = \rho(\hat{q}_L + \hat{q}_F) = \rho \frac{(b - \delta)[4b^2 \Psi - \delta^2(3b + \delta)](a - c)}{4bX(b^2 - \delta^2)} \quad (159)$$

Assume that the government decides to reduce emissions by a fraction $(1 - \psi)$. $\bar{E} = \psi E$ emission permits are issued and auctioned off. Each permit specifies one unit of allowable emissions. All sources are required to own permits in order to emit.

In what follows the case of price setting in the permit market is analyzed and compared to the case of perfect competition in the permit market.

1. Perfectly competitive market for permits

Under the assumption of price taking behaviour in the permits market, each firm treats the permit price, P^e , as parametric. The equilibrium price of permits is then the price at which the total demand for permits equals the supply, $\bar{E}$.

The product market follower chooses its profit maximizing price level and abatement per unit of output taking the leader's product market price as given.

$$\max_{p_F, \alpha_F} \Pi_F = p_F(\theta - \beta p_F + \gamma p_L) - [c + d_F \alpha_F + P^e(\rho - \alpha_F)](\theta - \beta p_F + \gamma p_L) - e \alpha_F^2 (\theta - \beta p_F + \gamma p_L)^2$$

The first order conditions are solved for the follower's price reaction function and its optimization condition in the permit market.

$$p_F = \frac{\theta + \beta(c + \rho P^e)}{2\beta} + \frac{\gamma}{2\beta} p_L \quad (160)$$

$$P^e = d_F + 2e \alpha_F (\theta - \beta p_F - \gamma p_L) \quad (161)$$

The leader maximizes profits subject to the follower's response to its own choice of price in the product market, given by equation (160).

$$\max_{p_L, \alpha_L} \Pi_L = p_L(\theta - \beta p_L + \gamma p_F) - [c + d_L \alpha_L + P^e(\rho - \alpha_L)](\theta - \beta p_L + \gamma p_F) - e \alpha_L^2 (\theta - \beta p_L + \gamma p_F)^2$$

The first order conditions are solved for the leader's output price as a function of the

permit price and its optimization condition in the permit market:

$$p_L = \frac{(2\beta + \gamma)\theta + [\beta(2\beta + \gamma) - \gamma^2](c + \rho P^e)}{2(2\beta^2 - \gamma^2)} \quad (162)$$

$$P^e = d_L + 2e(\theta - \beta p_L + \gamma p_F) \quad (163)$$

Substituting equation (162) into equation (160) yields the follower's output price as function of the permit price.

$$p_F = \frac{(4\beta^2 - \gamma^2 + 2\beta\gamma)\theta + [2\beta^2(2\beta + \gamma) - \gamma^2(\beta + \gamma)](c + \rho P^e)}{4\beta(2\beta^2 - \gamma^2)} \quad (164)$$

Substituting equations (162) and (164) into the direct demands yields both firms' output as a function of the permit price.

$$q_L = \hat{q}_L - \frac{(b - \delta)\Psi \rho P^e}{4b(b^2 - \delta^2)} \quad (165)$$

$$q_F = \hat{q}_F - \frac{(b - \delta)(4b^2 + 2b\delta - \delta^2)\rho P^e}{4X(b^2 - \delta^2)} \quad (166)$$

The equilibrium value of the permit price is derived by setting the total demand for permits equal to the supply, $\bar{E}$:

$$P^e = \frac{2bX(b^2 - \delta^2)[2e\rho(\hat{q}_L + \hat{q}_F) + (d_L + d_F) - 2e\bar{E}]}{\Theta} \quad (167)$$

$$\text{where: } H = 4b^2\Psi - \delta^2(3b + \delta), \quad \Theta = (b - \delta)[4bX(b + \delta) + He\rho^2]$$

From equations (137) and (167) the difference between the competitive permit price derived under Stackelberg leadership in quantities and under Stackelberg leadership in prices is obtained.

$$P_p^e - P_q^e \geq 0, \quad \forall b \geq \delta > 0 \quad (168)$$

The competitive permit price is higher under product market leadership in prices than under quantity leadership. This result is expected since the pre-regulation aggregate output and thus the level of emissions is higher under leadership in prices than in quantities. Thus, the demand for permits is higher under leadership in prices while the supply of permits is increasing by only a proportion of the increase in demand.

2. The leader is the price setter in the permits market

Assume that the Stackelberg leader in product prices sets also the price of emission permits. This situation is modeled as a one stage game.

The follower/permit price taker's profit maximization problem does not change. Its decision rules are given by equations (160) and (161).

The leader/permit price setter maximizes profit subject to the follower/permit price taker's product price reaction function and the market clearing condition in the permit market. That is, the leader/permit price setter's constrained profit maximization problem is:

$$\max_{p_L, \alpha_L} \mathcal{L} = TR_L - TC_L + \lambda_L^{\mu} (\bar{E} - E_L^d - E_F^d)$$

The first order conditions of the Lagrange maximization problem with respect to the leader's choice variables are solved for its product price as a function of the permit price and the Lagrange multiplier and its optimization condition in the permit market.

$$p_L = \frac{(2\beta + \gamma)\theta + (2\beta^2 - \gamma^2 + \beta\gamma)(c + \rho P^{\mu}) + (2\beta^2 - \gamma^2 - \beta\gamma)\rho\lambda_L^{\mu}}{2(2\beta^2 - \gamma^2)} \quad (169)$$

$$P^{\mu} + \lambda_L^{\mu} = d_L + 2e\alpha_L(\theta - \beta p_L + \gamma p_F) \quad (170)$$

Substituting equation (169) into (160), the price of the follower as a function of the permit price is derived.

$$p_F = \frac{(4\beta^2 - \gamma^2 + 2\beta\gamma)\theta + [2b^2(2\beta + \gamma) - \gamma^2(\beta + \gamma)](c + \rho P^\mu) + \gamma(2\beta^2 - \gamma^2 - \beta\gamma)\rho\lambda_L^\mu}{4\beta(2\beta^2 - \gamma^2)} \quad (171)$$

Substituting equations (169) and (171) into the direct demand functions, yields the output of each firm:

$$q_L = \hat{q}_L \cdot \frac{(b - \delta)\Psi\rho(P^\mu + \lambda_L^\mu)}{4b(b^2 - \delta^2)} \quad (172)$$

$$q_F = \hat{q}_F - \frac{(b - \delta)[(4b^2 + 2b\delta - \delta^2)\rho P^\mu + \delta\Psi\rho\lambda_L^\mu]}{4X(b^2 - \delta^2)} \quad (173)$$

The first order condition of the Lagrange maximization problem with respect to the Lagrange multiplier gives the permit market clearing condition. Substituting the leader's and follower's output, equations (172) and (173), and their level of abatement, equations (170) and (161), into the permit market clearing condition, yields the following relationship between the permit price and the Lagrange multiplier:

$$\lambda_L^\mu = \frac{2bX(b^2 - \delta^2)[2e\rho(\hat{q}_L + \hat{q}_F) + (d_L + d_F) - 2e\bar{E}] - \Theta P^\mu}{I} = \frac{\Theta}{I}(P^\varepsilon - P^\mu) \quad (174)$$

$$\text{where: } I = 2bX(b^2 - \delta^2) + \Psi^2(b - \delta)^2 e\rho^2$$

The first order condition of the Lagrange maximization problem with respect to the permit price yields the following relationship represented in terms of the parameters of the indirect demands.

$$\lambda_L^\mu = \frac{2b(b^2 - \delta^2)[2\Psi(b - \delta)e\rho\hat{q}_L + Xd_L] - IP^\mu}{\Theta} \quad (175)$$

Equations (174) and (175) are solved simultaneously for the level of permit

price and the Lagrange multiplier. The leader/permit price setter's profit maximizing choice of permit price is:

$$P^\mu = \frac{2b(b^2 - \delta^2) \left[X \Theta \left[2e\rho(\hat{q}_L + \hat{q}_F) + (d_L + d_F) - 2e\bar{E} \right] - 1 \left[2\Psi(b - \delta)e\rho\hat{q}_L + Xd_L \right] \right]}{\Theta^2 - 1^2} \quad (176)$$

The difference between the leader's choice of permit price and the competitive permit price is derived using equations (106) and (97).

$$P^\mu - P^\varepsilon = \frac{2b(b^2 - \delta^2) \left[X \left[2e\rho(\hat{q}_L + \hat{q}_F) + (d_L + d_F) - 2e\bar{E} \right] - O \left[2\Psi(b - \delta)e\rho\hat{q}_L + Xd_L \right] \right]}{\Theta(\theta^2 - 1^2)} \quad (177)$$

The sign of the right hand side of equation (177) depends on the degree of product differentiation. The permit price is higher under price setting than under competition when the degree of substitutability is very high. For δ approaching b (the problem is not defined for $\delta = b$) the permit price difference approaches the following value:

$$\lim_{\delta \rightarrow b} P^\mu - P^\varepsilon = \frac{b}{2(b + e\rho^2)} \frac{2be\rho(1 - \psi)(a - c) + b^2(d_F - d_L) - 2be\rho^2 d_L}{3b^2 + 4be\rho^2 + 12e^2\rho^4} > 0 \quad (178)$$

In the case of zero substitutability, $\delta = 0$, the permit price chosen by the leader is lower than the competitive permit price.

In contrast to the Stackelberg leader in quantities/permit price setter, the Stackelberg leader in prices/permit price setter, chooses a permit price higher than the competitive. This is because the pre-regulation product market share of the Stackelberg leader in price is smaller than that of a Stackelberg quantity leader in quantity. That is:

$$\hat{\xi}_L^q = \frac{2b\Phi}{2X + \Phi^2}, \quad \hat{\xi}_L^p = \frac{X^2}{H}, \quad \text{with } \hat{\xi}_L^p < \hat{\xi}_L^q \quad (179)$$

where $\hat{\xi}_L^q$ and $\hat{\xi}_L^p$ are the pre-regulation product market shares of the Stackelberg

leader in quantities and prices respectively, under the assumption of constant and equal marginal production costs.

In summary, a Stackelberg leader in prices that also sets the permit price, finds that the benefit derived from raising its follower's cost outweighs the increase in its own costs resulting from a higher permit price.

The case in which the follower in product prices is the price setter in the permit market has the same characteristics. Two factors determine the behaviour of the price setter in the permit market. These are, the degree of product differentiation and the pre-regulation product market share. The closer is the substitutability between the products, the greater is the incentive for the permit price setter to set a price above the competitive level. The larger is the permit price setter's pre-regulation product market share the less likely it is that it will be profitable for it to increase the permit price above the competitive level. The follower in product prices' share in the product market is bigger than the leader's.⁵² Thus, the follower/permit price setter chooses a permit price below the one that the leader/permit price setter chooses, equation (176), and probably lower than the competitive, equation (167).

In conclusion, the three cases examined above, prove that, in order for a permit price setter to choose a price above the competitive level, there must be substitutability in the product market and that the permit price setter must not already have a large share of the product market.

⁵²For a discussion of Stackelberg leadership on quantities and prices, see Tirole(1989) Ch.8.

CHAPTER VI

CONNECTION WITH THE LITERATURE

INTRODUCTION

A paper by Misiolek and Elder(1989), is similar to the analysis in Chapter V in that it examines the behaviour of a firm with price setting power in the permit market with the framework of a dominant firm model. As it is noted in Chapter I, this is the only paper that explores the case in which a permit price setting firm uses its power in the permit market to increase its rivals' costs.

SECTION I. PERMIT PRICE SETTING IN A DOMINANT FIRM MODEL

Misiolek and Elder examine two alternative approaches to strategic price manipulation in the permit market. According to the first approach, the permit price setting firm concentrates on minimizing its costs of compliance with environmental regulation. These costs are the sum of abatement and emission permit costs. This case is labelled cost-minimizing manipulation. According to the second approach, the permit price setter uses its power in the permit market in order to raise its rivals' costs. This case is labelled exclusionary manipulation. The two approaches are compared with respect to their effects on resource allocation. The analysis assumes that the emission permits are initially grandfathered to the polluting firms.

The case of a permit price setter seeking only to minimize its costs of compliance is well established in the literature⁵³. This behaviour occurs when a permit price setter either operates in a perfectly competitive product market or has a product market monopoly. In both cases the firm with the power in the permit market is unable to engage in profit-shifting in the product market and confines itself to straight monopsony (monopoly) actions that lead to buying (selling) fewer than the efficient number of permits. Regardless of whether the permit price setter firm is a net buyer (monopsonist) or seller (monopolist) of permits, too little trade takes place. This leads to inefficiencies compared to perfectly competitive permit market.

⁵³Hahn (1986) examines this case in a great extent. See also Lyon (1986) and Eheart *et al.* (1980).

The possibility that a permit price setter will seek to raise its rivals' costs arises when there is imperfect product market competition among the firms participating in the permit market. In this case, the firm with the power in the permit market might use its power in the permit market to increase its rivals's costs. By doing so it increases profits at the expense of its product market rivals.

Misiolek and Elder use a dominant firm model for their analysis assuming that permits are initially grandfathered. They justify the choice of the dominant firm model by arguing that the raising rivals' costs strategy is more profitable --and thus more possible to be taken on by the permit price setter-- the bigger the permit price setter's share in the product market is. The work of Krattenmaker and Salop(1986) is used in support of their argument.

It has been demonstrated in the thesis that the permit price setter's incentive to raise the permit price above the competitive level in order to increase its rivals' costs is negatively related with its product market share. The contradiction between the results obtained in this thesis and the assertion of Misiolek and Elder is resolved demonstrating that the argument by Krattenmaker and Salop does not necessarily hold when the permit price can be manipulated only through purchases of permits.⁵⁴ The case examined by Misiolek and Elder is modeled in detail and some of their predictions are discussed in the light of the solution of this model.

1. A review of the raising rival's costs theory

In their paper, Krattenmaker and Salop(1986) make the following assertion: "Following Salop *et al.*(1983), this analysis has two important implications. First, exclusion is more likely when the predator is big and the excluded rivals are small..."⁵⁵

⁵⁴It should be noted that both Salop *et al.*(1983) and Krattenmaker *et al.*(1986) as well as most of the work in the raising rival's costs "area" examine cases in which the value of the strategic variable can be manipulated without any effect on the cost of the manipulator. In this case the above assertion of Krattenmaker *et. al.*(1986) is correct.

⁵⁵Krattenmaker and Salop(1986), p.111.

In Salop *et al.* (1983) a dominant firm model is employed. The dominant firm chooses the product price, p , and can also select a second strategy variable, α , to which the fringe must react. The industry's demand is $D(p)$. The supply of the fringe firms is a function of the price level and the strategy variable, $S(p, \alpha)$. The dominant firm's cost is a function of its output level, x , and the strategy variable, $C(x, \alpha)$. Assuming that the strategy does not affect the industry's demand, the dominant firm's profit maximization problem is:

$$\begin{aligned} \max_{p, \alpha} \quad & \Pi = px - C(x, \alpha) \\ \text{subject to} \quad & x = D(p) - S(p, \alpha); \alpha \geq 0 \end{aligned}$$

where adoption of a cost-raising strategy implies that: $\alpha > 0$.

From the solution of this problem the necessary condition for a strategy $\alpha > 0$ to be chosen is⁵⁶:

$$\frac{1}{1 + \frac{\varepsilon}{\sigma_s \varepsilon_s}} \left[-\frac{\partial S / \partial \alpha}{\partial S / \partial p} \right] > \frac{\partial C / \partial \alpha}{x}, \quad (180)$$

$$\text{where: } \varepsilon = -\frac{dD}{dp} \left[\frac{p}{D} \right], \quad \varepsilon_s = \frac{\partial S}{\partial p} \left[\frac{p}{S} \right], \quad \sigma_s = \frac{S}{D}$$

There are three points to be made with respect to condition (180) and the size of the fringe. First, the expression outside of the parenthesis at the left hand side of equation (180) is increasing in the fringe firms' market share. Second, the term, $-\partial S / \partial \alpha$, is increasing in the fringe firms' output if the change in the fringe supply curve due to a change in the strategy variable is a rotation as the case is with the diagrammatical representation in Salop *et al.* ('983), or at least does not change if it is a parallel shift. Third, the expression on the right hand side of the condition is not necessarily decreasing in the dominant firm's output level. If the change in dominant firm's cost due to a change in the strategy variable is a function of the dominant

⁵⁶This condition is equation (2), p. 269, originally derived in Salop *et al.* (1983). See Huang (1991) for the full derivation of this result including a correction to the condition.

firm's output then the right hand side of the condition is either not a function of dominant firm's output or an increasing function of it.

Therefore, the above condition does not imply in general that the use of exclusionary manipulation is more likely when the predator is large as is argued by Krattenmaker and Salop(1986) and assumed by Misiolek and Elder(1989). On the contrary when the strategy variable is the price of emission permits the profitability of using exclusionary manipulation is greater the smaller is the predator. Since the smaller the predator the bigger are the gains that can be realized from exclusionary manipulation of the permit price, it is clear that it is more likely that a small predator will use its power in the permit market strategically.

This argument is also supported by the results of Chapter II where it was shown that a Stackelberg leader in quantities, contrary to a quantity taking Cournot rival that has a much smaller market share, does not use its power in the permit market strategically but rather he acts as a compliance cost minimizer by choosing a permit price below the competitive level.

2. Strategic manipulation in the Emission Permit Market

i. The permit price setter seeks to minimize costs

It should be stressed again that a firm with power in the permit market will act as a simple compliance costs minimizer only when it cannot carry its power in the product market. One such case is that of firms producing completely different products but emitting the same pollutant. In this case the firms participate in a common emission permit market but different output markets. The case of zero substitutability, when firms are behaving in the product market as either Cournot rivals--case developed in Chapter II (auctioning) and Chapter IV (grandfathering)--or one firm is a Stackelberg leader--case examined in Chapter V--can be used to illustrate this situation.

A clear diagrammatical treatment of the case in which permits are initially grandfathered and the permit price setter minimizes its cost of compliance can be found in Misiolek and Elder. Their conclusion is that although compliance cost

minimization "...inhibits the efficient exchange of permits.. any transactions which do occur reduce the disparity in abatement costs across polluters and thus some gain in efficiency is achieved relative to the pre-trade allocation"[Misiolek and Elder(1989), p.164]. The pre-trade allocation of permits can be thought of as a situation representing the outcome of a source-specific standards system (such as command and control). In this case, tradeable permit system is more efficient than command and control even when is susceptible to power in the permit market as long as the permit price setter acts as a compliance cost minimizer.

The results in Chapter IV are consistent with Misiolek and Elder's result. In Chapter IV it was shown that when the permit price setter acts as a simple monopolist or monopsonist it chooses a permit price very close to the competitive level regardless of whether the firm with power is a net seller or buyer of permits. This implies an efficiency loss over competitive permit market but in the same time an efficiency gain over command and control (alternatively thought of as the pre-trade situation).

However, this result cannot be extended to every pre-trade allocation of permits. There are initial allocations of permits that result in big gains in efficiency over command and control--allocations that reduce the effect of the permit price setter's power--but there are other allocations resulting in efficiency losses. An example of such an allocation is the extreme case of auctioning of permits (zero permit endowment for the permit price setter). In Chapter II it is shown that in the case of auctioning, command and control is more efficient than a tradeable permit system. Misiolek and Elder also refer to the case of auctioning: "...in some cases the auctioning of permits may produce a less efficient distribution of pollution control efforts than source-specific standards..".⁵⁷ However, auctioning is only one of the possible allocations of permits that could result in a less efficient allocation of abatement effort than command and control. In conclusion, the regulator's decision on permit allocation determines the efficiency of the permit market mechanism when the permit price setter acts as a simple compliance cost minimizer.

⁵⁷Misiolek and Elder(1989), footnote 4, p.159.

ii. The permit price setter seeks to raise rivals' costs

The analysis of the case in which the permit price setter seeks to raise its rivals' costs, is conducted in two steps. First, the dominant firm model sketched in Misiolek and Elder is fully specified using a general functional form in order to point out its structural assumptions. Second, the same assumptions about the demand and the production and abatement technologies used elsewhere in the thesis are employed in order to derive the closed form solution of the model.

Before engaging the analysis of this case, it should be noted that a dominant firm that has the power to set the price in the permit market will always derive bigger benefits by raising its rivals' costs rather than acting as a simple cost minimizer. Since the product is homogeneous, the foregoing analysis suggests that the dominant firm/permit price setter always chooses to raise its rivals' costs rather than act as a compliance cost minimizer. Therefore, the comparison between simple cost minimizing behaviour and raising rivals' cost behaviour in the case of a dominant firm model is not meaningful and is not addressed here. Instead the efficient case of perfect competition in the permit market is used as a benchmark.⁵⁸

Consider now a situation where there is a dominant firm in the product market with the ability to set product price, and a fringe of smaller firms acting as price takers. Production is assumed to result in pollution which is the only form of pollution that is targeted by regulation in the area. Under the assumption of a uniformly mixed pollutant, the policy can focus in controlling total emissions. A total of $\bar{E}$ units of pollution is allowed in the area, with $\bar{E}_i^0$ pollution rights initially distributed to each firm free of charge, with $\bar{E} = \sum \bar{E}_i^0$. Furthermore, it is assumed that the dominant firm has the power to set the price in the permit market.

The permit price takers' optimization problem is:

⁵⁸The use of the case of perfect competition in the input market as a benchmark for detecting predatory behaviour is suggested by Salop and Sheffman(1987).

$$\begin{aligned} \max_{q_F, E_F^d} \quad & \Pi = pq_F - C(q_F) - C(A_F) - P^m(E_F^d - \bar{E}_F) \\ \text{subject to} \quad & A_F = E(q_F) - E_F^d \end{aligned} \quad (181)$$

where p is the product price, q_F is the fringe firms output, $C(q_F)$ is the cost of production, with $C' > 0$, $C(A_F)$ is the cost of abatement, with $C' > 0$, $A_F(q_F, E_F^d)$ is the level of abatement, with $A'_q > 0$ and $A'_E < 0$, P^m is the permit price, E_F^d is the number of permits held by the fringe firms after trading, and $E(q_F)$ is the fringe firms emission level assumed to be a function of the level of output⁵⁹.

The first order conditions of the above constrained profit maximization problem with respect to the choice variables are⁶⁰:

$$\frac{\partial \Pi_F}{\partial E_F^d} = 0 \Rightarrow P^m = -\frac{\partial C(A_F)}{\partial A_F} \frac{\partial A_F}{\partial E_F^d} \Rightarrow A_F = A_F(P^m) \quad (182)$$

$$\frac{\partial \Pi_F}{\partial q_F} = 0 \Rightarrow \frac{\partial C(q_F)}{\partial q_F} = p - \frac{\partial C(A_F)}{\partial A_F} \frac{\partial A_F}{\partial q_F}$$

$$\begin{aligned} \text{using eq. (182): } \frac{\partial C(q_F)}{\partial q_F} &= p - P^m \frac{\frac{\partial A_F}{\partial q_F}}{\frac{\partial A_F}{\partial E_F^d}} \Rightarrow q_F = q_F(p, P^m) \end{aligned} \quad (183)$$

Equation (182) indicates that the fringe firms are price takers in the permit market--buying permits to the point that the marginal cost of permits, P^m , equals the marginal cost of abatement--while equation (183) gives the fringe firms' output supply.

Given the fringe firms supply of output, q_F , and their demand for permits, $E_F^d(A_F, q_F)$, derived by substituting the fringe's optimal level of abatement from

⁵⁹This is a commonly used assumption. See Malueg(1991) and Dasgupta(1982).

⁶⁰Note that the constraint of the profit maximization problem is expressed in terms of abatement, while up to now was expressed in terms of the demand for permits. In this way the selection by Misiolek and Elder of the permits demand as a choice variable is accommodated. The solution of the model does not change.

equation (182) into the profit maximization constraint, the dominant firm's profit maximization problem is:

$$\begin{aligned}
 \max_{p, P^m, E_L^d} \quad & \Pi_L = pq_L - C(q_L) - C(A_L) - P^m(E_L^d - \bar{E}_L) \\
 \text{subject to} \quad & A_L = E(q_L) - E_L^d \\
 & q_L = D(p) - q_F(p, P^m) \\
 & \bar{E} = \bar{E}_L + \bar{E}_F = E_L^d + E_F^d(A_F, q_F)
 \end{aligned} \tag{184}$$

where D is the market demand for the industry's product, q_L is the output of the dominant firm, $A_L(q_L, E_L^d)$ is the dominant firm's abatement level, with $A'_q > 0$ and $A'_E < 0$, and E_L^d is the dominant firm's permit holdings after trading.

It is assumed that the permit price is sensitive to the net permit demand (purchases or sales) of the dominant firm. Since the dominant firm knows both the total, fixed supply of permits, $\bar{E}$, and the fringe firms, net demand for permits, $E_F^d - \bar{E}_F$, it can derive the permit price as a function of its own net demand for permits using the permit market clearing condition. This is illustrated by the third constraint from the dominant firm's profit maximizing problem.

Substitute the first and second constraint into the objective function and write the Lagrange function with respect to the third constraint, so as to be able to solve for the Lagrange multiplier, λ^m , which is the shadow value of a permit for the dominant firm.⁶¹ The Lagrange function is:

$$\max_{p, P^m, E_L^d} \quad \mathcal{L}_L = pq_L - C(q_L) - C(A(q_L, E_L^d)) - P^m(E_L^d - \bar{E}_L) + \lambda^m[\bar{E} - E_L^d - E_F^d(A_F, q_F)]$$

The first order conditions are:

⁶¹It should be noted that λ^m is not what Misiolek and Elder call the "exclusionary value of a permit", since λ^m incorporates the total effect of exclusionary manipulation.

$$\frac{\partial \mathcal{L}_L}{\partial p} = 0 \Rightarrow q_L + \left[p - \frac{\partial C(q_L)}{\partial q_L} - \frac{\partial C(A_L)}{\partial A_L} \frac{\partial A_L}{\partial q_L} \right] \left[D'(p) - \frac{\partial q_F}{\partial p} \right] - \lambda^m \left[\frac{\partial E_F^d}{\partial q_F} \frac{\partial q_F}{\partial p} \right] = 0 \quad (185)$$

$$\frac{\partial \mathcal{L}_L}{\partial E_L^d} = 0 \Rightarrow P^m + \lambda^m = - \frac{\partial C(A_L)}{\partial A_L} \frac{\partial A_L}{\partial E_L^d} \quad (186)$$

$$\frac{\partial \mathcal{L}_L}{\partial P^m} = 0 \Rightarrow \left[p - \frac{\partial C(q_L)}{\partial q_L} - \frac{\partial C(A_L)}{\partial A_L} \frac{\partial A_L}{\partial q_L} \right] \left[- \frac{\partial q_L}{\partial q_F} \frac{\partial q_F}{\partial P^m} \right] = (E_L^d - \bar{E}_L) + \lambda^m \left[\frac{dE_F^d}{dP^m} \right] \quad (187)$$

$$\frac{\partial \mathcal{L}_L}{\partial \lambda^m} = 0 \Rightarrow \bar{E} = E_L^d + E_F^d(A_F, q_F) \quad (188)$$

Equation (186) indicates that the Lagrange multiplier is the shadow value of being able to affect the permit price. In order to exploit all possible gains from its power, the dominant firm in the permit market chooses a permit price on a schedule which is marginal to the permit price taking firms' aggregate demand for permits.

Substituting equation (185) into (187) an expression similar to that of equation (180) is derived:⁶²

$$\frac{\left[q_L - \lambda^m \frac{\partial E_F^d}{\partial q_F} \frac{\partial q_F}{\partial p} \right]}{\left[D'(p) - \frac{\partial q_F}{\partial p} \right]} \left[\frac{\partial q_L}{\partial q_F} \frac{\partial q_F}{\partial P^m} \right] = (E_L^d - \bar{E}_L) + \lambda^m \left[\frac{dE_F^d}{dP^m} \right] \quad (189)$$

Without making any assumptions about the functional form of demand, production and abatement technology, it cannot be determined whether a dominant firm with a large market share has a greater incentive to use the permit price to

⁶²The difference with equation (180) is due to the explicit modelling of the permit market constraint. Salop and Scheffman(1987) discuss the use of the input market constraint in Section IV, where they examine the case of overbuying strategies. Equation (19) on page 28 in their paper, is similar to equation (189).

increase the fringes' costs. The arguments made in conjunction with equation (180) can, however, be made. Moreover, in the case of emission permits, the left hand side of equation (189) is an increasing function of the dominant firm's output since its net demand for permits increases with its output.

The optimal values of the product price, the permit price, the after trade holdings of permits and the Lagrange multiplier are derived from the system of equations (185) to (188). Using the optimal level of product and permit price, the fringe firms' output supply and its permit holdings after trading are derived from equations (182) and (183).

In order to derive a closed form solution of the model, the following set of assumptions about the demand, the production and abatement technology is employed.

$$\begin{aligned} Q &= q_L + q_F = \theta - \beta p, \\ C(q_F) &= \frac{q_F^2}{2\kappa_F}, \quad C(q_L) = (c + \kappa_L q_L)q_L, \quad C(A_i) = d_i A_i + e A_i^2 \\ A_i &= \alpha_i q_i, \quad E(q_i) = \rho q_i, \quad i = L, F \end{aligned} \quad (190)$$

where, α_L and α_F are the abatement per unit of output of the dominant firm and the fringe respectively, P^m is the price of permits that the dominant firm chooses and P^c is the price of permit under competition in the permit market.

Under these assumptions, the fringe firms' choice variables, equations (182) and (183), take the following form:

$$q_F = (p - \rho P^m) \kappa_F \quad (191)$$

$$P^m = d_F + 2e\alpha_F q_F \quad (192)$$

The first order conditions of the dominant firm's profit maximization, equations (185) to (188), are:

$$q_L + \left[p - c - 2\kappa_L q_L - (d_L + 2e\alpha_L q_L - P^m - \lambda^m)\alpha_L - \rho(P^m + \lambda^m) \right] [-(\beta + \kappa_F)] - \lambda^m \rho = 0 \quad (193)$$

$$P^m + \lambda^m = d_L + 2e\alpha_L q_L \quad (194)$$

$$\begin{aligned} & \left[p - c - 2\sigma_L q_L - (d_L + 2e\alpha_L q_L - P^m - \lambda^m)\alpha_L - \rho(P^m + \lambda^m) \right] \kappa_L \rho \\ & = \left[(\rho - \alpha_L)q_L - \bar{E}_L \right] - \lambda^m \frac{2\kappa_F e \rho^2 + 1}{2e} \end{aligned} \quad (195)$$

$$\bar{E}_L + \bar{E}_F = (\rho - \alpha_L)q_L + (\rho - \alpha_F)q_F \quad (196)$$

Substituting the levels of output and abatement of both the dominant firm and the fringe, from equations (193), (191), (194) and (192) respectively, into the permit market clearing condition, equation (196), yields the following relationship between the Lagrange multiplier and the permit price:

$$\lambda^m = \frac{GJ[2e\rho\hat{Q} + (d_L + d_F) - 2e\bar{E}] - [2GJ + \beta[(\beta + 2\kappa_F) + 2\kappa_L\kappa_F G]e\rho^2]P^m}{GJ + \beta^2 e \rho^2} \quad (197)$$

$$\text{where: } G = \beta + \kappa_F, \quad J = 1 + \kappa_L G$$

Rearranging terms in equation (195) yields a second relationship between the permit price and the Lagrange multiplier.

$$\lambda^m = \frac{J[2\beta e \rho \hat{q}_L + G(d_L - 2e\bar{E}_L)] - R P^m}{2GJ + \beta[\kappa_F + G(2\kappa_L\kappa_F + 1)]e\rho^2} \quad (198)$$

$$\text{where: } R = GJ + \beta^2 e \rho^2$$

The system of equations (197) and (198) is solved for the permit price and the Lagrange multiplier. The former is:

$$P^m = J \frac{GV[2e\rho\hat{Q} + (d_1 + d_2) - 2e\bar{E}] - R[2\beta e\rho\hat{q}_L + G(d_L - 2e\bar{E}_L)]}{V^2 - R^2}$$

where: $V = 2GJ + \beta[\kappa_F + G(2\kappa_L\kappa_F + 1)]e\rho^2$, and

(199)

$$\hat{Q} = \frac{[(\beta + 2\kappa_F) + 2\kappa_L\kappa_F G]\theta - \beta Gc}{2GJ}, \hat{q}_L = \frac{\theta - Gc}{2J}$$

where $\hat{Q}$ is the industry's pre-regulation level of output and $\hat{q}_L$ is the dominant firm's pre-regulation level of output.

In a dominant firm model, comparison between the case in which the permit price setter is seeking to raise rival's costs and the case that it is seeking only to minimize cost of compliance is not useful since a dominant firm with power in the permit market always incorporates the raising rivals' costs effect into its decision. In order to examine the effect of permit price setting behaviour on welfare, this case is compared to the case of perfect competition in the permit market.

When both the fringe and the dominant firms are price takers in the permit market, the permit price is derived by setting the aggregate net demand for permits equal to zero.

$$P^c = \frac{GJ[2e\rho\hat{Q} + (d_L + d_F) - 2e\bar{E}]}{V}$$
(200)

From equations (199) and (200) the difference between the permit price chosen by the dominant firm and the competitive permit price is derived.

$$P^m - P^c = \frac{JR}{V} \frac{GR[2e\rho\hat{Q} + (d_L + d_F) - 2e\bar{E}] - V[2\beta e\rho\hat{q}_L + G(d_L - 2e\bar{E}_L)]}{V^2 - R^2}$$
(201)

Equation (201) indicates that the permit price difference between price setting and competitive behaviour is decreasing in the price setter's pre-regulation level of output. This result proves the proposition made in the first part of this Section. The

smaller the dominant firm is the higher is the permit price that it will choose relative to the competitive price.

Substituting the values of the industry's and dominant firm's pre-regulation output into equation (201) yields:

$$P^m - P^c = \frac{JR}{V(V^2 - R^2)} Ge\rho \left[[(2\kappa_F - \beta) + 2\kappa_L\kappa_F G]\theta + \beta(G + 2\beta\kappa_F e\rho^2)c \right] \\ + \frac{JR}{V(V^2 - R^2)} \left[GR(d_F - 2e\bar{E}_F) + G(R + V)\bar{E}_L - G(V - R)d_L \right] \quad (202)$$

The permit price setter is more likely to choose a permit price above the competitive level the higher is its production cost (the smaller its pre-regulation product market share) and the better is its abatement technology relative to the fringe firms. The sign of the above expression also depends on the slope of the market demand, β , relative to the slope of the fringe firms' production cost, κ_F , and the size of the dominant firm's endowment of permits relative to the fringe firms' endowment. Consistent with the results of Section I of Chapter II, the dominant firm is more likely to be a net purchaser of permits at a price above its marginal cost of abatement, the smaller is the slope of the fringe supply, $1/\kappa$, relative to the slope of the direct demand. This last result is in contrast to the one derived in Misiolek and Elder and Salop and Scheffman(1987). However, Salop and Sheffman(1987) derive their result, that the profitability of cost raising strategy is more likely the less elastic is the fringe supply curve, under the assumption that the dominant firm can raise the input price without increasing its purchases of the input. Salop and Sheffman(1981) consider a situation closer to the one examined here and they conclude that "...the dominant firm is more likely to be a net purchaser of the input at a price above his marginal production cost of the input, ... the more elastic is the fringe supply"⁶³.

⁶³Salop and Sheffman(1981), p.28.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The main result of the thesis is that under imperfect competition the product and the permit markets are interdependent. The efficiency of a tradeable emission permits system relative to the alternative command and control system cannot be judged by examining the efficiency of abatement effort in isolation. The outcome in each market and thus the welfare consequences depend on the structure of both markets. In addition, the equilibrium in the permit market depends on the system by which the emission permits are allocated initially. Thus, the superiority of a tradeable emission permit system over command and control holds for some types of product and permit market structures and permit allocation methods but not for others.

Table 4 presents a summary of the results derived in the thesis.

Table 4. Summary of results

			product	market	structure	
ERA	PIA	PMS	Cournot	Stack.Q	Stack.P	D.firm
CAC			CAC can be SB*	CAC can be SB*	CAC can be SB*	CAC can be SB*
TEP	auct.	compet	efficient	efficient	efficient	
		power	RRC for δ close to 0 or b. SB for $\delta=0$.	RRC more likely when the follower is the price setter	RRC more likely when the leader is the price setter	
	grandf	compet	efficient			efficient
		power	RRC both for LAC & HAC, if $\delta=b$. RRC more likely for LAC if δ close to δ^* . SB for $\delta=0$.			RRC for D.firm if $\delta=b$.

*Command and control can be Second Best in cases that the permit price setter chooses a price substantially larger or smaller than the competitive price.

where the following abbreviations are used: Raising Rivals' Costs behaviour (RRC), Second Best (SB), Low Abatement Cost firm (LAC), High Abatement Cost firm (HAC), Environmental Regulation Approach (ERA), Permits' Initial Allocation (PIA), Permit Market Structure (PMS), Command and Control (CAC), Tradeable Emission Permit system (TEP), Stackelberg in Quantities model (Stack.Q), Stackelberg in Prices model (Stack.P), Dominant firm model (D.firm), auctioning (auct.), grandfathering (grandf.), competition (compet.) and price setting power (power).

Under Cournot behaviour in the product market, a tradeable permit system is more efficient than a source-specific system in the following cases: 1) when the permit market is perfectly competitive for all degrees of product differentiation and for both auctioning and grandfathering; 2) when one of the firms in the permit market is a permit price setter, and i) with auctioning and for intermediate cases of product differentiation, and ii) with grandfathering and a high degree of product differentiation. In all other cases, command and control is more efficient than a tradeable permit system when power exists in the permit market.

The welfare results described above are driven by the following processes. First, through trading of emission permits, a competitive permit market allows a more efficient allocation of abatement effort than source-specific regulation regardless of the degree of product differentiation and the initial allocation of permits.

Second, when one of the firms sets the price in the permit market, the efficiency of tradeable emission permit system relative to command and control depends on both the degree of product differentiation and the system of permit allocation. When there is zero substitutability ($\delta = 0$), there is no interaction between the product and the permit markets and the price setter seeks to minimize the costs of compliance. With pro-rata grandfathering, the distribution of abatement effort though inefficient, is more efficient than command and control. With auctioning, the monopsonist is monopsonizing on the total supply of permits rather than the net supply of permits. As a consequence, a tradeable permits system is less efficient than command and control.

If products are imperfect substitutes, ($b > \delta > 0$), the permit market price setter raise rivals' costs and sets the permit market price so as to increase its share of the oligopoly rents in the product market. The net gain realized depends on the price setter's pre-regulation product market share, its abatement technology, the degree of product differentiation and the system of permits allocation.

Other things being equal, the more substitutable are the products the higher is the price setter's net gain from raising rivals' costs and the higher is the permit price it sets. For high degrees of substitutability, ($\delta \approx b$), the permit market is less

efficient than command and control. For some degree of substitutability, ($\delta \approx \delta^*$), the costs and benefits of raising rivals' costs balance each other and the price setter sets a permit price close to the competitive price. In this case, the permit market is more efficient than command and control.

Other things being equal, the permit price setter's cost of raising rivals' costs is smaller under grandfathering than under auctioning. Thus, under grandfathering the price setter always sets a higher permit price than under auctioning. The difference between the price setter's optimal permit price under auctioning and grandfathering respectively, affects both the efficiency of tradeable permit system and entry decisions in the industry. A tradeable permit system is more efficient under auctioning than under grandfathering for low degrees of product differentiation and less efficient for high degrees of product differentiation. The possibility that a firm might find entry unattractive is greater under grandfathering than under auctioning. This is because grandfathering gives an additional advantage to the incumbent firms through the endowments of permits.

The magnitude of all the above results are sensitive to the assumptions about the production technology and the number of firms in the industry. Qualitatively though, the above results continue to hold.

Under Stackelberg leadership in quantities, a competitive tradeable permits market is more efficient than command and control. In the case of price setting behaviour, the results differ from the Cournot case for all cases except zero substitutability. If the permit price setter is the Stackelberg leader in the product market, the net gain from raising rivals' costs is negative except in some extreme cases. Thus, although it takes the effect of its actions in the permit market on its share of the product market into account, the leader/permit price setter sets a price lower than the competitive price. The leader/permit price setter's choice of price is closer to the competitive price the lower is its pre-regulation product market share, the lower is the degree of product differentiation and the higher is the percentage reduction in emissions required by the government.

If the follower is the permit price setter, it sets a permit price higher than the competitive price for a broader range of degrees of product differentiation than a Cournot duopolist. This is because the follower has a smaller pre-regulation product market share than a Cournot duopolist and thus the net gain from raising rival's costs is larger than that of a Cournot duopolist. Under Stackelberg leadership in prices, the results of the last two paragraphs are reversed since the follower in prices has the larger pre-regulation product market share.

The results of the thesis suggest that, other things being equal, the efficiency of tradeable permits relative to command and control depends on the structure of the industries involved. If the product and the permits markets are not competitive, command and control is more efficient under a variety of circumstances. These results do not suggest that tradeable permits systems are inefficient. Rather they suggest that the design of a tradeable emission permits system should take into consideration the structure of the industries whose emissions are controlled.

The cases examined in the thesis offer a number of suggestions for the design of tradeable emission permits systems. First, grandfathering is the dominant approach of allocating emission permits because it is more acceptable to the firms for distributional reasons. It also reduces the dead-weight loss associated with pure monopsony in the permit market. However, the results of this thesis suggest that grandfathering aggravates a raising rivals' costs problem and also makes entry deterrence strategy more feasible. Raising rivals' costs problems can be made less severe by including a variety of industries in the permit market. The use of permit holdbacks reduces the effect of grandfathering on entry deterrence strategy.

Second, contrary to what is widely believed, raising rivals' costs behaviour is more likely when the permit price setter has a small share in the product market. This implies that if a large product market share is a pre-condition for price setting power in the permit market, then raising rivals' costs behaviour might not be a serious problem. If however, a large product market share is not a pre-condition and a firm with small product market share is seeking to raise its rivals' costs, then auctioning is more efficient than grandfathering.

Third, in the case that the government has full (some) information on the demand functions, the product market structure and the firms production and abatement technologies, it can eliminate (reduce) the inefficiency of price setting power by choosing the appropriate initial allocation of permits.

Further research could be directed towards examining the following cases: first, the case that firms manipulate their current emission levels in anticipation of a regulatory system of grandfathered emission permits; second, in the case of differentiated Bertrand oligopoly in the product market; third, in the case of strategic entry deterrence in the presence of grandfathering.

REFERENCES

- Atkinson S.E. and Tietenberg T.H. (1991), "Market failure in incentive based regulation: The case of emissions trading", *Journal of Environmental Economics and Management*, Vol. 21, pp.17-31.
- Atkinson S.E. and Tietenberg T.H. (1987), "Economic implications of emissions trading rules for local and regional pollutants", *Canadian Journal of Economics*, Vol.20, pp.370-386.
- Baumol W.J. and Oates W.E. (1988), "*The Theory of Environmental Policy*", Cambridge University Press, Cambridge. (2nd Edition)
- Besanko D. (1991), "Performance versus design standards in the regulation of pollution", *Journal of Public Economics*, Vol. 81, pp.622-34.
- Bressers H.T. (1988), "A comparison of the effectiveness of incentives and directives: The case of Dutch Water Quality Policy", *Policy Studies Review*, Vol.7, pp.500-18
- Brown G.Jr and Bressers H.T. (1986), "Evidence supporting efficient charges", *Mimeo*. The Netherlands: Twente University of Technology.
- Brown G.Jr and Johnson R.W. (1984) 'Pollution control by efficient charges: It works in the Federal Republic of Germany, why not in the U.S.", *Natural Resources Journal*, Vol. 24, pp.929-66.
- Burrows P. (1981), "Controlling the monopolistic polluter: Nihilism or electicism?", *Journal of Environmental Economics and Management*, Vol. 8, pp. 372-380.
- Burtraw D. and Portney P. (1991), "Environmental Policy in the United States". In "*Economic Policy Towards the Environment*", Ed. D.Helm, Blackwell, Oxford.
- Canada (1991), "Marketable permits: U.S. experience and lessons for Canada", *Environment Canada*, Corporate Policy Group, Policy Branch.
- Canada (1992a), "Economic instruments for environmental protection. Discussion Paper", *Canada's Green Plan*, Minister of Supply and Services.

- Canada (1992b), "Emission trading. A discussion paper", Published by *Emission Trading Working Group* Under the Auspices of Canadian Council of Ministers for the Environment.
- Coase R.H. (1984), "The problem of social cost", *Journal of Law and Economics*, Vol. 99, pp.753-765.
- Copeland B.R. (1990), "Taxes versus standards to control pollution in imperfectly competitive markets", *Working Paper*, University of British Columbia.
- Cropper M.L. and Oates W.E. (1992), "Environmental Economics: A Survey", *Journal of Economic literature*, Vol. XXX, pp.675-740.
- Dasgupta P. (1982), *The Control of Resources*, Harvard University Press, Cambridge.
- David M., Eheart W., Joeres E. and David E. (1980), "Marketable permits for the control of phosphorus effluent into Lake Michigan", *Water Resource Res.*, Vol. 16, pp.263-270.
- Dixit A.K. and Stiglitz J.E. (1977), "Monopolistic competition and optimal product diversity", *American Economic Review*, Vol.67, pp.297-308.
- Farber S.C. and R.E. Martin (1986), "Market structure and pollution control under imperfect surveillance", *The Journal of Industrial Economics*, V. 25, pp.147-160.
- Hahn R.W. (1984), "Market power and transferable property rights", *Quarterly Journal of Economics*, Vol 99, pp.753-765.
- Hahn R.W. (1989), "Economic prescriptions for environmental problems: How the patient followed the doctor's orders", *Journal of Economic Perspectives*, Vol. 3, pp.95-114.
- Hahn R.W. and Hester G.L. (1989a), "Where did all the markets go? An analysis of EPA's Emissions Trading Program", *Yale Journal of Regulation*, V.6, pp.109-53.
- Hahn R.W. and Hester G.L. (1989b), "Marketable Permits: Lessons from theory and practice", *Ecology Law Quarterly*, Vol. 16, pp.361-406.

- Hahn R.W. and Noll R.G. (1982), "Designing a market for tradable emission permits". In *"Reform of Environmental Regulation"*, Ed. W.A. Magat, Ballinger, Cambridge, MA.
- Hausker K. (1992), "the politics and economics of auction design in the market for sulphur dioxide pollution", *Journal of Policy Analysis and Management*", Vol. 11, pp.553-72.
- Helfand G.E. (1991), "Standards versus standards: The effects of different pollution restrictions", *American Economic Review*, Vol.81, pp.622-34.
- Helm D. (1991), *"Economic Policy Towards the Environment"*, Blackwell, Oxford, U.K.
- Helm D. and Pearce D. (1991), "Economic policy towards the environment: An overview". In *Economic Policy Towards the Environment*, Ed. D. Helm, Blackwell, Oxford, U.K.
- Huang H. (1991), "Erratum: Raising rivals' costs", *American Economic Review*, Vol.81,p.1453.
- Kelman S. (1981), *What Price Incentives? Economists and the Environment*, Auburn House Publishing Company, Boston, Massachusetts.
- Kolstad C.D. (1986), "Empirical properties of economic incentives and command and control regulations for air pollution control", *Land Economics*, V.62, pp.250-268.
- Krattenmaker T. and Salop S. (1985), "Anticompetitive exclusion: Raising rivals' Costs to achieve power over price", *Yale Law Journal*, Vol. 96, pp.209-95.
- Krattenmaker T. and Salop S. (1986), "Competition and cooperation in the market to exclusionary rights", *American Economic Review, Papers and Proceedings*, Vol.16, pp.109-13.
- Lyon R.M. (1986), "Equilibrium properties of auctions and alternative procedures for allocating transferable permits", *Journal of Environmental Economics and Management*, Vol. 13, pp.129-152.

- Malueg D.A. (1990), "Welfare consequences of emission credit trading programs", *Journal of Environmental Economics and Management*, Vol. 17, pp.66-77.
- McGartland A.M. and Oates W.E. (1985), "Marketable permits for the prevention of environmental deterioration", *Journal of Environmental Economics and Management*, Vol. 12, pp.207-228.
- Misiolek W.S. and Elder H.W. (1987), "Exclusionary Manipulation of markets for pollution rights", *Journal of Environmental Economics and Management*, Vol. 16, pp.156-166.
- O'Neil W.B. (1983), "Transferable discharge permit trading under varying stream conditions: A simulation of multiperiod permit market performance on the Fox River, Wisconsin", *Water Resource Res.*, Vol. 19, pp.608-612.
- O'Neil W., M. David, C. Moore and E. Joeres (1983), "Transferable discharge permits and the economic efficiency, The Fox River", *Journal of Environmental Economics and Management*, Vol 10, pp.346-355.
- Pezzey J. (1992), "The symmetry between controlling pollution by price and controlling it by quantity", *Canadian Journal of Economics*, Vol.25, pp.983-91.
- Salop S.C. and Scheffman D.T. (1981), "Strategic interaction in multiple markets: A beginning to a general theory of dominant firm industries", *Mimeo*, Presented at the Summer Meetings of the Econometric Society in San Diego in June 1981.
- Salop S.C. and Scheffman D.T. (1983), "Raising rivals' costs", *American Economic Review Papers and Proceedings*, Vol.73, pp. 267-271.
- Salop S.C. and Scheffman D.T. (1987), "Cost-raising Strategies", *Journal of Industrial Economics*, Vol.26, pp.19-34.
- Silberberg E. (1990), *The Structure of Economics*, McGraw-Hill, New York, N.Y..
- Singh N. and X. Vives (1984), "Price and quantity competition in a quantity competition in a differentiated duopoly", *Rand Journal of Economics*, Vol. 15, pp. 546-554.

- Spence A.M. (1976), "Product selection. Fixed costs and monopolistic competition", *Review of Economic Studies*, Vol.43, pp.217-36.
- Spulber D. (1985), "Effluent regulation and long-run optimality", *Journal of Environmental Economics and Management*, Vol. 12, pp.103-16.
- Tietenberg T.H. (1985), *Emissions Trading: An Exercise in Reforming Pollution Policy*, Resources for the Future Inc., Washington, DC.
- Tietenberg T.H. (1991), "Economic Instruments for environmental regulation", *Oxford Review of Economic Policy*, Vol. 6, pp.122-48.
- Tietenberg T.H. (1992), *Environmental and Natural Resource Economics*, Harper Collins Publishers Inc. New york, N.Y.(3rd Edition).
- Tirole J. (1989), *The Theory of Industrial Organization*, the MIT Press, Cambridge, Massachusetts.

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