On the Initial Allocation of Tradeable Pollution Permits

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Declaration

In accordance with Regulations for Higher Degrees by Research, I hereby declare that this thesis now submitted for the candidature of Doctor of Philosophy is a result of my own research and independent work except where reference is made to published literature. I hereby certify that the work embodied in this thesis has not already been submitted in candidature for any other institute of higher learning.

All errors remain my own.

Candidate:

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Preface

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Abstract

The objective of this thesis is to investigate the initial allocation of pollution permits in a dynamic tradeable market. Tradeable pollution permit markets are an increasingly common method of environmental regulation and it is apparent that future schemes may have a number of repeated compliance periods. It is important to consider how and to what extent the dynamic allocation of pollution permits determines the market efficiency at the equilibrium. This objective is developed in three parts. First, Part I introduces the topic and sets out the current relationships that exist between the initial allocation of permits and market efficiency and finds strong links between the two. It is shown that markets with imperfect competition, transaction costs or multiple periods can result in links between the initial allocation and market efficiency. In Part II, a generalised model is created to investigate the optimality of dynamic permit allocations and finds the dynamic use of grandfathering (free allocation based on emissions information) permits is, in general, sub-optimal. It is argued that alternative dynamic mechanisms should be considered, such as auctions and other relative performance mechanisms. Part II is concluded by an investigation into the link between market efficiency, dynamic initial allocations and firms' lobbying over a permit allocation. Firms have the ability to determine their permit allocation by their choice of emissions and lobbying activity. It is shown that in some circumstances, lobbying activity may alter market efficiency and may result in reductions in social welfare. In Part III, an alternative dynamic allocation mechanism is considered, namely a rank-ordered contest, which can optimally allocate permits and simultaneously accomplish a predetermined secondary policy objective.

The thesis concludes with a discussion of the policy implications and future work associated with this research.

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Part I

Introduction

Chapter 1

General Introduction

1.1 Background and Development of Environmental Regulation

1.1.1 What is Environmental Regulation?

As a consequence of economic growth over the last 50 years, public concern for the state of the environment has steadily increased to a point where present day governments have now established an array of policies to control and prevent environmental damage (see, for example, Gray 1995; Jänicke and Weidner, 1997; Desai, 2002, Jordan 2005). Environmental policies considered by governmental regulators tackle many diverse problems such as air and water pollutants, the disposal of household and hazardous waste and the conservation of ecosystems and species, to name but a few. The variety of environmental problems has illustrated the need for diverse and focused regulation, for example, many environmental problems cause damages that are both local and specific to individual governments (e.g. non-point pollution), however there are also problems that create transboundary issues and must be regulated by international agreements, such as the control of greenhouse and ozone depleting gases. This thesis concentrates on pollution control.

Given the variety of pollution regulations that aim to protect our environment, it is useful to make a distinction between two broad categories of regulations: command-and-control regulation and market-based mechanisms.[1]

It is generally assumed that command-and-control policies regulate by the use of prescriptive requirements on the technology or performance of a firm (Freeman and Kolstad, 2007). First, command-and-control regulations can involve regulatory requirements where a technology (technique) standard is specified. A regulator may require regulated firms to adopt specific technologies, for example they may have to implement the Best Available Control Technology (BACT), 'Best Available Technology Not Entailing Excessive Cost (BATNEEC) or Best Practicable Environmental Options (BPEO) (Pearce and Brisson, 1993). By definition, this type of regulation is 'rigid' insofar as the regulated firm's technology/technique decisions are restricted. The remaining command-and-control regulations are performance-based standards in which firms are specified a maximum limit of pollution where any violation of the standard is met with a monetary penalty. To reach a specified regulatory goal, performance standards allow firms greater flexibility in the techniques and technology than do technology standards.

Command-and-control policies tend to be considered as the 'traditional' regula-

[1] Of course, other types of pollution control do exist, for instance, a third category may include firms' non-mandatory (voluntary) pollution reductions (See, for example, Khanna, 2001; Gunningham et al. 2003).

tion in which the regulator dictates either technology or performance requirements that must be achieved by the regulated firms. By way of contrast, market-based mechanisms use the "aspects of law and regulation that encourage behaviour through market signals" (Stavins, 2007 p19) (for a recent survey of market-based instrument experience, see Stavins, 2003). Two of the most widely documented market-based approaches to environmental policy are pollution taxes (Pigou, 1932; Rajah and Smith, 1993) and tradeable permit markets (Coase, 1960; Crocker, 1966; Dales 1968a; 1968b; Montgomery 1972; Anderson and Leal 2001; Tietenberg, 2006).

As pollution is a definitive example of a negative externality, it is possible for a regulator to correct for market failure by levying a tax on an amount of pollution equal to the marginal social damage at the socially optimal level of pollution (Baumol and Oates, 1988). Polluting firms face a charge on every unit of emissions and as a result, the firm will internalise the full social cost of the emissions choice. Instead of setting a 'price' for emissions a regulator could, as an alternative, create tradeable licenses for pollution. In such a process, firms are entitled to pollute a level of emissions equal to the amount of licenses they hold (which can be bought and sold amongst other regulated firms).[2] We discuss this mechanism in more detail later in the chapter.

As Hahn and Stavins (1991; 1992) and Stavins (2007) has suggested, other types of market-based mechanisms do exist but are used infrequently, such as deposit-refund systems (Porter, 1983), information disclosure regulation (Hamilton, 1995) and the reduction in market barriers and government subsidies.

[2] The choice between whether a regulator should use either a tax or tradeable permit market was initially investigated by Weitzman (1974).

1.1.2 Market-Based Versus Command-And-Control Regulation

During the past 50 years economists have strongly advocated the use of market-based regulation as an efficient alternative to command and control policies (Kneese and Schultz, 1975; Schultz, 1977; Ackerman and Hassler, 1981; Anderson and Leal, 2001). As Harrington and Morgenstern (2007) have set out, there are number of key benefits of implementing market-based mechanisms. The most important, from an economic perspective, is cost effectiveness.

Consider a regulator whose objective is to achieve a specified reduction in pollution under a command-and-control system. As already discussed, using such an approach implements standards (emission and/or technology) which are relatively costly for society as firms tend to have heterogeneous abatements costs (due to differences in production, age of plants, knowledge, experience and so on), which means that firms that find pollution control relatively costly will experience identical standards to firms that find pollution control relatively cheap.

In contrast, market-based mechanisms embrace the heterogeneity in the control cost of firms and allow a pre-specified level of aggregate pollution to be reached at the lowest cost to society. Instead of requiring identical emissions reduction or technology adoption, market-based mechanisms, through the use of price signals, induce firms to choose a level of emissions whereby firms' marginal abatement costs are equated and as a consequence the burden of pollution abatement is efficiently distributed among firms at the lowest cost to society (Montgomery, 1972; Baumol and Oates 1971, Tietenberg 1985). In essence, market-based mechanisms achieve a pre-specified aggregate pollution target at lowest cost by allowing firms the freedom to choose different levels of pollution.

Although, cost effectiveness is the central argument for advocating the use of market-based mechanisms, there are many other possible reasons for implementation.[3] We briefly discuss a selection below.

A key benefit of market-based mechanisms is the potential creation of incentives to reduce emissions over time by developing and adopting new abatement technology (see Kerr and Newell 2003, Jaffe et al. 2003; Requate, 2005 and references therein). Due to the prescriptive standards associated with command-and-control regulation, firms have very little (monetary) incentive to over-comply with uniform standards.[4] Reducing emissions by way of technology adoption can reduce a firm's compliance cost of meeting a standard, however, firms that overcomply with regulatory standards may experience further stringent standards in the future—the 'Ratchet Effect'. In contrast, this 'Ratchet Effect' seldom occurs in market-based mechanisms. For example, in a tradeable permit market (or tax system), firms that create and adopt abatement technology can reduce their emissions and as a result can sell their surplus permits (reduce their tax burden) for monetary gain.

Market-based mechanisms have also been advocated due to lower informational requirements. In a command-and-control system, the regulator must acquire information on the most up-to-date and cost effective technologies whilst obtaining

[3]For surveys on the theoretical advantages of market-based mechanisms over command-and-control policies see Stavins (2003) and Harrington and Morgenstern (2007).

[4]However, overcompliance of technology or performance standard is possible and does exist, even if limited in scope and longevity (Gunningham et al. 2003). Fiorino (2006) suggests, firms may choose to overcomply and incorporate voluntary environmental management systems to: reduce the risk of occurring penalties, anticipate new regulations, improve relationship with regulator, improve resource use and production efficiency and improve public image.

information about each firms marginal cost curves. As market-based mechanisms generally emphasize the aggregate reduction in emissions this information is not required. For instance, theoretically, a tradeable permit market regulator only requires information to create, allocate and monitor the pollution permits—there is no requirement for information on firms' marginal costs.[5]

Market-based mechanisms have some key advantages over command-and-control policies, however, the arguments that advocate the use of market-based mechanisms have not gone unchallenged. Fundamentally, critics of market-based mechanisms often note the ethical and moral problems that are encountered and argue that this type of regulation should be avoided. Other criticisms focus on the inherent bias in the economic literature in favour of market-based mechanisms.

In contrast to the 'Free-Market Environmentalism' (Anderson and Leal, 2001), which advocates the establishment of property rights to solve environmental problems, a body of literature has countered these claims by arguing that the use of market-based mechanisms are immoral and unethical (Kelman, 1981; Sagoff, 1988; Goodin, 1994; Chinn, 1999; Nash, 2000).

It is often argued that society has a 'stewardship' role regarding the earth's environmental system whereby society needs to prevent environmental degradation for ourselves and future generations. As Goodin (1994) suggests, market-based mechanisms are objectable as governments cannot sell what they do not own. Using market-based mechanisms create prices and markets for non-marketable goods.

[5]However, the true extent to which market-based mechanisms can reduce information needed depends on the heterogenous circumstances of the problem in question. With respect to optimal setting of an environmental tax, a large amount of information on firms' marginal abatement cost curves may be required.

Yet, it may be difficult to monterise the damages that are caused by the pollution, especially at the limiting case where pollution may create irreversible damages, such as the loss of human life (Kelman, 1981).

Moreover, Kelman (1981 p27) argues that the use of market-based mechanisms makes a "social statement of indifference toward the motives of polluters in reducing pollution". This means that society cares about the 'ends but not the means' of obtaining a desirable level of pollution.[6] Firms that reduce pollution in market-based mechanisms primarily do so with the aim of higher (lower) profits (costs) and the altruistic reduction of pollution is not given much consideration. Yet society may care about environment quality *and* the motives behind polluters reducing emissions.

Not only do market-based mechanisms portray an indifference to the motives of polluters, it is also argued that these schemes fail to fully stigmatise polluting firms (Goodin, 1994). If an individual or firm is fined for some social disorder they pay the debt to society. However, the action still remains wrong from the viewpoint of society even after payment of the fine. However, this is not the case in market-based mechanisms. It is argued that taxes and tradeable permits are used to legitimise pollution by allowing firms to pollute by conditioning this action on some form of payment. In other words, a firm is allowed to legitimately pollute. However, this argument fails to recognise the existence of this problem in command-and-control regulation, where the rights to pollute require no financial payment.

[6]However, it has been argued that market-based mechanisms 'force democracy' by providing a focus on what level of pollution in society is desirable (Ackerman and Stewart, 1985; Heinzerling, 1995). In contrast, it is argued that command-and-control regulation is determined by self-interested factions such as lobbying groups.

As firms are allowed to pollute conditional on a financial payment (such as a tax or the price of a permit) it leads on to the issue of environmental justice (Goodin, 1994: Chinn, 1999). This system allows firms to pollute given some financial payment, however this may be unfair on firms that are unable to provide such payments. Moreover, in market-based mechanisms, firms usually have a choice as to the level and location of pollution. Therefore it is possible, without prescriptive regulations forcing the location and limit on emissions, that low-income and minorities groups in society may be exposed to larger amounts of pollution by firms relocating and increasing emissions in less prosperous areas (Chinn, 1999).

Aside from the ethical and moral issues discussed above, other, less fundamental, criticisms do exist. Cole and Grossman (1999) and Driesen (1998) argue that a large amount of the analysis (especially early studies) that compared market-based and command-and-control mechanisms oversimplified and exaggerated the differences between the two types. As Harrington and Morgenstern (2007) have commented, both command-and-control and market-based regulation do use elements of prescriptive regulation (coercive methods) and economic instruments (penalties) to reach a required outcome—few schemes are ever 'pure'. Indeed, both types of mechanisms suffer from common regulatory weaknesses such as problems with the monitoring and enforcement of pollution (Freeman and Kolstad, 2007). Cole and Grossman (1999) argue that command-and-control regulation are not 'inherently' inefficient and the benefits of this type of regulation are underplayed whereas market-based mechanisms have often been inefficient (see, for example, Hahn and Noll, 1982).

Furthermore, early studies did not accurately take into account the institutional and political contexts of implementing environmental policy, however it is vital that "comparison between market instruments and prescriptive regulation must be fair to be meaningful" (Freeman and Kolstad, 2007 p7). Accordingly, the literature is slowly becoming aware that the benefits of market-based mechanisms over command-and-control are conditional on the context in which the policies are placed (Atkinson and Tietenberg, 1991; Hahn and Stavins 1991; Tietenberg 2006; Harrington and Morgenstern, 2007). In other words, market-based mechanisms may not be the most desirable types of regulation for all environmental problems. This is especially true when the pollutant has local and threshold effects (Hahn and Hester, 1989a; 1989b; Hahn and Stavins, 1991; Tietenberg, 2007). But in what contexts do market-based mechanisms thrive compared to command-and-control regulation?

First, market-based mechanisms, especially tradeable permit markets, work well when there are significant differences in firms' pollution control costs (Newell and Stavins, 2003; O'Ryan, 2006; Stavins 2007). With respect to tradeable permit markets, the wide variation in pollution control costs allow larger gains from trades to exist. In contrast, if pollution control costs are similar among firms then fewer gains from trade exist and it may be desirable to implement uniform performance and technology standards.

Second, the gains from trade in a market-based mechanism will depend on the number of participating firms. A larger number of firms will mean a possible larger variation in control costs and a 'sustainable' market (taxation system). However, if few firms are regulated then market-based mechanisms can suffer as the gains from trade may be small due to 'thin' markets (Hanley and Moffat, 1993) and a loss in revenue from a pollution tax. This has additional problems when the 'thin' market is affected by strategic behaviour (Hahn, 1984).

Third, the effectiveness of the two types of regulations depends on the nature of the pollutant. Market-based mechanisms do not allow for source specific control and this may pose a problem when the regulated pollutant is non-uniformly mixed in the atmosphere. Under market-based mechanisms, non-uniformly mixed pollutants may cause 'hot spots' where higher level of emissions concentrations occur at some geographical areas. To solve this issue, regulators must use spatially or temporally differentiated emissions charges or introduce additional trading rules. However, these additional mechanisms may cause a reduction in the cost effectiveness (e.g. larger transaction cost (Stavins, 1995)) and it may be possible to use command-and-control regulation at lower cost.

Fourth, with respect to tradeable permit markets, the costs of monitoring and enforcement may also reduce the desirability associated with such a mechanism (Hahn and Axtell 1995; Montero 2007). If it is difficult to legitimately monitor and enforce a permit market, it may easier and more cost effective to introduce technology standards.

Fifth, market-based regulation to be (cost) effective has to overcome the political barriers of implementing such schemes. This may be troublesome when firms and the regulator prefer the status quo (Buchanan and Tullock, 1975; Ackerman and Stewart 1985; Hahn and McGarthland, 1989).

Up to this point we have discussed what types of regulation occur in most industrialised countries and briefly explained the debate around whether it is desirable to use command-and-control or market-based regulation. Yet, what has happened in reality? Is there a trend in implementing environmental policy within industrialised countries? If so, what has caused this trend in regulation? Our next subsection will attempt to answer these questions.

1.1.3 The Trend in Environmental Regulation

As discussed above, modern environmental regulation began in the late 1960s and early 1970s where command-and-control regulations were predominantly used. Initially using command-and-control regulation was an obvious choice as regulators in industrialised countries were uncertain and inexperienced with respect to the science of pollution, the regulatory process and the relationships between industry and the government. It seemed plausible that regulation should take the form of prescriptive regulation where uncertainty over environmental results was minimised. Indeed, there was a belief in bureaucratic rationality where "social and economic problems can be solved through the application of technical, hierarchy, uniform rules and neutral compliance" (Fiorino, 2006 p39). As Eisner (2007) suggests, regulation in this early stage (especially in the US), focused on the adversarial relationship between the conflicting objectives of the regulator and industry. As a product of the command-and-control regulation movement, the UK implemented the 1956 Clean Air Act (McCormick, 2002) and the US followed by legislating the amendments to the Clean Air and Water Acts in 1970 and 1972 respectively (Eisner, 2007).

From the introduction of command-and-control regulation, the last 50 years (especially in the last 15 years) has seen a movement towards a greater use of market-based mechanisms. For example, many countries in the EU have introduced taxes and charges for pollutants and in 2005, the EU introduced a tradeable permit market for carbon dioxide. A similar trend has occurred in the US where market-based mechanisms have been used to control the levels of lead, CFCs, sulphur dioxide and nitrous oxides. Recently, seven northeastern US states have implemented plans to create a Regional Greenhouse Gas Initiative (RGGI) to control carbon dioxide (Burtraw et al. 2005). The movement towards an increased use of market-based mechanisms can be placed in the context of a movement towards 'Reflexive law' (Teubner, 1983; Orts, 1995). Unlike substantive law, which is rather prescriptive and reactionary, reflexive law "is playing a role in the transition to a new, more adaptable regulation. The goal of a reflexive strategy is to induce people and organizations to assess their behaviour continually, so they may respond to new information, emerging technologies and changing expectations" (Fiorino, 2006 p161). This differs from command-and-control regulation as this can be used to create "incentives and procedures that induce people and organizations to assess their actions and...adjust them to achieve socially desirable goals, rather that tell them what to do" (Fiorino, 2007 p159).

Although, the movement towards market-based mechanisms has had a paradigm shift in the culture and ethos of environmental regulation, command-and-control regulation still accounts for the majority of environmental legislature even though, as discussed above, market-based mechanisms are typically the most cost effective policy (Ackerman and Stewart, 1985; Hahn and Stavins, 1991; Kehone et al. 1998; Hahn, 2000). What can account for the shift in environmental regulation? and why has the shift in regulations been smaller than expected?

An important motivation for moving towards market-based mechanisms is due to the dissatisfaction created from implementing command-and-control policies (Hahn and Stavins 1991 Fiorino 2006; Stavins 2007).[7] As described above, in the last 50 years of stable economic growth, the associated cost burden of command-and-control regulation has continually increased (Eisner, 2007).

Since the adoption of command-and-control regulation in the 1970s, the political and cultural perspectives on how we view regulation and pollution has altered greatly (which is a consequence, in part, of the political culture in the 1980s and 1990s). As described earlier, Kelman (1981) opposed the use of market-based mechanisms as it was unethical and immoral, however, in the 1980s and 1990s, this argument has generally dissipated. Presently, the 'right to pollute' no longer poses significantly issues as it once did and as Stavins (2007 p35) suggests, market-based mechanisms have moved "from being politically problematic to politically attractive". Indeed, Stavins (2007) comments on the widespread support for market-based mechanisms from environmental non-governmental organisations.

The two most important determinants of environmental policy may be the financial cost of the mechanisms and the political acceptability of mechanisms, however, there are other, additional reasons for the change. After 50 years of regulation, regulators have learned a great deal about the design and implementation of environmental policies. Regulators have had the opportunity to implement a diverse range

[7] Note that the choice of environmental policy is a result of the political pressure and negotiations of stakeholders in regulation (Tietenberg, 1998; Hahn, 2000; Desai, 2002). An obvious influence is the regulator, however, the choice of policy and instrument use also depends on lobbying from interest groups and political parties (e.g. Greenpeace, WWF,CBI), the transfer and impact of information through media services, international organisation (e.g. UN), among others.

of policy instruments and as a result have improved their experience of market-based instruments.

As science and technology have progressed, most industrialised countries have become aware of new and diverse pollution problems, such as the reduction of the ozone layer and global climate change. Yet as new pollution problems are realised, command-and-control has proven to be insufficient at tackling the problem. Many pollution problems are transboundary and need effective policy instruments, something market-based instruments can potentially assist in.

Market-based mechanisms are being used extensively on ‘new’ and previously unregulated pollution problems, such as the reduction of carbon dioxide. This tends to be much easier to implement as regulators do not need to consider the political barriers that are created when there is an incumbent policy instrument.

Although market-based mechanisms have increased in popularity there still appears to be an inherent resistance against such schemes. As Kehone et al. (1998) and Stavins (2007) have suggested, there are a number of reasons for the slow movement towards market-based instruments. Generally, the slow movement is due to the preference for the status quo from the majority of stakeholders. Regulated firms often prefer command-and-control as it may be less costly. In market-based mechanisms regulated firms may have to ‘bid’ for permits in an auction or pay an emissions tax—something that does not occur in command-and-control policies. Indeed, market-based mechanisms may be least-cost on aggregate, however, it is possible that some firms may find market-based mechanisms more costly than traditional regulation (Buchanan and Tullock, 1975). Moreover, moving to market-based mechanisms may reduce firms' lobbying effectiveness. In general, within command-and-control regulation, regulated firms may have invested time and resources into lobbying. However, the adoption of market-based mechanisms focuses attention on aggregate pollution (instead of firm specific standards) and as a consequence may make firms' lobbying activities less effective (or at least requires firms to adjust their lobbying techniques for market-based mechanisms).

Regulators may also prefer to use command-and-control policies. If regulators are risk averse they may prefer instruments that accomplish environmental outcomes with greater certainty. Implementing, technology or performance standards may achieve an environmental outcome with more certainty than say, a tax.[8] Regulators that use command-and-control policies have scope in which to use symbolic politics so they can appear to be 'strict on polluters' by requiring high levels of technology or performance standards but allow relaxations or exemptions in other areas of production. As Eisner (2007 p53) suggests "regulatory design is driven not by a quest for efficiency or effectiveness but by the goals of achieving certainty of results and preserving today's victories". Although command-and-control regulation is often seen as costly and inflexible, the regulator may be slow to adjust as it may have obtained specialist skills and information that may be irrelevant in a market-based approach (such as activities to determine the best available control technology).

The discussion thus far has only considered a 'typical' industrialised country, however, countries have differences in the advocation, development and implementation of market-based mechanisms. Although, it is not in the scope of this chapter

[8]Indeed, a reason why tradeable permit markets continue to be a preferred instrument over emissions taxes is the greater certainty regarding the aggregate emissions level.

to give a detailed analysis of the differences of environmental policy between different industrialised countries, we do highlight some fundamental difference in the American and European experience of market-based mechanisms.[9] First, US and the EU have very different relationships between the government and regulated industry. As Fiorino (2006) argues, the EU countries tend to create a regulatory climate where cooperation and consensus is the norm, for example in European environmental policy, there tends to be a large amount of voluntary agreements and cooperative behaviour between the regulator and firms. In contrast, the US federal government and industry have been kept at 'arms' length' due to the reliance on formal regulations (Fiorino, 2006). Second, the US is narrower in scope (with respect to technology processes and techniques) and more prescriptive than the EU. This has lead to a greater need for legal compliance and deterrence procedures than the EU. Third, US environmental policy is centralised to the Federal government (Environmental Protection Agency (EPA)). As Harrington and Morgenstern (2007 p107) argue, a centralised process was necessary as "[m]ost states had, in the minds of many, demonstrated that they could not act quickly enough or forcefully enough to deal with the multitude of environmental problems facing the country". In contrast, as the EU consists of 27 sovereign member states, a large proportion of environmental regulation is decentralised. However, due to continuing economic integration there is a tendency for harmonisation of polices to occur in the EU. Currently, many policies are centralised to the European Commission yet

[9] For discussion of the UK environmental policy see Vogel (1986), Gray (1995), for the U.S. see Fiorino (2006) and Eisner (2007). For discussion of other industrialised countries see Jänicke and Weidner (1997) and Desai (2002). For a comprehensive guide to contemporary European environmental policy see Jordan (2005).

there appears still to be flexibility within the process (Weale, 2005). For example, the European Union Emissions Trading Scheme (EU-ETS) is centralised with the aggregate carbon dioxide target and broad guidance, yet each member state has an active involvement in creating, developing, implementing and enforcing the permit markets rules (Watanabe and Robinson, 2005). Finally, as Harrington and Morgenstern (2007) highlight, different types of mechanisms are used in the US and EU. The majority of market-based instruments in the US are tradeable permit markets whereas, in Europe, emissions taxes and charges are the norm. This composition of mechanisms may occur due to the US's centralised regulatory system and the EU's decentralised framework and issues with national borders and sovereignty.

1.2 Tradeable Permit Markets

One of the most innovative market-based mechanisms, and the subject of this thesis, is a tradeable permit market. The fundamental idea of a tradeable permit market is credited to Dales (1968a; 1968b) and Crocker (1966) who argued for a system of pollution regulation where firms can legitimately pollute when they hold a well-defined and tradeable pollution right.[10]

To implement a tradeable permit market the regulator must determine (through discussions with the general public and industry) a desirable, or socially optimal, level of emissions. The target level of emissions is then partitioned into individual pollution rights which allows the holder to emit a specified level of emissions of the

[10] The terminology 'right' is used loosely. As Raymond (2003) explains, this is not a property right as it is licensed to firms from the government. Instead, one might consider 'licensed property'.

pollutant within a certain time period (e.g. one tonne of carbon dioxide in time period 2007-2012). The regulator creates trading rules for the pollution rights and then allocates the individual pollution rights to the regulated firms. After initial allocation, the pollution rights can be traded among the regulated firms.

Allowing for the transferability of pollution rights results in the environmental target being satisfied at the lowest social cost. A firm that finds pollution abatement relatively costly has the opportunity to lower its cost by purchasing allowances from the market. Moreover, firms that find pollution abatement relatively cheap have the ability to sell any excess permits to the market. In equilibrium, the lowest social cost will be achieved when each firm chooses a level of emissions (pollution reduction) so that their marginal abatement cost is equated to the permit price. Put differently, the social cost of a specified pollution reduction target is minimised when firms' marginal abatement costs are equated—the level of abatement is efficiently distributed among the regulated firms.

As discussed above, market-based mechanisms, and in particular tradeable permit markets, have become an increasingly common regulatory tool. Tradeable permit markets are used most frequently in controlling air pollutants. Schemes include the sulphur dioxide trading program or 'Acid Rain Program' (Ellerman et al. 2000; Carlson et al. 2000), NO_x budget program (Farrell, 2000; 2001), Regional Clean Air Incentives Market (RECLAIM) (Foster and Hahn 1995), Lead-phase down program (Kerr and Maré, 1998), Ozone depleting gases (CFCs) (Hahn and McGartland, 1989), volatile organic matter (Shannon; 1995), European Union Emissions Trading Scheme (EU-ETS) (Watanabe and Robinson, 2005) and the Regional Greenhouse

Gas Initiative (RGGI) (Burtraw et al. 2005).

Although the application of tradeable permit markets to air pollution has been the most successful and well known application, others do exist. Applications have be discussed in water pollution and water supply (Eheart, 1980; Hanley and Moffat; 1993; Hanley et al. 1998), fishery quotas (ITQs) (Newell et al. 2005), waste disposal (Miranda et al. 1994), biodiversity conservation and land use (Mills 1980; MacMillan, 2004), forestry (Chomitz, 2004), recycling (Dinan, 1992), Energy (Berry, 2002) and even outerspace (Scheraga, 1987).

A frequently discussed issue in most tradeable permit markets is the regulator's initial allocation of permits to the regulated firms. Early in the theoretical discussions of tradeable permit markets, the seminal work of Montgomery (1972) argued that the efficiency at the permit market equilibrium was independent from the regulator's initial allocation of permits. Therefore, a regulator could allocate permits focusing on equity issues and continue to maintain efficiency in the permit market. However, as will be explained later in this thesis, the initial allocation of permits can affect both the equity and efficiency of a tradeable permit market. It is generally agreed that "the initial allocation matters a great deal, not only in terms of its impact on the fairness of the program but also on its cost-effectiveness. The initial allocation process also turns out in many emissions trading systems to be the most controversial aspect of the implementation process" (Tietenberg 2006 p127). This issue is the focus for the thesis.

1.3 Objective of Research

The general aim of this thesis is to investigate issues in the initial allocation of pollution permits which affect the efficiency in a tradeable permit market. This thesis investigates two central characteristics about permit markets, namely, (i) a market with multiple periods and (ii) the free allocation of permits to firms. It is true for both characteristics that they predominantly occur in tradeable permit markets and it is important to understand their link with market efficiency. To investigate this area, this research attempts to answer three sub-questions:

- What are the consequences for market efficiency in a tradeable permit market when firms are initially allocated permits in a multi-period market?
- What are the consequences for market efficiency in a dynamic tradeable permit market when firms lobby over permit allocations?
- Are there optimal alternative initial allocation mechanisms that can be used in a dynamic setting?

In answering these questions, this thesis aims to contribute to the literature in a number of areas. By creating a generalised allocation mechanism that can model all types of distribution, the consequences for market efficiency can be explained in a dynamic permit market. From this, specific types of mechanisms can be advocated to distribute permits in a multiple period market. Moreover, we introduce lobbying activity to a multi-period permit market and investigate the impact of efficiency. As a result, it is shown that regulators, in certain circumstances must take this into consideration when allocating permits. Finally, given the investigation into the impacts of market efficiency from the initial allocation mechanism, we offer a possible solution to problems with current allocation mechanisms.

From the outset, this thesis restricts research to the theoretical investigation of tradeable permit market efficiency, insofar as the wider economy is not our main focus. Indeed, this research is theoretical and (mainly) analytical, therefore the extension to empirical investigation is left for future work. Moreover, as our primary focus is on the efficiency of the tradeable permit market, we do not focus on the equity and fairness issues but do indicate, in passing, suggested literature for the interested reader.

1.4 Outline of Thesis

The thesis is separated into three distinct sections, Part I introduces the thesis topic with this general introduction and a review of the literature that focuses on the theoretical issues of efficiency and permit allocation. Part II, investigates the efficiency of a tradeable permit market when (i) there are multiple periods and (ii) when firms lobby over permit allocations. Part III concludes the thesis by illustrating a possible alternative allocation mechanism and concludes the findings of this thesis.

In Chapter 2 the conventional 'independence of the initial allocation' result is explained. We then review the key studies that illustrate the importance of the initial allocation with respect to the efficiency at the market equilibrium and find that the initial allocation may be important to market efficiency when the permit market is imperfectly competitive, transaction costs exist and the market is dynamic.

In Chapter 3 we generalise the analysis of initial allocation mechanisms that are based on inter-firm relative performance comparisons (including grandfathering and auctions, as well as novel mechanisms). We show that using firms' historical output for allocating permits is never optimal in a dynamic permit market setting, while using firms' historical emissions is optimal only in closed trading systems and only for a narrow class of allocation mechanisms. Instead, it is possible to achieve social optimality by allocating permits based only on an external factor, which is independent of output and emissions. We then outline sufficient conditions for a socially optimal relative performance mechanism.

In Chapter 4, we investigate the effects of lobbying over permit allocation in a multi-period tradeable permit market. We model a permit distribution that is based on rent-seeking – the combined effect from each firm's (updated) historical emissions and lobbying activity. We find, permit market efficiency is determined by the rent-seeking costs. If rent-seeking costs are separable (independent), then distortions are created in the permit market. However, when costs are non-separable (interdependent), the "fusion" of past emissions and lobbying activity can maintain efficiency in the permit market. Moreover, when permits are distributed using static grandfathering the permit market is efficient. Allowing the aggregate emissions cap to become endogenous (variable) reduces social welfare.

In Chapter 5, we investigate an alternative permit allocation mechanism, namely, a rank-ordered contest. Each firm is rank-ordered with respect to a pre-determined 'action' chosen by the regulator which is independent from firms' choices of emissions and output. We find that using a permit allocation contest can optimally allocate pollution permits to firms in the tradeable permit market. It is shown that a permit allocation can be chosen in the contest to maximise some ‘secondary’ policy objective pre-determined by the regulator. We conclude with a numerical estimation of what choice of permit allocation maximises the ‘secondary’ policy objective.

In Chapter 6, the thesis concludes with a general discussion of the results and possible recommendations this thesis can give to policymakers

Chapter 2

Theoretical Developments in the Initial Allocation of Permits: A Review

2.1 Introduction

Tradeable permit markets are an increasingly popular method of controlling pollution, for example, they are used in sulphur dioxide regulation in the US (Ellerman et al. 2000) and more recently, as regional carbon dioxide regulation in the EU (Watanabe and Robinson, 2005). Due to the heterogeneous circumstances encountered in tradeable permit markets, success of a scheme depends extensively on the regulator's choice of market design. When implementing tradeable pollution markets, the regulator must carefully consider issues that involve market participation (exclusion), pollutant type, trading and reporting rules and so on. One important design issue is the regulator's initial allocation of pollution permits to market participants.

Within a tradeable permit market, the regulator has significant informational asymmetries regarding the participating firms and, as a result, the regulator is unable to distribute permit allocations that anticipate the least-cost (efficient) equilibrium outcome (if they could, trading would not be required). It follows that the initial allocation of permits may be an important issue for the regulator and firms as it has the potential to determine the distribution of firms' rents (equity) and pollution reduction incentives (market efficiency). Due to the importance of the initial allocation, this chapter aims to survey the theoretical developments in the initial allocation of permits.

In this chapter, we discuss the major contributions in the literature that have extended the theoretical analysis of the initial allocation of permits.[1] We begin the survey by illustrating the seminal work of Montgomery (1972). Montgomery (1972) proved that under a perfectly competitive market the efficiency at the equilibrium outcome was independent of the choice of initial allocation (although it will affect the equity of the market). In policy terms, the perfectly competitive market will establish the least-cost outcome with *any* initial allocation vector. However, the independence between the initial allocation of permits and the least-cost outcome only holds due to a number of strong (and often unrealistic) assumptions. We therefore, discuss the major contributions in the literature that have advanced the theoretical developments in the permit market literature on the initial allocation process. In particular, we focus attention on how (and to what extent) the initial allocation

[1] Other surveys relating to aspects of tradable permits include Tietenberg (1980) who discusses general implementation issues in permit trading and Koutstaal (1999) who discusses imperfectly competitive behaviour and transaction costs in emissions markets.

affects market efficiency when three assumptions are relaxed (i) imperfectly competitive markets (ii) the existence of transaction costs and (iii) a dynamic market.

We find that when a permit market involves imperfectly competitive behaviour, transaction costs or dynamic periods, the initial allocation may be an important determinant for permit market efficiency at the equilibrium outcome. Therefore, allocating permits based only on equity and distributional arguments should not be considered. Instead, when regulators implement a permit market, they should consider the likely issues that may arise (e.g. strategic behaviour of firms) in that permit market and devise an appropriate allocation mechanism. As permit market circumstances are largely heterogeneous, the initial allocation choice should be considered on a case-by-case basis.

Due to the vast selection of literature that, directly or indirectly, discusses the initial allocation process, our chapter is restricted in two main directions. First, we restrict our attention to grandfathering permits—the *free* allocation of permits based on historical emissions or output—as this method is frequently used in existing schemes. However this is not the only option for initial allocation. One alternative to grandfathering is the auctioning of permits and it is generally considered that auctions can efficiently allocate permits and allow the auction revenue to be 'recycled' (something that does not happen with grandfathering) (see, for example Cramton and Kerr, 2002). However, auctions have been used infrequently due to firms' political pressure (lobbying activity) for a grandfathering method (Svendsen, 2005). Second, we restrict our literature survey to *theoretical* issues of initial allocations that relate to market efficiency. It follows that we do not consider issues that relate to distributional and equity arguments in permit allocation, such as the 'fairness' of certain initial allocations (see, for example, Raymond, 2003). Although important, as these issues often determine the viability of schemes, we neglect discussions which involve the political and equity issues. This survey does not propose how to choose optimal mechanisms as this must take into consideration both the efficiency and distributional arguments and will inevitably depend on the circumstances of the tradeable permit market.[2] Moreover, although we discuss the empirical, experimental and simulation evidence to support the theoretical results, this is not the focus of our chapter. It is our objective to consider the theoretical consequences for market efficiency when key assumptions about the permit market are violated.

The chapter is organised as follows, in section 2.2 we discuss the independence of the initial allocation with respect to the efficiency of the equilibrium outcome, in section 2.3 we discuss three distinct developments of the permit market literature that focus on the initial allocation of permits, namely imperfectly competitive behaviour, transaction costs and dynamic markets and finally section 2.4 has some concluding remarks.

2.2 The Independence of Initial Allocations

We begin the discussion of initial allocations by explaining the rationale for a property rights-based approach to pollution and show, under certain conditions, that

[2]There is a large amount of literature associated with comparing the efficiency and equity differences in alternative initial allocation processes (e.g. grandfathering vs. auctioning). Examples of this literature include Lyon (1982; 1986), Bovenberg and de Mooij (1994), Goulder (1995), Jaffe and Stavins (1995), Kverndokk (1995), Bovernberg and Goulder (1996), Goulder et al. (1997), Parry (1997), Rose et al. (1998), Parry et al. (1999), Goulder et al. (1999), Burtraw et al. (2001; 2002), Cramton and Kerr (2002), Kampas and White (2003) and Requate (2005).

the permit market equilibrium outcome is independent from the initial assignment of permits. This sets up our subsequent analysis of the results of relaxing these conditions.

2.2.1 Theoretical Underpinnings

Pollution is the definitive example of an externality, as the polluter inadvertently reduces the sufferers' utility without equal compensation for the damages that it causes (Baumol and Oates, 1988). One proposed method to counter the problem and hence reduce the effects of pollution on the environment is to define legal and enforceable property rights where an economic agent holds the right to pollute or conversely the right *not* to be polluted.

One of the first expositions to define property rights for externalities was the seminal paper by Coase (1960). Coase argued that an efficient level of pollution can be achieved by relying on the polluter and sufferer bargaining given a set of well defined property rights. Coase began by assuming a bargaining system for well defined property rights which assumed that there were no informational deficiencies such as moral hazard and adverse selection problems when transactions occurred (i.e. no transaction costs). Given these assumptions, if property rights were allocated to either of the agents (polluter or sufferer) then a Pareto efficient bargaining equilibrium will exist.

Consider a firm that in the production of a good creates a harmful pollutant.[3]

[3] Assume that the marginal net private benefit and marginal external cost are linear and continuous so that the unique intersection point is the efficient outcome for the externality (Baumol and Oates, 1988)

Suppose an affected household is endowed with the right to be protected from the pollution. The household may allow pollution to occur by accepting suitable compensation (for at *least* the suffering caused) from the firm. This is essentially the minimum compensation level the household is willing to accept. Simultaneously, the firm may choose to compensate the household if the amount it spends reimbursing the household is less than the fall in income it would experience if not allowed to pollute. This is the maximum compensation level the firm is willing to pay. The outcome is that the firm and household can enter into a Pareto efficient bargaining agreement if the minimum compensation level the household is willing to accept is lower than the maximum the firm is willing to reimburse.

In the above example, the household was allocated the property rights for the pollutant. Yet it is possible to distribute the property rights to the firm. In our example, this would mean that the ownership of the property right switches so that the firm has the right to pollute. It follows that the household may be willing to reimburse the firm (for not polluting) until the cost of compensation makes it more rational to take other actions e.g. move to a new (unpolluted) household property. Therefore, there is a maximum level of compensation the household will award to the firm. On the other hand, the firm is willing to accept a compensation payment only if it covers at *least* the cost of reducing the pollutant- the minimum amount it will accept. When the firm's minimum willingness to accept compensation is lower than the household's maximum willingness to compensate, then there is a viable Pareto efficient bargaining equilibrium and a socially optimal level of emissions.

In summary, the property rights for pollution can be initially allocated to either the firm (the right to pollute) or the household (the right not to be polluted). Regardless of the initial allocation, bargaining between the agents results in an efficient equilibrium for the property rights. As Coase (1960) argues, if property rights are well defined and no transaction costs exist, the efficient equilibrium outcome for an externality is *independent* of the initial distribution of property rights.

Under an emissions trading program a similar logic applies, firms (agents) bargain over the ownership of the pollution permits (property rights) in a tradeable market and the initial distribution of permits is independent to the efficiency at the equilibrium. In his (1972) paper, Montgomery used the analytical framework of an emissions trading scheme and formally proved Coase's result that the efficient equilibrium outcome is independent of the initial allocation of property rights.

2.2.2 The Original Independent Initial Allocation Solution

In this subsection, we attempt to follow Montgomery (1972) and illustrate that efficiency at the equilibrium is independent of the initial allocation. To provide a focus for discussion, we restrict attention to an ambient permit system (APS) which refers to a permit system where the property rights are in terms of air or water quality. It is beyond the scope of this chapter to analyse alternative pollutant systems, for this, the reader is referred to Baumol and Oates (1988), Hahn (1986), Krupnick et al. (1983) and Tietenberg (1985) for a comprehensive discussion.

Montgomery in his 1972 study, constructed a tradeable pollution market and in the process, proved that the equilibrium outcome in the market was independent of the initial allocation of pollution permits. To obtain this result three key restrictions are assumed (1) the product and permit markets are *perfectly competitive* so that there is no strategic behaviour (2) there are no *transaction costs* involved in trading the pollution permits and (3) the product and permit markets are *static* and therefore the regulator and polluters are myopic in their analysis of emissions and other regulatory issues.

Montgomery (1972) essentially assumes that firm i ($i = 1, 2, \ldots, n$) emits a single pollutant e_i at a cost of $c_i(e_i)$, which is convex and twice differentiable, where the aggregate emissions vector for the pollutant is $E = (e_{1,\ldots,}e_n)$. There are $j = 1, 2, \ldots, k$ geographical receptor regions where the damage from a pollutant may vary due to factors (such as the wind speed and direction, locality of sources), and is represented by a $n \times k$ matrix H where h_{ij} is the transfer coefficient showing the impact of one unit of emissions from firm i at the point j.

Socially Optimal Condition

A regulator determines, through the political process, a level of desirable emissions that are required, denoted by $Q = (q_{1,\ldots,}q_k)$. The goal of the regulator is to achieve this emissions target at the lowest possible cost. A vector of emissions E is chosen to

$$Min \sum_i c_i(e_i)$$

subject to

$$EH \leq Q, E \geq 0$$

From the Kuhn-tucker conditions, the least cost allocation occurs when

$$c_i'(e_i) + \sum_j \lambda_j h_{ij} \geq 0, \quad \sum_i e_i(c_i'(e_i) + \sum_j \lambda_j h_{ij}) = 0 \tag{2.1}$$

$$q_j - \sum_i e_i h_{ij} \geq 0, \quad \sum_j \lambda_j(q_j - \sum_i e_i h_{ij}) = 0 \tag{2.2}$$

where λ_j is the value placed on relaxing the emissions constraint (q_j) by one unit. Equation (2.1) illustrates that at the least cost allocation, every firm will equate their marginal cost of reducing emissions with the weighted marginal cost of reducing concentration at each receptor (Tietenberg, 1985). Equation (2.2) illustrates that the level of emissions (damages included) will equal the number of permits available.

Market Equilibrium

By assuming l_{ij} is the quantity of permits allowing firm i to emit at point j, l_{ij}^0 is the initial allocation and p_j is the price of a permit at the j^{th} receptor, we can focus on the existence and efficiency of the market equilibrium. As the pollutant is non-uniformly mixed, k markets will be created where each firm must hold a number of permits for each receptor. Firm i's objective is to minimise the cost of emissions and net demand for pollution permits. Formally, we have

$$\min_{e_i} c_i(e_i) + \sum_j p_j(l_{ij} - l_{ij}^0) \text{ subject to } l_{ij} \geq e_i h_{ij}$$

This occurs when

$$c_i'(e_i) + \sum_j \lambda_j h_{ij} \geq 0, \quad e_i(c_i'(e_i) + \sum_j \lambda_j h_{ij}) = 0 \tag{2.3}$$

$$p_j - \lambda_j \geq 0, \quad \sum_j l_{ij}(p_j - \lambda_j) = 0 \tag{2.4}$$

$$l_{ij} - \sum_i e_i h_{ij} \geq 0, \quad \sum_j \lambda_j(l_{ij} - \sum_i e_i h_{ij}) = 0 \tag{2.5}$$

$$\sum_i (l_{ij} - l_{ij}^0) \leq 0, \quad \sum_j p_j(\sum_i (l_{ij} - l_{ij}^0)) = 0 \tag{2.6}$$

where equation (2.6) is a market clearing condition. Comparing (2.1)-(2.2) and (2.3)-(2.5), it is easily seen that the market equilibrium coincides with the least-cost allocation, when $p_j = \lambda_j$, as the same set of sufficient conditions are satisfied with the market equilibrium and the aggregate cost minimisation problem (Baumol and Oates 1988). Intuitively, in the market, each firm competitively exchanges permits to minimise their abatement costs and net expenditure on permits and therefore equates their marginal abatement costs (the shadow values of pollution control) to the price in *each* receptor. As the market is competitive, this happens for all firms which results in the sufficient condition for the aggregate cost minimisation problem being satisfied. Throughout this chapter (and thesis) we denote this outcome as the least-cost equilibrium.

Observing equations (2.3)-(2.6) illustrates that l_{ij}^0, the initial allocation of permits, is not an influential parameter (it does exist in the market clearing equation (2.6) but only as a summation and hence total supply). This effectively says that if a firm receives an arbitrary allocation of permits (given that the markets are *static*, *perfectly competitive* with no *transaction costs*) a firm can costlessly trade permits until the firm minimises its abatement cost. In other words, the firm's behaviour is independent from the number of permits that it receives. It follows that the market equilibrium (the vector of emissions and prices as well as the portfolio of permits held by each firm) is *independent* of the initial allocation.

The independence of initial allocations suggests a regulator can choose *any* initial allocation rule and be assured that the resulting equilibrium will be efficient. The choice of an allocation rule can therefore be based on equity considerations alone.

2.3 Modifications to the independent initial allocation

Montgomery (1972) proved permit market efficiency is independent from the choice of initial allocation. However, the assumptions used to obtain the result are often unrealistic for current tradeable permit markets. Therefore, it is important to understand the implications for market efficiency when the assumptions of the tradeable permit market are modified. We attempt to understand how and to what extent the initial allocation determines the equilibrium outcome by surveying the important theoretical developments in the literature regarding (i) imperfectly competitive permit and output markets (ii) costly permit trading and (iii) dynamic permit markets.

	Competitive permit market	**Imperfectly competitive permit market**
Competitive product market	Perfectly competitive permit and product market, e.g. Montgomery (1972).	Cost Minimisation Manipulation (CMM), e.g. Hahn (1984)
Imperfectly competitive product market	Imperfect product market with perfectly competitive permit market, e.g. Malueg (1990).	Exclusionary Manipulation (EM), e.g. Misiolek and Elder (1989).

Table 2.1: Permit and Output Market Structures

2.3.1 Imperfectly competitive pollution and product markets

There are a number of permutations available for the perfectly competitive assumption to be relaxed. As can be seen in Table 2.1, one must consider three forms of imperfect competition, either in the permit market, the product market or both. We consider each in turn.

Imperfectly competitive permit market and competitive product market

First, we consider an imperfectly competitive permit market.[4] It may be possible for a dominant (permit market) firm to act as a monopolist/monopsonist in which it manipulates the permit market to minimise their expenditure on abatement and purchase of permits. This is known as Cost Minimisation Manipulation (CMM).

[4] Throughout this chapter, we implicitly assume there is complete compliance in the permit market. Van Egteren and Weber (1996) and Malik (2002) consider the relevance of the initial allocation for firm non-compliance.

Hahn (1984) was the first study to suggest that the efficiency at the equilibrium is related to the initial allocation of permits. Focusing on CMM, he analysed an optimisation problem by allowing the firm with market power to choose a permit price.

It was shown that if the dominant firm was allocated permits differently from what it would choose at equilibrium then an incentive would exist for the firm to trade in a manner not consistent with the least-cost equilibrium (that is, allocation of too many or too few permits would result in monopolist and monopsonist behaviour, respectively). The dominant firm will choose a permit price to obtain their optimal permit holdings whilst minimising *their* financial burden at the expense of reduced market efficiency. Doing so would result in an uncompetitive permit price and cause aggregate abatement costs, across the sum of polluters, to be higher than would occur at the least-cost allocation. Hahn (1984) also found that as the initial allocation deviates from the equilibrium level (in both directions) the aggregate cost (inefficiency) would increase. In policy terms, it is possible to achieve the least cost allocation by allocating a number permits to the dominant firm identical to the number chosen by the firm in equilibrium. If the dominant firm obtained permits equal to the choice made in equilibrium then there is less requirement for the firm to participate in trading and hence the manipulatory behaviour and inefficiency is reduced.

The importance of the initial allocation with respect to the least-cost equilibrium outcome is not dependent on a monopolist or monopsonist having the ability to influence the permit price as similar theoretical results exist when a small number of firms act as price-makers. For example, Westskog (1996) extended the CMM model by applying it to an international permit market with multiple market power countries. The market contained a number of leaders which acted like Cournot countries within that group, and the remaining countries followed as a competitive fringe. Here, the market efficiency was still influenced, in a similar manner, by the initial allocation of permits.

As discussed, the traditional view of CMM focuses on the ability of a market power firm to manipulate the permit price due to the divergence between the initial allocation and the permit holdings chosen by the firm in equilibrium. However, the extent to which a dominant firm manipulates the market may depend on the size of permit (mis)allocation. Recently, this reasoning has been adapted by Maeda (2003). Maeda (2003) found that a necessary condition for CMM to exist is the requirement that the number of excess permits allocated to the monopolist must be larger than the net demand (net shortage) for permits in the market. In other words, If a firm obtains excess permits but this is small in proportion to the net demand in the market, then there is very little potential of the firm being able to significantly manipulate the permit price. Therefore, a dominant firm can hold permits over and above its optimal holdings without participating in uncompetitive behaviour. As a consequence, an upper limit of permit holdings exists where additional permit holdings below this level do not affect the efficiency of the market and therefore, the initial allocation is independent of the equilibrium outcome. Over and above this threshold, market power becomes prevalent and market efficiency may reduce.

It appears that CMM is theoretically important in linking the initial allocation to the efficiency at the equilibrium, yet the theory may be of lesser importance due to the small number of possible scenarios. CMM may be an important issue when (i) the market is *thin*, that is, there is a small number of traders and (ii) when excessive permits are allocated to firms over and above net demand (over some threshold).

The *thinness* or lack of potential traders, may occur due to the geographical boundaries of an emissions scheme where very few firms have the opportunity to participate in the scheme (e.g. Hanley and Moffat (1993)). Even if a large number of firms participated in the market, trading restrictions (used mainly for non-uniformly mixed pollutants) may restrict the number of potential traders (e.g. O'Neil et al. (1983)).

Also, CMM may be an important issue when a firm is allocated too many (few) permits and, due to their market dominance, has the opportunity to influence the market (e.g. Böhringer and Löschel (2003)). The experimental evidence regarding the existence of CMM opportunities is in general agreement with Hahn's hypothesis. Godby (2000; 2002) investigated a permit market with one dominant firm and a small number of traders using an experimental approach. By specifying a dominant trader and altering the magnitudes of the initial allocation to the traders, the evidence suggested that Hahn's hypothesis was correct. As an alternative to Godby's (2002) small number of players, Böhringer and Löschel (2003) simulated an international carbon trading scheme where one country had a dominant position due to an excess allocation of permits. The excess permits are known as *hot-air*: an allocation given over-and-above the expected emissions of a country (the former Soviet Union countries are likely to experience this in an international permit market due to a dramatic economic downturn after the Kyoto baseline period). They found the initial allocation of permits can affect the efficiency of the market. More recently, Klepper and Peterson (2005) discussed different institutional and permit allocation designs in *hot-air* economies. They found, in agreement with Hahn's hypothesis, that the permit allocation choices in *hot-air* economies were important in determining the equilibrium outcome.[5]

An imperfectly competitive permit and product market

Up to this point we have discussed market power in relation to a dominant firm minimising its abatement cost and purchasing of permits with detrimental effects to the permit market—*simple* market power. However, it is possible that a dominant firm in the permit market has the possibility of manipulating the amount of permits (and consequently the permit price) to increase rivals' production costs in the output market—Exclusionary Manipulation (EM). In other words the dominant permit market firm will choose a permit price (or permit holdings) to try and exclude fringe firms from the product market by increasing their production costs. For example, this may occur when a permit market is established where a large proportion of the regulated firms are in the same regional product market (such as energy producers).[6]

The value of a permit to a dominant firm now includes the benefit it obtains from influencing the product market vis-à-vis the permit price. Misiolek and Elder

[5] CMM has also been analysed through a double auction allocation system with mixed results with respect to the control of market power and the subsequent effects on the market efficiency (Brown-Kruse et al., 1995; Carlén, 2003; Cason et al., 2003; Muller et al., 2002).

[6] We assume that the firm is dominant in both the permit and product market, however, it can be assumed that the firm is a price taker in the output market. The key issue to understand is the firm has dominance in the permit market which will raise rivals' costs, irrespective of whether the firm is a price-taker or dominant in the product market (Salop and Scheffman, 1983; Rogerson, 1984; Salop and Scheffman, 1987).

(1989) were the first to formally show the effects of such a scenario. They described two cases: a monopolist and a monopsonist in the permit market.[7]

Similar to the CMM case above, a monopolist in the permit market experiences 'traditional' incentives in which the firm would supply too little to the permit market (abate too little) to increase profit from permit sales. With exclusionary manipulation, the dominant firm has an added incentive to increase the permit price (restrict supply) as this may enhance its monopoly power in the product market by raising the per-unit production costs of the product market firms (to exclude rival firms). Therefore, for a monopolist, both incentives motivate the dominant firm to reduce the permit supply (the dominant firm holds more permits than without EM).

For a monopsony in the permit market, the incentives are more complicated. The firm, as a traditional monopsonist, will purchase too *few* permits (abate too much) compared to the least-cost equilibrium. However the monopsonist has an incentive to purchase *more* permits to increase the permit price so that the per-unit production cost of other firms in the industry increase (in an attempt to increase the product price). Therefore, a monopsonist has two conflicting incentives. Paradoxically, due this conflict, as the exclusionary value of a permit increases, the dominant firm will increase its purchase of permits and thereby improve the distribution of permits and market efficiency (again, the firm will hold more permits than without EM). In the extreme case, it is even possible for the monopsonist to purchase more permits than in a competitive market.

[7] Alternatively, Innes et al. (1991) considered the case where a firm is a monopolist in the product market with potential market power in the permit market. The competitive fringe, although participating in the permit market has a separate product market. They find, in contrast to Hahn (1984), to maximise welfare, the initial allocation to the dominant firm should be larger than the firms choice of emissions in equilibrium (Remark 3, p331).

Recently, this framework was adapted to illustrate the criterion needed for an efficient permit allocation. Eshel (2005), with imperfect competition in the permit and product markets, found if the dominant firm is a net supplier of permits, then similar to Misiolek and Elder (1989), there is an incentive for the firm to increase the permit price to raise the remaining firms' costs. Eshel (2005) finds, the firm may have an incentive to increase the permit price even if it is a net demander of permits (as a monosponsit one would expect the price of permits to be chosen below the dominant firm's marginal abatement cost). Although increasing the permit price will increase the dominant firm's cost, it is willing to do this if the profit obtained from the product market outweighs the increased cost from the permit market. In other words, raising the permit price will reduce the remaining firms output in the product market which increase the dominant firm's profit in the output market.

Exclusionary manipulation is not just a problem when one dominant firm can exert power in both permit and product markets. Von Der Fehr (1993) introduced a duopoly in the permit and product market and found that changing the market structure does not appear to alter the results of EM: strategic considerations in both markets continue to motivate each firm to minimise their permit market cost whilst simultaneously attempting to increase their rival's product market cost. Similarly, Sartzetakis (1997a) modelled a Cournot Duopoly product market where only one of these firms had dominance in the permit market and found the permit price increased when the initial allocation of permits was increased to the dominant firm. Again, the dominant firm's ability to increase the price was used as a strategy to raise rivals' cost (and deter entry in the product market). Indeed, Sartzetakis (1997a) found by controlling (reducing) the initial allocation of permits to the dominant firm, market power could be controlled in the permit market. Therefore, under a theoretical duopoly setting, the initial permit allocation appears to influence the efficiency at the market equilibrium.[8]

Competitive Permit Market and Imperfectly Competitive Product Market

The final scenario involves a competitive permit market and an imperfectly competitive product market. For example, this could occur if a competitive permit scheme (due to a large number of participating firms) covered multiple product industries which, in their own right, were imperfectly competitive, such as the European Union Emission Trading Scheme (EU-ETS). In order to analyse the possible consequences, Malueg (1990) and Sartzetakis (1997b) have considered the welfare issues of an imperfectly competitive product market with a competitive permit market. Both studies assume a link between the output of a firm and the emissions it creates so that abatement efforts (and costs) influence production decisions (and costs).

As discussed in section (2.2.2), given a competitive permit market, abatement effort will be redistributed so that firms' marginal abatement costs are equated. A firm that finds abatement cheap relative to the permit price (a 'low-cost' firm) will increase its abatement and sell any surplus permits to the market whereas a firm that finds it relatively expensive to abate (a 'high-cost' firm) will reduce its abatement whilst purchasing permits in the market. As a consequence, the aggregate cost of

[8] Fershtman and de Zeeuw (1995) also consider a duopoly in the permit and product market and find trading may lead to inefficient choices of production and abatement.

reducing pollution is minimised. It follows that with the introduction of a tradeable permit market, the equalisation of marginal abatement costs *improves* welfare due to the pollutant being reduced at the lowest possible cost.

A second effect occurs in the product market. Due to imperfect competition in the product market and each firms' specific abatement technologies, output from product market may be redistributed from the 'low-cost' to the 'high-cost' firms which will result in a reduction in welfare (profit reduction). 'High-cost' firms in the permit market acquire permits and thereby reduce their marginal abatement cost (which has direct affects on their marginal production costs). In the imperfect product market, 'high-cost' firms reduce marginal production costs and as a result increase output. The exact opposite is experienced by 'low-cost' firms.

Malueg (1990) suggested that the net effect on welfare was ambiguous for the case of an oligopolistic product market. He finds the extent to which social welfare can improve depends on the distribution of cost reductions. In particular, if the tradeable permit market 'evenly' ('unevenly') distributes cost reductions among firms then social welfare will rise (fall). Intuitively, an 'even' distribution of cost reductions means that the relative affect on output choice is negligible whereas an 'uneven' distribution results in 'high-cost' firms altering their output relatively more than 'low-cost' firms.

By modelling a Cournot duopoly, Sartzetakis (1997b) found different results. Although a redistribution of output from the 'high-cost' firm to the 'low-cost' exists, this effect was proven to be smaller than the benefit obtain from the reduced aggregate abatement costs from the permit market. The negative welfare effect is limited due to the fact that firms will, in equilibrium, adjust their abatement until their marginal abatement cost is equal to the permit price. As a result, the change in marginal production costs of all firms is limited.

It is clear from both studies that an imperfectly competitive product market has an effect on social welfare. Yet it appears not to affect the equilibrium outcome in the permit market: the imperfectly competitive product market has no efficiency effects on the permit market and as the permit market is competitive, the initial allocation does not alter the equilibrium outcome. This mirrors the result of Montgomery (1972) discussed earlier.

In summary, the discussion of the last three subsection leads to the following remark;

Remark 1 *An imperfectly competitive permit market is a sufficient condition for the initial allocation to determine the equilibrium outcome in the permit market.*

2.3.2 Transaction Costs

In the 'traditional' model of a tradeable permit market, it is assumed that participating firms can costlessly trade permits. Yet this assumption is often unrealistic as transaction costs occur in a variety of forms. Prior to the exchange of permits, firms may find it costly to search for potential traders. Transaction costs can occur due to the existence of informational deficiencies in the permit market, such as the imperfect and asymmetric information on the location of traders, the availability of permits for purchase or sale, and so on. Moreover, transaction costs may continue to pose a problem after a trading partner has been found as trade negotiation may be costly (which also includes the cost of time spent bargaining).[9]

Hahn and Hester (1989a; 1989b) found clear confirmation of large transaction costs (and reduction in market efficiency) due to the large amount of trading and administrative restrictions in the EPA's Emissions Trading Program and in the permit program for the Fox river, Wisconsin.[10] The existence of transaction costs was supported by Foster and Hahn (1995) whereby they analysed the trading activity in the Los Angeles basin (RECLAIM) and found transaction costs significantly altered behaviour in the permit market. Moreover, Gangadharan (2000) econometrically tested the existence and severity of transaction costs in the RECLAIM emissions program. Transaction costs appeared to be most influential in the earlier periods of the program which suggests at the beginning of emissions programs, as very little trading has taken place, the search and informational costs are large but as firms gain knowledge and experience of the market, the cost of trading falls. That is, as the market develops, firms' experiences of trading are enhanced and the search and informational costs will diminish. This argument is supported by evidence from the SO_2 emissions trading program. Doucet and Strauss (1994), Conrad and Kohn (1996), Joskow et al. (1998), Schmalensee et al. (1998) and Ellerman et al. (2000) provide evidence that transaction costs declined throughout time as firms gained more experience with trading permits (as time progressed the permit price was relatively

[9]We do not consider the regulator's costs throughout the planning, implementation and enforcement of a trading scheme. For instance, when the structure of the market is first chosen preliminary consultations with industry and government are needed, and once a program has become operational the regulator faces costs through the implementation and enforcement of the administrative structure (Krutilla, 1999; Kohn, 1991). Henceforth, we neglect the costs associated with the regulator and instead focus on firm-to-firm transaction costs.

[10]See also Atkinson and Tietenberg (1991) for a discussion about the Emissions Trading Programs divergence from the cost effective allocation.

stable). A fundamental reason for the successful development of this market was the improved market information and price discovery experienced by firms through the annual auction mechanism. Similarly, Kerr and Mare (1998) econometrically analysed the US lead permit market and found evidence that suggested transaction costs existed and were important to the cost effectiveness of the market.

It is evident from the above discussion that transaction costs, if present, can change market efficiency. With this in mind, Stavins' (1995) study was the first to analyse the relationship between the initial allocation, transaction costs and market efficiency. By associating a cost with exchanging permits, Stavins (1995) modelled a firm optimisation problem which explicitly considered transaction costs.

Stavins (1995) found that introducing transaction costs created a 'wedge' (the marginal transaction cost) between a firm's marginal abatement cost and the permit price. Consequently, if marginal transaction costs were non-zero, the equalisation of firms' marginal abatement cost will not be achieved (a reduction in efficiency). According to Stavins (1995), the affect of changing initial allocation is dependent on the specific functional form of the transaction cost (the second derivative of the transaction cost function). In particular, he found that when the marginal transaction cost is constant (second derivative is zero), the initial allocation does not alter the efficiency at equilibrium, similar to Montgomery (1972).

However, non-constant marginal transaction costs do appear to alter the efficient equilibrium of abatement. If marginal transaction costs are increasing (decreasing), then a movement of the initial allocation away from the efficient equilibrium allocation level will increase (decrease) the departure from the least-cost equilibrium.

When marginal transaction costs are increasing, the cost of additional transactions increases at an increasing rate. Therefore it will be relatively expensive to reach the efficient market equilibrium with an allocation level that is further away from the efficient level. Conversely, decreasing marginal transaction costs allow scale economies to occur in transactions. Therefore, it will be relatively easier for a firm to reach the efficient equilibrium with an allocation that is further away from the least-cost equilibrium level.

Supporting these findings, Cason and Gangadharan (2003) experimentally tested the effects of the initial allocation with transaction costs. A laboratory experiment was created where subjects were placed into a situation with zero, constant and decreasing transaction costs and the initial allocation was altered to determine the effects on the equilibrium outcome.

Up to this point, the theory has focused on the consequences of transaction costs when trading has been approved. Yet costly trading can also be encountered when firms are uncertain about the regulator's approval of trade. This is evident in non-uniformly mixed pollutant markets where regulatory trade approval is necessary due to the increased likelihood of the ambient environmental target being violated (Hahn and Hester, 1989a). Each firm in the emissions market has the option to trade. If the firm decides not to trade then zero transaction costs are experienced and the emissions (abatement) choice is the only required action. However, if the firm decides to trade then the firm will incur transaction costs associated with searching for potential trading partners with the possibility that the trade will not be approved.

Using this logic, Montero (1998) extended the Stavins' (1995) transaction cost model to include a firm's uncertainty over trade approval. This model assumes that firms place a probability on the success of an approved trade. With this general setting, transaction costs and uncertainty in trade approval tend to strengthen the causation between the distribution of permits and the efficiency at the equilibrium outcome, although, the explicit levels of transaction costs and trade probability make detailed descriptions of the effects troublesome. To support his findings, Montero (1998) simulated a permit market using discontinuous marginal abatement costs for each firm and found the initial allocation was able to determine the efficiency at the equilibrium even with constant marginal transaction costs (due to the discontinuous abatement costs).

It appears that transaction costs, with or without uncertainty, create an important link between the equilibrium outcome and the allocation of permits.[11] In summary;

Remark 2 *The existence of non-constant marginal transaction costs is a sufficient condition for the initial allocation to determine the equilibrium outcome in the permit market.*

Although studies focusing on transaction costs and the initial allocation of permits appear to be well founded, there has been little attempt to extend the theory significantly. Imperfectly competitive permit markets are a significant issue when

[11] A number of papers have extended the use of transaction costs but without significant comment on the relationship between the initial allocation of permits and the efficiency of the equilibrium outcome. For instance, Netusil and Braden (2001) examined the effects of sequential and bilateral trading with transaction costs and Nagurney and Dhanda (2000) modelled an oligopolistic product market with multiple pollutants and transaction costs.

designing and implementing programs and it may be important to include analysis of the relationship between transaction costs, initial allocation and the equilibrium outcome in an imperfectly competitive permit environment. Also, transaction costs appear to be significant when the target pollutant is non-uniformly mixed, yet no studies attempt to analyse the consequences for the initial allocation in such schemes. The role of dynamic transaction costs may also be an important extension as market learning and experience may alter the significance and characteristics of transaction costs.

2.3.3 Dynamic Permit Markets

Up to this point we have reviewed the relationship between the initial allocation and market efficiency in a *static* tradeable permit market—a scheme with one compliance period and one initial allocation. However, the static analysis is often limited in effectiveness as many tradeable permit schemes have multiple compliance periods (e.g. EU-ETS and the two phases of the SO_2). In this subsection, we discuss the relationship between the initial allocation and market efficiency when a tradeable permit market is *dynamic*— a market in which there are multiple compliance periods and permit allocations (initially allocated at the start of *every* period).

In order to analyse the affect of the initial allocation on market efficiency, one must consider a number of additional concepts: the use of updated baselines (historical information on emissions and output) and the intertemporal exchanging of permits (banking and borrowing).

It may become necessary for a regulator to alter the baseline of historical emissions and/or output throughout a dynamic permit market, for example, this may be of importance when a regulator has to consider how to accommodate new entrants and firm closures in a compliance period (Åhman et al. 2007). Without some type of dynamic revision of permit allocations, firms that close plants will continue to receive permits in every future period and new entrants would have to purchase all permits from the market (which may not be desirable).

Throughout this review (and thesis), we define an *updating* grandfathering mechanism as one that reviews a firm's allocation based on their historically updated production and/or emissions choices. The use of a firm's output (and emissions) to allocate permits has been widely discussed in a static setting. Fischer (2001) considered environmental policy schemes (tradeable performance standards, taxes and tradeable permits) that rebated revenues based on output market shares. For a tradeable permit market this meant an output-based grandfathering allocation. Fischer (2001) found that using such an allocation process provided an implicit output subsidy.[12] This conclusion was supported by Burtraw et al. (2001; 2002) and Burtraw et al. (2005; 2006) who investigated the cost-effectiveness of alternative allocation mechanisms in the electricity sector of a tradeable permit scheme. Moreover, Fischer (2003b), Fischer and Fox (2004) and Bernard et al. (2007) extend the basic model to include imperfect competition in the output market and a general

[12]Output-based allocation has similar effects to a rate-based target or 'intensity' cap—where energy intensity is capped instead of absolute emissions (Dewees, 2001; Ellerman and Wing, 2003; Kuik and Mulder, 2004). Both types of allocation system result in similar implicit output subsidies. The noticeable difference between the two types concentrates on the cap. In output-based allocations, the aggregate emissions cap is generally fixed so that average allocation per unit of output has to be altered to take into account (changing) total output. Whereas under a rate-based mechanism allocation per unit of output is held constant and instead the aggregate emissions cap is altered (effectively there is no absolute aggregate emissions cap) (Fischer, 2003a). It is not in the scope of this review to consider these types of mechanisms in detail (See, Sterner and Höglund, 2000; Fischer, 2001; Fischer 2003b).

equilibrium analysis, respectively.

As output-based allocations create an implicit output subsidy, Edwards and Hutton (2001) used a computable general equilibrium model of the UK to investigate a number of possible allocation mechanisms and found an output-based allocation improved GNP and welfare in the economy (encourages a switch to domestically produced goods). Similarly, Haites (2003) finds this type of mechanism can be used in a tradeable permit markets to reduce the output decline of industries that are adversely affected by international competition. Furthermore, Åhman et al. (2007) has advocated an updated system (with a sufficiently long time lag of ten years) for the EU-ETS to incorporate new entrants and firm closures and suggests that it may weaken firms' perverse incentives in the market.

In general terms, the regulator can allow firms to exchange permits *within* and *between* periods (either with themselves or other firms) so that firms have the option to 'bank' and 'borrow' permits. Banking is the term used to describe a firm reserving current period permits for use in a future compliance period, whereas borrowing arises when a firm uses a proportion of future period permits in the current period. Cronshaw and Kruse (1996) modelled the banking of permits and found that the competitive equilibrium was least-cost. By allowing for borrowing and continuous time, Rubin (1996) showed the equilibrium least-cost outcome is reached and detailed emissions and price paths for the duration of the dynamic market. Schennach (2000) considered bankable permits in the context of the SO_2 trading program and found firms' behaviour can be split into two periods: the first period where a proportion of permits are banked and the second period, where all permits are used immediately with the remaining banked permits. Schennach (2000) is able to determine permit price and emission paths as well as the length of banking period and also extends the model to include the consequences for banking incentives when uncertainty regarding the demand for electricity and technological innovations exists. Another important aspect of intertemporal trading is the extent of the damage caused by the timing of emissions. Kling and Rubin (1997) argued that allowing intertemporal trade may mean that a firm delays abatement till later periods which results in higher present value abatement costs and damages above the efficient level. Yet, when a stock pollutant is considered the efficient level can be achieved (Leiby and Rubin, 2001).

We now turn to the discussion of studies that analyse the relationship between the initial allocation and market efficiency by making a distinction between studies that allow for inter-temporal trading and those that do not.

No Inter-temporal Trading

Initially consider a competitive permit market which allocates a lump-sum endowment to each firm at the start of (possibly infinite) periods, such as an 'one-off' grandfathering mechanism. Without banking and borrowing, the dynamic model is similar to a continually repeated static market. Therefore, it follows that firms' behaviour (the choice of output and emissions) is independent of the permit allocation received and the firms' marginal abatement costs will equate—market efficiency is independent from the choice of initial allocation.

However, as mentioned above, there may be a need to periodically review the baselines of historical emissions and output (e.g. new entrants and closures). Under updated grandfathering a link is created between a firm's permit allocation and the historical choices of output and emissions. Essentially this is the '*Ratchet Effect*', which uses current firm performance to determine the targets and endowments allocated to the firms in future periods (see for example, Freixas et al. 1985; Harrison and Radov, 2002). The first paper to formally analyse a dynamic permit market with an updated allocation mechanism was Böhringer and Lange (2005a).

Böhringer and Lange (2005a) found that the efficiency at the equilibrium was determined by the structure of the market *and* whether firm-specific information was used to allocate permits. Böhringer and Lange (2005a) considered two types of permit market: an open and closed market. In an open system, firms obtain permits from a regulator but can also purchase permits from 'outside' the market such as a domestic allocation within an international market. In contrast, a closed permit market does not allow trading to occur outside the market in so far as the regulator has full control over the supply of permits, such as in the SO_2 program.

It was found that when the market is open, an allocation process that uses updated historical information on emissions and/or output creates distortionary incentives for firms to increase emissions and output (similar to Fischer (2001)). Consequently, the initial allocation can only achieve the least-cost equilibrium outcome when the endowments to firms are distributed using a method which is independent of firm emissions and output, such as an auction.

However, under a closed system, Böhringer and Lange (2005a) found it is possible to allocate permits using historical updated emissions information and still reach a least-cost equilibrium. By allocating permits to firms based on identical allocation rules, all firms experience the same marginal benefit of obtaining permits, and although the demand for permits increases, this is reflected by an increase in the nominal permit price (as the supply of permits is fixed) (This will be discussed extensively in Chapter (3)).

For both an open and closed market, Böhringer and Lange (2005a) showed that using an updated output-based allocation will never obtain the least-cost equilibrium outcome. Jensen and Rasmussen (2000) supports this outcome by creating a dynamic general equilibrium numerical model that used auctioning and allocations based on output and emissions to distribute pollution permits and found output-based allocation is more costly than either auctioning or 'one-off' grandfathering.

In a separate model without considering the 'openness' or 'closedness', Sterner and Muller (2006) discuss the static, updating and current period methods of allocation based on emissions, inputs and outputs of firms and find, similar to Böhringer and Lange (2005a), that the use of emissions and output (except when static) have a suboptimal price, abatement and output effect compared to the least-cost outcome.

Further support for Böhringer and Lange (2005a) is supplied by Martinez and Neuhoff (2005). Martinez and Neuhoff (2005) considered the electricity sector in the EU-ETS that allocates permits through the updated historical information of emissions and finds that such a scheme distorts the permit price. Inefficiencies in the market will be created if permits are traded between sectors/regions that face *different* updating rules and discount factors. In other words, similar to the Böhringer and Lange (2005a) result, if the allocation rule is identical across, sectors and firms, then it is possible to allocate permits in a least-cost manner. Similarly, Neuhoff et al. (2006) numerically simulated the consequences for the EU-ETS electricity sector with an updating output-based allocation and found clear evidence of implicit output subsidies and noticed that the number of plant closures falls when using an output-based allocation and accelerated construction of plants occurs for new entrants. Demailly and Quirion (2006) numerically simulated the cement sector in the EU-ETS and compared 'one-off' grandfathering and updated output-based allocation and again find updated output-based allocation, induces an implicit output subsidies and reduces abatement compared to auctioning and 'one-off' grandfathering.

Given the regulator knows the permit market structure, it can choose a form of initial allocation than can induce efficiency at the equilibrium. In particular, if the market is open then a lump-sum allocation (such as an auction) will induce efficiency whereas if the market is closed then it is possible to induce efficiency by distributing permits based on updated historical emissions information. Updated output-based allocation always produces distortionary incentives to increase output and consequently should not be used by the regulator.

However, by adapting Fischer (2001), Böhringer and Lange (2005b) compared output-based and emissions-based allocations with respect to output and employment and found the former is more desirable than the latter as emission-based allocations not only distorts output (as an output-based allocation would do), it additionally distorts the choice of emission rates due to the subsidy on emissions.[13]

[13] Bode (2006) also analyses updated emissions-based and output-based allocations for the electricity sector and finds installations, due to their alternative fuel types, can have varying degrees of rent distribution due to the different allocation rules. However, he does not consider the efficiency of the allocation schemes.

Inter-temporal Trading (Banking and Borrowing Allowed)

We now extend analysis to a dynamic permit market that allows banking and borrowing to occur.[14] Initially consider a competitive permit market which endows each firm with a constant (lump-sum) allocation at the start of each period, such as a predetermined allocation that is subdivided for each period. Assuming there are no informational deficiencies, in each period, a firm, will choose an optimal level of emissions to minimise the present value of abatement costs (Cronshaw and Kruse, 1996). In such a market the permit price will rise at the rate of interest similar to Hotelling's rule (Tietenberg, 1985).

Although the above studies (Cronshaw and Kruse, 1996; Rubin, 1996; Kling and Rubin,1997; Leiby and Rubin, 2001) are important in investigating the possibility of intertemporal trade, they do not focus on the link between initial allocation and efficiency at the equilibrium. Due to the assumption of complete information, the focus has concentrated on analysing the optimal emissions and price paths whilst portraying the initial endowment of permits as optimal for each firm and exogenous from their actions. However, some studies have begun to focus on the relevance of the initial allocation in a banking and borrowing setting. Yates and Cronshaw (2001) emphasised the importance of the initial allocation in determining the least-cost outcome. Assuming firms have better information than the regulator (e.g. firms will have more information on abatement costs) a choice of initial allocation can be found to obtain the least-cost outcome. In particular, the level of optimal

[14] Although not discussed in this chapter, a number of studies have combined the inter-temporal banking and borrowing of permits with market power (Hagem and Westskog, 1998; Liski and Montero, 2005).

allocations is dependent on the optimal permit discount rate (a regulatory rule that determines the rate at which the number of banked permits in the current period are exchanged for future permits). This framework was extended by Feng and Zhao (2005) who included uncertainty and focused on multiple effects on the banking permit redistribution compared to a 'no banking' scenario. The optimal level of permits appeared to be identical regardless if banking was included or not.

Very few studies have investigated the link between market efficiency and updated grandfathering when the banking and borrowing of permits is allowed. Martinez and Neuhoff (2005) introduced a permit market with banking and borrowing that allowed firms to be allocated permits based on updated historical emissions and find that banking and borrowing with updating causes emissions to move from the second period to the first.

Rehdanz and Tol (2007) investigated a two period model with updated grandfathering. By introducing banking and borrowing, it was shown that there is a tendency for borrowing to occur when updated grandfathering is used. Intuitively, borrowing allows firms the option to increase current period emissions and as a result obtain a larger future period allocation. In particular, there is net borrowing when future emissions reduction obligations are large relative to the current period.

In a dynamic permit trading market, the initial allocation may alter the efficiency of the equilibrium outcome when a link exists between firm actions and permit rent. However, it was discussed that in some special circumstances (e.g. Böhringer and Lange, (2005a)), historical updated emissions can be used to achieve a least-cost equilibrium. This will be the focus of the preceding chapter. When banking and borrowing is allowed, recent findings show that the updating and banking effects can switch emissions to current periods and distort incentives. It follows that:

Remark 3 *The initial allocation based on updated emissions and/or output may determine (dynamic) market efficiency at the equilibrium.*

In a dynamic market setting, research that focuses on the link between the initial allocation and the efficiency at the equilibrium is in its infancy. This is especially true when one considers the lack of studies which discuss this link with banking and borrowing. As it appears that dynamic permit markets are increasingly important in the current regulatory climate, attempts need to be made to fully understand the link between the dynamic market, the initial allocation and permit market efficiency in equilibrium.

2.4 Conclusion

Tradeable permit markets are a frequently used instrument to control pollution. Within existing schemes, the choice of permit allocation is controversial as it can determine the efficiency and equity in the market. A change in the initial allocation may distort firms' pollution reduction incentives with consequences for the market efficiency and simultaneously alter the distribution of rents (with consequences for equity in the market).

The purpose of this chapter is to discuss theoretical studies that attempt to investigate the link between the initial allocation of permits and market efficiency. We restrict our chapter in two main directions. First, we focus on 'grandfathering' of

Permit market developments	**Importance of the Initial Allocation**
Uncompetitive Behaviour	Initial Allocation may be important when uncompetitive behaviour exists in permit market
Transaction costs	Initial Allocation may be important when non-constant transaction costs exist
Dynamic Market	Initial Allocation may be important when firm choice variables are used as the allocation criterion

Table 2.2: Implications for Market Efficiency

permits—free allocation based on historical emissions and/or output information—as it is a frequently used mechanism. Second, we concentrate on studies that analyse the theoretical consequences for market efficiency insofar as we neglect discussions that relate to the equity and distributional arguments of initial allocations.

We first examined the competitive permit market then relaxed the models assumptions in three distinct ways: market imperfections, transaction costs and dynamic permit markets. We found that the initial allocation of permits in a perfectly competitive permit market can be distributed arbitrarily to the firms as the least-cost equilibrium will be achieved by the competitive trading of permits. As table (2.2) suggests, when the competitive model assumptions are relaxed, the market efficiency and initial allocation of permits are found to be linked.

That is, when a permit market is imperfectly competitive, experience transaction costs or is modelled dynamically then links exist between efficiency at the market equilibrium and the initial allocation.

Existing pollution permit markets experience, to some degree, elements of market power, transaction costs and dynamic behaviour. Therefore, this review illustrates the need for regulators to not only consider equity but also market efficiency issues when creating appropriate initial allocation mechanisms.

Part II

Issues in the Dynamic Initial Allocation of Pollution Permits

Chapter 3

The Optimal Initial Allocation of Pollution Permits: A Relative Performance Approach

3.1 Introduction

Tradeable permit markets have become an important policy tool in the control of pollution.[1] Schemes such as RECLAIM and the SO_2 market in the US have shown that tradeable permits are a viable and cost effective market-based mechanism (e.g. Stavins, 1998; Schmalensee et al., 1998). Yet there is still an active debate about how to allocate permit endowments among the participating firms at the beginning of each trading period. As Böhringer and Lange (2005a) argue, some initial allocation mechanisms may create inter-temporal distortions and result in socially suboptimal

[1] This chapter has been adapted from MacKenzie et al. (2007a).

outcomes.

In this chapter, we extend the results of Böhringer and Lange (2005a) to accommodate most of the existing dynamic initial allocation mechanisms (including grandfathering and auctions, as well as novel mechanisms). We show that using firms' historical outputs for allocating permits is never optimal, while using firms' historical emissions is optimal only in closed trading systems and only for a narrow class of allocation mechanisms. Instead, it is possible to achieve social optimality by allocating permits based only on an external factor, which is independent of output and emissions. We outline sufficient conditions for a socially optimal relative performance mechanism and discuss the issues related to the choice of a suitable mechanism for initial allocation.

In our analysis, we discuss two types of mechanisms that are commonly considered for allocating initial endowments of permits. The first mechanism, which we call an *Absolute* Performance Mechanism (APM), involves permit allocations based on the *levels* of individual firm activity. The second mechanism, which we call a *Relative* Performance Mechanism (RPM), involves permit allocations based on how the levels of a firm's activity compare to the levels of other firms' activities, or on inter-firm *relative comparisons*. The distinction between these two mechanisms is crucial as firms' behaviour in the permit market is subject to whether firms' believe they are obtaining permits individually or, as under a RPM, as part of a game where a firm's allocation is dependent on other firms' actions. We show in this chapter that a mechanism that allocates permits based on firms' absolute performance (APM), as used by Böhringer and Lange (2005a), is a special case of a generalized relative performance mechanism (RPM), and thus that the two mechanisms share a number of optimality properties in a dynamic setting. We however argue that mechanisms which are based on relative performance might be superior over those based on absolute performance and offer a promising alternative to auctioning and grandfathering, namely a rank-order contest.

Both types of mechanisms have had important applications in existing tradeable permit markets. Absolute performance mechanisms have been advocated in the form of relative emissions or intensity-based emissions caps (Fischer 2001; Ellerman and Wing, 2003; Fischer, 2003; Kuik and Mulder, 2004; Pizer, 2005; Newell and Pizer, 2006).[2] In such a scheme *intra-firm* relative comparisons exist, where the performance of a given firm is evaluated relative to its own activity, but not relative to the activity of other firms. Rather than having a cap on absolute levels of emissions, an intensity-based cap involves a ceiling on the emissions intensity (i.e. emissions per one unit of output). This type of approach is becoming increasingly common, for example, Bode (2005) notes that a number of participants in the UK emissions trading scheme were given an intensity target. Furthermore, the Bush administration in the US has strongly advocated this type of approach to tackle climate change (Kolstad, 2005; Pizer, 2005). When a trading system is based on emissions intensity, each firm can unilaterally increase both their output and emissions without changing emissions intensity and without any effect on other firms

[2] We make a distinction between intensity-based caps and output-based allocation (although they do both act as an implicit output subsidy). In intensity rate-based mechanisms the emission cap is adjusted to maintain a constant emissions intensity and hence allocation is not dependent on other firms' behaviour (e.g. the levels of other firms' emissions and output choices). In contrast, output-based mechanisms alter the average allocation per unit of output to maintain a fixed emissions cap (allocation is dependent on firms' behaviour).

(the permit allocation is an adjustable grandfathering mechanism).

However, the majority of distribution rules which have been discussed are relative performance mechanisms. The two most common RPMs include auctions (where firms' are allocated permits based on their relative bids) and grandfathering with a fixed cap (where firms' are allocated permits based on their relative emissions levels with respect to some fixed cap) (see Hahn and Noll, 1982; Lyon, 1984; 1986; Oehmke, 1987; Milliman and Prince, 1989; Van Dyke, 1991; Franciosi et al., 1993; Parry, 1995; Parry et al., 1999; Cramton and Kerr, 2002). However, there is a large selection of RPMs that have not been extensively considered in the literature. For example, yardstick competition, where each firm's performance is assessed relatively to the performance of other firms has been suggested (Shleifer, 1985; Franckx et al., 2005; Nalebuff and Stiglitz, 1983a; 1983b). Moreover, a novel RPM that could be envisaged to allocate permits is the use of contests or tournaments where firms spend resources in order to 'win' a proportion of the permit allocation (Moldovanu and Sela, 2001; 2006).

Inter-firm comparisons using relative performance mechanisms have a number of general regulatory advantages which have been widely documented in the literature (Lazear and Rosen, 1981; Holmström, 1982; Green and Stokey, 1983; Nalebuff and Stiglitz, 1983a; 1983b; Mookherjee, 1984; Shleifer, 1985; Moldovanu and Sela, 2001; 2006). Relative performance mechanisms can also be advantageous in an environmental context. Govindasamy et al. (1994) suggested the use of a tournament to control non-point pollution, and found that a RPM results in a number of desirable outcomes. Franckx et al. (2005) extended the work of Govindasamy et al. (1994)

by using a different RPM, yardstick competition, and conducted the analysis in a more general environmental regulatory setting. They find that this RPM will be desirable when a large number of firms participate and common shocks (such as similar technology shocks or oil price changes) are experienced by all firms.

Rather fewer authors have focused on relative performance issues in emissions trading. Using a rent-seeking model, Malueg and Yates (2006) examine the effects of citizen participation in a permit market to determine the endowment and price of permits. They find that citizens' choice of lobbying and permit purchases in a market depends on the initial allocation mechanism chosen (auctioning or grandfathering). Finally, Groenenberg and Blok (2002) outline an initial allocation mechanism for a permit market that bases distribution on benchmarking the production process of each firm and find it eliminates a large amount of problems associated with existing allocation mechanisms.

For a number of decades the free allocation (grandfathering) of permits has been discussed as a feasible method of allocation (e.g. Tietenberg, 1985). Indeed, the majority of actual emissions trading schemes to date use grandfathering as the primary allocation mechanism due to its political viability: market participants will always lobby for the free allocation of permits (Stavins 1998). Grandfathering might also be seen as offering a closer fit to existing regulatory approaches, since it does not involve any fundamental change in property rights compared with, for instance, a system of performance standards for polluting emissions. Grandfathering might also be preferred by governments on competition grounds, since the avoidance of a lump-sum distribution from industry to government can avoid disadvantaging domestic firms relative to their international competitors. On the negative side, grandfathering could be seen as rewarding firms who have engaged in relatively low pollution control efforts in the past. As grandfathering is a commonly used tool, the discussions regarding the effects of the mechanism have been widespread. In particular, Requate and Unold (2003) have shown that substantial innovation incentives exist for firms in a grandfathered emissions scheme. However, Goulder et al. (1997) found grandfathering to be a rather inefficient allocation mechanism compared to alternative allocation procedures. Recently, grandfathering has been adapted to include a dynamic element (Bode, 2006; Böhringer and Lange, 2005a). In particular, Böhringer and Lange (2005a) have discussed *updated grandfathering* which continually updates the free allocation of permits based on historical emissions and output.[3] Similarly, Sterner and Muller (2006) discuss the static, updating and current period methods of allocation based on emissions, inputs and outputs of firms and find, similar to Böhringer and Lange (2005a), that the use of emissions and output (except when static) have a suboptimal price, abatement and output effect compared to the least-cost outcome.

Another important aspect of the mechanisms in question involves multi-period choice problems in pollution permit markets. Several studies have focused on general design considerations for multi-period permit markets (Cronshaw and Kruse, 1996; Rubin, 1996; Kling and Rubin, 1997; Schennach, 2000; Leiby and Rubin, 2001; Yates and Cronshaw, 2001), yet only a few studies have focused on the initial allocation of permits in this setting. In the context of the electricity sector, Bode (2006)

[3] Also see Fischer (2001), Haites (2003) and Fischer and Fox (2004) who consider output-based allocation.

finds considerable variation in the distributional impacts among different allocation mechanisms within a dynamic emissions trading scheme. Jensen and Rasmussen (2000) model a number of allocation mechanisms in a dynamic setting and find that welfare and employment vary drastically across allocation mechanisms.

The work which is the most relevant to our chapter is by Böhringer and Lange (2005a), who compare the efficiency of dynamic permit allocations based on output, emissions and a lump-sum transfer. In comparing efficiency, they make a distinction between markets that are open (i.e. when firms can trade outside the domestic market) and closed (i.e. when participating firms cannot trade in permits outside the domestic market). This distinction is important to policy analysis as tradeable permit markets are becoming increasingly varied in size and scope and have the potential to have either an open or closed market structure. They find in a closed market it is optimal to allocate permits on criteria not related to output, whereas for an open market, an efficient allocation occurs when the permits are distributed using a lump-sum approach. However, in their treatment of the initial allocation mechanism, Böhringer and Lange (2005a) assume that the permit distribution to a firm is based *only* on firms' absolute levels of output and emissions, so that other firms actions do not affect the allocation of a given firm. Yet, given the fixed emission cap considered by Böhringer and Lange (2005a), the permit allocation to a firm is also crucially dependent on the behaviour of rival firms. This is because a fixed emissions cap implies that if in the current period rival firms, say, increase their output and emissions relative to a given firm, then the current-period aggregate output and emissions increase, thus decreasing the proportion of future permits that each firm can receive per each unit of current output and emissions. As the result, even if a given firm does not alter its own choices, its own future allocation of permits will change. Thus we argue that the initial allocation process considered by Böhringer and Lange (2005a) should take into account other firms' actions and thus should be modelled as a relative performance mechanism.

Our chapter therefore attempts to extend Böhringer and Lange (2005a) by implementing a more general design of a dynamic initial allocation mechanism, which allows for the allocation of permits to be based on each firm's choices *relative to other firms*. Following Böhringer and Lange (2005a), we consider allocation mechanisms which are based on choices of output and emissions, but in addition we consider possible permit allocations based on an "external" factor which is independent of output and emissions. This allows us to create an encompassing model for most existing types of initial allocation mechanisms such as grandfathering, auctioning and contests. We show that a RPM can efficiently (socially optimally) allocate pollution permits if the criteria used to compare firms is based on such an external factor, in a contest. Given the variety of potential external factors, we suggest a number of criteria that a regulator may take into account when choosing a suitable factor. Given the political economy problems with both auctions and grandfathering as a way of initially allocating permits, this new mechanism may well be of interest to policy makers.

Our contribution is thus two-fold. First, we extend the results of Böhringer and Lange (2005a) to a wider class of mechanisms, so-called *relative performance mechanisms*, such as grandfathering with fixed cap, yardsticks, auctions, contests, etc. Although such mechanisms create a situation where firms' choices are interdependent, the general intuition of Böhringer and Lange (2005a) holds in the Nash equilibrium of the ensuing game. That is, for a wide range of mechanisms, for the initial allocation to be cost-efficient, it should not depend on firms' outputs, and may depend on firms' emissions only in limited circumstances. Second, we propose that the lump-sum distribution advocated by Böhringer and Lange (2005a) can be implemented better with a relative performance mechanism based on an external factor. Such a cost-efficient mechanism allows the regulator to achieve a secondary target, such as raising revenue, - thus "killing two birds with one stone".

To the best of our knowledge, this research is the first to introduce a generalised RPM into a permit market which allows us to model most existing relative-based mechanisms and has the added advantage of encompassing APMs. The chapter is organised as follows: section 3.2 outlines our model and presents the social optimality conditions and firm's optimisation problem. A socially optimal dynamic initial allocation mechanism, when the market experiences both exogenous and endogenous permit prices, is considered in section 3.3. Section 3.4 discusses the external factor, while section 3.5 concludes.

3.2 The Model

We follow Böhringer and Lange (2005a) and consider a multi-period partial equilibrium model. The technology of firm i ($i = 1, 2, \ldots, n$) at time t ($t = 1, 2, \ldots$) is given by a cost function $c_{it}(e_{it}, q_{it})$, where q_{it} is the firm's output level, and e_{it} the firm's emissions resulting from production. Costs c_{it} are assumed to be twice differentiable and convex, with $\frac{\partial c_{it}}{\partial e_{it}} \leq 0, \frac{\partial c_{it}}{\partial q_{it}} > 0$, $\frac{\partial^2 c_{it}}{\partial e_{it}^2}$, $\frac{\partial^2 c_{it}}{\partial q_{it}^2}$, $-\frac{\partial^2 c_{it}}{\partial e_{it} \partial q_{it}} \geq 0$ and $\frac{\partial^2 c_{it}}{\partial q_{it}^2} \cdot \frac{\partial^2 c_{it}}{\partial e_{it}^2} - \left(\frac{\partial^2 c_{it}}{\partial e_{it} \partial q_{it}} \right)^2 > 0$.

The firm sells its output in a competitive product market at a price of p_t. Finally, the firm is regulated by a competitive emissions-trading program and receives an initial allocation of permits A_{it}.

We further assume that each firm i also "produces" a factor z_{it} which has no direct relevance in the product and emissions market, and thus is outside the regulator's interests and/or jurisdiction. This "external" factor is "produced" by each firm *independently* of output and emissions at a cost $v_{it}(z_{it})$ (possibly zero), with $\frac{dv_{it}}{dz_{it}} \geq 0$. While this external factor is irrelevant to the product and emissions market, it may determine firms' permit allocations A_{it} in a manner to be specified later.

3.2.1 The Generalised Allocation Mechanism

Böhringer and Lange (2005a) considered a mechanism whereby pollution permits are allocated based on the *levels* of firm's historical production q_{it} and emissions e_{it}.[4] We first extend this mechanism by assuming that in addition to output and emissions, some "external" factor may play a role in how many permits will be allocated to a given firm, but this factor has no relevance to the product and emissions market, and thus is beyond the interest or jurisdiction of the regulator (and it is this factor which determines the lump-sum allocations in the model of Böhringer and Lange, 2005a).

[4] Böhringer and Lange (2005a) considered a number of historical observation periods, $l = (1, 2 \ldots, s)$. For expositional simplicity, we restrict our model to $l = 1$ (the historical period is simply the previous period). It is straightforward to generalise our model to $l > 1$ historical observation periods.

Examples of a possible external factor include population size in a firm's locality, a firm's socially responsible activities, a firm's emissions of other pollutants, a random event such a lottery draw and so on. We denote such external factors as z_{it}. While we will discuss the external factor more in section 3.4, it is worth noting here that the nature of the external factor determines both the cost of this factor to the firm, as well as the degree of firm's control over this factor. For example, population size is both beyond the firm's control and it is "free" to the firm. On the other hand, lottery tickets can be bought by firms, or can be allocated to firms by the regulator (and thus are beyond firms' control). In contrast, in a permit auction, both success and costs of each firm's bid depends on the bids of other participating firms.

Thus, the allocation mechanism based on absolute performance (APM) is given by

$$A_{it}^{APM} = \lambda_{q,it}^{t-1}\tilde{h}(q_{i(t-1)}) + \lambda_{e,it}^{t-1}\tilde{g}(e_{i(t-1)}) + \lambda_{z,it}^{t-1}\tilde{f}(z_{i(t-1)}) \tag{3.1}$$

where $\tilde{h}, \tilde{g}, \tilde{f}$ are increasing and continuously differentiable functions, and $\lambda_{q,it}^{t-1}$, $\lambda_{e,it}^{t-1}$, $\lambda_{z,it}^{t-1} \geq 0$ are the weights (in period t) placed on period $t-1$'s performance. The weights reflect the relative importance of a particular activity, and can vary across time periods and across firms.

We extend equation (3.1) by allowing for firms' performance to be evaluated in comparison to other firms, i.e. how a given firm i's performance at time t in production q_{it}, emissions e_{it}, an external factor z_{it} compares relatively to the performance of every other firm $-i = \{1, \ldots, i-1, i+1, \ldots, n\}$. Formally, firm i's performance at time t in output relatively to other firms' output q_{-it} is given by a relative performance function $h = h(q_{i(t-1)}, q_{-i(t-1)})$. Similarly, relative performance in emissions and external factor are given by $g = g(e_{i(t-1),}e_{-i(t-1)})$, and $f = f(z_{i(t-1),}z_{-i(t-1)})$, respectively. We assume $h_i = \frac{\partial h}{\partial q_{it}}$, $g_i = \frac{\partial g}{\partial e_{it}}$, $f_i = \frac{\partial f}{\partial z_{it}} > 0$ so that, for given levels of other firms' performance, higher levels of emissions, output, and the external factor result in a larger permit allocation. We also assume that $h_{-i} = \frac{\partial h}{\partial q_{-it}}$, $g_{-i} = \frac{\partial g}{\partial e_{-it}}$, $f_{-i} = \frac{\partial f}{\partial z_{-it}} \leq 0$, so that for a given level of firm's performance, its allocation does not increases if other firms' increase their levels of emissions, output, or the external factor.[5]

We take a rather general view of the relative allocation functions. That is, to allow for uncertainty over allocations, we treat these functions as *expectations* over possible realisations. Thus allocations can be distributed using deterministic rules (such as yardstick competitions) devised by the regulator, as well as by lotteries, auctions, or contests. For analytical tractability, we assume that the relative allocation functions h, g, f are continuously differentiable.[6] For example, a firm's relative allocation can be determined continuously based on how its own output compares to aggregate output, e.g. $h(q_{i(t-1)}, q_{-i(t-1)}) = \alpha \frac{q_{it}}{q_{it}+\sum_{-i} q_{-it}}$. Another example of a continuous relative allocation function includes Tullock-type (winner takes all) contest allocations, where a firm's expected amount of permits is given by all participating firms' outputs as follows: $h(q_{i(t-1)}, q_{-i(t-1)}) = \beta \frac{q_{it}^r}{q_{it}^r+\sum_{-i} q_{-it}^r}$ - i.e. the size of the permit lot β multiplied by the probability of winning the contest (see Skaperdas,

[5] Instead, one can assume that h_i and g_i are negative.

[6] Our argument will not change if we relax the assumption of continuity to include relative performance mechanisms such as winner-pay and all-pay auctions involving discontinuities in firms' payoff functions. To deal with such discontinuities, one typically assumes that all firms face commonly known continuously differentiable distribution of firms' "types", and that all firms follow symmetric strictly increasing and differentiable strategy, so that each firm's expected payoff function becomes continuously differentiable.

1996).

Thus, the permit allocation for firm i at time t, according to the generalised Relative Performance Mechanism is

$$A_{it}^{RPM} = \lambda_{q,it}^{t-1} h(q_{i(t-1)}, q_{-i(t-1)}) + \lambda_{e,it}^{t-1} g(e_{i(t-1)}, e_{-i(t-1)}) + \lambda_{z,it}^{t-1} f(z_{i(t-1)}, z_{-i(t-1)}) \quad (3.2)$$

Comparing this relative performance allocation mechanism to that based on absolute performance (3.1), one can observe the following:

Remark 4 *If $h_{-i} \equiv g_{-i} \equiv f_{-i} \equiv 0$ then a relative performance allocation mechanism reduces to an absolute performance allocation mechanism.*

In other words, the absolute performance mechanism considered by Böhringer and Lange (2005a) is a special case of relative performance mechanism when firm i's allocation is independent of the remaining firms' actions. In this case, the remaining firms' actions have no impact on firm i's allocation, and a firm i can obtain permits by optimally choosing q_{it}, e_{it} and z_{it}, *without* considering other firms' actions.

Note that Böhringer and Lange (2005a) implicitly assume that the grandfathering mechanism is an absolute performance mechanism. However, with a fixed emission cap, for a given behaviour of other firms, if a particular firm increases/decreases its output and/or emissions, that would affect the aggregate output and emissions of domestic firms, ultimately affecting how many permits both that firm and all other firms will receive. Thus, it is implicit in Böhringer and Lange (2005a) that the factor weights will change each period to reflect changes in the aggregate activities. To see this, suppose that at time t a fixed amount of permits $\bar{E}_t$ is allocated among n firms proportionally to each firm's output q_{it}. In other words, each firm i receives an allocation $\gamma_t q_{it}$, where $\gamma_t = \frac{\bar{E}_t}{q_{it}+\sum_{-i} q_{-it}}$. Thus, the output weight γ_t has to be adjusted each period to reflect changes in aggregate production. It is easy to see that such a fixed cap grandfathering mechanism is a RPM with $h(q_{i(t-1)}, q_{-i(t-1)}) = \bar{E}_t \frac{q_{it}}{q_{it}+\sum_{-i} q_{-it}}$.

When a relative performance mechanism is used, firm i's choices affect the number of permits allocated to firm $j \neq i$, and thus affect firm j's profits, and vice versa. In other words, a RPM creates a situation where firms' choices are *interdependent*. In such a situation, a rational firm will make its choices strategically, by taking into account the anticipated actions of its rivals. The relative performance permit allocation mechanism thus results in a game among participating firms, which leads firms' behaviour to be typically different from their behaviour when faced with an APM. To explore the distortionary effect of such behaviour, we first need to consider the socially optimal situation.

3.2.2 The Socially Optimal Outcome

We now consider the regulator's point of view. Following Böhringer and Lange (2005a) we assume that the regulator cares about profits and costs associated with the production of output and emissions of the specific pollutant but is not interested in the external factors such as population size, lottery draws, or auction bids (we will come back to this assumption in Section 3.4). Thus, the regulator's objective is to maximise (minimise) the aggregate profit (cost) that all the domestic firms incur while producing the product of the regulator's interests or jurisdiction whilst being constrained by the emissions program.

When trade in emissions permits is not restricted to the regulator's jurisdiction, firms can import/export emissions across the system's borders. From a regulator's point of view, this is a (small) *open* emissions trading system, where the permit price is exogenously determined, and the aggregate emissions in the jurisdiction are not capped. This may occur when the market is open to transactions from other (possibly larger) schemes. For example, in the European Union Emissions Trading Scheme (EU-ETS), member states allocate permits domestically, but firms in each member state can trade permits with firms in other member states.

In such a system, the regulator's objective takes into account the balance of the trade in the emission permits. Thus, given the set of prices (σ_t, p_{it}), the regulator's objective is to

$$\underset{q_{it}, e_{it}}{Max} \sum_t \left[\sum_{i=1}^{n} p_{it} q_{it} - c_{it}(e_{it}, q_{it}) - \sigma_t \left(\sum_{i=1}^{n} e_{it} - \overline{E_t} \right) \right] \tag{3.3}$$

where σ_t is the exogenous permit price determined by the (international) demand and supply of permits in the open market and $\overline{E_t}$ is the domestic emissions cap at time t. For each firm i and each of it's rival $-i = \{1, \ldots, i-1, i+1, \ldots, n\}$, the socially optimal conditions are as follows:[7]

$$p_{it} = \frac{\partial c_{it}}{\partial q_{it}} \tag{3.4}$$

$$-\frac{\partial c_{it}}{\partial e_{it}} = -\frac{\partial c_{jt}}{\partial e_{jt}} (= \sigma_t) \tag{3.5}$$

for all $i, j \neq i, t$. That is, at period t all firms will simultaneously equate their

[7] We follow the language of Böhringer and Lange (2005) and refer to the least-cost outcome and corresponding conditions as socially optimal.

marginal production costs to their firm-specific product price (3.4). Also, in the equilibrium, firms' marginal abatement costs will be equalized (3.5), and will be equal to the (exogenously determined) common permit price.

In contrast, in a *closed* emissions trading system, a single regulator distributes the total supply of permits, and thus ensures that the aggregate emissions are capped: $\sum_i e_{it} = \overline{E}_t$. The emissions permit price is endogenously determined by the (domestic) demand and supply in the closed market. The regulators objective function is thus:

$$\underset{q_{it},e_{it}}{Max} \sum_t \left[\sum_{i=1}^{n} p_{it} q_{it} - c_{it}(e_{it}, q_{it}) \right] \text{ subject to } \sum_{i=1}^{n} e_{it} = \overline{E_t} \tag{3.6}$$

The socially optimal conditions are identical to the conditions (3.4-3.5), except the permit price is now endogenously determined.

3.2.3 Firm Optimisation

We first extended the allocation model of Böhringer and Lange (2005a) by allowing for evaluations based on an independent external factor such as population size, socially responsible activities, emissions of other pollutants, lottery draw, and so on. We now focus our attention on the firm-specific problem. Given the profile of other firms' actions, the set of prices (σ_t, p_{it}), and its permit allocation A_{it} for the target pollutant, a firm i will choose a level of emissions, output and an external factor,

$(q^*_{it,}, e^*_{it,}, z^*_{it})$ to maximise its total stream of profits:

$$\underset{q_{it},e_{it},z_{it}}{Max} \sum_{t=1} [p_{it}q_{it} - c_{it}(e_{it}, q_{it}) - v_{it}(z_{it})] - \sigma_t(e_{it} - A_{it})$$

Thus, when a relative performance mechanism (3.2) is used to allocate pollution permits, firm i's objective function is:

$$\begin{aligned} \underset{q_{it},e_{it},z_{it}}{Max} \sum_{t=1} \quad & ([p_{it}q_{it} - c_{it}(e_{it}, q_{it}) - v_{it}(z_{it})] - \sigma_t e_{it} \\ & + \sigma_t[\lambda^{t-1}_{q,it} h(q_{i(t-1),} q_{-i(t-1)}) + \lambda^{t-1}_{e,it} g(e_{i(t-1),} e_{-i(t-1)}) + \lambda^{t-1}_{z,it} f(z_{i(t-1),} z_{-i(t-1)})]]) \end{aligned}$$

For each firm i and its rivals $-i = \{1, \ldots, i-1, i+1, \ldots, n\}$, the optimal choices are determined by the first order conditions as follows:

$$p_{it} + \sigma_{t+1}\lambda^t_{q,i(t+1)} h_i(q_{it,} q_{-it}) = \frac{\partial c_{it}}{\partial q_{it}} \tag{3.7}$$

$$\sigma_t - \sigma_{t+1}\lambda^t_{e,i(t+1)} g_i(e_{it,} e_{-it}) = -\frac{\partial c_{it}}{\partial e_{it}} \tag{3.8}$$

$$\sigma_{t+1}\lambda^t_{z,i(t+1)} f_i(z_{it,} z_{-it}) = \frac{dv_{it}}{dz_{it}} \tag{3.9}$$

Similarly to the absolute performance allocation mechanism of Böhringer and Lange (2005a), when a firm's current output and emissions determine its *future* allocation of permits (and thus its profits), each firm will take this intertemporal effect into account.[8] Thus, relative to the socially optimal conditions (3.4) and (3.5), a mechanism which uses past performance in output and emissions will generate an

[8]Moreover, the longer historical period over which firm's historical relative performance in output and emissions is taken into account by the scheme designers, the more important is the effect of each current choice on future allocations. Because we assume that only one previous period affects current allocation, we do not explicitly address this point here.

intertemporal distortion of firms' incentives.

Importantly, this holds both for the absolute performance mechanism (3.1) but also for the relative performance mechanism (3.2). To see that, compare equations (3.7) to (3.4), as well as (3.8) to (3.5). Given that g_i and h_i are both positive, such a mechanism creates an implicit incentive to increase production and emissions beyond socially optimal levels.[9] Because the external factor z is outside the interests or jurisdiction of the social planner, it does not distort incentives when either a relative or absolute performance mechanism is used (3.9). For a given profile of other firms' actions, firm i chooses external factor z^*_{it}, optimally, so that the marginal cost of obtaining the factor equals the marginal future benefit obtained from the permit allocation. In summary, we have the following generalisation of the intuition of Böhringer and Lange (2005a):

Remark 5 *When firms' permit allocations are at least partially determined by output and emissions, all permit allocation mechanisms of the general form (3.2) create distortionary incentives in the product and permit markets.*

As we noted above, the absolute performance mechanism (3.1) is a special case of the relative performance mechanism (3.2). Thus, any mechanism that allocates permits based on historical output and/or emissions will distort firm's incentives to produce output and emissions optimally. Not only would the distortions occur when the adjustable cap grandfathering scheme (which is an APM) is used, but also any other scheme which utilizes firms' relative performance with respect to each other in output and/or emissions.

[9] Similarly, if either or both g_i and h_i are negative, there would be an incentive to decrease either production or emissions or both to a suboptimal level.

This problem, of increased output and emissions, is associated with the "ratchet effect"- using current performance to determine future targets and future initial allocations (Weitzman, 1980; Freixas et al., 1985; Bergland et al., 2002). If a firm decided not to increase emissions (output) then their permit allocation would be "ratcheted" down, as their emissions (output) would be *relatively* lower than all other firms. If such a system was implemented, firms that actively lowered emissions (output) would be implicitly punished. Therefore, each firm has an incentive to increase its *relative* emissions (output) to stop their future permit allocation from being lowered. Thus, both RPMs and APMs will create distortions in the output and permits market when the criteria used to allocate permits is based on historical output and/or emissions information.

However, RPMs possess an additional important feature that APMs do not, namely, that a RPM results in a game among participating firms. This is because when each firm is evaluated relatively to other firms, firms' actions become interdependent. In the Nash equilibrium of this game, each firm chooses a profile $(q_{it}^*, e_{it}^*, z_{it}^*)$ according to equations (3.7)-(3.9) given the equilibrium beliefs about other firms' choices.

3.3 Socially Optimal Allocation Mechanisms

In the last section we examined the inefficiencies caused by a generalised relative performance mechanism where the criteria used to allocate permits were based on historical output, emissions, and an external factor. In this section we will extend the argument of Böhringer and Lange (2005a) against the use of historical outputs in generalized relative performance mechanisms. Moreover, when the system is open, so that the permit price is determined exogenously, the external factor should be the sole determinant of the firm's allocations. When the closed system is used, where the permit price can endogenously adjust to the aggregate supply of emissions, there is a possibility of using a linear performance scheme in emissions.

3.3.1 Open System

Recall that in a (small) open permit trading system, the aggregate supply of permits is determined jointly by the domestic allocation of permits and by the allocations of permits to all other foreign participants. Thus, the permit price is determined exogenously. Following Böhringer and Lange (2005a), the market equilibrium outcome (3.8), can be transformed into the socially optimal outcome (3.5), by implementing the sufficient condition $\lambda^t_{e,i(t+1)} = 0$ for all i. Similarly, one can ensure that the individually optimal production level (3.7) corresponds to the socially optimal production level (3.4), by setting $\lambda^t_{q,i(t+1)} = 0$ for all i. This leads us to the following:

Proposition 6 *In a (small) open trading system, a socially optimal outcome can be achieved by allocating permits based on relative performance in an external factor* z_{it} *only. That is, an optimal mechanism involves setting* $\lambda^{t-1}_{q,it} \equiv \lambda^{t-1}_{e,it} \equiv 0$*, for all* i, t *in the allocation equation (3.2):*

$$A_{it} = \lambda^{t-1}_{z,it} f(z_{i(t-1)}, z_{-i(t-1)}) \tag{3.10}$$

That is, in open trading systems, to achieve the socially optimal outcome, a regulator should place a zero weight for historical output and emissions, and design a system that is based solely on firms' performance in an external factor, which is *not* related to the output and emissions choice variables. By restricting allocation to variables that do not affect the permit and product market, the firms' incentives remain undistorted. This occurs because using an external factor breaks the intertemporal link between the permit rent (output subsidy) and the incentive to alter the choice variables. Our results agree with the commonly held view that one can obtain a socially optimal outcome by distributing permits based on an external factor (Goulder et al., 1997; Cramton and Kerr, 2002). Because an absolute performance mechanism is a special case of relative performance mechanism, the above result can be reduced to the result of Böhringer and Lange (2005a, Proposition 2). That is, if the allocation function for each firm i is independent of rivals' actions, it is socially optimal to use historical external factor to allocate permits.

3.3.2 Closed System

We now consider an emissions program where the permit price is endogenously determined by the demand and supply in a closed permit market. This includes a conventional closed market system where the sole supply of permits originates from one regulator and where the permit price is determined by the aggregate level of emissions in the emissions program.

Comparing equations (3.4) with (3.7) and equations (3.5) with (3.8) one can obtain the following socially optimal conditions for output and emissions:

$$\lambda_{q,i(t+1)}^{t} h_i(q_{it}, q_{-it}) = 0 \tag{3.11}$$

$$\lambda_{e,i(t+1)}^{t} g_i(e_{it}, e_{-it}) = \lambda_{e,j(t+1)}^{t} g_j(e_{jt}, e_{-jt}) \tag{3.12}$$

$\forall i$, $j \neq i$ and $-i = \{1, \ldots, i-1, i+1, \ldots, n\}$.

Similar to the exogenous case, equation (3.11) suggests that to achieve social optimality, the marginal benefit to firm i from increasing output should be equal to zero. Thus, a sufficient condition for achieving social optimum involves the regulator placing a zero weight on each firm's historical output:

$$\lambda_{q,i(t+1)}^{t} = 0 \ \forall \ i, t \tag{3.13}$$

In contrast, equation (3.12) suggests that the marginal permit allocation should be equal across firms. This condition is difficult to ensure for all firms and for all functional forms of g. We could find only one set of sufficient conditions for social optimality in emissions which holds for *all* functional forms of g, which is similar to the sufficient conditions for output:

$$\lambda_{e,i(t+1)}^{t} = 0 \ \forall \ i, t \tag{3.14}$$

that is, the regulator should put a zero weight on each firm's historical emissions choices. These conditions not only ensure social optimality for any relative (and thus absolute) performance mechanism, but also requires less problem solving by the regulator and participating firms.

Instead, if a non-zero weight for historical emissions choices is selected then only a narrow class of RPMs satisfy the social optimality condition (3.12). In other words, only RPMs that create an identical marginal allocation can obtain a socially optimal outcome. An example of such a mechanism is a yardstick mechanism that allocates permits to each firm based on how its historical emissions compare to the other firms' average historical emissions e.g. $g(e_{it}, e_{-it}) = \frac{1}{\lambda^t_{e,i(t+1)}} \left(\frac{\bar{E}_{t+1}}{n} + \alpha_t \left(e_{it} - \frac{\sum_{-i} e_{-it}}{n-1} \right) \right)$ for all i and t (as well as its "absolute"counterpart $g(e_{it}) = \frac{\alpha_t}{\lambda^t_{e,i(t+1)}} e_{it}$). Obviously, equating emissions "weights" $\lambda_{e,it}$ across firms makes the problem easier.

Thus, any RPM with identical marginal allocations across firms can socially optimally allocate permits based on firms' relative performances with respect to historical emissions and an external factor. Our results agree with Böhringer and Lange (2005a) who were able to prove that the optimality result holds for a linear APM. Therefore, RPMs and APMs that have identical marginal allocations across firms can obtain a socially optimal outcome.

Thus, it follows from inspection of equations (3.11) and (3.12) that:

Proposition 7 *In closed trading system, a socially optimal outcome can be achieved by allocating permits based on relative performance in an external factor z_{it} as well as using suitably chosen relative performance schemes in historical emissions, and ignoring firms' historical outputs, i.e. $\lambda^{t-1}_{q,it} \equiv 0$, for all i, t. Thus, the allocation equation (3.2) becomes:*

$$A_{it} = \lambda^{t-1}_{e,it} g(e_{i(t-1)}, e_{-i(t-1)}) + \lambda^{t-1}_{z,it} f(z_{i(t-1)}, z_{-i(t-1)}) \tag{3.15}$$

where function g is chosen such that condition (3.12) is satisfied.

Again, because absolute performance mechanisms are a special case of relative performance mechanism, the above result can be reduced to the result of Böhringer and Lange (2005a, Proposition 1). Importantly, one can achieve social optimality in the closed system by using the same permit allocation scheme as in the open system:

Corollary 8 *In closed trading system, a socially optimal outcome can be achieved by allocating permits based on relative performance in an external factor z_{it} only, i.e. $\lambda_{q,it}^{t-1} \equiv \lambda_{e,it}^{t-1} \equiv 0$, for all i, t. Thus, the allocation equation (3.2) becomes:*

$$A_{it} = \lambda_{z,it}^{t-1} f(z_{i(t-1)}, z_{-i(t-1)}) \tag{3.16}$$

In other words, regardless of the nature trading system, one can implement the socially optimal permit allocation mechanism based on the relative performance in the external factor. Thus, the external factor plays a key role in optimal permit allocation scheme, calling for further issues to be considered by the allocation mechanism designer.

3.4 The External Factor

We argued in the previous section that one can achieve social optimality in the product and target pollutant markets by using firms' relative performance with respect to an external factor to allocate target pollution permits. In this section, we will describe the external factor, possible mechanisms based on relative performance in this external factor, as well as the benefits of this approach.

3.4.1 Criteria for the Choice of an External Factor

We define the external factor as anything which has no direct relevance to the product and target pollutant emissions markets, and which is thus beyond the interest or jurisdiction of the regulator. Examples of possible external factor include population size in firm's locality, firm's socially responsible activities, firm's emissions of other pollutants, a random event such a lottery draw, and so on. Since the external factor can take a variety of forms, the regulator faces a choice of a suitable external factor. However, there are a number of issues involved in the external factor choice.

> *Independence:* To achieve social optimality, the "production" of the external factor has to be independent of firms' output and emissions of the target pollutant. Obviously, if the external factor is correlated with firm's output and/or emissions, firms' incentives will be distorted, and social optimality will not be achieved.
>
> *Ease of use:* As the main objective of the regulator is to minimise the aggregate cost of the emissions program, a desirable external factor should be easy for the regulator to observe.
>
> *Reward of Effort:* The regulator may choose the external factor to reward firms' efforts. When heterogeneity of firms' is substantial, the external factor may take a form of "intensity", or within-firm relative assessment - for example, proportion of firm's community activities relative to the size of locality.
>
> *Equal Opportunity:* The regulator may wish to ensure that all firms

have equal opportunity to obtain permit allocations, and thus that the external factor can be produced by every participating firm. When the regulated firms believe they are being treated “fairly” in a sense of *equality of opportunity*, then the emissions program may have a higher chance of success.

Political Acceptability of the External Factor: The success of the allocation scheme may depend on political acceptability of the external factor by the regulated firms and regulator (as well as possibly by the general public).

Fair Allocations: As psychologists suggest, judgments of allocative fairness are affected by the *relative* merits of the recipients, thus suggesting that relative performance mechanisms may be perceived to be “fair” as long as the external factor is considered to be meritorious.[10]

Double Dividend: Of particular interest may be those external factors where the marginal benefits will typically exceed the marginal social costs. In other words, the external factor may be chosen so that it confers some additional benefit to the regulator other than the control of emissions. The regulator could define a costly z_{it} in such a way as it would prefer to observe higher (or lower) values.

As the last three of these issues may be of particular interest to mechanism designers, we will discuss them in detail.

[10] Note further that, as Mellers (1982, 1986) demonstrated, the allocations (of salaries and taxes) judged to be “fair” by human subjects, depended on the *rank* of each recipient’s merit in the merit distribution of the comparison group. In other words, a rank-based contest may be a good candidate for a “fair” relative performance mechanism.

3.4.2 A Non-Monetary External Factor

As it was mentioned above, one of the possible reasons why regulators avoid allocating permits based on firms performance in external "monetary" factor - such as auction bids - is that it is politically unpopular. We thus suggest that perhaps a mechanism that is based on relative performance in a non-monetary external factor, may have a better political acceptability, in particular if they involve a possibility of social betterment. When a non-monetary external factor is chosen as a basis for permit allocations, there are no direct financial transfers. Firms instead are rewarded for the (non-monetary) actions they choose. This reasoning is very similar to the arguments that advocate a grandfathering system rather than an auction (Stavins, 1998). However, as we showed above, grandfathering schemes involving historically updated outputs and emissions are distortive. Yet we suggest that a regulator can choose a non-monetary external factor that is agreeable for firms (or at least less controversial than other criteria).

There is a variety of possible non-monetary external factors. Charitable activities such as support of improvements in education and health infrastructure in the local community may be viable. This may prove to be a meritorious allocation process; firms are given the "right" to pollute based on the degree of their social responsibilities within a community. Another set of alternative external factors may be of particular relevance to environmental regulator. These may include reduction of an external "basket" of environmental pollutants or environmental indicators, for example noise pollution, or investments in energy efficiency. That is, firms could be allocated permits for the target pollutant based on their reduction of completely separate and independent pollutants.

However, we have to emphasize again that, to achieve social optimality in output and emissions markets, a potential non-monetary external factor z_{it} has to be independent from the firm's emissions and output choices. Thus special care has to be taken in regulator's choice of non-target pollutants as external factors as emissions of some pollutants can be correlated with emissions of the target pollutant, leading to potential inefficiencies in target pollutant emissions market.

3.4.3 The Regulator's Secondary Objective

As we mentioned above, there may exist external factors which are irrelevant to the product and target pollutant emissions market, but nevertheless the regulator may be interested in firms engaging in production of this external factor. If this is the case, the regulator may have a primary objective of controlling emissions at lowest social cost, as well as a secondary objective of increasing the aggregate amount of the external factor, or its net benefits.

One obvious example of multiple regulatory objectives is the "double dividend" argument for the use of auctions for permit allocations. As Cramton and Kerr (2002, p.335) suggest, a permit auction can raise revenue whilst enforcing emissions control. This revenue can be used to reduce distortionary taxes in the economy (e.g. Parry, 1997) or reduce the burden on auction participants through a revenue neutral auction (Hahn and Noll, 1982; Hahn, 1988).

Alternatively, there can be two (non-competing) regulators with different objectives. For example, the energy (electricity) industry may be required to participate in an emissions program whilst simultaneously being overseen by social/public policy regulator to promote firms' anti-discriminatory personnel policies. The environmental policy regulator aims to control aggregate emissions at the lowest possible cost and is not concerned about the size or cost of the external factor in any way. The second regulator is possibly a social/public policy regulator whose aim is to maximise the aggregate external factor produced by the participating firms. Another example of a double objective may be the regulation of two environmental targets, with one target being controlled by target pollutant permit market, and another target currently being unregulated - for example, emissions of CO_2 and a basket of other greenhouse gases. In any case, the secondary objective involves maximization of firms' aggregate activities, expenditures, or efforts (for a similar objective see for example Moldovanu and Sela, 2001).

As we argued above, one can achieve the socially optimal outcome in product and target pollutant markets by allocating permits using an external factor only. Therefore, using such an approach simultaneously achieves the primary target of socially optimal outcome in the two markets *and* a secondary target of maximisation of the aggregate external factor. Formally, let $\Delta \in (0, 1]$ represent the relative importance of the primary target (emissions control), and let us consider the closed system (the argument for the (small) open system will be only slightly different). In this case, the "combined" regulatory objective is:

$$\underset{q_{it},e_{it},z_{it}}{Max} \sum_t \sum_{i=1}^{n} [\Delta(p_{it}q_{it} - c_{it}(e_{it}, q_{it})) - (1 - \Delta)z_{it}] \text{ subject to } \sum_{i=1}^{n} e_{it} = \overline{E_t} \quad (3.17)$$

The first order conditions for emissions and output are identical to the socially optimal equations (3.4) and (3.5). Moreover, this combined regulatory objective allows for firms' individually optimal choice of the external factor. It follows from inspection of equations (3.7)-(3.9) and (3.17) that:

Remark 9 *If a RPM is used to allocate permits based on a costly external factor then a secondary (regulatory) target can be achieved whilst still achieving the socially optimal outcome with respect to the target pollutant.*

In other words, by allocating target pollutant permits among firms based on their relative performance in a suitably chosen external factor, a regulator can "kill two birds with one stone" by achieving emission control at the lowest social cost in output and permit markets, and maximizing aggregate production of a socially beneficial external factor.

3.5 Conclusion

The purpose of this chapter was to analyse the impact and optimality of implementing a generalised (dynamic) relative performance mechanism for the initial allocation of pollution permits. We extend the results of Böhringer and Lange (2005a) to accommodate most of the existing dynamic initial allocation mechanisms, including grandfathering and auctions, as well as novel mechanisms, such as rank-order contests. We show that using firms' historical outputs for allocating permits is never optimal, while using firms' historical emissions is optimal only in closed trading systems and only for a narrow class of allocation mechanisms. Instead, it is possible to achieve social optimality by allocating permits based on an external factor which is independent of output and emissions. We outline sufficient conditions for a socially optimal relative performance mechanism and discuss the issues related to the choice of a suitable mechanism for initial allocation.

Due to these potential benefits, we advocate using a relative performance mechanism with an external factor for the dynamic allocation of permits. The numerous advantages of using a relative performance mechanism include its adaptability to changing economic, technological, and other conditions, as well as a possibility of transferring risk of possible systemic shocks (such as oil price changes) to the regulator. The advantage of using an external factor involves a possibility of achieving secondary regulatory goals, such as revenue maximization, social betterment or reduction in other environmental problems. Moreover, if the secondary goal is political agreeable, the permit trading scheme may also enjoy greater public acceptance.

Allocating permits for a target pollutant based on firms' relative performance in external factor increases firms' flexibility in meeting both regulatory goals by choosing the most cost-effective approach. That is, firm's cost-effective behaviour may depend on whether it has comparative advantage in abatement of the target pollutant, or in the production of the external factor. We think that such potential asymmetries among firms are important for the optimal design of permit allocation schemes, a topic of potential future research.

We also propose a novel allocation mechanism involving a rank-order contest, which is a generalization of an all-pay auction. In an external factor rank-order contest, firms are ranked in the order of their relative production of the external factor, and it is firm's rank, and not the level of the external factor, that determines firm's permit allocation. As the theoretical literature suggests, an allocation scheme with a suitably chosen "prize" structure is expected to achieve the secondary goal of maximizing aggregate production of the external factor - the goal which may not be achievable with other allocation mechanisms. In other words, by allocating target pollutant permits among firms using a rank-order contest in socially desirable activities (including abatement of unregulated greenhouse gases or even charitable activities) a regulator can "kill two birds with one stone" by achieving emission control at the lowest social cost in output and permit markets, and maximizing aggregate amount of a socially beneficial activity.

The external factor rank-order contest has some advantages over the presently used grandfathering scheme. While regulators seem to prefer grandfathering due to its political agreeability among the regulated firms, these schemes can be unpopular with the general public. In contrast, an external factor contest not only has a potential of achieving social optimality, but also it achieves a secondary regulatory goal (which may be perceived as achieving "fairness"), while the grandfathering scheme involving historical output and emissions achieves none of these two goals.

While we have presented arguments in favour of using RPMs based on an external factor in allocating permits, we nevertheless appreciate the potential practical difficulties involving in the choice of a suitable external factor. The success of the trading scheme rests on the regulator's ability to find an external factor that is desirable, politically agreeable, independent from output and emissions, and allows for an adequate comparison between firms. We nevertheless hope that the arguments presented in this chapter may be of relevance to environmental policy makers.

Chapter 4

Lobbying Activity in a Tradeable Permit Market

4.1 Introduction

Tradeable permit markets, in principle, allow cost effective pollution control (Montgomery, 1972).[1] As shown in Chapter 2, in a perfectly competitive permit market, equilibrium efficiency is independent from the choice of initial allocation as each firm trades permits until their marginal abatement cost is equated to the permit price. However, as discussed in Chapter 3, there is still an active debate about the efficiency properties associated with initial allocation mechanisms when permits are allocated over multiple trading periods. This debate, however, has largely overlooked a common phenomenon in existing tradeable permit markets – namely, firm and/or industry lobbying to obtain advantageous distribution rules and permit allocations

[1] This chapter has been adapted from MacKenzie et al. (2007b).

(see for example, Svendsen, 1999; 2005). Firms and/or industries may lobby the regulator to reduce their costs of regulation either by gaining larger permit allocations or by "improved" trading rules (e.g. allowing banking and borrowing, allowing grandfathering instead of auctions). Yet very little is known theoretically about the effects of lobbying activity on the efficiency of permit markets. We therefore aim to explore analytically the consequences of lobbying in a tradeable permit market with multiple periods.

In this chapter we model an initial permit allocation mechanism in a multi-period setting when the allocation of permits is determined *jointly* by two factors: the historical emissions of participating firms and the extent to which each firm lobbies for additional permits.[2] We denote the combination of the two activities as *rent-seeking* activity. We show that distortions in the tradeable permit market occur when the costs of rent-seeking (emissions and lobbying activity costs) are separable (i.e. independent from each other). However, when the rent-seeking costs are non-separable (i.e. interdependent), the least-cost equilibrium can be reached. We also show, in the presence of lobbying activity, that a tradeable permit market can maintain efficiency when permits are distributed using static grandfathering instead.

In our model, one of the key factors determining firms' permit allocations is their historical emissions. Here, we refer to *updated* grandfathering as the free allocation of permits based on historical emissions that are continually updated throughout time,

[2] Our analysis would also hold for alternative scenarios where, in addition to historical emissions, the regulator bases permit allocations on some other activities (such as abating other pollutants and so on), rather than on lobbying. While such scenarios are theoretically plausible (and would be covered by our analysis), they do not capture the current situation in the existing permit markets.

whilst lobbying activity is considered to be any legal or political activities of the firm aimed at increasing their proportion of the permit allocation.[3] The popular view in the literature is that updated grandfathering is a politically viable distribution rule because it mirrors changes in the output and emissions market by allowing recent information about output and emissions to alter current period permit allocations, such as altering permit allocation with respect to new entrants and plant closures (Åhman et al. 2007). It is likely that some form of updated grandfathering will exist in future periods of the EU Emissions Trading Scheme (EU-ETS) (Böhringer and Lange, 2005a; Keats Martinez and Neuhoff, 2005; Bode, 2006; Rosendahl, 2006; Neuhoff et al. 2006). Updated grandfathering may also be a feature of a post-Kyoto flexible mechanisms for reducing carbon dioxide emissions. However, the dynamic nature of updated grandfathering introduces additional complexities that may reduce market efficiency. Böhringer and Lange (2005a) have discussed updated grandfathering finding that the dynamic allocation has to be carefully considered to reduce distortions in the product and permit market. More recently, Rosendahl (2006) extended the Böhringer and Lange (2005a) study by showing additional conditions for first best outcomes, and detailed the effects on the permit price due to the updated grandfathering system.

We also assume that firms can adjust the permit allocation obtained from the grandfathering mechanism by investing in lobbying activity. The majority of literature analysing lobbying activity uses rent-seeking theory as first formalised in the seminal work of Tullock (1980). As shown by Tullock (1980), rent-seeking firms

[3]See Fischer (2001) for a static analysis of permit allocation based on output.

dissipate some or all of the available rent and this has the possibility of creating welfare losses. As discussed in Nitzan (1994), most subsequent studies attempt to extend and apply the simple rent-seeking theory of Tullock (1980) to evermore complicated and realistic situations. In contrast, the literature regarding environmental policy lobbying, although well established, has generally avoided analysis incorporating theory of rent-seeking behaviour (Heyes, 1997; Michaelowa, 1998; Svendsen, 1999; Damania, 2001; Brandt and Svendsen, 2004; Hanoteau, 2005; Markussen and Svendsen, 2005; Svendsen, 2005; Malueg and Yates, 2006). Two broad directions of research are followed instead. The first concentrates on environmental policy choice, for instance, Svendsen (1999) and Damania (2001) analyse lobbying activity for the choice of an environmental instrument (emissions trading versus emissions standards). Second, lobbying activity has been modelled by Brandt and Svendsen (2004), Markussen and Svendsen, (2005) and Svendsen (2005) to show the effects of lobbying in determining the allocation rule and market design in the EU emissions trading scheme. Similarly, Hanoteau (2005) analyses a permit market where a regulator determines the choice of allocation rule and emissions cap and finds that the choice of distribution rule is important as this affects industry lobbying activity and as a result, the aggregate emissions cap.

A common aspect in the majority of literature is the assumption that lobbying activity only exists prior to policy implementation. Firms and industries lobby to obtain advantageous allocation rules and permit market designs before the scheme begins. However, as our chapters suggests, it is apparent that when a tradeable permit market is operational, lobbying activity can, and most likely will, continue to play a prominent role in the determination of permit distributions and the aggregate emissions cap in each period.

In a perfectly competitive permit market, efficiency at the equilibrium outcome has been shown to be independent of the choice of initial allocation (Montgomery, 1972; Tietenberg, 1985). However, many studies, by relaxing the assumption of a perfectly competitive permit market, have shown links between the initial allocation of permits and efficiency at the market equilibrium. As explained in Chapter 3, the initial allocation of permits has consequences for the market efficiency when there are: strategic and imperfectly competitive firm behaviour (Hahn 1984; Misiolek and Elder 1989); transaction costs (Stavins, 1995) and multiple periods (Böhringer and Lange 2005a). Yet few studies have attempted to analyse lobbying activity in this 'least-cost' context—something this chapter aims to achieve. Recently, Lai (2007) formally analysed the social welfare consequences when firms and environmental groups lobby over the determination of an aggregate emissions cap and finds grandfathering may be more efficient than auctioning. However, no allowance is made for firms to lobby to obtain an individually larger permit allocation, irrespective of whether the permit cap increases or not. Indeed in Lai's (2007) analysis, the permit market equilibrium is found to be 'least-cost' with no distortions altering firms' abatement choices. To the best of our knowledge, no study has thus inquired into the post-implementation aspects of lobbying activity in a permit market where the allocation rule has already been determined and firms use political activities to increase their own permit allocation. Also, no studies formally analyse the interactions between firms that are competing for a proportion of an aggregate emissions cap. Indeed, there has been no analysis on the consequences for permit market efficiency in the presence of lobbying activity. This, then, is our contribution to the literature.

We begin from a situation where a regulator has implemented an emissions trading scheme with updating grandfathering as the main allocation mechanism. Each firm will obtain a distribution of permits through a grandfathering mechanism and lobbying activity. Our multi-period, partial equilibrium model allows the regulator to allocate permits to firms based jointly on their previous emissions and lobbying activity levels relative to every other firm using a permit allocation rule which is formally similar to a Contest Success function (CSF) (Tullock, 1980; Skaperdas, 1996, Groenenberg and Blok, 2002; Bode, 2006). Note that we do not consider the wider welfare implications of lobbying activity here, focusing solely on the permit market.

Two papers are particularly relevant for our argument – namely, Böhringer and Lange (2005a) and Chung (1996). Böhringer and Lange (2005a) compare the efficiency of a multi-period permit allocation based on output, emissions and a lump-sum transfer. They find in a closed market (i.e. when participating firms cannot trade in permits outside the domestic market) that it is optimal to allocate permits on criteria not related to output, whereas for an open market (i.e. when firms can trade outside the domestic market), an efficient allocation occurs when the permits are distributed using a lump-sum approach. Our model uses a similar framework for the multiple trading periods but introduces lobbying activity as a determinant of the permit allocation and allows the absolute aggregate emissions cap to change. Chung (1996) extends a Tullock-style rent-seeking contest model to include a rent that is endogenously determined by aggregate efforts, that is, the rent increases with aggregate effort. He finds that the extended contest generates excessive effort levels which are socially wasteful. We use the concept of an endogenously determined "prize" to investigate the effects of lobbying on a tradeable permit market.

Following Chung (1996), we extend the basic model to allow a regulator to be influenced by the aggregate lobbying activity in the permit market. Consequently, the regulator can be 'persuaded' into increasing the aggregate emissions cap when aggregate rent-seeking activity increases. We allow the aggregate emissions cap to be non-responsive (i.e. exogenous) and responsive (i.e. endogenous) to aggregate lobbying activity. We find that market efficiency is not altered by the type of aggregate emissions cap, however social welfare is reduced when the emissions cap is endogenous. Interestingly, this reduction in welfare also exists for a market with static grandfathering.

The chapter is organised as follows: section 4.2 outlines the model, while section 4.3 presents the benchmark model of updated grandfathering with a fixed aggregate cap. Section 4.4 contains the main results on the efficient allocation rule based on rent-seeking activity, where the costs of rent-seeking are separable and non-separable. Section 4.5 explores the effects of exogenous vs. endogenous aggregate emissions cap, while section 4.6 is devoted to situation where the allocation is based on lobbying activity only. Section 4.7 details some policy implications of the analytical model, and the last section concludes.

4.2 The Basic Model

Consider a set of firms $\Theta = \{1, \ldots, N\}$ that participate in a competitive tradeable emissions market in order to control a pollutant over an infinite time horizon ($t = 1, 2, \ldots$). Firms differ in their abatement costs, so that firm i has cost function $c_{it}(e_{it})$ with $c'_{it} \leq 0, c''_{it} \geq 0$ for $i \in \Theta$. It is well-known that the emissions permit trading outcome controls a specified level of pollution at least-cost (or it is allocatively efficient) if firms' marginal cost of emissions are equated, i.e.

$$\frac{dc_{it}}{de_{it}} = \frac{dc_{jt}}{de_{jt}} \qquad \forall\ i \in \Theta,\ j \in \Theta \backslash \{i\},\ \forall\ t \tag{4.1}$$

otherwise the outcome is '*distortionary*' (e.g. Montgomery, 1972; Tietenberg, 1985). Thus, the question of interest to us is how to allocate permits in a non-distortionary way.

To create a realistic allocation mechanism, let us suppose that permits are distributed in accordance with two key determinants. Firstly, firms obtain permits through an *updated* grandfathering scheme in which each firm receives a free allocation of current period permits based on a previous period's emissions level (Böhringer and Lange, 2005a; Keats and Neuhoff, 2005; Bode, 2006). Therefore, the firm's baseline allocation will be "updated" as time progresses. Secondly, firms can alter their current period permit allocation by investing in a previous period's lobbying activity – the use of political activities, persuasion, and so on, to increase their permit allocation by influencing the regulator's decisions (see for example, Brandt and Svendsen, 2004; Svendsen, 2005; Hanoteau, 2005; Markussen and Svendsen, 2005; Malueg and

Yates, 2006; Lai, 2007).[4]

We assume that the tradeable permit market has already been implemented, with the initial permit allocation (at time $t = 0$) to be exogenously determined by means of auctioning or grandfathering. Assume that the timeline of decisions is as follows. In period $t-1$, firm i selects a level of emissions $e_{i(t-1)}$ and lobbying activity ($s_{i(t-1)}$) which will become common knowledge in period t.[5] As a result, the regulator allocates period t permits to each firm based on their size of historical emissions and lobbying activity relative to every other participating firm.[6]

It seems to be plausible that, when grandfathering is implemented, both a firm's choice of historical emissions and lobbying activity, combined, determine the permit allocation it receives. To capture this possibility, we assume that, when a regulator makes a decision about firm i's permit allocation, the regulator responds to the *combination* of firm i's choice of net emissions and its lobbying activity. More specifically, the regulator views historical emissions and lobbying as two elements of $x_{it} = x_{it}(e_{i(t-1)}, s_{i(t-1)})$ which represents rent-seeking activity of firm i with historical emissions $e_{i(t-1)}$ and lobbying $s_{i(t-1)}$. We initially assume that the costs of emissions and lobbying activity are separable (independent from each other) so that the cost of lobbying activity is $v_{it}(s_{it})$ with $v'_{it} > 0$, $v''_{it} \geq 0$ and $v_{it}(0) = 0$. The relaxation of this assumption will be discussed later.

Assuming no permit banking and/or borrowing exists – no transfer of permits

[4] This model only considers legal forms of lobbying activity, illegal activities such as bribery and corruption are not considered.

[5] The model bases permit allocations on one period of historical emissions for analytical tractability, but similar results can be found when extended to multiple historical periods.

[6] A similar result occurs when current period (s_{it}) lobbying is used instead of historical levels ($s_{i(t-1)}$).

between separate time periods – and focusing only on the permit market, each firm maximises (minimises) the profit (cost) in the permit market for each period by choosing suitable levels of lobbying activity and emissions. Formally, given a period t permit price p_t and the discount factor δ, firm i's objective is:

$$\max_{e_{it},s_{it}} \Pi_i = \sum_t \delta^t \left[p_t(a_{it}(x_{it}(e_{i(t-1)}, s_{i(t-1)})) - e_{it}) - c_{it}(e_{it}) - v_{it}(s_{it})\right] \tag{4.2}$$

where $a_{it}(x_{it})$ is the regulator's allocation of period t permits to firm i. Intuitively, each firm wants to maximise the sale of permits to the market whilst minimising the costs of emissions abatement and lobbying activity.

We further assume that each firm's permit allocation is determined by how its rent-seeking activity compares to that of other participating firms, i.e.

$$a_{it} = \frac{x_{it}}{x_{it} + \sum_{j\in\Theta\setminus\{i\}} x_{jt}} \cdot E_t \tag{4.3}$$

for $i \in \Theta$, $j \in \Theta\setminus\{i\}$ where x is rent-seeking action and E_t is the total permit supply issued by the regulator at time t. From equation (4.3), it is clear firm i receives a permit allocation in period t equal to a proportion of the aggregate emissions cap and this proportion is determined by its combined lobbying and emissions relative to every other firm. This mechanism captures the realistic scenario that firms will be allocated permits based on historical emissions but they also have an ability to influence the regulator's final decision by investing in lobbying activity (see for example, Grubb et al. 2005).

Notice that this formulation of the permit allocation, a_{it}, is formally similar to a Contest Success Function (CSF) (Tullock, 1980; Skaperdas, 1996), commonly used in the literature on lobbying. Typically, a CSF describes the probability of firm i winning a single indivisible "prize" based on how its lobbying activity stands relatively to that of other firms. Here, instead, we assume that a total "pie" of permits is divided into multiple permit allocations based on how each firm's rent-seeking activity stands relatively to that of other firms.[7] This method allows a clear explanation of how permits can be distributed amongst firms with respect to any relative choice of emissions and lobbying activity.

Notice that this formulation allows for two special cases. The first case is grandfathering with a fixed cap, which distributes a fixed allocation of permits (the reward) using each firm's relative choices of historical emissions. That is, a firm will receive a proportion of the aggregate cap based on their historical emissions relative to every other firm (see for example, Groenenberg and Blok 2002; Bode, 2006). The second case is "pure" lobbying, when a permit allocation can be distributed amongst firms using the relative lobbying activities of each firm compared to others in the permit market. Both special cases will be discussed later.

We also allow for the possibility that the aggregate emissions cap E_t is endogenously determined with respect to aggregate rent-seeking activity (Chung, 1996), i.e. that the aggregate emissions cap may increase when aggregate rent-seeking activity increases:

$$E_t = \bar{A}_t \cdot (\sum_{i \in \Theta} x_{it}(e_{i(t-1)}, s_{i(t-1)}))^{\psi_t} \tag{4.4}$$

where $\bar{A}_t$ is some "fixed" aggregate emissions cap and $\psi_t \in [0, 1)$ models the regu-

[7] Imperfectly discriminating contests with multiple prizes have been investigated by Van Long and Vousden (1987), Berry (1993) and Clark and Riis (1996).

lator's responsiveness towards aggregate rent-seeking activity at time t (we assume that $\sum_{i\in\Theta} x_{it} > 1$). To reach the socially optimal level of pollution, the regulator selects the "fixed" aggregate emissions cap ($\bar{A}_t$) so that the marginal benefit is equated to the marginal damage of pollution, $B'(A_t) = D'(A_t)$ where $B'(.)$, $D'(.)$, $D''(.) > 0$ and $B''(.), < 0$. The regulator's responsiveness, ψ_t, determines to what extent aggregate rent-seeking activity affects the aggregate emissions cap. The range of ψ_t is chosen so that the aggregate emissions cap can capture two realistic situations. The first one is a fixed cap ($\psi_t = 0$) and the second one is an emissions cap where an increase in aggregate lobbying effort increases the emissions cap at a decreasing rate ($0 < \psi_t < 1$) – implying diminishing returns from aggregate lobbying effort (Chung, 1996).

4.3 Benchmark Model: Updated Grandfathering

To aid comparison between a permit market with and without rent-seeking, consider a benchmark case where permits are allocated amongst the firms using an updated grandfathering system with a fixed aggregate emissions cap *without* any lobbying activity. That is, each firm obtains a permit allocation in period t based *only* on how its previous emissions ($e_{i(t-1)}$) stand relative to that of every other firm. For this benchmark case, we also assume that the total emissions cap E_t is fixed at time t, i.e. $E_t = \bar{A}_t$. Without lobbying activity, equation (4.2) gives the following objective function for firm i:

$$\max_{e_{it}} \Pi_i = \sum_t \delta^t \left[p_t(a_{it}(e_{i(t-1)}) - e_{it}) - c_{it}(e_{it}) \right] \quad \text{for } i \in \Theta \tag{4.5}$$

where the permit allocation a_{it} is given by:

$$a_{it} = \frac{e_{i(t-1)}}{e_{i(t-1)} + \sum_{j \in \Theta \setminus \{i\}} e_{j(t-1)}} \cdot \bar{A}_t \tag{4.6}$$

where $\bar{A}_t$ is again, the strictly fixed, non-zero, absolute aggregate emissions cap in time period t. The first-order condition is:[8]

$$p_t \underbrace{- \delta p_{t+1} \frac{\partial a_{i(t+1)}(e_{it})}{\partial e_{it}}}_{Distortion} = - \frac{dc_{it}}{de_{it}} \tag{4.7}$$

where

$$\frac{\partial a_{i(t+1)}(e_{it})}{\partial e_{it}} = \bar{A}_{t+1} \cdot \frac{\sum_{j \in \Theta \setminus \{i\}} e_{jt}}{\left(e_{it} + \sum_{j \in \Theta \setminus \{i\}} e_{jt} \right)^2} \tag{4.8}$$

From equation (4.8), firm i's permit allocation is dependent on its proportion of emissions with respect to every other firm in the previous period and the aggregate emissions cap, and thus each firm makes its decision strategically. Due to the updating grandfathering process, each firm's choice of Nash equilibrium emissions depends on the expected future permit allocation value, the current period permit price and own marginal abatement cost, as well as other firms' equilibrium choices. Comparing this first order condition to the least-cost condition (4.1), it can be observed that each firm has a distortionary incentive to increase emissions, as their choice of current period emissions will determine future allocations (Böhringer and Lange, 2005a). From equation (4.7), the equalisation of marginal abatement costs across all firms only occurs in the unlikely event of $e_{it} \equiv e_{jt}$ for $\forall t$, $i \in \Theta$ and

[8] It can easily be shown that $\frac{\partial^2 \Pi}{\partial e_{it}^2} < 0$.

$j \in \Theta\backslash\{i\}$. Therefore, the use of an updated grandfathering mechanism to allocate permits in a tradeable permit market is inefficient (not least-cost) (Böhringer and Lange, 2005a).

4.4 Permit Allocation with Rent-Seeking Activity

We now consider a more realistic, but also more complex, case when firm's permit allocation depends on its relative level of rent-seeking activity, $x_{it} = x_{it}(e_{i(t-1)}, s_{i(t-1)})$. That is, each firm can alter its permit allocation by adjusting the level of emissions *and* lobbying activity. We make a distinction between two cases: separable and non-separable costs of rent-seeking. Separable rent-seeking costs allow both the cost of emissions and lobbying activity to vary independently of each other, whereas non-separable costs of emissions and lobbying activity are interdependent.

4.4.1 Separable Rent-Seeking Costs

Suppose that firm i has separable costs of rent-seeking so that the costs of emissions and lobbying activity are independent. Firm i's maximisation problem will then be determined by its objective function (4.2), allocation rule (4.3), and aggregate emissions cap (4.4). Thus, firm i's optimal choices of emissions e_{it} and lobbying s_{it} for all t will be given by the following system of first order conditions:

$$
\begin{aligned}
-\delta^t p_t - \delta^t \frac{dc_{it}}{de_{it}} + \underbrace{\delta^{t+1} p_{t+1} \frac{\partial a_{i(t+1)}}{\partial x_{i(t+1)}} \frac{\partial x_{i(t+1)}}{\partial e_{it}}}_{Distortion} &= 0 &\quad (4.9)\\
\delta^{t+1} p_{t+1} \frac{\partial a_{i(t+1)}}{\partial x_{i(t+1)}} \frac{\partial x_{i(t+1)}}{\partial s_{it}} - \delta^t \frac{dv_{it}}{ds_{it}} &= 0 &\quad (4.10)
\end{aligned}
$$

where

$$
\begin{aligned}
\frac{\partial a_{i(t+1)}}{\partial x_{i(t+1)}} &= \frac{\sum_{j \in \Theta \setminus \{i\}} x_{j(t+1)}}{(x_{i(t+1)} + \sum_{j \in \Theta \setminus \{i\}} x_{j(t+1)})^2} \cdot \bar{A}_{(t+1)} \cdot (\sum_{i \in \Theta} x_{i(t+1)})^{\psi_{(t+1)}} &\quad (4.11)\\
&+ \frac{x_{i(t+1)}}{x_{i(t+1)} + \sum_{j \in \Theta \setminus \{i\}} x_{j(t+1)}} \cdot \bar{A}_{(t+1)} \cdot \psi_{(t+1)} \cdot (\sum_{i \in \Theta} x_{i(t+1)})^{\psi_{(t+1)}-1}
\end{aligned}
$$

That is, firm i selects a level of emissions to equate their marginal abatement cost with the permit price plus an additional distortionary term (Böhringer and Lange, 2005a). The distortionary term is effectively the net benefit obtained by choosing a particular level of rent-seeking. This distortionary term includes the future expected allocation of permits $p_{t+1} \frac{\partial a_{i(t+1)}}{\partial x_{i(t+1)}}$ and the marginal return in rent-seeking given a change in emissions $\frac{\partial x_{i(t+1)}}{\partial e_{it}}$.

To examine the distortion in the emissions market, let us rearrange equations (4.9) and (4.10) as follows:[9]

[9] To ensure optimality, we assume $\frac{\partial^2 x_{i(t+1)}}{\partial e_{it}^2}, \frac{\partial^2 x_{i(t+1)}}{\partial s_{it}^2} \leq 0$ and $\frac{\partial^2 x_{i(t+1)}}{\partial e_{it}^2} \cdot \frac{\partial^2 x_{i(t+1)}}{\partial s_{it}^2} - \left(\frac{\partial^2 x_{i(t+1)}}{\partial e_{it} \partial s_{it}}\right)^2 \geq 0$.

$$p_t - \delta p_{t+1} \frac{\partial a_{i(t+1)}}{\partial x_{i(t+1)}} \frac{\partial x_{i(t+1)}}{\partial e_{it}} = -\frac{dc_{it}}{de_{it}} \tag{4.12}$$

$$\delta p_{t+1} \frac{\partial a_{i(t+1)}}{\partial x_{i(t+1)}} \frac{\partial x_{i(t+1)}}{\partial s_{it}} = \frac{dv_{it}}{ds_{it}} \tag{4.13}$$

Substituting equation (4.13) into (4.12) gives:

$$p_t - \frac{dv_{it}}{ds_{it}} \cdot \left(\frac{\frac{\partial x_{i(t+1)}}{\partial e_{it}}}{\frac{\partial x_{i(t+1)}}{\partial s_{it}}} \right) = -\frac{dc_{it}}{de_{it}} \tag{4.14}$$

where $\frac{\frac{\partial x_{i(t+1)}}{\partial e_{it}}}{\frac{\partial x_{i(t+1)}}{\partial s_{it}}}$ is the technical rate of substitution between current period emissions and lobbying activity. From equations (4.12) and (4.14) it follows that:

Proposition 10 *Given firms' separable rent-seeking costs and a positive level of rent-seeking activity the tradeable permit market does not reach the least-cost equilibrium.*

From Proposition (10), as long as the marginal cost of lobbying and the marginal return from emissions and lobbying activity are positive then an incentive exists for firm i to increase emissions above the least-cost level. In comparison, from equation (4.14), when $\frac{\partial x_{i(t+1)}}{\partial e_{it}} = 0$ (i.e. if rent-seeking does not depend on past emissions), there is no distortionary incentive to increase emissions and the permit market is least-cost as shown in equation (4.1) (we discuss this later in section (4.6)).

In the benchmark model, the distortion was created as the level of current period emissions altered the firm's future permit allocation. In comparison, when lobbying activity is introduced, the distortionary choice in emissions still exists but now it is dependent on the marginal costs of lobbying and the firm's relationship between future rent-seeking, emissions and lobbying activity. To summarise, in the presence of lobbying activity, a permit market that uses an updated grandfathering allocation mechanism (and where costs are separable) does not reach the least-cost equilibrium.

4.4.2 Non-separable Rent-seeking Costs

We assume now that the costs of rent-seeking are not separable. In certain circumstances it may be beneficial to consider the cases where, for instance, a regulator believes a 'large' polluter finds lobbying relatively cheaper to implement than a 'small' polluter, say due to internal organisational structures. In other words, in equation (4.2) we can substitute $v_{it}(s_{it})$, the costs of lobbying activity, for a cost of rent-seeking given by $\phi_{it}(x_{it}(e_{i(t-1)}, s_{i(t-1)}))$ with $\frac{\partial \phi_{it}}{\partial x_{it}} > 0, \frac{\partial^2 \phi_{it}}{\partial x_{it}^2} \geq 0$. Assume also that $\phi_{it}(x_{it}(e_{i(t-1)}, 0)) \equiv 0$, i.e. when a firm does not engage into lobbying, its rent-seeking cost is zero.

Firm i's maximisation problem is determined by substituting the new cost function for rent-seeking ($\phi_{it}(x_{it})$) into equation (4.2) along with equations from the previous subsection for the allocation rule (4.3) and aggregate emissions cap (4.4). Thus, firm i's optimal choices of emissions e_{it} and lobbying s_{it} for all t will be given by the following system of first order conditions:

$$-\delta^t p_t - \delta^t \frac{dc_{it}}{de_{it}} + \underbrace{\delta^{t+1} p_{t+1} \frac{\partial a_{i(t+1)}}{\partial x_{i(t+1)}} \frac{\partial x_{i(t+1)}}{\partial e_{it}} - \delta^{t+1} \frac{\partial \phi_{i(t+1)}}{\partial x_{i(t+1)}} \frac{\partial x_{i(t+1)}}{\partial e_{it}}}_{Distortion} = 0 \quad (4.15)$$

$$\delta^{t+1} p_{t+1} \frac{\partial a_{i(t+1)}}{\partial x_{i(t+1)}} \frac{\partial x_{i(t+1)}}{\partial s_{it}} - \delta^{t+1} \frac{\partial \phi_{i(t+1)}}{\partial x_{i(t+1)}} \frac{\partial x_{i(t+1)}}{\partial s_{it}} = 0 \quad (4.16)$$

where $\frac{\partial a_{i(t+1)}}{\partial x_{i(t+1)}}$ is given in equation (4.11). Similar to the previous section, firm i selects a level of emissions to equate their marginal abatement cost with the permit price plus an additional distortionary term.

Let us rearrange equation (4.15) as follows:

$$p_t - \underbrace{\delta \left[p_{t+1} \frac{\partial a_{i(t+1)}}{\partial x_{i(t+1)}} - \frac{\partial \phi_{i(t+1)}}{\partial x_{i(t+1)}} \right] \frac{\partial x_{i(t+1)}}{\partial e_{it}}}_{Distortion} = -\frac{dc_{it}}{de_{it}} \tag{4.17}$$

That is, the distortionary term has two components - first, the marginal return in rent-seeking given a change in emissions $\frac{\partial x_{i(t+1)}}{\partial e_{it}}$, and second, the *currently* anticipated marginal return to *future* rent-seeking $p_{t+1}\frac{\partial a_{i(t+1)}}{\partial x_{i(t+1)}} - \frac{\partial \phi_{i(t+1)}}{\partial x_{i(t+1)}}$.

Again, notice that if $\frac{\partial x_{i(t+1)}}{\partial e_{it}} \equiv 0$ the distortion is zero. As we argued above, if permit allocation depends on past emissions and lobbying with separable costs then the distortion will persist. Surprisingly, however, if firm's permit allocation is determined *jointly* by past emissions and current lobbying via rent-seeking (non-separable costs), a permit allocation may be non-distortional provided that the regulator announces a pre-specified rule that "fuses" firms' choices of emissions and lobbying into rent-seeking, which, in turn, is used to allocate permits in a pre-specified way. In other words, the potential inefficiency in the permit market is 'drawn out' by lobbying activity.

To see this, recall that current emissions affects the level of rent-seeking, and consider firm i's current-period lobbying decision. Rearranging equation (4.16) gives:

$$\delta \left[p_{t+1} \frac{\partial a_{i(t+1)}}{\partial x_{i(t+1)}} - \frac{\partial \phi_{i(t+1)}}{\partial x_{i(t+1)}} \right] \frac{\partial x_{i(t+1)}}{\partial s_{it}} = 0 \tag{4.18}$$

That is, given the permit allocation rule, firm i anticipates that given its optimal choice of current emissions e_{it}^*, it will choose optimally lobbying s_{it}^*, so that the two choices will be combined to determine the next-period rent-seeking level $x_{i(t+1)}^*$, and thus its next-period permit allocation $a_{i(t+1)}^*$.

If both emissions and lobbying play a pre-specified role in determining allocation via rent-seeking then notice that, from equation (4.18) firm i's optimal choice of s_{it}^* implies that

$$p_{(t+1)} \frac{\partial a_{i(t+1)}}{\partial x_{i(t+1)}} = \frac{\partial \phi_{i(t+1)}}{\partial x_{i(t+1)}} \qquad \text{for } i \in \Theta, \ \forall \ t \tag{4.19}$$

so that each firm, in each time period, will choose a level of rent-seeking activity $x_{i(t+1)}$ to equate their marginal expected permit allocation to their marginal cost of rent-seeking activity. In turn, this condition implies that the first order condition for emissions (4.15) (and thus equation (4.17) as well), reduces to

$$p_t = -\frac{dc_{it}}{de_{it}} \tag{4.20}$$

which is a non-distortionary outcome! That is, when making an emissions choice at time t, the firm takes into account its use of optimal lobbying, and, as the result, this emissions choice turns out to be non-distortionary, resulting in an (allocatively) efficient tradeable permit market.

Proposition 11 *Given an allocation rule that uses the past choice of updated emissions and lobbying activity where the costs of rent-seeking are non-separable in emissions and lobbying then the tradeable permit market reaches the least-cost equilibrium.*

Proposition 11 is counter-intuitive as it suggests that *when permit allocations depend on past emissions*, lobbying activity can actually improve efficiency in a tradeable permit market as long as the costs of rent-seeking are non-separable. We are not suggesting that lobbying activity is efficient or desirable by itself. Instead, we show that the distortions arising from updated grandfathering schemes may be corrected by "fusing" lobbying with updated historical emissions. The existence of lobbying activity "draws out" the inefficiency from the choice of emissions and focuses it on a choice of legitimate lobbying activity. Simply put, firms can "substitute" lobbying activity for historical emissions. In contrast, as the benchmark model shows, updated grandfathering, where no lobbying activity exists, is inefficient because the only possible method to obtain a larger proportion of permits is to increase current period emissions. Therefore, it follows that fusing historical emissions with historical lobbying activity allows (allocative) efficiency to be maintained in the permit market by allowing firms two methods to achieve their desired permit allocation.

4.5 Exogenous and Endogenous Aggregate Emissions Caps

In the last section, we found that the efficiency in a tradeable permit market with updated grandfathering and lobbying activity depends on the relationship between the costs of rent-seeking. Assuming separable costs between emissions and lobbying activity results in distortions being created in the permit market. However, when the costs are "fused" (i.e. non-separable) into combined rent-seeking activity it is possible that the tradeable permit market is least-cost. This is in contrast to the benchmark model that showed distortions in the permit market exist because of the use of an updated grandfathering allocation mechanism without any lobbying activity. In this section, we explore the potential consequences of the responsiveness of the regulator to aggregate rent-seeking activity. We begin by discussing the exogenous (or fixed) aggregate emissions cap.

Observe that, as equation (4.11) shows, on the margin, there are two effects from a unit increase in rent-seeking activity. The first term in equation (4.11) represents firm's marginal permit gain given the size of the permit "pie", and the second term represents the effect of firm's rent-seeking activity on the size of the total permit "pie".

When the regulator is unresponsive to aggregate rent-seeking ($\psi_t = 0$), the aggregate emissions cap is exogenous. Although the lobbying activity does not alter the cap, it is still being used by the regulator to distribute permits among the participating firms. For both types of rent-seeking costs, when the aggregate emissions cap is fixed, the socially optimal level of pollution is produced ($B'(A_t) = D'(A_t)$).[10]

When the costs of rent-seeking are separable, firm i's level of optimal rent-seeking is found by substituting $\psi_t = 0$ into equation (4.11) and substituting into equations (4.12) and (4.13) where $x_{i(t+1)}$ is found by the (independent) choice of emissions and

[10] As explained earlier, we do not explicitly analyse welfare consequences of rent-seeking activity for the wider economy (Lai, 2007). However, it is implicit in our analysis that lobbying activity in general is welfare reducing. What is important, from our analysis, is that we consider the direction of welfare changes from an exogenous to endogenous aggregate emissions cap.

lobbying activity so that $x^*_{i(t+1)} = (e^*_{it}, s^*_{it})$. As shown in section (4.4), distortions exist in the tradeable market.

For non-separable rent-seeking costs, to find the level of rent-seeking when the aggregate cap is exogenous, again we substitute $\psi_t = 0$ into equation (4.11) to get the future marginal change in allocation given a change in future rent-seeking, $\frac{\partial a_{i(t+1)}}{\partial x_{i(t+1)}}$. Substituting this into equation (4.19) reveals that the optimal level of future rent-seeking activity must satisfy:

$$p_{(t+1)} \frac{\sum_{j \in \Theta \backslash \{i\}} x_{j(t+1)}}{(x_{i(t+1)} + \sum_{j \in \Theta \backslash \{i\}} x_{j(t+1)})^2} \bar{A}_{(t+1)} = \frac{\partial v_{i(t+1)}}{\partial x_{i(t+1)}} \tag{4.21}$$

From section (4.4), the tradeable permit market can reach the least-cost equilibrium outcome.

However, an exogenously determined aggregate emissions cap, although prominent in theoretical discussions of emissions trading, is unrealistic in many scenarios, as the aggregate emissions cap is often altered by a regulator in response to firms' lobbying activity and emissions choices. For instance, in the EU-ETS phase I allocation, the majority of member states allocated more permits than the market required, due partly to industrial lobbying activity and the large emissions of participating firms (Grubb et al. 2005 p128).

We now model a situation where the aggregate emissions cap depends on rent-seeking activity. Allowing $\psi_t \in (0, 1)$ illustrates a realistic scenario of the regulator allowing the emissions cap for the market to increase at a non-increasing rate in response to aggregate lobbying activity (see Chung, 1996). Intuitively, the regulator, after observing the total rent-seeking activity, may be persuaded to increase the aggregate permit cap if they become convinced that the cap is too small and that the costs of meeting this reduction in pollution will be too large. A firm's choice of emissions and lobbying will determine not only their own share of permit allocation, but will also affect the size of the aggregate permit "pie" (which is the aggregate emissions cap).

For rent-seeking costs that are separable, substituting $\psi_t \in (0,1)$ into equation (4.11) and substituting equation (4.11) into equations (4.12) and (4.13) gives the optimal levels of emissions and lobbying activity when the aggregate emissions cap is endogenously determined by rent-seeking activity. Similar to the exogenous cap, the optimal level of rent-seeking activity firm i will choose, when the cap is endogenous, depends on $x^*_{i(t+1)} = (e^*_{it}, s^*_{it})$. Note the distortions in the tradeable permit market continue to exist with an endogenous cap.

For the case with non-separable rent-seeking costs, similar to above, given the allocation rule, and using $\psi_t \in (0,1)$, we get

$$p_{(t+1)} \left[\begin{array}{c} \frac{\sum_{j\in\Theta\setminus\{i\}} x_{j(t+1)}}{(x_{i(t+1)}+\sum_{j\in\Theta\setminus\{i\}} x_{j(t+1)})^2} \cdot \bar{A}_{(t+1)} \cdot (\sum_{i\in\Theta} x_{i(t+1)})^{\psi_{(t+1)}} \\ + \frac{x_{i(t+1)}}{x_{i(t+1)}+\sum_{j\in\Theta\setminus\{i\}} x_{j(t+1)}} \cdot \bar{A}_{(t+1)} \cdot \psi_{(t+1)} \cdot (\sum_{i\in\Theta} x_{i(t+1)})^{\psi_{(t+1)}-1} \end{array} \right] = \frac{\partial v_{i(t+1)}}{\partial x_{i(t+1)}} \tag{4.22}$$

For both types of rent-seeking costs, holding everything else constant, direct comparison of the choice of rent-seeking under an exogenous and endogenous cap reveals that when rent-seeking can alter the aggregate emissions cap, then there is an incentive to increase lobbying and emissions. Moreover, the more responsive the regulator is to aggregate rent-seeking activity ($\psi_{(t+1)}$), the more firms increase their rent-seeking activity. The intuition is fairly clear, the more the regulator is known to respond to rent-seeking activity, the more each firm will increase their rent-seeking to obtain a larger permit allocation. Yet the optimal choice of rent-seeking is chosen so that the tradeable permit market is efficient.

Furthermore, in contrast to the exogenous cap, when the aggregate emissions cap is endogenous, the supply of permits increases, resulting in a lower permit price, and higher emissions. This has direct consequences for social welfare. Recall that the regulator's choice of fixed cap was based on equating the marginal benefit and damage of pollution. It then follows that when aggregate rent-seeking activity increases the aggregate emissions cap, social welfare is reduced ($B'(E_t) < D'(E_t)$). In summary:

Corollary 12 *Given the regulator uses an allocation rule based on historical emissions and lobbying, allowing for an endogenously determined aggregate emissions cap reduces social welfare, however permit market efficiency is invariant to the permit cap.*

4.6 Lobbying Activity as the Only Allocation Determinant

In the last section we considered the case where a firm's permit allocation was determined by both historical emissions and lobbying activity. In this section we consider a simpler case where the rent-seeking of each firm is a function of lobbying activity, $x_{it} = x_{it}(s_{i(t-1)})$ and we assume that this is *independent* from the choice of emissions (we assume $\frac{\partial x_{it}}{\partial e_{i(t-1)}} \equiv 0, \frac{\partial x_{it}}{\partial s_{i(t-1)}} > 0 \; \forall \; i, t$). This then means that the allocation of permits to each firm will depend only on their relative choice of historical lobbying activity.

It is important to note that this section and all the results associated with it illustrate the outcome of static ("pure") grandfathering, where the only emissions level that affects firm i's permit allocation is the historical emissions level chosen before the permit scheme started. In a static grandfathering allocation system with lobbying activity, firm i's rent-seeking term is $x_{it} = x_{it}(\tilde{e}_i, s_{i(t-1)})$ where $\tilde{e}_i$ is the historical emissions chosen before the start of the permit scheme, which is thus not a decision variable in the current period. Therefore, although firm i obtains an allocation based on $\tilde{e}_i$ in each period, the allocation can adjust due to the firm's historical lobbying activity relative to every other firm. In summary:

Remark 13 *A tradeable permit market with static grandfathering allocation and lobbying activity is represented by* $x_{it} = x_{it}(s_{i(t-1)})$.

In this case, from equation (4.2) replace $x_{it}(e_{i(t-1)}, s_{i(t-1)})$ with $x_{it} = x_{it}(s_{i(t-1)})$ and it follows that firm i's optimal choices are as follows:[11]

$$p_t = -\frac{dc_{it}(e_{it})}{de_{it}} \tag{4.23}$$

$$\delta p_{t+1} \frac{da_{i(t+1)}}{dx_{i(t+1)}} \frac{dx_{i(t+1)}}{ds_{it}} = \frac{dv_{it}}{ds_{it}} \tag{4.24}$$

where $\frac{da_{i(t+1)}}{dx_{i(t+1)}}$ is similar to that in equation (4.11). Firm i chooses e_{it}^* so that equation (4.23) holds and given x_{it}^*, firm i selects s_{it}^* so that $x_{it}^* = x_{it}(s_{it}^*)$. In contrast from

[11] A similar first order condition occurs when we alter the cost of rent-seeking in equation (4.2). In other words, the cost of rent seeking would be $\phi_{it}(x_{it}(s_{i(t-1)}))$. This produces the first order condition $0 = \delta \left[p_{t+1} \frac{da_{i(t+1)}}{dx_{i(t+1)}} - \frac{d\phi_{i(t+1)}}{dx_{i(t+1)}} \right] \frac{dx_{i(t+1)}}{ds_{it}}$

section (4.4), the level of emissions is now independently chosen from the level of rent-seeking. From equation (4.23) it is immediate that:

Proposition 14 *If allocation is determined by lobbying activity only,* $x_{it} = x_{it}(s_{i(t-1)})$*, then the tradeable permit market achieves the least-cost equilibrium.*

A commonly held view in the literature is that lobbying activity from firms are a set of wasteful actions that are used to distort the permit market, either through altering the permit market structure or trading rules (for example, Svendsen, 2005). If lobbying activity is the only determinant in permit allocation and is independent from emissions, then the actions have no affect on the permit market efficiency. Again, we do not suggest that lobbying activity is desirable or efficient in itself, rather that the deadweight loss created by the use of wasteful lobbying activity does not alter the permit market cost-efficiency.

We showed in section 4.3 that an updated grandfathering scheme with no lobbying creates intertemporal distortionary incentives to emit. In comparison, given $x_{it} = x_{it}(s_{i(t-1)})$, it is clear from Proposition 14 that there is no distortionary incentive to emit here. The permit allocation to each firm is now independent of the level of emissions within the period of operation of the permit market and hence there is no incentive for any firm to increase emissions over and above the optimal choice at equilibrium.

Similar to section 4.5, it is possible to model both an exogenous ($\psi_t = 0$) and endogenous ($\psi_t \in (0, 1)$) aggregate emissions cap. Under an endogenous permit cap, similar to section 4.5, emissions will increase as the permit supply increases and as a result, social welfare is reduced. However, unlike the previous (non-separable cost) case, the level of lobbying is independent of emissions so that lobbying activity is selected by $x_{it}^* = x_{it}(s_{i(t-1)})$. Again, we do not suggest that lobbying activity is desirable and do not consider the welfare consequences for a fixed permit cap, but allowing an endogenous aggregate emissions cap may reduce welfare to a larger extent than when an exogenous permit cap is implemented (as the marginal benefits and damages are no longer equated under an endogenously determined permit cap).

Equation (4.23) shows that the choice of current period emissions (e_{it}) is independent from the optimal level of future rent-seeking (x_{it}^*). It follows that firm i then chooses a level of current period emissions to equate its marginal abatement cost with the permit price with no consideration of what lobbying is chosen.

As the relationship between lobbying and current period emissions no longer exists, it implies that the regulator's future permit allocation rule will not distort firms' choices of emissions. In other words:

Corollary 15 *Under a static grandfathering market with lobbying activity, the tradeable permit market reaches the least-cost equilibrium. However, welfare is reduced if an endogenously determined aggregate emissions cap is implemented.*

4.7 Policy Implications

The analysis in this chapter suggests that different relationships between the rent-seeking costs of emissions reductions and lobbying may have different incentives for firms' behaviour, and thus are important for policy making. It was noted that, when tradeable permits are distributed using updated grandfathering, then distortions occur in the permit market. A similar distortion is present when updated grandfathering and lobbying activity are combined, where the costs of rent-seeking are separable. Yet when the cost of rent-seeking is assumed to be non-separable then the updated grandfathering process is 'fused' with lobbying activity and market efficiency may be maintained. Due to this information, firms plan future levels of rent-seeking activity and then begin to optimally choose current period emissions and lobbying activity. It was also noted that the use of static grandfathering created no distortions in the tradeable permit market. However, for all types of allocation, if the regulator is responsive to aggregate rent-seeking (i.e. the aggregate emissions cap is endogenous) then social welfare is reduced assuming the cap is initially set optimally.

When the regulator's sole objective is to maintain efficiency in the tradeable permit market, the use of updated grandfathering should only be considered as a feasible allocation mechanism when the regulator considers the firms' costs of rent-seeking to be non-separable. On the other hand, static grandfathering reduces the incentive to increase current period emissions for a larger future period permit allocation. Moreover, if the regulator adjusts the aggregate emissions cap due to pressure from aggregate rent-seeking then, welfare is reduced as a higher level of emissions exists than is socially optimal (yet permit market efficiency is invariant).

Considering existing tradeable permit markets, such as the EU-ETS, it is most likely that rent-seeking activity will not only redistribute allocation amongst firms but also increase the aggregate emissions cap and thereby reduce welfare. Therefore, it is imperative that regulators must put in place mechanisms and procedures that credibly commit themselves to specific permit allocations and exogenous aggregate emissions caps. We leave this mechanism design problem for future work.

Although auctioning and other lump-sum methods of allocation may be desirable from the perspective of efficiency, if the regulator wants to distribute permits for free, it should focus on using static grandfathering, as using updated grandfathering in the presence of lobbying activity may induce distortionary incentives in the tradeable permit market.

4.8 Concluding Remarks

The purpose of this chapter is to analyse the impact and optimality of a multiple period permit market when firms lobby the regulator to obtain a larger permit allocation. In the model, the regulator distributed permits amongst firms based on their historically updated emissions. However, each firm may affect its permit allocation by investing in lobbying activity, persuading the regulator to increase their permit allocation. We discussed cases where historical emissions and lobbying activity combined to produce a signal for the regulator to distribute permits and when *only* lobbying activity determined permit allocation (static grandfathering). Within these two cases we made a distinction with respect to the aggregate emissions cap. The first case restricted rent-seeking activity to alter the distribution *among* the firms, that is, the aggregate emissions cap was exogenously fixed in the market. The second case additionally dealt with the possibility that aggregate rent-seeking activity could, to some extent, alter the aggregate emissions cap. In our model, firms' cooperation in lobbying activity is not necessary for a larger emissions cap. For instance, this could occur when there is industry-wide condemnation of a regulator's announced aggregate emissions cap, such as happened in the phase I allocation process EU-ETS of the UK government and other member states.

We initially show that a market that allocates permits through updated grandfathering and lobbying activity, where the costs are separable, can experience reduced permit market efficiency. Yet when the costs are assumed to be non-separable, efficiency in the permit market may be maintained. We allowed the absolute aggregate emissions cap to be exogenous and then endogenous to the level of aggregate rent-seeking - however, when the regulator is responsive to the lobbying activity, welfare is reduced.

From the regulator's perspective, if it believes that it cannot credible commit to a future allocation rule which is unresponsive to aggregate rent-seeking activity, it should avoid updated grandfathering and instead grandfather permits in the static form (or even better auction the permits).

This chapter has focused on the equilibrium conditions and market efficiency levels in a permit market where lobbying activity with an updated grandfathering allocation combines to signal to the regulator a firm's "desire" for permits. The model could be extended by relaxing the assumption of a competitive permit market by analysing strategic considerations of imperfect competitive behaviour, by assuming asymmetry either in the rent-seeking cost functions of firms or in their ability to affect the regulator through lobbying activities and emissions choices.

Part III

Recommendations and Conclusion

Chapter 5

A Permit Allocation Contest for a Tradeable Permit Market

5.1 Introduction

In a tradeable pollution permit market, the regulator's choice of initial allocation mechanism is one of the most important and contentious design issues. The regulator must, among other issues, decide on the proportion of permits each firm obtains and the cost borne by each firm. As a result, the decisions surrounding the initial allocation have significant effects on the distribution of rents, political viability and success of a scheme. Due to the importance of the initial allocation mechanism in the design of a tradeable permit market, it is our aim in this chapter to illustrate a new design in permit allocation.

In this chapter we model an initial allocation mechanism in a static tradeable permit market.[1] Our mechanism, denoted by a Permit Allocation Contest (PAC),

[1] We use a static tradeable permit market for analytical simplicity. Similar results occur when

distributes permits to the firms based on their rank. This ranking is achieved by ordering the firms based on their observable 'external action' where the external action is an activity or characteristic of the firm that is independent of their choice of emissions in the tradeable permit market. The ranking criterion (the 'external action') is determined by the regulator who chooses to fulfil a public policy objective. We show that this mechanism efficiently allocates permits and as a result the tradeable permit market is cost-effective. Moreover, we determine the symmetric equilibrium strategy of each firm to choose their external action. We find the choice of external action is dependent on each firm's ability at producing the action, expected value of allocation, permit price and the cost of producing the action.

Allocation mechanisms that use the ranking of agents have frequently been applied in areas such as labour market and sporting competition analysis (see, for example, Lazear and Rosen, 1981; Szymanski, 2003). Within the literature two main types of ranking mechanism exist: rank-order tournaments and contests. Rank-order tournaments are incentive schemes used in situations where firms' performance is observed with some exogenous noise. Rank-order tournaments typically outperform absolute, or individualistic schemes, in particular when the observation noise is common to all firms (Lazear and Rosen, 1981; Holmström, 1982; Green and Stokey, 1983; Nalebuff and Stiglitz, 1983b; Mookherjee, 1984).

When there is no individual-specific noise involved in the observation of firms' actions, one can implement a rank-order contest, which is, in effect, a multi-prize all-pay auction (Glazer and Hassin 1988; Barut and Kovenock 1998; Clark and Riis

the model is extended to include multiple periods.

1998; Moldovanu and Sela, 2001; 2006). In a rank-order contest, there is a finite number of prizes to be distributed among the participating agents, with the size of each prize known before the onset of the contest. Firms compete in this contest by submitting costly (monetary or non-monetary) "bids". Firms then are ranked in order of their bids, and the "prizes" are distributed to the firms according to firms' rankings. That is: a firm that submits the highest bid is ranked first, and thus gets the largest permit allocation ("first prize"); the firm that submits the second-highest bid is ranked second, and thus gets second-largest allocation ("second prize"), and so on, up to the firm that submits the lowest bid being ranked last, and thus receiving the smallest allocation (possibly nothing). Rank-order contests, like tournaments, tend to outperform alternative types of individualistic and contract based regulation.

The rationale for implementing rank-based mechanisms is clear when we consider the literature that focuses on environmental policy issues. By applying the seminal work of Lazear and Rosen (1981), Govindasamy et al. (1994) advocated the use of a tournament to control non-point pollution, whereby each polluting firm is ranked on its input use or pollution abatement effort. Govindasamy et al. (1994) found that a tournament can work well as it can achieve the same efficiency conditions as a pigouvian tax but with less costly information requirements. Franckx et al. (2004) extended the work of Govindasamy et al. (1994) by introducing the abatement of multiple pollutants and found that tournaments outperform emissions taxes when the "pollution specific errors" (such as weather and climatic conditions) are highly correlated amongst firms' emissions level. Shogren and Hurley (1997) experimentally tested a tournament reward system to consider the implication for environmental policy (for example, Coase bargaining and environmental conflict) and found that using such a reward system obtained the theoretical predictions quicker than standard mechanisms.

The above tournament studies have all assumed a realisation of a random error and as a result, assumed a probabilistic link between firm action and reward. Although correct in many circumstances, for example when considering emissions of air and water pollutants (as they are often stochastic in nature), cases do exist in environmental policy where the effort of the firm is deterministically linked to their observable action, that is, situations do exist where rank-order contests can be desirable. To the best of our knowledge, there has been no attempt at implementing a rank-order contest to environmental issues and, in particular, no attempt at implementing a rank-order contest as a mechanism to initially allocation pollution permits. This, then, is our main contribution to the literature.

In existing tradeable permit markets, allocation types can usually be distinguished into two broad categories: the grandfathering and auctioning of permits. The grandfathering of permits occurs when the regulator freely allocates allowances to each firm based on their historical emissions (perhaps output or some other proxy). Although a popular and frequently used mechanism, grandfathering is far from an ideal allocation mechanism as it is often viewed as politically cumbersome and inefficient (Stavins, 1998, Cramton and Kerr, 2002). Firms may have an incentive to lobby the regulator in favour of larger permit allocations which, due to the wasteful use of resources, may reduce welfare in the economy. Moreover, when grandfathering is used with information that is updated over time (updated grandfathering), a link is created between a firm's current level of emissions and its future permit allocation which may result in a distortionary incentive to increase emissions (Böhringer and Lange, 2005; Keats and Neuhoff, 2006).

A feasible alternative to grandfathering is generally considered to be auctioning. In an auction, permits are allocated to each firm based on their monetary bid relative to every other firm (Oehmke, 1987; Cramton and Kerr, 2002; Hahn and Noll, 1982; Franciosi et al. 1993; Lyon, 1984; 1986). Auctions are often considered to be a representative example of a 'lump-sum' allocation mechanism as permits are distributed to each firm independent of their size of historical emissions. Due to this characteristic of auctioning, it is viewed as a desirable and efficient method of allocating permits (see, for example, Cramton and Kerr, 2002). However, the main drawback, and as a result, the main reason for the infrequent use of auctions is the political difficulty in implementing such a mechanism. As the winners in the auction are obliged to pay for the permits, resistance against implementing auctions (in the form of lobbying for grandfathering) have been a severe restriction on the implementation of such schemes.[2] It is often possible to reduce firms' resistance against auctions by redistributing the revenue to the participants (revenue neutral auction (Hahn and Noll, 1982)) or to reduce distortionary taxes in the economy (the revenue recycling effect (Parry, 1995; Parry et al., 1999)).

With problems associated with both grandfathering and auctioning it is desirable to try and engineer alternative mechanisms that may be better suited for tradeable permit markets—something this chapter aims to achieve.

[2]Auctioning, however, is slowly becoming an increasingly important and favoured initial allocation mechanism in existing tradeable permit markets, such as the European Union Emissions Trading Scheme (EU-ETS).

Our partial equilibrium model attempts to reach a middle ground between grandfathering and auctioning. As our model is a type of 'all-pay auction' it has many similarities to a standard permit auction. Yet, as the ranking criterion in the PAC can be non-monetary, it is possible to have characteristics similar to a grandfathering mechanism. Our model has two stages, in the first stage every firm is ranked in order of their size of external action. Each firm obtains a permit allocation which is directly related to their ranking in the PAC. In the second stage, the firms obtain the permit allocation and choose a level of emissions to minimise the cost of participating in the tradeable permit market.

The works that are most relevant to our argument are Glazear and Hassin (1988) and Moldovanu and Sela (2001). Glazer and Hassin (1988) study the design of a contest to try and maximise the expected aggregate output of a set of firms. They find that with identical firms, the prizes should be set equal (apart from the lowest prize which should be zero). Moreover, when firms have different abilities, it is optimal to choose only one prize. In a similar vein, Moldovanu and Sela (2001) study a rank-order contest with several risk neutral agents and a contest designer aiming to maximise the total expected effort. Moldovanu and Sela (2001) separate their model into three distinct cases: when the costs of choosing effort are linear, concave or convex. Restricting the model to two prizes, they find it is optimal to allocate a single prize when contestants costs are linear or concave and to allocate two (possibly equal or unequal) prizes when costs are convex. Our model uses a similar contest structure to the above studies by allowing a number of permit allocations to be allocated to several firms in a tradeable permit market. We study an allocation system in which there are no random errors present to alter firms' external action choices (a perfectly discriminating contest), so that the regulator observes each firms level of external action without random errors. Although not attempted in this chapter, it is entirely possible to extend our model to introduce random shocks into the determination of firms' external actions (an imperfectly discriminating contest).

The chapter is organised as follows: section 5.2 introduces the concept of a PAC and explains the rationale for its use. Section 5.3 discusses the general properties of the model. Section 5.4 discuses the tradeable permit market. section 5.5 details the PAC mechanism discuses the firm's problems and analyses the regulators optimal choice of permit allocations, Section 5.7 details some policy implications and Section 5.8 concludes.

5.2 An Alternative Initial Allocation Mechanism Design

The choice of initial allocation mechanism is one of the most important design issues of a tradeable permit market and as mentioned above, the majority of regulators tend to choose an allocation mechanism that resembles either the grandfathering or auctioning of permits. However, problems are associated with both types of mechanism. Among others, grandfathering is generally considered to be an inefficient mechanism as significant lobbying activity and distortionary incentives are encountered in the distribution process, whereas auctions, although more efficient, tend to be difficult to implement due to the political pressure from firms (see, for example, Cramton and Kerr, 2002; Svendsen, 2005; Böhringer and Lange, 2005a). In this section, we start by introducing an alternative candidate mechanism and highlight the rationale for using this approach.

This chapter concentrates on a rank-order contest: a mechanism where agents are rank-ordered with respect to their (costly) bids (Lazear and Rosen, 1981; Holmström, 1982; Green and Stokey, 1983; Nalebuff and Stiglitz, 1983a; 1983b; Mookherjee, 1984; Glazer and Hassin, 1988; Moldovanu and Sela, 2001; 2006). In our model, we use a rank-order contest to allocate permits in a tradeable permit market, which we denote as a Permit Allocation Contest (PAC). To keep the ranking criterion as general as possible, we assume that firms will be ranked on their choice of an observable 'external action'.[3] The observable 'external action' is an activity or characteristic of the firm which is independent from it's choice of emissions and the permit market. For example, possible 'external actions' include the improvement in noise reduction in firms' facilities, the record of health and safety incidents or some corporate and social responsibility criterion and so on. The regulator aims to select an appropriate criterion to rank all firms so that the action is independent of emission choices and where the aggregate action can fulfil an objective set by the regulator, we return to this issue in the next section.

A Permit Allocation Contest is a special type of auction in which every participating firm, regardless of the final outcome, incurs the cost of choosing a 'bid' or 'action' (an all-pay auction). It follows that a PAC has a number of properties

[3] The external action can be, at the extreme, an invariant characteristic of a firm, e.g. population for a country under a global tradeable permit market. However, it is most likely that an external factor will be chosen so that firms have the ability to alter their permit allocation.

Properties of a PAC *Disproportionality*: At the margin, agents' actions may have disproportionate effects on their permit allocation resulting in a larger incentive to maximise the policy objective. *Adaptability*: An extensive choice of allocation criterion (external factor) may exist, which allows the scheme to be implemented in a larger number of scenarios. *Linkage*: A clear link exists between an agent's socially beneficial actions and the permit allocation they receive. An agent that produces 'better' actions will obtain a higher permit allocation. *Fairness*: A PAC can appear 'fair' to society as permits are allocated using an instrumentalist approach so that prior permit holdings have no influence.

Table 5.1: A Permit Allocation Contest

similar to a standard permit auction (and some unique to itself). Table (5.1) highlights some fundamental properties of a generalised PAC that may exist for permit allocation.

In a PAC, the decisions regarding the number and size of permit allocations has a substantially different effect on the incentives of each firm compared to alternative mechanisms, such as a 'winner-pays' auction. The permit allocations in the PAC are not *directly* related to the firms' external actions, but instead they are determined by firms' rankings according to the size of their external actions. Thus, a small increase in the firm's external actions may result in a disproportionately large change in permit allocation. For example, only a small increase in external action by the second-ranked firm could have made this firm the winner of the contest, and thus lead to the largest permit allocation (which is typically made to be substantially larger than the "second prize").[4] Rank-order contests, and in particular our PAC, involve a clear rule of allocation of prizes (i.e. no regulator's subjective judgement is

[4]This frequently happens in sport tournaments where the difference between prizes (and notably between first and second prizes) is non-linearly increasing (Szymanski, 2003).

involved), and are easily adaptable to changing market and technological conditions. Moreover, as Krishna and Morgan (1997) showed, all-pay auctions tend to generate higher aggregate bids than their winner-pay counterparts. In addition, as Moldovanu and Sela (2001) showed, when the prize structure is suitably chosen, such a contest will tend to generate the largest aggregate bids. As the choice of external action at the margin can significantly alter a firm's permit allocation, the robust incentives created in the PAC system should induce all firms to maximise their external action.

As the ranking criterion need not be monetary in value, there may be a wide variety of possible external actions to choose from (*any* action that is independent of emissions choices is possible). It follows that one may be chosen so that the scheme is politically acceptable for the regulator, market participants and the wider economy. Consequently, a PAC system has the possibility of being implemented in a wide variety of tradeable permit market contexts. For instance, a PAC could be implemented in an international permit market where the participating countries are allocated permits (or a burden is assigned to each country) based on their (country) external action, such as the proportion of recycling in that the country and so on. Yet, this system could also be adapted to smaller markets, such as firms choosing external actions based on their improvement in noise pollution. Every tradeable permit market has heterogeneous circumstances in which it operates and with a PAC, public policy objectives (and external actions) can be chosen to compliment the social 'norms' and prevailing political opinion in the specific emissions trading scheme. In contrast, although auctioning and grandfathering can be used in all tradeable permit markets, the only allocation criterion available is the comparison of firms' money 'bids' and historical emissions, respectively. The lack of other possible allocation criterion may make, especially for the case of auctions, implementation more difficult.

Using a PAC in a tradeable permit market may offer the (political) benefit of having a clear connection between permit allocations (including the differences between them) and some socially beneficial firm action. It is possible that a PAC system may actually appear 'fairer' to a larger number of groups in society than alternative mechanisms as it couples permit allocation (a reward to the firms) with some public policy objective. In contrast, grandfathering permits creates a perverse link between emissions and the permit rent each firm receives.[5] Therefore, large polluters are implicitly rewarded and small polluters are implicitly punished for their choice of emissions.

Similar to the auctioning of permits, a PAC takes an 'instrumentalist' perspective in that it ignores past and current permit holdings when determining permit allocations (Raymond, 2003). Therefore, this type of allocation approach treats all firms equally in that firms who invest early in pollution abatement are not implicitly punished (as would happen under a grandfathering scheme). However, unlike an auction, a PAC mechanism can be adapted so non-monetary criterion are used to rank the firms which may be more appealing to participating firms than an auction.

Although a PAC distribution mechanism appears to have a number of possible advantages over alternative mechanism a limitation of the PAC is the external

[5] The equitable issues associated with permit allocation are notoriously under researched, mainly due to the normative aspects involved (Raymond, 2003). All allocation mechanisms can appear 'fair' as it very much depends on the attitude to property and the specific circumstances, i.e. an industry level or global emissions trading scheme.

action must be defined in an appropriate manner. As noted above, an optimal external action has to be independent of emissions so that no distortions are created in the permit market whilst simultaneously being politically acceptable for all market participants. Unsurprisingly, the existence of an optimal external action may not necessarily occur. The ease at which an external action can be chosen crucially depends on the specific institutional context of the permit market. For instance, when the market participants are countries, such as in an international permit market, it may be relatively easy to find an external action that is both socially beneficial and independent of emissions. Countries in a carbon dioxide permit market, such as the EU-ETS, could be ranked on the proportional reduction of landfill waste from the non-trading sector (or the production of methane from it). As the market participants, become smaller in size (e.g. industries or firms), it may be more difficult to find an external action with the desirable qualities. Throughout this chapter, for analytical simplicity, we discuss firms as the participating agents, however, it can be adapted to a wider institutional context.

5.3 General Properties of Model

Let $\Theta = \{1, 2, \ldots, n\}$ be a set of firms that participate in a competitive tradeable permit market to control a pollutant. In this (static) tradeable permit market, firm i chooses a level of emissions e_i at a cost $c_i(e_i)$ with $\frac{dc_i(e_i)}{de_i} \leq 0$ and $\frac{d^2c_i(e_i)}{de_i^2} \geq 0$.

The regulator has a secondary objective, un-related to emissions reduction. To allow for analysis, we restrict our attention to public policy scenarios in which the regulator aims to minimise a social 'bad' produced by *all* firms in the permit market, such as the improvement of: health and safety incidents, noise pollution, other pollutants, labour laws, corporate responsibility and so on. Therefore, in our model, the regulator simply wants to minimise the aggregate social 'bad' (or maximise some social 'benefit') by using incentives in the form of permit allocations (without the need for standard command and control regulation). To adhere to the regulator's public policy objective, firm i chooses an *external* 'action' denoted by z_i, in which it bears a cost $v(z_i)$ with $\frac{dv(z_i)}{dz_i} \geq 0$ and $\frac{d^2v(z_i)}{dz_i^2} \geq 0$. In other words, the external action is an activity taken by each firm, independent of emissions choices, to comply with the regulator's goal of minimising some aggregate social 'bad'.[6]

The model is separated into two distinct stages. In the first stage, the regulator initially allocates the pollution permits to the market and in the second stage, firms are allowed to trade the pollution permits obtained in the first stage.

In stage one, the regulator chooses an ordered vector of permit allocations, $\mathbf{s} = (s_1, s_2, \ldots, s_n) \in \mathbb{R}_+^n$ subject to $s_1 \geq s_2 \geq \ldots \geq s_n \geq 0$ and $\sum_{j=1}^{n} s_j = E$ where s_j is the j^{th} permit allocation and E is the absolute aggregate emissions cap for the tradeable permit market (the regulator's precise choice of permit allocations will be considered later in this chapter). Using the permit allocation vector, the regulator distributes a (possibly unequal) permit allocation to each firm whilst ensuring the absolute emissions cap is binding. The specific permit allocation to a firm depends on each firm's size of external action relative to every other firm, so that firms that

[6]In most permit markets, the participation of firms in the permit market is usually dependent on their inclusion in a product market e.g. a permit market may require participation of all energy producers. Given the permit market participants have similar product markets, it is possible that each firm in the permit market has a number of characteristics or 'actions' that are comparable amongst all participants, independently chosen from its emissions and socially beneficial, which can be used as the external factor.

have a larger relative size of external action obtain a larger permit allocation.[7] In a PAC, the regulator observes the external actions of all firms and ranks them in descending order of their external action where the firm with the highest level of external action is ranked first, the second highest firm is ranked second and so on until all firms are ranked.[8] Each ranked-ordered firm obtains a corresponding permit allocation so that the firm with the top ranking obtains the largest permit allocation (s_1), the second ranked obtains the second highest permit allocation (s_2) and so on until all individual permit allocations are distributed to the firms.

In stage two of the model, given a known permit allocation, each firm decides to choose a level of emissions to minimise the cost of participation in the tradeable permit market.

As mentioned above, the regulator has two non-competing policy objectives.[9] Firstly, the regulator is motivated to choose a vector of permit allocations to minimise the aggregate abatement cost in the tradeable permit market–the standard permit market regulatory objective. Second, the additional objective of the regulator is to provide incentives for the permit market firms to maximise some predetermined public policy target which we define as the maximisation of expected aggregate external actions. As such, the regulator is not a strict social cost minimiser since it is not concerned with the firms' costs of obtaining an external action

[7] The regulator must choose an external action that is feasible for the tradeable permit market. To avoid size effects, it is likely the regulator could use changes in external action throughout time, for example, the relative reduction of noise pollution over time.

[8] Other possible mechanisms are also feasible, we could for example, apply a yardstick competition mechanism to the external factor. Using a yardstick model would allow each firm to obtain a continuous expected allocation, instead of a discontinuous allocation, as experience in a PAC. Apart from this difference all results should hold.

[9] Alternatively, the model can include two regulators with independent, non-competing policy objectives.

(it simply wants to maximise the aggregate action). Following this approach shows the realistic separation and independence between two legislative procedures which may commonly occur between a product and tradeable permit market. The regulator is not focusing on choosing an *efficient* level of aggregate external action for the second public policy objective, instead, the regulator wants to simple maximise the aggregate actions.

We solve the model backwards by investigating the permit market in the following section and then focusing on the initial allocation of permits in the subsequent section.

5.4 Stage Two: The Permit Market

In this section, we investigate firm i's optimal choice of emissions in a permit market when the tradeable permits have been allocated using a PAC.

From stage one, let us assume that firm i chose a positive level of external action (z_i) and, as a result of the firm's ranking, the regulator distributed a permit allocation $\tilde{s}_i \in \mathbf{s}$ to the firm where $\tilde{s}_i$ is independent of e_i. With the endowment of tradeable permit obtained, firm i aims to minimise (maximise) the cost (profit) of participating in the permit market. Formally, given a permit price p, firm i's objective function is:

$$\min_{e_i} \qquad c_i(e_i) + p(e_i - \tilde{s}_j) \tag{5.1}$$

Solving for firm i's emissions gives us:

$$-\frac{dc_i(e_i)}{de_i} = p \tag{5.2}$$

From equation (5.2), each firm will choose a level of emissions to equate their marginal abatement cost with the permit price and it follows from standard theory that:

Remark 16 *When a PAC distributes permits, the tradeable permit market is least-cost.*

A PAC is an efficient instrument to allocate permits as it is a 'lump-sum' mechanism—a mechanism by which permits are distributed independently of the choice variable (emissions). The criterion for allocating the permits (the external action) is independent of emission choices, therefore, no distortions exist in the tradeable permit market. Due to the 'lump-sum' characteristics of a PAC, efficiency in the tradeable permit market is independent from the vector of permit allocations chosen by the regulator (Montgomery, 1972).

5.5 Stage One: The Initial Allocation of Permits (PAC)

In the last section, it was noticed that when firms obtain tradeable permits through a PAC—a mechanism that ranks firms in order of their level of external action—the permit market can be least-cost. In this section, we investigate the PAC in more detail and, in particular, given an exogenously fixed permit allocation vector, find the conditions that affect each firm's choice of external action. We then investigate the optimal choice of permit allocation vector that can maximise the aggregate external action (public policy objective).

The Permit Allocation Contest in this chapter, follows closely to the work of Glazer and Hassin (1988), Barut and Kovenock (1998) and Moldovanu and Sela (2001; 2006). For analytical simplicity, we assume throughout that every firm participates in the PAC. Therefore, we are implicitly assuming the cost involved in participating in the PAC is less than the cost of abatement and/or purchasing permits from the market.[10] We begin by discussing the firm's problem.

5.5.1 Firm's Problem

Following Moldovanu and Sela (2001), we represent the ability of each firm to produce an external action by the parameter α_i where the costs of producing the external action are $\alpha_i v(z_i)$. The ability parameter is private information to each firm and is known before the PAC commences. We further assume that the ability parameter is separable to the external action and is independently drawn from a support $[\xi, 1]$ where $0 < \xi < 1$ with the (commonly known) distribution function $G(\alpha_i)$ with density $G'(\alpha_i) > 0$. Suppose firms' strategies to choose a level of external action are symmetric and strictly decreasing. Indeed, each firm follows a symmetric strategy of choosing a level of external action dependent on their ability, $z_i = h(\alpha_i)$ where h is a strictly decreasing, monotonic and differentiable function.

[10] The results would still be maintained if we assumed that some firms did not participate in the PAC. The vector of permit allocations would be distributed to the firms that did participate in the PAC and the remaining firms would purchase permits, reduce emissions or a mixture of both.

Although the permit allocation vector is common knowledge, the individual firm is unaware of the precise permit allocation obtained until the completion of the PAC. It follows that each firm will, given their knowledge of their ability (and distribution of abilities) and vector of permit allocations, use a value of expected permit allocation to choose an optimal level of external action. Conditional on all firms using their symmetric strictly decreasing strategies $h(\alpha_i)$ with the common distribution function $G(\alpha_i)$, the expected permit allocation to each firm is represented by:

$$B(G(\alpha_i)) = \sum_{j=1}^{n} s_j \binom{n-1}{j-1} (1 - G(\alpha_i))^{n-j} (G(\alpha_i))^{j-1} \tag{5.3}$$

The expected permit allocation in equation (5.3) is a linear combination of n order statistics where the probability of obtaining the j^{th} permit allocation is based on the probability of being ranked j^{th} in the PAC (Glazer and Hassin, 1988; Moldovanu and Sela, 2006). For example, the probability of winning the largest permit allocation is the probability of being ranked first ($(1 - G(\alpha_i))^{n-1}$), alternatively, it is the probability of $n-1$ firms being ranked below this firm. Equation (5.3) is strictly decreasing in α_i as a larger α_i implies a 'lower' ability and choice of external action and thus a lower expected permit allocation.

Example *For a PAC with $n = 2$ firms and $j = 2$ permit allocations, the expected permit allocation for firm i is:*

$$B(G(\alpha_i)) = s_1 (1 - G(\alpha_i)) + s_2 (G(\alpha_i))$$

Given the expected allocation of permits and the choice of external action from every other firm, each firm aims to choose a level of external action to maximise their allocation of permits for the tradeable permit market in the forthcoming period. Formally, given the permit price p and the external actions of every other firm, firm i's objective function is:

$$\max_{z_i} \quad p \cdot B(G(\alpha_i)) - \alpha_i v(z_i) \tag{5.4}$$

where $B(G(\alpha_i))$ is given in equation (5.3). From the objective function in equation (5.4), we now determine firm i's optimal choice of external action to obtain the largest amount of tradeable permits. Similar to Moldovanu and Sela (2006), we have the following proposition:

Proposition 17 *Given the external action of all other firms and a known vector of permit allocations, firm i will choose a level of external action so that:*

$$z_i = v^{-1}\left[p \cdot \int_{\alpha_i}^{1} -\frac{B'(.)(G'(t))}{t} dt\right]. \tag{5.5}$$

Proof. Given the common strategy $z_i = h(\alpha_i)$ which is strictly decreasing, monotonic and differentiable function, suppose firm i chooses a level of external action $\tilde{\alpha}_i$ so that $\tilde{z}_i = h(\tilde{\alpha}_i)$. Substituting this common strategy into the (5.4) equation gives

$$p.B(G(h^{-1}(\tilde{z}_i))) - \alpha_i v(\tilde{z}_i)$$

Differentiating with respect to $\tilde{z}_i$ is

$$p.\frac{dB}{dG} \cdot \frac{dG}{dh^{-1}(\tilde{z}_i)} \cdot \frac{dh^{-1}}{d\tilde{z}_i} - \alpha_i \cdot \frac{dv(\tilde{z}_i)}{d\tilde{z}_i}$$

In equilibrium, firm i will choose $\tilde{z}_i = z_i$ so that

$$p.\frac{dB}{dG} \cdot \frac{dG}{dh^{-1}(z_i)} \cdot \frac{dh^{-1}}{dz_i} - \alpha_i \cdot \frac{dv(z_i)}{dz_i} = 0$$

Multiplying by $\frac{dz_i}{dh^{-1}}$ and dividing by α_i gives

$$\frac{dv(z_i)}{dh^{-1}(z_i)} = \frac{p.B'(.)(G'(h^{-1}(z_i)))}{\alpha_i}$$

Again, using the common strategy $z_i = h(\alpha_i)$ gives

$$\frac{dv(z_i)}{d\alpha_i} = \frac{p.B'(.)(G'(\alpha_i))}{\alpha_i}$$

The n^{th} ranked firm has no incentive to choose a positive level of external action as it can obtain the same permit allocation by choosing an external action of zero. Notice that this gives the upper boundary condition $h(1) = 0$. Integrating with respect to α_i with the boundary condition gives

$$v(z_i) = p \cdot \int_{\alpha_i}^{1} -\frac{B'(.) \cdot (G'(t))}{t} dt$$

and as required

$$h(\alpha_i) = z_i = v^{-1} \left[p \cdot \int_{\alpha_i}^{1} -\frac{B'(.)(G'(t))}{t} dt \right]$$

■

From Proposition (17), it is clear to see that the cost of the external action has a crucial determination of the level chosen. Indeed, the 'less' convex a firm's cost function then the larger the choice of external action will be. Also, it is clear that as the value of each permit appreciates each firm will choose a larger value of external action ($\frac{dz_i}{dp} > 0$), as a result, a regulator is likely to experience a large increase in aggregate external actions. The value of the marginal permit allocation is also important when we consider the expected allocation ($B'(G(\alpha_i))$): a larger expected permit allocation will give the incentive for all firms to choose larger external actions. From equation (5.3), the expected permit allocation is determined by two variables: the choice of permit allocation vector and the distribution of firms' abilities. Therefore given a fixed distribution of abilities, the regulator has the ability to increase the size of aggregate external actions by choosing an appropriate permit allocation vector to maximise the expected permit allocation.

5.5.2 Regulator's Problem

In the last subsection, it was shown that, to obtain a permit allocation, each firm used a symmetric equilibrium strategy to determine their optimal level of external actions. Consequently, each firm based their decision of external actions on the value of permits (both the price of permits and the distribution of permits), the distribution of abilities, their own, privately known, ability and their cost function. In this subsection, we focus on the second policy objective of the regulator, namely, the regulator's motivation to maximise some public policy objective.

Up to this point, we have assumed that the vector of permit allocations has been exogenously fixed and known to all firms. In this sub-section, we relax this assumption and allow the regulator to choose a vector from the set of feasible permit allocations $\left\{(s_1, s_2, \ldots, s_n) \in \mathbb{R}^n_+ : s_1 \geq s_2 \geq \ldots \geq s_n \geq 0, \sum_{j=1}^n s_j = E\right\}$. Given the regulator has acknowledged some public policy objective prior to the PAC, the regulator's objective is to choose a vector of permit allocations to maximise this public policy objective. Formally, using the symmetric equilibrium strategy of each firm in equation (5.5), the regulator's objective is to:

$$T = n \int_{\xi}^{1} h(\alpha_i) \cdot G'(\alpha_i) d\alpha_i \tag{5.6}$$

subject to:

$$s_1 \geq s_2 \geq \ldots \geq s_n \geq 0, \text{ and } \sum_{j}^{n} s_j = E$$

where $h(\alpha_i)$ is the symmetric strategy for the external action given by equation (5.5). Therefore, T is the expected value of aggregate external actions given that each firm obtains an ability from the support $[\xi, 1]$ and each firm follows the symmetric equilibrium strategy.

Similar to Glazer and Hassin (1988), the regulator's objective in equation (5.6), is not easily analytically solvable without the introduction of specific functional forms. However, a number of key implications are discussed below.

It is often discussed in tradeable permit market literature that an egalitarian approach, where permits are allocated equally to all firms, is a possible permit allocation process (Rose and Steven, 1993; Raymond, 2003). Indeed, It has been strongly advocated as a distribution rule for an international permit market, where allocation is based on equal number of permits per capita (Kverndokk, 1995; Rose et al. 1998). However, the most extreme egalitarian approach is where every firm obtains an identical amount of permits independent of all information—a 'pure' lump-sum approach. In such a scenario, the regulator's vector of permit allocations is $\mathbf{s}^{egal} = (\frac{E}{n}, \frac{E}{n}, ..., \frac{E}{n})$, where each firm in the PAC obtains an identical share of the permit cap. If the regulator were to use such a vector of permit allocations, then from equation (5.6), it is immediate that:

Corollary 18 *If the regulator chooses an egalitarian permit allocation vector ('pure' lump-sum approach) ($\mathbf{s}^{egal}$) then no second public policy objective is achievable.*

Proof. Under an egalitarian distribution $\mathbf{s}^{egal} = (\frac{E}{n}, \frac{E}{n}, ..., \frac{E}{n})$. Therefore it follows that $B(G(\alpha_i)) = \frac{E}{n}$ and consequently we have $B'(.)G'(\alpha_i) = 0$ where there is no uncertainty in the permit allocation as the distribution of permits is independent of firm's external actions. Hence from equation (5.5) it follows that $z_i = v^{-1}\left[p \cdot \int_{\alpha_i}^{1} 0 \; dt\right] = v^{-1}[p \cdot (C - C)] = v^{-1}[0] = 0.$ ■

Under this type of egalitarian approach, individual allocations are identical which means the distribution of permits is independent of each firm's choice of external action, therefore, no incentive exists for firms to choose a positive level of external action. In policy terms, this type of egalitarian approach should not be chosen if the regulator wants to combine the permit allocation of a tradeable permit market with a public policy objective.

As can be observed from Corollary (18), for a regulator to succeed in a public policy objective, it must choose a vector of permit allocations that discriminates against firms with larger external actions compared to ones with smaller actions. For a policy objective to be met, even partially, a firm must be rewarded for choosing a higher level of external action relative to other participating firms.[11]

As Glazer and Hassin (1988) and Barut and Kovenock (1998) have proved, to maximise the aggregate external action, s_n must be a zero permit allocation. If this did not occur, there would be an incentive for firms with 'weaker' abilities (high α's) to reduce their level of external action and obtain a positive level of permit allocation. Choosing a vector of permit allocations with $s_n = 0$ will induce each firm to choose a non-zero level of external action. In essence, have $n-1$ non-zero permit allocations.

It is difficult to analytically solve for the permit allocations. Although it is known that a discriminatory vector of permit allocations is needed, to what extent this vector is discriminatory is answered in the subsequent sub-section.

5.6 Numerical Analysis

By using GAMS (General Algebraic Modelling System), we numerically estimate optimal permit allocation vectors for a tradeable permit market with three participants.[12] We neglect the numerical analysis of the competitive tradeable permit market and instead focus on the PAC mechanism. Each PAC participant chooses an external action with quadratic costs of the form, $\alpha_i v(z_i) = \alpha_i z_i^2$. In Table (5.2), we prescribe abilities for each firm (α_i) from a uniform distribution on the support $[0.5, 1]$ which gives the following ability parameters for the three participating firms where a lower value indicates a 'stronger' ability and vice versa.

[11] The 'large' external action can be a proportional change in their own actions. Therefore, large firms, in the absolute sense, do not have 'size effect' advantages

[12] For tractability, this analysis considers three firms. Of course, this analysis can be extended to more than three firms (with similar results).

Firm	Ability Parameter
Firm 1	0.875
Firm 2	0.75
Firm 3	0.625

Table 5.2: Firms' ability parameters from a uniform distribution

From Proposition (17), firm i will choose a level of external action so that:

$$z_i = 8(s_1 - s_2)[-1 - \ln \alpha_i + \alpha_i] + 4(s_2 - s_3)[-2 + \ln \alpha_i - \alpha_i] \tag{5.7}$$

given firm i's belief that all remaining firms use a symmetric strategy for their external action. From equation (5.7), the choice of firm i's external action is dependent on the permit allocations and their ability. In particular, the external action is dependent on the difference in size between first and second and second and third permit allocations. The regulator has two policy decisions to select. The first decision is whom to allocate permits to, here, a choice between one and three permit allocations is allowed (therefore there is a possibility that some participating firms do not obtain an initial allocation and have to purchase permits off the market). Second, within the three possible choices of permit allocation, the regulator is allowed to select an initial distribution of permits between the market participants. In particular, the regulator decides on a permit allocation 'vector' that ranges from complete equality (vector 1) and becomes increasingly discriminatory towards the choices of external action (vector 7). Given a permit allocation vector, the proportion of permits allocated to each firm is denoted by the rank ordering $(1^{st}, 2^{nd}, 3^{rd})$. For example, in Table (5.3), when three permit allocations are awarded to three participating firms,

Distribution type	Aggregate Action (T)
Three Permit Allocations	
1. $(33.3\%, 33.3\%, 33.3\%)$	0
2. $(40\%, 40\%, 20\%)$	1190.6628
3.$(50\%, 40\%, 10\%)$	1558.5242
4. $(60\%, 30\%, 10\%)$	1519.6218
5. $(70\%, 25\%, 5\%)$	1657.043
6. $(80\%, 15\%, 5\%)$	1610.0269
7. $(94\%, 5\%, 1\%)$	1680.7801
Two and One Permit Allocations	
1. $(50\%, 50\%, 0)$	1882.6032
2.$(55\%, 45\%, 0)$	1868.9567
3. $(60\%, 40\%, 0\%)$	1854.2658
4. $(70\%, 30\%, 0\%)$	1821.4074
5. $(80\%, 20\%, 0\%)$	1783.0847
6. $(90\%, 10\%, 0\%)$	1737.6872
7. $(100\%, 0\%, 0\%)$	1682.0963

Table 5.3: Aggregate External Actions

the first permit allocation vector is $(33.3\%, 33.3\%, 33.3\%)$ which illustrates that the firms ranked 1^{st}, 2^{nd}, 3^{rd} receive a third of the permit allocation each. Given the regulator distributes 100,000 permits to the market with a fixed market permit price of €10, Table (5.3) illustrates a selection of possible permit allocation vectors and the corresponding aggregate external actions. The aggregate external actions are the numerical estimates of the 'effort' of all participating firms, such as the amount of resources used for noise reduction, investment in health and safety procedures.

Graphically representing Table (5.3) in Figure (5-1) illustrates the level of aggregate external actions for all permit allocations. The x-axis represents the regulator's choice of permit allocation vector (a move rightward increases the discriminatory power of the vector).

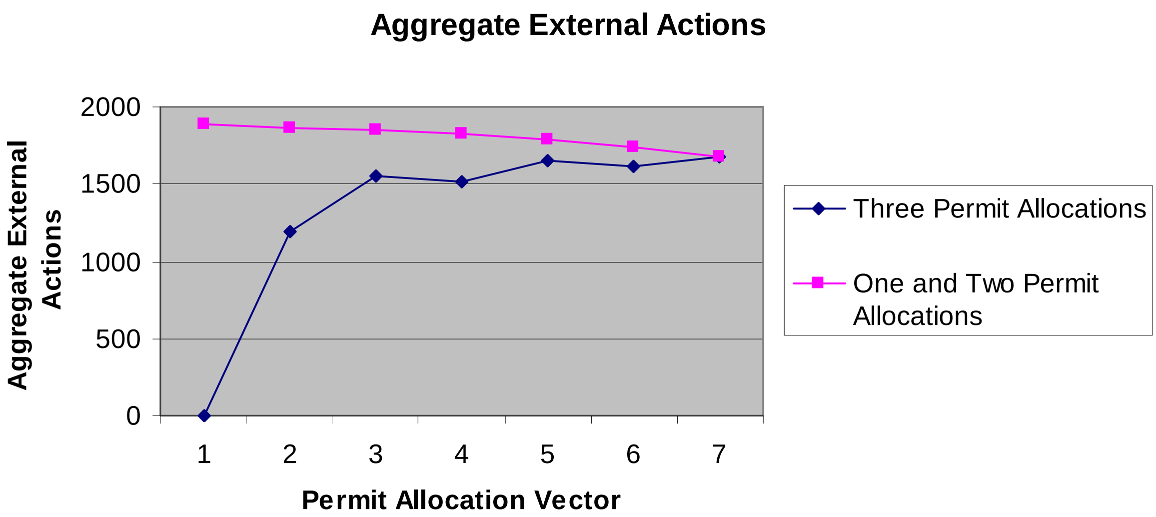

Figure 5-1: The Result of a PAC on Aggregate External Actions

From Figure (5-1), with three permit allocations, there is a tendency for aggregate external actions to initially increase as the permit allocation vector becomes increasingly discriminatory. Aggregate actions increase rapidly and the rate of change slows as the three allocations become more discriminatory. In contrast, with one and two permit allocations, as the vector becomes more discriminatory, there is a tendency for aggregate external actions to reduce.

Again, from Figure (5-1), a link exists between the number of permit allocations and the aggregate external action. In particular, it appears that the choice of a larger number of permit allocations results in lower aggregate external actions. The extent of this problem reduces as the permit allocation vector becomes more discriminatory.

In policy terms, the regulator has a trade-off. The regulator may find it desirable to distribute a large number of permit allocations. A larger number of permit allocations means fewer firms obtain no initial allocation which might improve the mechanisms implementation chances. However, the regulator also wants to maximise the aggregate level of external actions which is achieved by reducing the number of permit allocations. It is possible that the regulator could choose either a large number of permit allocations with a very discriminatory permit allocation vector (as the problem of low aggregate external action reduces with more discriminatory vectors) or choose a smaller number of permit allocations but allow more equality in distribution of permit allocations. The specific choice of how many permit allocations to distribute and the discrimination involved in the permit allocation vector will depend very much on the current political circumstances surrounding the tradeable permit market. The regulator must consider both elements carefully to create a desirable initial allocation mechanism. To analyse the choice of external actions further, we now discuss the external actions of individual firms.

5.6.1 Three Permit Allocations

When the regulator distributes three permit allocations all firms obtain a permit allocation. As proved in Corollary (18) and observed in Figure (5-2), when the permit allocation vector is egalitarian (permit vector one), each firm chooses a zero level of external action as there is no incentive to compete against the remaining firms. A movement to a more discriminatory vector (a rightward movement) shows that firms with 'stronger' abilities will always produce more external action than 'weaker' firms (this is also true for *all* other permit allocations). For example, for any permit allocation vector, firm 1 (the 'strongest' firm) produces the highest level of external action whereas the firm 3 (the 'weakest' firm) always produces the lowest

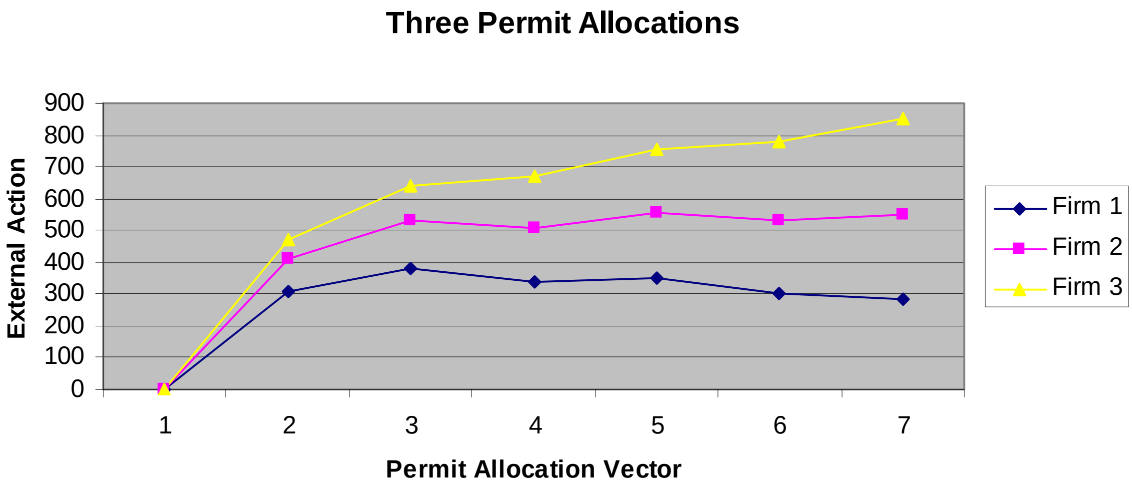

Figure 5-2: Three Permit Allocations and Corresponding External Actions

amount.

It is apparent from Figure (5-2) that as the regulator chooses more discriminatory vectors, firms with 'weaker' abilities will reduce their external action sooner that firms with higher abilities. For instance, firm 1 (the 'weakest' ability) reduces their external action from permit vector three onwards, whereas firms with stronger abilities do not reduce their external actions. The 'strongest' ability firms tend to increase their external actions as the permit allocation vector is made more discriminatory and they obtain a larger number of permits. For a PAC with three permit allocations, the aggregate external actions tend to increase as the strongest firms' actions outweighs the reductions from the 'weakest' firm.

5.6.2 One and Two Permit Allocations

Allowing for only one or two permit allocations means that at least one firm will not obtain a permit allocation and have to purchase permits on the market. Initially, two equal permit allocations are awarded and then increased in discriminatory power until the last allocation is a single allocation. As the permit allocations change in discrimination, it can be seen from Figure (5-3) that the weaker firms (firms 1 and 2) begin to reduce their choice of external actions as it becomes increasingly likely that they will not receive a permit allocation. Reducing the number of permit allocations has a negative effect on the aggregate external action. Although, the 'strongest' firm continues to increase their choice of external action this is outweighed by the reduction in the two 'weaker' firms' actions.

From the chosen vectors of Table (5.3), allowing two equal prizes results in the largest external action as this gives the 'weakest' firm some incentive to choose larger external actions, however, as the number of permits is reduced in the second allocation, it becomes less worthwhile for firms 1 and 2 to participate in the PAC. Similar to Moldovanu and Sela (2001), as the costs of the firms are convex, allowing a single permit allocation will never optimally maximise the external actions of the participating firms. Instead, two equal permit allocations will maximise the aggregate external action.

5.7 Policy Implications

Using a PAC mechanism gives theoretical benefits in that (i) permits are efficiently allocated and (ii) a secondary public policy objective can be fulfilled. One possible application of a PAC into an existing tradeable permit could be the European Union Emissions Trading Scheme (EU-ETS). Under the United Nations Framework Convention on Climate Change (UNFCCC) under articles 4.2 (a) and 20, the convention

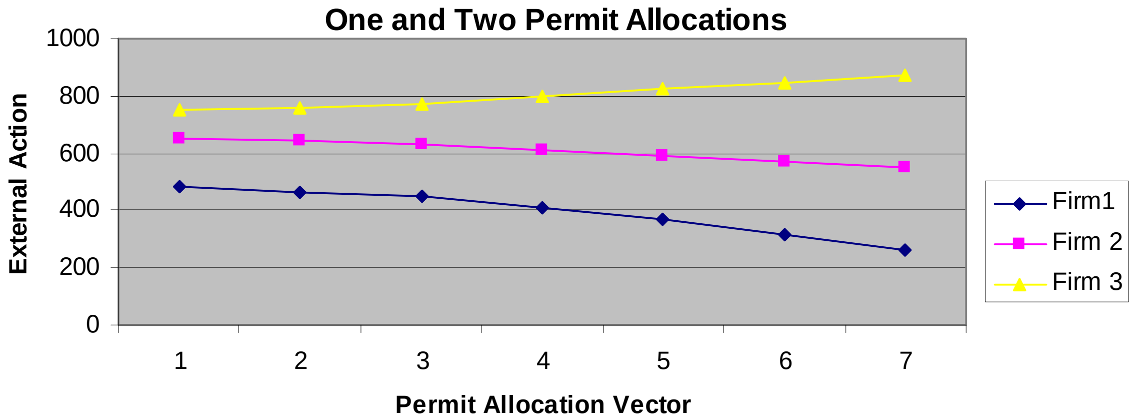

Figure 5-3: One and Two Permit Allocations and the Corresponding External Actions

outlined the concept that economic regions, such as the EU, could legitimately act, sign and ratify the convention (and any future protocols) on a EU scale whilst using internal procedures to differentiate targets amongst the member states (United Nations, 1992). In other words, the EU was allowed to create a 'bubble' where the burden of a common EU target could be redistributed between member states—commonly known as the Burden Sharing Agreement (BSA) (Phylipsen et al. 1998; Ringius, 1999; European Commission, 2000; Lacasta et al., 2002; European Union, 2003). After significantly costly and drawn-out political discussions an agreement was reached in 1998 where European carbon dioxide emissions would, in net, reduce by 8 per cent of 1990 levels. Five member states, including all the 'cohesion' states were allowed to increase their emissions in the commitment period 2008-2010 (Greece, Ireland, Portugal, Spain and Sweden) while the remaining member states reduced emissions (by differing amounts).[13]

One possible alternative to the BSA could be to use a PAC to determine the burden each member state has to bear in a tradeable permit market. The scheme could work as follows: the European Commission could outline a contest in which lower burdens of carbon dioxide reduction in a tradeable permit market (i.e. more permits allocated to member states) are awarded to higher ranked member states. As discussed in section (5.5), the ranking criterion must be independent of the tradeable permit market and must be an objective the European Commission would like to fulfil. A solution could be to rank member states on an activity associated with their non-permit trading sectors. A process could be created to rank and allocate permits to member states in order of their proportional improvements in pollution from domestic transport, pollution from landfills, recycling, and so on. In other words, a PAC can link the burden of emissions reduction (via a permit allocation) with reductions in national greenhouse gas emissions from the non-trading sector.

5.8 Conclusion

The objective of this chapter was to outline a new type of permit initial allocation mechanism. In our model, firms in a tradeable permit market were initially allocated permits using a Permit Allocation Contest (PAC). A PAC is a rank-order contest in which the firms are ranked in order of their size of external action. The external action is defined as an activity or characteristic of the participating firms that is

[13]Cohesion states refers to the group of member states (Greece, Ireland, Portugal and Spain) that obtain assistance under the European Cohesion fund which promotes economic development and convergence of living standards in low income countries (Dessai and Michaelowa, 2001; Aidt and Greiner, 2002)

independent of emissions choices. Each firm obtains an allocation of permits based on the ordinal ranking they achieved in the PAC.

In our model, the regulator was assumed to have two policy objectives. First, the regulator, by choosing a permit allocation vector, minimised the aggregate cost of reducing emissions in the permit market. Second, the regulator chooses a permit allocation vector to fulfil a pre-determined public policy objective, which defined as the maximisation of the aggregate external actions. The regulator will determine the external action 'type' so that it is independent of all firms' emissions and also socially beneficial, such as an improvement in health and safety policy and corporate and social responsibility. As discussed, an external action may not exist that complies with all the requirements.

We find the permit allocation vector is independent of the efficiency in the permit market. Therefore, from standard theory the permit market is cost-effective. Focusing on the PAC, we show that each firm uses a symmetric strategy to select a level of external action. Firms tend to choose their external actions based on their privately known ability and their expected permit allocation value. Moreover, the distribution of permits and permit price are also significant at altering the choice of external action.

To obtain the public policy objective, the regulator must choose an optimal permit allocation vector. We find that for a public policy objective to be achieved, the vector must be discriminatory. In other words, the regulator must reward firms for choosing larger external actions. We numerically analysed a PAC with three participating firms. We find that two equal permit allocations results in the largest size of aggregate external action.

The PAC, at its simplest, has attempted to reach the middle ground between grandfathering and auctioning. Firms generally lobby for grandfathering due to the enormous rents available. On the other hand, auctions, if implemented, would improve the market efficiency and allow revenue recycling. A PAC creates similar incentives to an auction and could, in theory, efficiently allocate permits. Moreover, a PAC could be designed so that it becomes politically feasible. The large potential criterion available to rank firms allows many possible tradeable permit market circumstances to be considered. However, it was noted, that the identification and implementation of an external action is a limitation to the PAC. For the PAC to work effectively, the external action must be independent of emissions and politically agreeable to firms, the regulator and a wider society. Yet this may prove to be less of a problem in the future. Pollution, and especially climate change, has become an important issue in the current political sphere and it likely that bolder steps to tackle pollution in the future will be needed. It may appear that a strong case for a PAC implementation exists in international permit schemes.

Chapter 6

Conclusions

6.1 Introduction

Tradeable permit markets allow firms the ability to trade pollution rights and as a result, pollution can be controlled at the lowest social cost. However, the initial allocation of permits can significantly alter the equity and efficiency of the market and the regulator must carefully consider the design of the initial allocation mechanism.

Due to the importance of the initial allocation of permits, the main objective of this thesis was to consider the link between the efficiency in a tradeable permit market equilibrium and the initial allocation of permits. In particular, this research investigated the link between market efficiency in a dynamic tradeable permit market and multiple initial allocations. To discuss the relationship between the initial allocation and market efficiency, this research focused on three sub-questions:

- What are the consequences for market efficiency in a tradeable permit market when firms are initially allocated permits in a multi-period market?

- What are the consequences for market efficiency in a dynamic tradeable permit market when firms lobby over permit allocations?

- Are there optimal alternative initial allocation mechanisms that can be used in a dynamic setting?

To answer these questions multi-period, partial equilibrium models were created in which one regulator supplied permits to firms in a perfectly competitive permit market where each firm attempted to minimise (maximise) the cost (profit) from the tradeable permit market.

This research attempted to contribute to the literature in a number of ways. First, this thesis extended the theoretical analysis of multi-period permit markets by creating a generalised mechanism that encompassed all known types of permit allocation in a dynamic setting. Second, this thesis has illustrated the first attempt at discussing the dynamic link between market efficiency and lobbying activity over permit allocations. Finally, this thesis attempted to add to the literature on initial allocation mechanism design by introducing a new, alternative design, namely, a rank-order contest.

To allow for this focus, the thesis was restricted in a number of directions. First, attention focused on the permit market efficiency and as a result, issues with the wider economy and especially in a general equilibrium setting were ignored. Second, although the political economy of tradeable permit markets is an important issue in determining the viability and success of certain schemes this is generally ignored in the thesis.

6.2 Research and Results

This thesis began in Chapter 2 by reviewing the literature that discussed the link between the initial allocation of permits and efficiency in the permit market equilibrium. The chapter began by discussing the reasons behind the independence between market efficiency to be independent and the initial allocation of permits (perfect competition, no transaction cost and a static market). The chapter focused on the attempts taken to relax the assumptions and it was shown that the introduction of firms' strategic behaviour, transaction costs or multiple periods may create a link between market efficiency at equilibrium and the initial allocation.

Chapter 3 created a generalised allocation mechanism for the initial allocation of pollution permits in a dynamic setting. This mechanism allowed permits to be allocated based on historical emissions, output and a factor independent of both—an 'external' action. This mechanism could encompass auctions, benchmarking and updated grandfathering—the use of updated historical information on firms' emissions and output levels. All these mechanisms were modelled through a relative performance approach where allocation to each firm is based on their 'action' relative to the remaining firms. In this chapter is was found that in a dynamic permit market the use of output as an allocation criterion is never optimal as an incentive to increase production always exists. The use of emissions as a dynamic criterion is generally not socially optimal. Instead it is argued that allocation should be based on the information of an external factor, such as the social beneficial 'actions' of firms. This not only optimally allocates permits but creates a secondary benefit which is a generalised 'double dividend' effect.

Chapter 4 considered the issue of lobbying activity over a permit allocation in a dynamic permit market. Each firm had the ability to determine their future permit allocation by their choice of rent-seeking activity—the combined choice of emissions and lobbying activity. It was found that market efficiency is altered by rent-seeking activity when the costs of emissions and lobbying activity are separable. In such a case, a direct link exists between the choice of emissions and lobbying and future rent. However, when the costs of emissions and lobbying activity are non-separable market efficiency may be maintained as lobbying can be chosen 'ex-post' to coincide with an efficient tradeable permit market. The model was extended to include the cases where (i) the choice of emissions no longer altered a firm's permit allocation (static grandfathering) and (ii) the aggregate emissions cap is partly determined by firms' rent-seeking activity. When the choice of emissions no longer alters permit allocation, it was found that the inter-temporal link between emissions and future permit rent was eliminated and the tradeable permit market was least-cost. Moreover, it was found that allowing for rent-seeking activity to partly determine the aggregate emissions cap did not vary the market efficiency, however, an increase in the cap reduced social welfare.

Finally in Chapter 5, an alternative initial allocation is advocated—a rank-order contest. This mechanism allocates permit to firms based on the rank ordering of firms based on some 'socially beneficial' activity pre-determined by the regulator. It was shown that the permit allocation contest efficiently allocated permits so that the tradeable permit market was least-cost. Moreover, a symmetric strategy was created to illustrate each firm's optimal choice of external action. A firm's choice of external action was found to be dependent on: the cost of the external action; the expected permit allocation, the permit price and the firm's ability parameter. The chapter was advanced by discussing the regulators problem in which it aimed to allocate the aggregate emissions cap to firms to maximise some socially beneficial goal. The chapter concluded by numerically simulating possible permit allocations and found that, with three firms, two equal permit allocations will maximise the secondary benefit.

6.3 Policy Implications

In general, this thesis can give guidance to policymakers and regulators on optimal methods of allocation in a dynamic setting. This research has produced a number of important policy implications that concentrate on the use of criterion and initial allocation mechanisms. Three clear policy implications have resulted from this research:

- The use of updated grandfathering—the use of updated historical information of firms' emissions and output levels—as an initial allocation mechanism should, in general, be avoided.
- Regulators should be concerned with lobbying activity in a tradeable permit market.
- An array of optimal initial allocation mechanisms do exist.

It was shown in Chapters 2 and 3 that the use of updated grandfathering allows an intertemporal link to be created between the choice of emissions and the future rent each firm receives which introduces an incentive to increase emissions above the socially optimal level. To eliminate this intertemporal link and improve market efficiency, regulators should avoid the use of historically updated emissions information. However, this may be politically problematic. Consider a tradeable permit market which has a number of compliance periods. It is inevitable that at some point, there will be new entrants and plant closures. Updated grandfathering is politically viable as it allows for these changes to occur whilst adjusting permit allocations. For example, new entrants and firms that close plants, will obtain and lose future permit allocations, respectively. Contrast this with a static grandfathering case. Under a '*pure*' static grandfathering case, permit allocation is fixed throughout all compliance periods. Therefore, new entrants may never receive permit allocations and firms that close plants (factories) continue to receive permit allocation till the completion of the permit market.[1] It may be possible for regulators to implement updated grandfathering if additional allocation rules can be implemented to reduce the distortionary incentive to increase emissions.

Regulators must also be concerned with respect to firms' lobbying. As Chapter 4 has shown, lobbying activity, in conjunction with firms' choice of emissions, can alter market efficiency. Also, lobbying activity can increase the aggregate emissions cap and as a result, reduce social welfare. Regulators must identify lobbying activity and implement rules and mechanisms to counter such actions. For instance, to maintain social welfare, regulators should consider policies that pre-commit the regulator to a specific level of aggregate emissions cap.

[1] Of course, as seen in the EU-ETS and the SO_2 market, it is possible for the regulator to 'reserve' a proportion of aggregate emissions for new entrants.

Finally, auctioning and grandfathering are the most common techniques to distribute permits to firms. However, Chapter 5, considers an alternative to both, namely, a rank-ordered contest. A rank order contest has similar efficiency properties to an auction but has the potential to be more politically viable and obtain a secondary policy objective. Optimal mechanism design is heavily dependent on the heterogeneous circumstances of area of regulation and thus it is important for regulators to understand and investigate an array of mechanisms to suit their requirements.

6.4 Future Work

This thesis has highlighted important issues in the initial allocation of pollution permits in a dynamic tradeable permit market. Although, the policy implications of the research appear to be apparently clear, a large amount of questions, not in the scope of this thesis, remain unanswered.

The natural direction for future work is the extension of the analysis in this thesis. The models can be extended to include general equilibrium analysis with possible uses in Computable General Equilibrium (CGE). Furthermore, the research presented in this thesis does not focus on inter-temporal trading, that is, the banking and borrowing of permits throughout time. As inter-temporal trading will become increasingly important in subsequent years, it is important to investigate the link between the banking and borrowing of permits, initial allocation and permit market efficiency.

As shown in this thesis, the investigation of dynamic allocation is important for market efficiency. One question arising from this work is how to implement allocation mechanisms in dynamic permit markets that allow (i) flexibility in the determination of permit allocation (e.g. to allow flexibility for new entrants and plant closures) and (ii) avoid inter-temporal distortions. It follows that one must investigate possible solutions that can achieve (i) and (ii) through optimal mechanism design—something initially attempted in Chapter 5.

As existing tradeable permit markets mature and new ones are created, participating firms will improve their knowledge of such schemes and, in particular, they may improve their lobbying skills. It is likely, then, that lobbying activity (in whatever form) will play an important role in the determination of market efficiency. However, the analysis of lobbying activity in a tradeable permit market is in its infancy and many directions and extensions of current work can be followed. Possible issues include the development of a model that can encompass imperfect competition in the permit market and collusive behaviour with respect to lobbying activity.

A growing trend in tradeable permit markets is the regulation by more than one regulatory agency. For instance, in the EU-ETS, all 27 member states have a role in allocation determination through their National Allocation plans (NAPs). Indeed with the continued introduction of multi-state markets (such as the Regional Greenhouse Gas Initiative (RGGI)) it will be important to consider models that have a number of participating regulatory agencies. For instance, analysis must consider the possible efficiency issues that are encountered where a number of regulators decide on permit allocation. Issues that must be considered include the timing of multiple regulators' allocations and the levels of permits that are distributed. Moreover, one must consider different levels of regulation from national to international and supra-governmental agencies within tradeable permit markets. Most tradeable permit markets encounter numerous regulations from multiple regulatory agencies such as a local and regional environmental protection agencies and intergovernmental agreements and coalitions. Future work in these directions can assist in the optimal design of future tradeable permit markets and as a result efficiently control pollution.

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