# Do emission permits markets' original advantages still hold?

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**World Congress of Environmental and Resource Economists**
**3rd Edition - Kyoto, Japan**
**03-07 July, 2006**

## ABSTRACT

Emission permits markets have been implemented all over the world but in very different conditions than those assumed in the original models developed by Dales (1968) or Montgomery (1972). This paper summarizes the assumptions that are violated when implementing this policy instrument. Reviewing the most significant literature in the area, we analyse the consequences of these violations for the outcome of emission permits markets, and derive conclusions about whether the traditional advantages associated with this instrument still hold. The major solutions that have been suggested for the identified market failures are also described. We find that despite the conflicting results reported in the literature, there are some conclusions unanimously accepted. Importantly, we find that the characteristics of market institutions are significant determinants of the outcome of these markets, which means that these aspects may no longer be treated as a mere detail as within the neoclassical approach. In addition, we find that these characteristics have important impacts on many other "market failures" identified in this paper. Since these aspects were not included in the original models, their predictions differ from the results effectively achieved with the implementation of an emissions permit market.

JEL Classifications: Q50, Q58

## 1. INTRODUCTION

Although Montgomery (1972) has rigorously proven that Dales (1968) original model for emission permits markets was the most efficient environmental policy instrument, and a vast literature has since then been devoted to the description and analysis of its advantages when compared to command-and-control instruments, many problems and limitations of this model have meanwhile been pointed out. Doubts about the superiority of emission permits markets have been particularly raised when environmental policy instruments are compared under the actual conditions of their implementation. This means that when one of the hypotheses of the model is broken, the results become dubious: the predicted gains from emission permits markets may not be achieved and social welfare may be greater under command-and-control policies when perfect competition is not the structure of emission permits market as assumed originally.

There has been a long experience with emission permit markets in the USA[1], where the importance of practical details of their implementation for their functioning and final results became clear. Market failures were also identified and concerns about their consequences along with actions to prevent them were debated. At the same time, the theoretical literature on environmental economics started to change Dales (1968) original model in order to analyse the introduction of market failures consequences'. It was also proven in this setting that results would change under different market conditions. Experimental economics' investigations also brought into attention some important issues concerning the violation of behavioural or structural hypotheses underlying the theoretical set up of emission permits market. Limited data on this kind of market make it difficult to use field data to evaluate its performance, and, as a result, laboratory data emerge as extremely valuable. Laboratory data also allows evaluating new market environments before its effective implementation, minimizing the costs of achieving a specific environmental goal, when compared, for instance, with field studies.

The main objective of this paper is to summarize and present a critical review of the literature that focus on the importance of practical details for emission permits market implementation, market failures and their consequences. The paper is organized in six sections, each concerning a different aspect of emission permits market. The final section concludes, summarizing the main findings of the paper.

[1] The USA first experiences with this kind of instrument occurred before the nineties: EPA Emissions Trading Program (1974- ); RECLAIM (1994- ); Lead Phasedown (1979-1987); Acid Rain Program (1992- ); CFC Phasedown (1989 - 1995); Effluent Trading (1983- ). See Solomon (1999, p. 377).

## 2. MARKET INSTITUTION

Potential buyers or sellers of any good use some form of market organization to carry out their transactions. The rules that govern the way transactions occur characterize a specific market institution. These rules include many details, such as the indication of which agent starts the offers in the market, its timing and order, the way contracts are announced and closed, and what kind of information is available at any moment in the market. Along with agents' behaviour, these rules contain information that will lead to a specific market outcome.

Neoclassical economics tends to minimize these issues, and excludes practical details from its models. However, empirical results from various markets have established the need to understand the consequences of different market institutions. What is often referred to as New Institution Economics (NIE), arises as an answer to the criticisms to the traditional economic models highlighting precisely the importance of market institutions for the final results attained. Solomon (1999), one of the economists of this economic stream, refers that only recently NIE reasoning has been applied to the specific case of environmental economics. In his paper, Solomon (1999) reviews some of the emission permits markets already in place, mainly in the USA, focusing on its institutional structures and processes. His goal was to identify the advantages and disadvantages of those market institutions in order to formulate recommendations for future programs, and to understand how it could influence some market failures like transaction costs, market power or uncertainty.

Solomon's work is in line with many other previous empirical studies (for example, Hahn (1989) or Atkinson and Tietenberg (1991)) concerning the USA emission permits markets, which demonstrate that market institutions matter and should not be treated as small details. These studies analyse specific proposals of the American government for the implementation of emission permits markets, comparing predicted results with effective ones and trying to explain the observed differences. Their common conclusion is that due to the transaction rules imposed to companies in the market, characterized by too many restrictions, the number of transactions was smaller than predicted, i.e, smaller than the optimal level.

The characteristics of market institutions have also been the subject of theoretical studies. Cason (1993), for example, modelled the specific case of the EPA's proposal for $SO_2$ emission trading market focusing on the auction rules imposed to emission permits transactions. Those rules included discriminative emission permits price and not a unique price in the market – each buyer would pay his bid price to the seller who asked the smaller value. Cason (1993) has shown that this particular rule is an incentive for distorted offers: sellers under estimate the true costs of pollution control in order to win the best bids in the

market. Cason (1993) concludes that the EPA choice for the auction rules in this market introduce market price bias and reduce its efficiency and advantages.

Montgomery (1972) formally proved the superiority of this environmental policy instrument compared to any other, whatever the initial allocation of permits (with different results concerning "equity" only). However, as the discussion in section 3 will show, this characteristic (initial allocation of permits) of the market institution is also an important determinant of the final emission permits market outcome, in particular when some of the hypotheses of the model are violated. Even when this is not the case, many authors defend the auctioning of emission permits instead of grandfathering as an initial method for its allocation.

Cramton and Kerr (2002) systematically point out arguments in favour of auctions as a method for the initial allocation of emission permits. First, they refer to the double dividend argument, which consists on the reuse of the auction revenues to reduce previous existing distortions such as those caused by other taxes. In this way, the environmental objective is achieved while correcting an existing market distortion. Secondly, these authors consider that auctions provide greater incentives to technological innovation, thereby reducing marginal abatement costs and the equilibrium price of emission permits. The logic is that when titles are grandfathered firms have no incentives to reduce their costs of abatement and emission permits prices: since firms do not have to buy the titles because they are offered under grandfathering, their price is not as important as it would if the firms had to enter in an auction for them. Thirdly, the authors argue that debates and political discussions are shorter and easier when auctions are chosen to initially allocate emission permits. There is no need to spend much time trying to get support from the different involved parties deciding how to distribute titles to firms, a time that is spent when grandfathering is the method for the initial allocation. Because this decision has important "equity" implications, it might even become a barrier to the implementation of this kind of program. While time and resources are spent because the market takes time to start functioning when grandfathering is the option adopted, auctioning needs only a clear specifications concerning the use of the revenues produced to get the necessary political support[2]. Finally, and related to the third point, Cramton and Kerr (2002) consider that auctions convey more flexibility to the abatement costs distribution.

[2] Hahn *et al.* (1982) proposal for a *Revenue Neutral Auction* (RNA) as a method for emission permits distribution intended, precisely, to solve the problem of political acceptance and support for the implementation of this kind of program. They suggested to grandfather emission titles and then ask firms to give back the titles to be auctioned by the regulatory entity. Each firm would then enter the market as a buyer, and the only seller would be the regulator. A particular aspect of Hahn *et al.* (1982) auction concerns the distribution of its revenues: each agent would receive the equivalent to the value of the titles initially received (given back to the regulator afterwards). So, those who bought more titles than those initially allocated make a positive payment to the regulator and those who bought less receive a liquid payment.

Equity is easily achievable by the auctioning of emission permits because there is more flexibility for the compensation of affected agents.

Kling and Zhao (2000) also studied the implications of different methods for the initial allocation of emission permits. These authors show that in the long run, the method chosen will have consequences not only on equity, as originally assumed, but also in the efficiency of the market. In their model, Kling and Zhao (2000) consider the case of global and local pollutants and conclude that the former should be auctioned, but some of the latter should be grandfathered.

Currently, the method for the initial allocation of emission permits is an issue generating an increasing amount of research. Even if this is an open field for future investigations, it seems clear that it represents one particular aspect of the functioning rules of the market defined by regulators that has important consequences on the market final outcome. This issue should therefore deserve considerable attention by politicians and economists so that emission permits markets may bring the most efficient results while accomplishing a specific environmental objective.

Another important characteristic of the market implemented for emission permits transaction relates to the choice between a cap-and-trade and a baseline-and-credit system. It was originally argued that these were equivalent schemes if the baseline established in the latter was the same as the total emission permits issued in the former. But while a vast literature emerged on the implementation of this instrument as a cap-and-trade system, almost none dealt with the alternative baseline-and-credit system. As some of the mechanisms predicted by the Kyoto Protocol are baseline-and-credit systems - CDM (Clean Development Mechanism) and JI (Joint Implementation)-, a growing interest on this type of system has recently emerged, especially because so little has been written and is known about it. Performance predictions for credits market, the link between these two mechanisms, and an international market for emission permits transaction are questions that deserve further scrutiny. Muller (1999), for example, studies these questions focusing on the properties of these two systems and the consequences of their interaction. This author concludes that cap-and-trade and baseline-and-credit are equivalent systems if the baseline is a fixed quantity but not if it is a baseline emissions ratio times current output. He also concludes that the combination of these two systems should not be allowed because it loosens up the quantity emissions cap on the cap-and-trade system. In the long run, the quantity constrain on emissions will even disappear with the combination of these two types of programs for emissions trading. This conclusion certainly requires further enquiry as it means that there is

the danger that the environmental goal established by the Kyoto Protocol signatories (reducing greenhouse gas (GHG) emissions) may not be achieved.

The objective of the experimental work of Buckley (2004) and Buckley *et al.* (2005a, b) consists precisely in studying the characteristics of cap-and-trade and baseline-and-credit programs, and test the theoretical predictions about their performance. Although much experimental work exists on emission trading markets considering a cap-and-trade system, these are the first experiments focusing on the baseline-and-credit version. They analysed short and long run theoretical predictions about the behaviour of these plans and concluded, as predicted, that in the short run they are equivalents but in the long run the baseline-and-credit program results on higher production and emissions than the cap-and-trade version.

However, to our knowledge, there is no experimental work analysing a different question: the consequences of those systems connection. And, as we referred above, this is an essential question considering the international agreements for greenhouse gas reductions. Therefore, this stands as an important research area for the future.

Several experimental studies exist focusing on other aspects of the market institutions chosen for the implementation of emission permits markets. Cason (1995), Cason *et al.* (1996) and Franciosi *et al.* (1999), for example, developed laboratory experiments to study the consequences of EPA's specific choice for $SO_2$ emission trading. These experiments tested Cason (1993) conclusions (as above summarized), and compared the results achieved with EPA's market institution with those resulting from uniform price auctions. All these experiments concluded that Cason (1993) theoretical predictions were correct since the transaction rules imposed by EPA cause price bias and reduced efficiency on the market due to the strategic behaviour of the agents.

The experimental work by Franciosi *et al.* (1993) tested the *Revenue Neutral Auction* (RNA) proposed by Hahn *et al.* (1982) checking whether the characteristics of this market institution would change final results, as it was similar to a single price auction except for the auction revenues redistribution. The authors concluded that this additional characteristic does not change usual behaviour in the market, corroborating Hahn *et al.* (1982) prediction of superiority of this kind of auction.

The objective of the experiments conducted by Cason *et al.* (1998) and Ishikida *et al.* (2000) was also to test the consequences of different market institutions for the RECLAIM program. Cason *et al.* (1998) compared the proposed electronic bulletin board institution with the double auction, and Ishikida *et al.* (2000) compared a uniform price double auction and a combined value call market. Although these authors studied different market institutions, and used different experimental designs, their relevant conclusion for our purposes was that the

efficiency of the specific emission permits program will vary depending on the characteristics of those market institutions.

The experiments conducted by Mestelman *et al.* (1999) and Cason *et al.* (1999) also had the objective of testing specific emission permits markets proposals. They focused on a specific characteristic of this markets related with the intertemporal transaction of these titles, a subject analysed in section 5 below. Once again, different rules imposed by the regulator proved to influence the final outcome of the emission permits market.

In summary, even using different methodologies or focusing on different aspects of the market institution chosen for the implementation of a program for emission permits transaction, all the studies reviewed here lead us to the same conclusion: *institutions do matter for the efficiency of this policy instrument*. In most cases, institutional details are responsible for different results from the anticipated ones. Thus, economists should not consider them a minor detail under the responsibility of governmental authorities, but engage in systematic research of these issues so as to provide specific guidance for policy decision makers.

The next sections will again stress the importance of the market institution chosen for the implementation of an emission permits program. Depending on this choice, some market failures will have more or less impact on the efficiency of the market. This means that the exercise of market power, the transaction costs imposed or the uncertainty felt by agents in the market are influenced by the market institution chosen. In addition, as will become apparent, these characteristics are also important for the final market outcomes concerning the incentives to innovation or the compliance with the limits imposed.

## 3. TRANSACTION COSTS

Although the original models for emission permits market did not consider the importance of transaction costs, empirical evidence showed it differently. Hahn (1989) and Atkinson and Tietenberg (1991) identified transaction costs, caused by market rules imposed by EPA, as a major responsible for less than optimal volume of traded $SO_2$ permits and consequently less efficiency gains than predicted. It was clear that regulators could influence the magnitude of transaction costs firms had to bear through the conception of the market institution to be implemented.

Foster and Hahn (1995) study also supports these conclusions. Their detailed analysis of emission permits trading in Los Angeles basin demonstrated that the big price dispersion and the different than expected equilibrium pattern were due to large transactions cost. These were, in turn, a consequence of the regulatory details of the implemented market.

As the existence of transaction costs and their consequence on the efficiency of emission permits markets became a consensual reality, increasing attention was devoted to it. Woerdman (2001), for example, evaluates and compares existing transaction costs for each of the mechanisms included in the Kyoto Protocol. Woerdman (2001) also stresses that an important contribution for the efficiency of an international climatic policy would be to find out ways to reduce transaction costs, as no doubt exists that all three mechanisms will entail such costs.

A seminal work in this area is Stavins (1995) model, which explicitly includes the transaction costs of abatement firms cost functions. With this modification of Montgomery's model, Stavins (1995) demonstrates that the transaction costs reduce the volume of emission permits trading, which becomes less than optimal. Transaction costs increase abatement costs because of emission trading reduction and add up to total costs of control. Stavins (1995) considers, however, that the distortions caused by the existence of transaction costs may be reduced if a big number of firms exist in the market because more information will be produced in the market, and it will be easier for firms to find a potential partner for trade. Stavins (1995) also analysed the impact of the initial allocation of emission permits on the market outcome when transaction costs exist. His conclusion depends on the specific transaction costs function. If this function is constant, the usual results of economic theory hold true (initial allocation of permits only impacts equity), but if it is increasing or decreasing, the efficiency of the market is also affected. According to Stavins (1995) this brings an additional argument in favour of auctions of emission permits as an initial allocation method. In order to avoid the need for many transactions in the market, initial allocations should be as close as possible to the efficient ones, and only emission permits auctions overcome the regulator's incomplete information problem. The author defends that the conception of these environmental programs should provide the maximum information as possible in order to reduce to the minimum the transaction costs for its acquisition.

Montero (1997) develops the Stavins' model adding some different aspects such as uncertainty about the regulator emission permits transaction's approval (a characteristic of some of the market institutions implemented for emissions transactions in the USA), and the possibility of discontinuities in the marginal abatement cost curves. Montero (1997)'s model focus on the impact of significant changes on transaction costs (and not marginal, as in Stavins' model), on uncertainty, and on initial allocation of permits, to the equilibrium market outcome. Montero's conclusions are similar to those of Stavins: transaction costs reduce social welfare of the system for the same reasons pointed out by Stavins. However, Montero demonstrates that emission permits markets are, even in the presence of transaction costs and

uncertainty, more efficient than command-and-control policy instruments since the total expected abatement costs of pollution are inferior. Thus, even if the potential efficiency gains are smaller than originally predicted, the choice of this instrument is still recommended. Montero concludes also that the initial allocation of emission permits influences market efficiency when transaction costs and uncertainty are present. Contrary to Stavins' conclusion, however, Montero points out that this is true even in the presence of constant marginal abatement costs and certainty. Finally, Montero recommends simplification of administrative proceedings, and clear legal directives concerning the approval processes for transactions in the market in order to reduce transaction costs and uncertainty.

Using the experimental methodology, Cason and Gangadharan (2003) also studied the impact of transaction costs on emission permits markets efficiency outcome. They focused on different transaction costs functions and their interaction with different emission permits initial allocation methods to evaluate the impact on total abatement costs, thereby testing Stavins (1995)'s conclusions. Their results show that the equilibrium of emission permits markets is affected by the existence of transaction costs: the volume of emission permits transactions is smaller in the presence of transaction costs, which means that efficiency and welfare is reduced. Also consistent with Stavins (1995) predictions, Cason and Gangadharan (2003) find that the final market outcome depends on marginal transaction costs functions and initial permits allocation. As predicted, if marginal transaction costs are constant, the initial permits allocation has no influence on the final market outcome. However, if those costs are increasing or decreasing, their impact on the market outcome depends on whether the initial allocation of permits is closer to or more distant from the optimal level.

Cason and Gangadharan (2003) corroborate Stavins' recommendations for regulators to first evaluate how the imposed market rules affect the transaction costs that firms must bear and only then choose the initial emission permits allocation rules according to the behaviour of those cost functions.

Summing up, the original efficiency predictions for emission permits markets are affected by transaction costs. This threat, however, depends on the type of cost functions involved and on the initial permits allocation. Nevertheless, it is clear that this constitutes an important aspect to take into consideration when conceiving a program for the transaction of emission permits.

## 4. MARKET POWER

Data from the first emission permits markets brought in to light another problem not predicted by Dales (1968) or Montgomery (1972) models: market power. This was one characteristic of

the market that violated one of the key hypotheses of the original model: perfect competition. The violation of this hypothesis raised the question of whether the efficiency gains associated to emission permits transactions would still hold.

Hahn (1984), Tietenberg (1985) and Misiolek and Elder (1989) theoretical works, for example, recognize this problem and try to evaluate its consequences on the advantages of this environmental policy instrument. Many other studies on this matter emerged since then, namely because the possible exercise of market power became a prominent issue in the international political agenda given the threat posed by Russia's monopolistic behaviour to the international market for emission permits transactions.

Hahn (1984) was the first to formally demonstrate that the properties and advantages of emission permits markets would not hold in the presence of market power. He proved that under market power emission permits transactions would not minimize total abatement costs, and the final result was dependent on its initial allocation. Much like Stavins' conclusions concerning the presence of transaction costs in emission permits markets, Hahn also contradicts the original model's prediction that the initial allocation only influences equity. In fact, Hahn shows that allowing for the possibility of market power, its exercise will be greater the farther the emission permits initial allocation is from the efficient one. Thus, not only equity but also efficiency is affected by political decisions. Hahn's suggestion for this market failure is for regulators to distribute emission permits the closest possible to the efficient level so that the firm with market power will not use them because it will decide not to enter the market. Although this solves the inefficiency problem caused by market power, it causes this environmental policy instrument to suffer from the same regulator's imperfect information difficulty about firms' true marginal abatement costs as other command-and-control instruments. This means that the advantage of less information requirements for the regulator of emission permits markets disappears.

Tietenberg (1985), although recognizing that market power exercise diminishes emission permits market efficiency, does not consider it a very serious problem. Even with market power, Tietenberg (1985) considers emission permits transaction still a better solution than the command-and-control ones, achieving a certain environmental objective at a smaller cost. Moreover, environmental quality is not affected by market power as the limit (cap) on emissions is the same, the difference on final results being on higher emission permits price and, consequently, higher abatement costs. For this reason, Tietenberg (1985) undervalues Hahn's (1984) results and conclusions.

Misiolek and Elder (1989) model evaluates a different type of problem concerning imperfect competition in emission permits market. These authors study strategic market

power and not simple market power, as we implicitly have been referring to. They focus on firms' capacity of strategic manipulation of emission permits in order to raise its rival's production costs rather than to minimize its own total abatement costs – simple market power. The authors emphasize that this is only possible when firms compete in the same industry, and the dominant firm believes it is able to influence other companies' costs through this type of manipulation, increasing its market power inside the industry. Misiolek and Elder (1989) consider a dominant price-maker firm in the product market and a competitive price-taker fringe of small firms. They also consider that emission permits prices are sensitive to the dominant firm orders in the market, which means that this firm determines the product price and its rival costs through emission permits. Using a different approach than previous studies, these authors also reach different conclusions. Strategic trade of permits might be an effective way to increase the dominant firm's market share and profits, always withholding more emissions permit than would be possible in any other circumstance. Misiolek and Elder (1989) conclude that strategic behaviour in emission permits markets may lead to such efficiency reduction that other traditional forms of regulation may become less costly, which is completely contrary to the original economic theory on this matter. Their conclusions are valuable for policy makers in the sense they alert to the need of different answers from regulatory authorities to these two different types of market power manipulation--simple and strategic.

Many experimental studies have bee conducted in order to test the true dimension of the market power problem. These studies also relate the market power problem to the type of market institution chosen by the regulator for emission permits transaction, in particular to the double auction institution though to be robust to imperfect competition conditions. Smith (1981), Smith and Williams (1989), Holt *et al.* (1986), Davis and Williams (1991) and Sbriglia *et al.* (1996) are some examples of experimental studies that tested the performance of different market institutions in the presence of a dominant firm in the product market. They conclude that the dominant firm's capacity to exercise market power depended on market institutions characteristics, and show that double auctions are capable of preventing its exercise. However, this result does not appear so consensual for the specific case of emissions trading markets.

Brown-Kruse *et al.* (1995) used the experimental methodology to test both simple and strategic market power implications on the emission permits market. They used a double auction institution and a sequential decision structure, considering first the decisions concerning the transactions on the emission permits market, and subsequently the decisions

about production on the product market[3]. The environment created by Brown-Kruse *et al.* also assumed information asymmetry between firms, as the dominant firm knew fringe costs and productive capacity and fringe firms only knew their own costs. The results of these experiments show that the impact on emission permits market outcomes is not substantial in the case of simple market power. With the parameters used in these experiments, most of the potential efficiency gains were realized even in the presence of this market failure.

However, when strategic manipulation is included the results are quite negative, even inferior to those of command-and-control, which is a worrying conclusion that corroborates Misiolek's *et al.* (1989) exclusionary theory. Brown-Kruse *et al.* (1995) also concluded that the emission permits initial distribution could influence this market's final outcome when market power is present. If a monopolist firm is able to exercise strategic market power, all of the emission permits should be initially allocated to fringe firms so that they impede the dominant firm to exclude them from the product market. Notice that when grandfathering is the initial allocation method chosen for emission permits distribution, and these are assigned mainly to the big firms in the market, there is a real danger that they will exclude rival firms from the market or potential new entrants. Since this is the most common method being used for the initial allocation of permits, the need for detailed studies considering the structure of the product market involved is obvious before adopting such program.

The experimental results of Brown-Kruse *et al.* (1995) bring a solution proposal for the strategic market power problem similar to that of Hahn's (1984) for simple market power. Thus, this experiment reinforces emission permits initial distribution importance for the efficiency of this market, which would be negligible if the perfect competition assumption of the original model was in fact the structure of the market. In addition, Brown-Kruse *et al.* (1995) results, contrary to precedent experiments on the product market, showed that the double auction institution was not capable of preventing the exercise of market power in emission permits markets.

Godby (1996) experiments corroborate Brown-Kruse *et al.* (1995)'s conclusions. First, the use of a double auction was not able to prevent the exercise of market power; second, strategic market power seriously hits the efficiency of the system making it inferior even to the command-and-control reference; third, the initial allocation of permits has influence on the final outcome of the market, specially when firms are vertically integrated. This last result is particularly important since the option to grandfather the permits tends to be politically more attractive.

[3] This structure included a context of uncertainty in the experiment. But we will focus on this particular aspect on the next section of our paper.

Godby's (1999) study aimed to evaluate the effect of the existence of a dominant firm on the potential benefits of an emission permit market and to the performance of double auctions institutions in these circumstances. His experimental work tested two specific characteristics of Smith's (1981) experiments on the product market that could be responsible for the results obtained: the dimension of the fringe and the parameters used. Smith (1981) concluded that the market equilibrium was closer to the competitive, even with a dominant firm in the market, when using a double auction institution, due to tacit collusive behaviour among the firms in the competitive fringe. Godby (1999) tests the robustness of Smith's results with respect to the number of firms in the fringe and their parameters (not allowing some firms to enter the market when the dominant firms exercised its power). Additionally, Godby introduced some asymmetry in the firms' information regarding costs.

The results obtained with these experiments showed that double auctions were not able to prevent market power exercise in the emission permits market, as the equilibrium prices were always closer to the monopoly prediction than to the competitive one. Even though, Godby (1999) concluded that most of the potential efficiency gains of this policy instrument were still achieved we cannot ignore the effects of market power since as equilibrium (monopolist or monopsonist) prices in the market did not reveal true marginal abatement costs, this market would not be able to induce the appropriate level of technological innovation in abatement technologies.

Muller *et al.* (2002) also tested the robustness of double auctions institution to prevent market power exercise in emission permits markets. They made some changes to the design of the previous experiments in order to allow a stronger comparison between a competitive and a monopolistic market structure: subjects participated, during the same session, in the two market structures alternatively. They found that the double auction institution rules were not sufficient to prevent the exercise of market power however the efficiency of the market was not seriously affected. The authors consider that there is a question that remains to be answered: which (if any) are the emissions permits market particular characteristics that explain the different results obtained with these experiments for emission permits market when compared with similar circumstances in the product market.

Carlén (2002) considered a different sequence in firms' decision. Instead of deciding first the behaviour in the permits market and then in the product market, Carlén (2002) argue that in most real world applications, firms decide their production plans before possessing the necessary emission permits. Carlén (2002) considers a wrong assumption to treat emission titles as a physic input, vital to production, so tested strategic market power manipulation under conditions he considered closer to the real one. In this experiments the context was

revealed to the participants, contrarily to what usually happens in this kind of experiences. Double auction was the market institution chosen for both the emission permits and the product market.

Carlén (2002) experiments results rejected Misiolek *et al.* (1989) strategic manipulation theory, as equilibrium prices and quantities were close to the competitive levels and not to the monopolistic ones. Results also showed that emission permits market was quite competitive but the dominant firm manipulated product market, reducing its offers. In this last case, the double auction institution was not enough to eliminate market power exercise as Smith (1981), Smith and Williams (1989), Holt *et al.* (1986), Davis and Williams (1991) and Sbriglia *et al.* (1996) argued.

The divergence between Carlén (2002) and Brown-Kruse *et al.* (1995) conclusions might be explained by differences in the design and parameters of the experiments. Which implies that some caution must be taken in generalising the results of any study.

Carlén (2003) experimental work studied a simple market power manipulation (and not strategic, as in 2002) for the specific case of an international emission permits market, using a double auction. The objective was to test the politicians' concerns about the possibility of exercise of market power in the greenhouse gas international market. With several modifications on the typical design of this type of experiments, Carlén (2003) aimed to make his lab experiment the closest possible to the one that would be the real international market for emission permits.

Carlén (2003) results were close to the competitive levels, so the emission permits market achieved high efficiency levels. As this experiment included most of real international emissions trading characteristics, it sheds some doubts on the validity of the concerns about reduced efficiency due to the existence of dominant firms in the international market. His conclusion indicates that this should not be a reason for concern, although Carlén (2003) himself points out the need for further experiments to test validity of these results, because of the reduced number of independent observations produced.

Cason *et al.* (2003) also developed some experiments to test the problem of the exercise of simple power market, and Hahn's (1984) proposals. The market institution chosen to the laboratory trades was again a double auction, to test if, as traditionally pointed out, this was robust to imperfect competition. The results of these experiments were closer to the competitive equilibrium values than to the monopolist ones therefore Cason *et al.* (2003) conclude that the double auction was robust to market power also for the specific case of emission permits markets, as previous experiments like Smith's (1981), for example, have concluded for the product market. This, however, is an opposite conclusion to Godby's (1999)

or Muller's *et al.* (2002) experiments, for instance. This contradiction should, therefore, be further investigated.

On the other hand, Cason's *et al.* (2003) results did not support Hahn's (1984) recommendation about initial allocation of permits since market performance was not significantly affected by emission permits initial allocation. So, accordingly to Cason's *et al.* (2003) the original property of emission permits markets would still hold: initial allocation of permits influences only the equity but not the efficiency of the market.

In summary, it seems clear that the existence of a dominant firm in an emission permits market is not irrelevant for its final outcomes. It may have bigger or smaller influence on the efficiency of the market, whether we are dealing with exclusionary or simple market power, respectively. But, as we have seen, various studies on this matter found different conclusions so further investigation is necessary. Some proposals have also been made and tested as a solution for this market failure but again in this respect no general consensus exists.

This is, however, one aspect that threats the advantages originally attributed to emission permits markets and obviously it should not be ignored. Even if it does not seriously affect static efficiency (in the case of simple manipulation), it always changes the dynamic efficiency of the market. When market power is present, equilibrium market prices do not reflect true marginal abatement costs hence they do not accomplish one of their main tasks. Consequently, incentives to innovation on abatement technologies are not at the appropriate level, dropping one of the major advantages of this instrument comparatively to those of command-and-control[4]. For this reason, when conceiving and effectively implementing an emissions permits market program, regulators should carefully analyse the structure of the market being created and decide on the method to perform the initial allocation of permits in accordance with the other characteristics of the market.

## 5. UNCERTAINTY

Dales's (1968) proposal for an emission permits market assumed perfect competition among the participants. One condition for perfect competition is the existence of perfect information. However this condition is rarely, if ever, verified in real world applications. In this section we examine the implications of imperfect information on market outcomes. Imperfect information affects market outcomes by creating uncertainty for all the agents involved in the

[4] We will treat about incentives to innovation of emission permits markets on the seventh section of this paper. This is an original advantage of this environmental policy instrument over all the others that have been questioned not only when market power is present.

market, including environmental regulators and regulated firms. We start the analysis by identifying the different types of uncertainty and how they impact market participants.

Regulators' uncertainty regards the quantity/quality of environmental damages as well as the social benefits of pollution abatement and the emissions social marginal abatement costs. As referred by Laffont and Tirole (1996), future scientific discoveries might show that environmental damages are much higher or much smaller than expected. This uncertainty is present when regulators must decide the amount of emission permits to put in the market (decide the value of the cap). Additionally, uncertainty affects the value of the change in the social welfare that would result from a different quantity if in the future new scientific information is revealed. However, given the uncertainty regarding the quantity or extent of the environmental damages, regulators set the environmental objective exogenously. The lack of scientific certainty regarding the physical impacts of human actions on the environment explains the difficulty in finding studies evaluating the environmental efficiency of an environmental policy. The methodology to evaluate efficiency of environmental policies is the cost-benefit analysis, which consists in valuing the costs of the policy and its benefits, and then compares both numbers. The problem arises because there is no correct number for the benefits' value given the scientific uncertainty regarding the environmental effects. This renders cost-benefit analysis an improper methodology to give a clean and unique answer to the question of efficiency. On the other hand, it is possible to evaluate the policy effectiveness by determining the best way to achieve a certain environmental goal at the least cost possible. Although emission permits market is commonly referred as the most efficient environmental instrument, rigorously when referring to the practical applications it should be said it is the most effective one, in other words, it achieves a certain environmental objective at the least possible cost[5]. This is, in fact, the question we consider in this paper, ignoring the imperfect information problem faced by the regulator when determining the total level of emission permits to allocate.

Regulator's imperfect information is also about firms' true marginal abatement costs. However, this does not constitute a problem in a tradable emission permits regime. Even if the initial allocation of emission permits is not the most efficient one, transactions in the market will originate an efficient equilibrium level. This constitutes an advantage of this policy instrument compared with command-and-control ones.

Uncertainty also exists on the regulated firms' side. Firms may have a deficient knowledge of its own true pollution abatement level at the end of the control period, and its curve of marginal abatement costs. As demand for emission permits depends on firms'

[5] However, we will use efficiency term to mean the same, as all environmental economics literature does.

pollutant discharges, and these depend on firms' technological choices and volume of production, neither perfectly controlled, then the exact amount of required emission permits to comply with the legal limits will also be uncertain. This is the type of uncertainty most commonly addressed in the literature.

Carlson and Sholtz (1994) study precisely the type of uncertainty just mentioned, its consequences and possible solutions. The authors argue that when firms are risk averse and do not know exactly the number of permits required for the control period, they tend to hoard some permits to face eventual needs to prevent being short on permits and be penalized by the control agency. This may cause some efficiency losses if at the end of the control period those permits are not necessary. In some applications a reconciliation market exist for firms to clear their positions at the end of the control period. However, as Carlson and Sholtz (1994) point out, regulated firms' activity tends to be correlated among them, which increases the probability of all firms being short or long, at the same time. A greater volatility of emission permits' prices by the end of the control period is therefore a natural consequence of this type of uncertainty. As prices volatility generates economic losses Carlson *et al.* (1994) make some suggestions for changing of the original model of emission permits market, thus developing a new market institution.

Carlson and Sholtz (1994) consider several proposals and find that the creation of permits with different emission and expiration dates (alternate emission permits) is the more effective. The idea is to allow more flexibility for market participants to react to random events such us changes in demand and production volume. Permits with different emission and expiration allow smoother reactions by firms to unpredicted emissions changes and consequently regulators are not faced with periods of huge pollution and consequently violation of environmental limits. Additionally, prices emission titles would reflect more closely firms' marginal abatement costs, a necessary condition for economic efficiency in the market[6].

Porter (1993) used experiments to test whether the uncertainty regarding firms' exact level of emissions was the cause of the effectiveness loss and if the solution proposed by Carlson and Sholtz (1994) just discussed solved the above-mentioned problems. The results of these experiments confirm the increased volatility of emission permits prices in the presence of uncertainty. However, the volatility is significantly reduced with alternate emission permits, in other words, price fluctuations were smoother and no price crashes were registered. Porter (1993) found that participants achieved higher profits with alternate

[6] However, Carlson and Sholtz (1994) consider these alternate emission permit titles should be used together with the reconciliation market, and not to be a substitute.

emission permits than with uniform titles, which indicates that this change in the market institution brought an increase in efficiency. Therefore, the creation of alternate emission permits seems to contribute to effectively solve the problem.

Other solution pointed in economic literature for the price volatility problem caused by uncertainty respects to the possibility of using emission permits beyond their original expiration date. This is usually named as *banking* of emission permits and consists of allowing firms to use permits not used in previous periods, in order to satisfy an unexpected demand of subsequent periods. Bankable permits are tradable through time rather than only through space[7].

Although one disadvantage of this proposal is a decrease in regulators' ability to control pollutant emissions distribution over the time, several studies have analysed possible positive consequences of this intertemporal use of emission permits.

Theoretical studies about the properties of emissions trading markets with banking (and borrowing[8]) appeared after policymakers introduced them in real world applications[9]. Rubin (1996) analyses firms' problem of minimizing abatement costs over time by heterogeneous regulated firms that periodically receive emission permits with indefinite horizon. Rubin's (1996) continuous model achieved a pattern for intertemporal pollutant emissions trading important not only for what concerns cost minimization but also for the knowledge about its impact on environmental damages. He concluded, that when banking is allowed and environmental standards become more stringent, total present environmental damages are reduced. However when borrowing is allowed the results are the reverse. Rubin's (1996) recommendation, is to include the possibility of intertemporal substitution in emission permits markets, since it gives firms a bigger flexibility to adjust their emissions flow, which reduces their abatement costs.

Rubin's (1996) work contributed to a better knowledge of the efficiency properties of emission permits markets when banking and borrowing is allowed. However various subsequent studies introduced several changes to his model[10]. These are described in detail bellow.

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[7] Although bankable permits are the most common solution suggested for uncertainty problems, other developments are referred, such as the introduction of futures and options. For instance, Godby *et al.* (1997) experimentally test the consequences of introducing futures in emission permits markets – as we will refer below – and Unold and Requate (2001) study the impact of combining an emission trading system with a call options menu. The effects of this type of instrument,, very common in financial markets, are still not very clear for emission permits markets. Therefore, it is an area for further research.

[8] When borrowing is allowed a firm might pollute more than its current limit but compensate that emission permits deficit in a future period, before the end of the control period.

[9] For example, $SO_2$ EPA's emission trading program already allowed banking of permits.

[10] Some of these studies also treated simultaneously some of the market failures we mentioned. Hagem and Holtsmark (1998), for example, studied the consequences of having a system with bankable permits and a

Kling and Rubin (1997) criticize Rubin's (1996) work as it did not include the social regulator's problem and the optimality of bankable permits. These authors highlight the fact that even if intertemporal transaction of permits may minimize firms' total abatement costs this does not necessarily mean that the solution will be the social optimum. This may be true if total social damages are higher when pollutant emissions are moved in time (in other words, when the timing of emissions affects total social damages) In sum, Kling and Rubin's (1997) main contribution was to evaluate efficiency properties of an intertemporal emissions trading scheme from the society and the private firms perspectives. They found that in many cases the private solution was not the same as the social one, for that reason Kling and Rubin (1997) suggested that the intertemporal trade of emission permits should not be made on a case by case but instead it should rely on an appropriate rate of discount. This discount rate could be smaller or bigger then the interest rate of the market but would allow the private and social solutions to converge, assuming that social damages are constant and linear. This was also Yates and Cronshaw's (2001) conclusion about social discount rate cost minimization, even in a different scenario considering asymmetric information regarding abatement costs between regulator and private firms.

Yates and Cronshaw (2001) also concluded there were certain situations where intertemporal emission permits trading increased social welfare but this result was not universal. The authors show that the critical parameters for determining the answer to the question "to allow or not intertemporal emission permits trading" are the slopes of the marginal abatement costs and marginal damage curves[11]. In sum, Yates and Cronshaw's (2001) conclude that before implementing an emissions trading program with intertemporal substitution careful attention should be given to the abatement cost and damage functions, as well as to the nature of the informational asymmetry. Therefore, they recommend no generalizations in this field, and a case-by-case analysis in order to find the correct answer for each case.

Leiby and Rubin (2001) and Stevens and Rose (2002) develop models to evaluate the consequences of banking and borrowing emission permits in an international market,

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dominant firm, with market power. His conclusion was that allowing banking and borrowing in these conditions would not originate the best result.

On the sixth section of this paper we will refer to Innes (2003) study, and this relates intertemporal trading of emission permits with firms decision on whether to comply or to violate emissions limits imposed by the regulator.

[11] As we will see bellow, this is a similar conclusion to that of Weitzman (1974). However, it does not even respect to the same problem as Yates and Cronshaw (2001) model was about firms' behaviour in an emission permits market, which would not be the same if the policy instrument chosen was a different one. And Weitzman (1974) model respects to the comparison between different environmental instruments, namely price or quantity ones.

particularly reflecting Kyoto's Protocol conditions[12]. Although the authors use different models, they both look for the correct rate of intertemporal transaction in this situation. However, Leiby and Rubin (2001) and Stevens and Rose (2002) find different results' regarding the consequences of non-unitary emission permits intertemporal trade. Leiby and Rubin (2001) conclude that if the discount rate is correctly determined banking and borrowing generate greater efficiency gains, while Stevens and Rose (2002) argue the net gains that could be achieved are very small. The explanation for this divergence might in fact be related to the differences in the models used.

On this matter there are a few experimental studies. Muller and Mestelman (1998), for example, argue in favour of the implementation of intertemporal trade of emission permits based on some of the results in experimental studies.

However, different experimental studies don't reach the same results. While Godby *et al.* (1997) find that the introduction of bankable coupons and shares would result in increased efficiency, Muller and Mestelman (1994) conclude the opposite. This disparity may be explained by the fact that these authors used very different market institutions and this, as we have seen at the beginning of this paper, has influence on the final result. And more importantly, Muller and Mestelman (1994) did not introduce uncertainty in their experiments in the same fashion as Godby *et al.* (1997). Therefore, these experiences are not comparable.

Godby *et al.* (1997) lab experiment assumed an uncertain context and the results show that price instability although present it almost disappears with the introduction of bankable coupons and shares. Consequently efficiency in emission permits market significantly increases even with a much more complex environment for decision-making. However, Godby *et al.* (1997) could not explain these results nor economic theory predicts them. So, this remains an open field for investigation.

Cronshaw and Brown-Kruse (1999) also use lab experiments to study the consequences of intertemporal trading of emission permits, but for the specific case of the market institution used by the EPA's $SO_2$ market proposal. Although bankable titles increase the complexity of the market, Cronshaw and Brown-Kruse (1999) conclude that the market institution proposed by EPA could achieve efficiency gains by adding intertemporal trade. Although this is not an experiment comparable to that of Godby *et al.* (1997), as it was conceived in a context of certainty, it also brings arguments in favour of the introduction of bankable coupons.

[12] Stevens and Rose (2002) also aim to evaluate Kyoto's flexible mechanisms (CDM and JI) potential for abatement cost reduction. And according to these authors simulation model this mechanisms may effectively bring additional efficiency gains.

A totally different question about uncertainty consists of evaluating the robustness of the advantages of emission permits market in comparison to all the alternative instruments, in an uncertainty context. Weitzman (1974) is the first study on this matter and his conclusions are the following: the original absolute advantage of an emission permits market (from Dales' (1968) or Montgomery's (1972) papers) does not hold in the presence of uncertainty. Weitzman's (1974) conclusion on the efficiency of price (ex. taxes) *vs* quantity (ex. emission permits market) instruments, under uncertainty, is that it depended on the slope of the cost and benefit curves at the optimal output level. In sum, emission permits market could no longer be considered *the* policy instrument since its superiority depends on several parameters.

Weitzman (1974) argues that under uncertainty the best policy instrument is the one that has a higher probability of avoiding a big error relative to the environmental limit imposed. Thus, under uncertainty, if marginal benefits are more sensitive to the control level a quantity restriction is preferred but if marginal costs change faster than marginal benefits, a price instrument is advisable.

Stavins (1996) and Newell and Stavins (2003), for example, develop Weitzman' s (1974) model to make it applicable to other situations. Stavins (1996) includes simultaneous and correlated uncertainty with respect to costs and benefits of pollution abatement, and not in separate as Weitzman (1974) and concludes that only the uncertainty about abatement costs is relevant to the choice of a instrument policy. Moreover, Stavins (1996) shows that Weitzman's (1974) rule about the relative slopes of marginal abatement cost and benefit curves could not be applied when simultaneous and correlated uncertainty on costs and benefits exists. He even concludes the rule was totally reversed in this case. Newell *et al.* (2003), on the other hand, introduce the necessary changes to Weitzman's (1974) model in order to apply it specifically to the case of stock pollutants, and the problem of uncertainty about its costs of abatement. These authors' analysis is dynamic, and not static as Weitzman's (1974), allowing them to address the problem of global climatic changes due to greenhouse gases concentration. Even with the several adjustments made by Newell and Stavins (2003), these authors found the same rule as Weitzman (1974) for the choice of the best environmental policy instrument. Moreover for the environmental policies concerning greenhouse gases they conclude that price instruments should be chosen since they allow higher welfare gains than quantity instruments.

Newell and Stavins' (2003) have important implications in the current debate over Climate Change. International $CO_2$ emissions trading markets predicted in the Kyoto Protocol, or the recently created European market, are examples of the choice of a quantity

instrument for a pollutant that Newell and Stavins (2003) considered should be treated with a mixed instrument including price and quantity instruments[13].

Weitzman himself (Weitzman (1978)) and Roberts and Spence (1976) had already made this suggestion for the use of mix or hybrid mechanisms. Weitzman (1978) develops precedent work and concludes that price and quantity instruments should not be regarded as separate instruments. On the opposite, the optimal solution would pass by a mixed system, with the relative advantages of each instrument being those he presented in his 1974 paper. Roberts and Spence (1976) also studies the advantages and problems associated with the price and quantity instruments and corroborated Weitzman (1974) rule. Roberts and Spence (1976) also confirms the same result in favour of using a mixed policy scheme. The argument presented was that if the regulators' objective was to limit pollutant emissions, a quantitative restriction could be imposed through the cap on tradable emission permits. But, if abatement costs revealed to have been overvalued, an additional incentive for abatement might be necessary, and this could be a subsidy. If, on the other hand, abatement costs come to be too high a *safety valve* would be necessary, through a penalty for exceeding emissions imposed by the quantitative restriction. The same proposal is advocated in Jacoby and Ellerman's (2004).[14]

However, there is a different between the theoretically correct policy choice and the real world political choice. The Kyoto Protocol used a quantity instrument to control emissions instead of using a price instrument, which given the specific characteristics of the environmental problem is the theoretically adequate instrument. To solve this incompatibility between economic policy recommendation and politic agreements, Jacoby and Ellerman (2004) suggest at least a safety valve should be adopted, which combines price instrument superiority for stock pollutants with the seemingly politically more attractive quantitative instrument. To limit the probability of imposing a quantitative restriction, in a cap-and-trade system, which imposes costs well above the benefits of abatement, a price should be established to work as a safety valve, getting close to the avoided marginal damages[15].

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[13] Aldy *et al.* (2003) critical study about Kyoto Protocol (and thirteen other policy alternatives presented by different authors to the global climate change problem) reached a similar conclusion. Price mechanisms should be the key element of the approaches based on the market to the solution of this type of problem. And if it was not possible to directly tax emissions, these authors suggested hybrid schemes with quotas and taxes.

[14] Jacoby and Ellerman (2004) work comes in line with Weitzman's (1974) and starts by confirming his results. Then, they exemplify with different situations the key parameters for the choice of the correct policy instrument. And for the GHG combat policies, Jacoby and Ellerman (2004) show that price instruments are the most appropriate. Climatic damages are expected to increase with GHG concentration but each period emissions are just a small contribution for the existent stock pollutant. Therefore, single period additional emissions marginal damages are almost constant and the bigger uncertainty is on marginal abatement costs. This situation is the case for a price instrument to be adopted.

[15] However, criticisms exist about the consequences of implementing this safety valve. Namely, environmental groups consider it might diminish the quantitative restriction on pollutant emissions and consequently decrease

Mandell (2004a) considers this hybrid mechanisms are seldom used because of the complexity for its implementation. Therefore, he recommends that some polluters should have their emissions taxed and others should be included in a cap-and-trade mechanism, instead of using the two instruments simultaneously for the same group of firms. Based on the results obtained, Mandell (2004a) concludes that dividing the regulated firms in two groups brings efficiency gains due to the decrease in emission permits market distortions, which are higher than the efficiency losses created by the ineffective regulated sector's division (that do not equalizes marginal abatement costs, those subject to a price mechanism).

Furthermore, instead of a fixed price for the safety valve, Mandell (2004b) develops a regulatory mechanism that includes a price function with positive slope, which means there is the possibility of price increases with the number of permits issued. Compared with the performance of the other instruments, under uncertainty about marginal abatement costs, this generalized hybrid mechanism revealed to be the best.

We should, however recall that this and all the studies we referred, from Weitzman (1974) on, did not include the developments suggested for emission permits markets we pointed above in this section. Namely, none considered the intertemporal trading possibility, of using bankable coupons, which could make this quantity instrument more flexible and efficient. This is a modification that should be made in the future in order to verify if the conclusions on the superiority of price instruments for GHG emissions abatement would still hold. Recommendations for the international environmental policy responsible would depend on the results of that potential investigation.

## 6. IMPERFECT COMPLIANCE AND ENFORCEMENT

Emission permits market equilibrium and market outcomes are usually determined under the assumption that firms comply with the environmental limits imposed by regulators. Consequently, predicted results for the use of this policy instrument assume this hypothesis of perfect compliance and enforcement. However, in reality, violations of environmental limits occur and regulators face difficulties concerning enforcement, as they have scarce budgets to pay for the control and monitor costs[16]. Therefore, it is important to know whether the

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the environmental quality established by the quantity instrument. This and other arguments against the use of the safety valve are described on Jacoby's *et al.* (2004) paper.

[16] Aldy *et al.* (2003) and Barret and Stavins (2003), for example, express their concern about Kyoto Protocol mechanisms capacity, as well as the alternative proposals for an international climatic policy, to induce the correct level of participation and compliance. These two studies consider these policies did not properly cared about this aspect and Barret and Stavins (2003) even suggests some incentives that could be introduced in these international agreements in order to overcome this failure. They recognize, however, the difficulties in their implementation, as the parts are sovereign countries.

efficiency gains from using emission permits market still hold under imperfect compliance and monitoring. This section reviews studies on this question.

Malik (1990) shows that when firms violate the environmental limits imposed, emission permits market do not result in the minimization of abatement costs. In other words, in the presence of this market failure, emission permits market is not efficient. The emission permits demand from a noncompliant firm depends, according to Malik (1990), on its attitude towards risk as well as the regulator enforcement policy. Therefore, emission permits price is also going to depend on these two factors.

Malik (1990) concludes that the relationship between compliant and noncompliant firms emission permits demand depends on the characteristics of the compliance audit probability function considered by firms. This is something already considered by Beavis and Walker (1983a) and Beavis and Walker (1983b) previous models. Stochastic pollutant emissions abatement decisions by firms were made considering the information they had on what they knew to be the regulator's imperfect information on their disposal and the monitoring frequency. For a given penalty function, these authors conclude that the way and frequency of regulators monitoring influences the firms pollutant discharges, and violation levels. Regulator should therefore, simultaneously chose emission permits level to put in the market as well as the monitoring rate.

Malik (1990) highlights the relation between non-compliance, monitoring, penalty parameters and equilibrium permits price and the importance it should have at the moment of design and implementation of an emission permits market. These are aspects not originally taken into account when considering the adoption of this environmental policy instrument. However Malik (1990) demonstrates they effectively cannot be ignored.

Keeler (1991) work comes as a continuity of Malik's (1990) but his objective is somewhat different. Keeler (1991) compared emission permits market performance with a command-and-control instrument (a standard) when compliance is not perfect. The motivation was to evaluate if the superiority usually attributed to the market-based mechanism was still true under this circumstances. Keeler (1991) focus on the penalty function, as a critical factor for the final results of an emission permits market. He concludes that emission permits market was not always more efficient than the standard, the result depends on the type of penalty function used (constant, increasing or decreasing).

Keeler (1991) used equal monitoring probabilities and penalty functions for all firms but considers that it should be tested whether different regulating efforts towards firms with different abatement costs matter for market outcomes. Keeler (1991) assumes that high abatement costs can be taken as synonymous of higher violation probability, so the regulator

should direct more monitoring efforts towards this type of firms. However, Stranlund and Dhanda (1999) conclusions show there is no need for regulators to apply different resources on firms with different abatement costs to increase compliance.

Stranlund and Dhanda (1999) objective was slightly different from the precedent studies. Assuming an emission permits market with noncompliant firms, the authors try to understand in which way regulators should apply their limited budget to monitoring and to penalties over heterogeneous, noncompliant firms in order to enforce the specified environmental objective.

Stranlund and Dhanda (1999) model consisted of a competitive emission permits market, with price-takers, risk neutral and heterogeneous firms. They assume that emissions are grandfathered and that the competitive market would establish a constant price for permits. Stranlund and Dhanda (1999) wanted to evaluate the probability of regulators' monitoring and penalty strategies affecting the market equilibrium and, consequently, firms' equilibrium compliance choices. Therefore, the authors model different possibilities of audit probability, as well as different announced penalty structures. They focused, however, on the case of increasing penalties for increasing firms' violation rates. This is the main difference between Malik (1990) and Keeler (1991) studies: to explicitly deal with penalty and control system design for an emission permits trading market.

Stranlund and Dhanda (1999) results surprisingly show firms' decisions on emission levels, and violations, are independent both of audit probabilities and penalty function. There is, however, an indirect price effect of the regulator's policy on equilibrium emissions level and violations and consequently on firms' emission levels (through permits' price). Moreover, compliance or violation decisions are independent of firms' own exogenous characteristics. In other words, for constant monitoring and penalty functions, a variation on firms' parameters affecting their abatement costs has no influence on their decision on violation or compliance with the environmental limit. Two different firms, one using a more pollutant productive technology than the other, facing the same monitoring probability and the same penalty function will present the same level of compliance or violation[17]. Therefore, Stranlund and Dhanda (1999) refer that the reason for different compliance behaviour between different firms must be the difference in monitoring and penalty efforts from the regulator. Equilibrium violations are not, however, completely independent of firms' exogenous characteristics

[17] Each firm chooses its emission level to make its marginal abatements costs equal to market emission permits price. It also chooses the number of permits to hold in such a way marginal expected penalty equals again emission permits price. Consequently, as all firms face the same emission permits price, they all have the same marginal abatement costs and marginal expected penalties, whatever the regulator's strategy is.

because there is an indirect price effect: these firms' characteristics affect emission permits demand and consequently emission permits equilibrium price and violations.

Stranlund and Dhanda (1999) conclude that different monitoring and penalty functions applied by the regulator to different firms, determined from an optimal program of monitoring and issuing penalties, are independent of firms' exogenous characteristics. Therefore, in order to decide how and where to apply its scarce enforcement resources the regulator cannot use those characteristics. Yet, this same authors refer these theoretical results should be empirically tested but rigorous econometric tests are not possible because there is not enough data. In this case, they consider that the experimental methodology could give a good contribution for the test of these results[18].

Other studies have been conducted to simultaneously evaluate the performance of the emission permits market policy in the presence of two market failures: imperfect compliance and enforcement, and marker power[19]. van Egteren and Weber (1996), for example, base their work on Hahn's (1984) model for market power and Malik's (1990) model for imperfect compliance and enforcement . With the combination of these two models, van Egteren and Weber (1996) try to determine the impact of market power on emission permits equilibrium price and on firms' compliance level. They find that when market power is present, initial allocation of permits plays a very important role on market's final result, both concerning emission permits price and firms' compliance levels. Lower initial allocation of permits to the firm with market power increases compliance levels of the competitive fringe firms but reduces compliance level of the dominant firm. In this case, van Egteren and Weber (1996) suggest that monitoring and penalty efforts should be concentrated on the dominant firm. In sum, they suggest that the initial allocation of permits may be used to control both market power and the regulators' enforcement policy effectiveness.

Malik (2002) work comes in the same line as van Egteren and Weber (1996) but reaches different conclusions. Malik (2002) considers that some non-compliance might be socially desirable because it diminishes market power distortions. This might be so if the fringe competitive firms are the ones violating the environmental objective and their permits demand becomes more price elastic. As the dominant firm decides to exert its market power, competitive non-compliant firms reduce the dominant firm's market power and the

[18] This work has been partially done by Murphy and Stranlund (2004 and 2005) that confirm Stranlund and Dhanda (1999) results.

[19] We will refer with some detail to studies that consider this two market failures. However, non-compliance problem has been studied together with other failures, different from market power. Rousseau and Proost (2004), for example, use a second-best general equilibrium model to study different environmental policy instruments efficiency when previous to environmental regulation distortions exist, like labour taxes, and there is also some non-compliance of the environmental limits imposed. We will not consider this type of studies here but the ranking of this policy instruments changes when non-compliance possibility is included.

differences between their marginal profits. Although Malik (2002) concludes there are social benefits associated with the non-compliance behaviour he refers that those benefits must be compared with the social costs, i.e., costs associated with a higher level of pollutant emissions. In sum, Malik (2002) argues in favour of a second-best solution since it is not socially optimal to eliminate one of the market failures without correcting the other.

In the precedent studies compliance was assumed as a choice variable within the model. Chavez and Stranlund (2003) assumes that compliance is exogenous and analyses whether the regulators' decisions regarding the enforcement of a cap in an emission permits market varies with the existence of a dominant firm and how it varies with the method used for the initial allocation of emission permits.

Chavez and Stranlund (2003) conclude fringe competitive firms and the dominant firm should be controlled differently, and according to their position in the market – either emission permits buyer or seller. Moreover, firms' abatement and compliance costs can be at the efficient level if the dominant firm chooses to enter in the emission permits market. This conclusion is opposite to the one in Hahn's (1984). Additionally, market power may be explored to diminish total costs of an emissions trading program implying that market power should not be regarded as always undesirable, on a case by case basis the efficiency loss from the exercise of market power should be compared with the reduction in enforcement costs possible by the exercise of that market power. Regarding the method for the initial allocation of permits, the efficient allocation of permits may be one that implies the participation of the dominant firm participation in the market, which means that the final result will not equalize marginal abatement costs across firms. As Chavez and Stranlund (2003) underline this conclusion has an important implication for empirical analysis on the efficiency of the market: when compliance and enforcement costs are considered efficiency is no longer a marginal costs equalization matter.

However, the implementation of Chavez and Stranlund (2003) recommendations is difficult since it requires knowledge of firms' marginal abatement costs thus, regulators might be more tempted to limit market power than to adjust initial allocation of permits in the way suggested[20].

Either in competitive or monopolistic markets, the enforcement and monitoring of emission reduction is still a problem for the regulator. Several studies have analysed this problem in the context of an international GHG emissions market. Werksman (1999), Mullins (1999) and Baron (1999), for example, consider the enforcement problem for global climate

[20] In this situation, distributing permits using an auction is usually recommended. Chavez and Stranlund. (2003) refer that it has not yet been evaluated enforcement costs of grandfathered and auctioned permits, and consider it is a necessary work in the future.

change policies as proposed by the Kyoto protocol. To penalize each non-compliant country is a complex and expensive task. Therefore, an alternative enforcement rule appears in these studies: the buyer responsibility rule. In other words, if the emission permits seller does not abate the corresponding emissions, the buyer is not allowed to use the bought titles. Emission permits buyers have, in this case, all the interest in buying permits to the most trustable entities in the market.

However, if the buyer responsibility rule may solve the non-compliance risk it may also involve high transaction costs, reduced liquidity in the market, and it may be a complex rule to implement. Cason (2003) experimental study evaluates the benefits of using this rule, in terms of the incentives it brings to compliance of the environmental limits imposed. The experimental results show that seller of emission permits invest on the guarantee of its permits (i. e, insures himself against non-compliant buyers), increasing in this way the efficiency in the market, and that buyers are willing to pay a prize for trustable permits. Therefore, emission permits would be sold at different market prices, because these would reflect the non-compliance risk. Furthermore these market prices would effectively constitute an incentive for sellers to comply with their emission abatement limits. Cason (2003) experiment is the only we are aware of that addresses this issue, which means tests on the robustness of its results are in order. Moreover, Cason (2003) refer some extensions should be done to this work, and some simplifying assumptions should be relaxed in order to make the conclusions obtained more useful in practice.

Cason and Gangadharan (2005) experiment's studies the interaction between three pertinent questions in emission permits markets: uncertainty, banking and compliance and enforcement. Although other experimental studies have already analysed all those questions, this is the first to address them simultaneously.

The results Cason and Gangadharan (2005) show that banking decreases emission permits price volatility but reduces compliance and, consequently, increases emission levels.[21] This result has no explanation in economic theory and thus future investigation on this matter is necessary. Innes (2003) evaluates the impact of banking under uncertainty and found another argument in favour of the intertemporal substitution of permits: to increase emission permits market efficiency through reduction of enforcement costs. Therefore, to find out the compliance incentives, in the presence of banking, is still a research objective for the future.

[21] Although even without banking, non-compliance of environmental limits exists, the participants in this experiment chose to violate more frequently when they could use their titles in future periods. Apparently, these subjects considered having more benefits with non-compliance when they could sell banked permits in subsequent periods. Innes (2003) found the opposite result.

To conclude this section despite the diversity of results, it is clear that imperfect enforcement and non-compliance behaviour influence emission permits market efficiency. However, the best strategy for the regulator in this situation as well as other depends on characteristics of the market institution that are not yet consensual.

## 7. INCENTIVES TO INNOVATION

In the previous sections we analysed how emission permits market outcomes are affected by a series of market failures in the sense that they represent circumstances where the assumption of Dales (1968) original model are not met. In this section we analyse one of the advantages attributed to this policy instrument, which is its ability to promote innovation, and consequently contribute to attainment of dynamic efficiency.

Even if environmental regulation, of any kind, usually obliges firms to adopt procedures that they otherwise would not adopt, the choice for emission tradable permits was originally assumed to be the one that was capable of inducing a higher level of technological innovation. Emission permits was the market-based policy instrument considered to originate the best result concerning dynamic efficiency. Command-and-control policy instruments were, on the contrary, referred as the least efficient, especially when consisting of the imposition of a standard technology of abatement. In this case, firms had no incentives to innovate and introduce new ones.

In theory there is no ranking of environmental policy instruments regarding their effect on technological innovation. And, what is more troubling, some of the studies do not find emission permits markets to be at the top of the list. Jaffe *et al.* (2002) describe various studies on environmental policy evaluation concerning dynamic efficiency to try to conclude about emission permits market advantage. They suggest that obviously different environmental policy instruments might have different impacts on technological innovation. Therefore, the design and evaluation of environmental policies should consider technological development as an endogenous variable and not exogenous as frequently happens. In fact, Tietenberg (1985) considered this to be one of the major factors responsible for the differences between expected results and real outcomes from the implementation of emission permits markets.

Since Magat (1978), numerous studies have evaluated the differences across environmental policy instruments concerning their ability to induce technological innovation. Downing and White. (1986), Malueg (1989), Carraro and Siniscalco. (1994), Biglaiser *et al.* (1995), Jung *et al* (1996), Parry (1998), Requate (1998), Keohane (1999), Montero (2002) and Fischer *et al.* (2003) are some of the references in this subject.

Although differing in many aspects of their analysis several of these studies positioned the instruments in the following order with respect to efficiency. First, auctioned emission permits; second, taxes and subsidies on emissions; third grandfathered emission permits; and fourth, performance standards. Accepting the order it should be stressed that grandfathered emission permits is the worst positioned instrument based on the market. This result is important because grandfathering has generally been the method chosen for emission permits initial allocation. Further, the initial distribution of emission permits is not irrelevant for the final results with respect to the dynamic efficiency of the market. Consequently, Dales's (1968) or Montgomery's (1972) argument that initial permits distribution was irrelevant for efficiency of the market, with impacts just on equity, is contradicted. Auctioned permits seem to bring higher incentives to technological innovation than grandfathered permits, in several studies[22].

Malueg's (1989) conclusions, on the other hand, are even more troubling than the one we just mentioned. He concludes that emission permits markets might reduce firms' incentives to innovate, which is totally opposite to the advantages originally attributed to this environmental policy. Incentives to innovation from command-and-control instruments comparatively to emission permits market explicitly depend on the position of the firm in this market, before and after the adoption of the new technology. Malueg (1989) shows that if the firm is a buyer in the emission permits market before and after the new technology adoption, the incentives for new technology adoption are lower than if an environmental standard was adopted. He justifies this result with the fact that emission permits market gives a relatively cheap option to comply with the emissions abatement imposed, which reduces its benefits and need to adopt a new technology. Therefore, according to Malueg (1989) it is not true emission permits markets have an absolute advantage over the command-and-control policy instruments with respect to its incentives to innovation.

Fischer *et al.* (2003), for example, included technological innovation as an endogenous variable of environmental policies and found that there was no clear ordering of the environmental policy instruments since the incentives to innovate depend on the costs of innovation, the environmental damage function, the capacity of the innovating firm to appropriate the effects of innovation on the other firms, and also depends on the number of pollutant firms.

Montero (2002) considers imperfect competition in the permit and product markets and finds result totally opposite to economic literature: command-and-control instruments

[22] Not all agree with the same ranking of the different instruments. Keohane (1999), for instance, argues auctioned permits do not cause more induced technological innovation than grandfathered permits.

such as environmental standards may provide higher incentives to innovation than tradable emission permits. Montero (2002) explained this conclusion as a result of the combination of two effects: a direct effect of cost minimization, and a strategic effect. For environmental standards, the strategic effect is always positive as R&D firms' investment diminishes its own costs but not its rivals, which increases its output and profits. For emission permits, on the other hand, R&D investments cause external impacts on the market, which can reduce firm's rival costs. As R&D diminishes emission permits prices this strategic effect is positive for permits buyers but negative for permits sellers. In sum, Montero (2002) finds the same result as Malueg (1989), emission permits markets have no absolute advantage comparatively to environmental standards, with respect to induced technological changes, but this result depends on whether firms are buyers or sellers of emission permits.

Laffont and Tirole (1996) focused their attention only on emission permits markets incentives to technological innovation and not on its comparison to other policy instruments. The main conclusion was that emission permits markets do not produce incentives for an efficient level of innovation[23]. Laffont and Tirole (1996) suggest firms invest too much in new technologies, comparatively with the optimal level, because they do not internalise the revenue losse imposed on other firms when they do not enter in the emission permits market. As originally conceived, these markets would not induce the correct level of innovation so Laffont and Tirole. (1996) propose some changes, such as the introduction of a futures market.[24] They also studied the regulator's ability to influence firms' decisions regarding R&D investment through the level of emission permits issued. The solution proposed however would harm the trust that firms pose in the market, due to the uncertainty caused by potential fluctuations on the volume of permits.

Dowlatabadi (1998), Goulder *et al.* (1999) and Kemfert (2004) included technological changes as an endogenous variable of their models, in order to find what they considered a true value for the abatement costs of GHG like $CO_2$. In this way, estimated impacts of global environmental policies would come closer to reality, as the main dynamics and interactions between socio-economic and natural systems were characterized. And as the inclusion of this endogenous variable resulted in smaller estimated costs of abatement of GHG, arguments in favour of international emission permits market creation are strengthened.

Nicklisch and Zucchini's (2005) experimental study explicitly considered the strategic trade off between investing in new abatement techniques and the emission permits price. The

[23] The question of achieving a socially optimal level of innovation was not under consideration in the studies referred before.
[24] If the regulator sells, at the present moment, emission permits for the next period at smaller price than the one in the spot market, investment in innovation is discouraged.

objective was to test two different questions. First, to investigate whether theoretical equilibrium predictions would still hold when firms have two choice variables (emission permits quantity and abatement investments). Second, to study the strategies firms would chose to adjust to permit market quantities (imitative, collusive, competitive behaviour). They conclude that the market approached the Nash equilibrium. On the other hand, they concluded that agents generally adapt their emission permits demand imitating their successful rivals. These results also identify two spillover effects. The first, explicitly included in the market mechanism, is the fact that one firm investment causes a decrease in emission price. The second, reflecting the adaptation rules adopted by the majority of firms in this environment, concerns the fact that successful permits demand by one agent have a great probability of being imitated. Therefore, Nicklisch *et al.* (2005) conclude that an emission permits market with a competitive equilibrium will create, in the long run, a strong incentive for small investments in abatement technology.

In experimental work the concern has been on static efficiency and not on dynamic efficiency. Therefore, this is obviously one field where much research is necessary because it is not totally clear, as theoretical studies we mentioned demonstrate, the dynamic efficiency characteristics of emission permits markets. If for a long time this was an absolute advantage associated to this policy instrument, presently the innovation induced by emission permits market is not unquestionable. However, consensus on this matter is yet to be found.

## 8. CONCLUSION

Economic models are a simplification of reality. No news in that, but one should keep it in mind while reviewing some of the criticisms to Dales (1968) original model for emission permits markets. It assumed perfect competition while it is obvious that such market structure is almost impossible to exist in practice. Thus, to question the announced efficiency of emission permits markets seems justifiable.

As we have seen section 2 of this paper, transaction rules established for emission permits markets cannot be considered a mere detail since they influence the behaviour of market participants and, consequently, affect the market's final outcome. Although there are opposite results concerning the capacity of market institutions to prevent or minimize some market failures identified in emission permits markets, it is by now consensual that its characteristics are not neutral with respect to the efficiency of this policy instrument.

Experimental and field evidence has shown that the market institution chosen determines how close the final outcome will be to the competitive equilibrium. As we pointed out along this paper, the characteristics of the market institution also determine the transaction

costs and the uncertainty level firms have to face, their capacity to exercise market power, their compliance decisions, as well as firms' innovation incentives. The method for the initial allocation of permits is singled out as an important regulator's choice for the efficiency of the emission permits market, and that may influence, at higher or lower degree, the various aspects considered in the different sections of this paper. This is the first important conclusion we found from all the studies analysed: the initial distribution of permits not only has equity consequences, but also impacts on the efficiency of the market. Transaction costs and the exercise of market power are market failures that can be minimized if the correct initial allocation of permits is implemented, as first demonstrated by Stavins (1995) and Hahn (1984), respectively.

The capacity of different market institutions to prevent the exercise of market power, identified as a problem in some emission permits markets, has been the subject of an extensive research. The double auction institution is maintained as the best choice when this market failure is present, but there are still some opposite results concerning the factual superiority of this market institution in such cases. Moreover, the very impact of imperfect competition on the efficiency of emission permits market does not show up as a serious problem in several studies. It depends on whether we are dealing with simple or exclusionary market power, which also means that the policy recommendations to deal with this market failure depend on the type of market power under consideration. However, even if the exercise of market power may not have severe consequences for the outcome of emission permits markets in a static framework, it certainly diminishes the dynamic efficiency of this policy instrument. Because market prices are not at the competitive level, they do not give the correct information necessary to induce the efficient level of technological innovation. Therefore, this advantage of emission permits markets comparatively to other policy instruments is reduced at best.

As detailed in section 5 of the paper, several studies have proven that the consequence of uncertain marginal abatement costs or uncertain effective emissions is price volatility in the market. This distorts the information transmitted by prices and causes efficiency reductions, both in dynamic and static contexts. Alternate titles, concerning its validity date, and bankable titles, allowing its intertemporal substitutability, are two changes in the original emission permits design that have been suggested as a solution for this problem. These two title properties have been studied and their advantages identified. They are both capable of reducing the price volatility caused by uncertainty, but no generalization should be made for their use since the correct discount rate for intertemporal substitution, for example, depends on the parameters of marginal abatement costs and of marginal damage functions.

The most troubling conclusion we found concerning the consequences of uncertainty in emissions trading markets is that it may lose its efficiency advantages over other policy instruments, namely command-and-control ones. For the specific case of global climate change policies, it has been clearly demonstrated that, under uncertainty conditions, price instruments, like taxes, should be preferred to quantity instruments, like the ones recommended in the Kyoto Protocol. Grandfathered emission permits are the most affected by the presence of uncertainty, with its efficiency gains more reduced, which is worrying because it is the mostly used method for the initial allocation of permits. Suggestions to use a hybrid instrument have appeared in order to overcome the problem of having policy choices opposite to theoretical recommendations. Known as a safety valve, a price limit on emission permits close to avoided marginal damages should be set. However, the complexity of this hybrid instrument makes it difficult to be implemented and that is probably the reason why it has not yet been applied.

The identification of imperfect compliance and enforcement of imposed environmental limits also shed some doubts on the advantages of emission permits market. As examined in section 6, this market failure implies that efficient results are not achieved with this policy instrument. Although the negative impact of imperfect compliance and enforcement for the efficiency of emission permits market has been recognized, the necessary changes to market institutions to deal with this problem have not yet been identified. Such an endeavour requires an understanding of the compliance incentives agents face in the presence of different characteristics of the market, and this is a research area where the experimental methodology can clearly make important contributions.

Section 7 of the paper reviews various studies that question one of the main advantages always attributed to emission permits markets: to induce a higher level of innovation than any other environmental policy instrument. These studies demonstrate that this is not an effective absolute advantage of tradable emission permits over the other instruments, although no consensual ranking of the different environmental policy instruments was found. However, some consensus exists concerning the fact that the method chosen for the initial allocation of permits is not neutral with respect to innovation incentives. Again, the initial auctioning of permits instead of grandfathering is recommended on the grounds that it brings higher incentives to technological innovation. Section 7 also examines another question related to the emission permits market incentives to innovation, that is, the question of its dynamic efficiency. It has been argued that this must be considered an endogenous variable of the model, not an exogenous variable as it is usually considered. The studies we examined show that if this variable is endogenously included the estimated

emissions abatement costs are smaller than when technological innovation is considered an exogenous variable. Importantly, such a more accurate estimation brings further arguments in favour of policies to protect the environment.

In summary, in this paper we address the main questions concerning the effective performance of emission permits markets under realistic circumstances, examining the most relevant studies on the subject. This work provides, therefore, a systematic vision of the problems regulators face with the implementation of this policy instrument. Every section of this paper points out the controversial results in the most important studies completed thus far and highlights the main issues yet to investigate. It becomes clear that Dales (1968) theoretical market for emission permits transaction is far from the cumbersome reality faced when implementing this policy instrument, and several changes are necessary to adapt this model to reality.

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