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Exclusionary Manipulation of Carbon Permit Markets: A Laboratory Test

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Exclusionary Manipulation of Carbon Permit Markets: A Laboratory Test

Björn Carlén[†]

Abstract

The experiment reported here tests the case of so-called exclusionary manipulation of emission permit markets, *i.e.*, when a dominant firm—here a monopolist—increases its holding of permits in order to raise its rivals' costs and thereby gain more on a product market. Earlier studies have claimed that this type of market manipulation is likely to substantially reduce the social gains of permit trading and even result in negative gains. The experiment designed here parallels institutional and informational conditions likely to hold in real trade with carbon permits among electricity producers. Although the dominant firm withheld supply from the electricity market, the outcome seems to reject the theory of exclusionary manipulation. In later trading periods, closing prices on both markets, permit holdings and total electricity production are near competitive levels. Social gains of emissions trading are higher than in earlier studies.

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1. INTRODUCTION

Several European countries have decided to use tradable permits to control their greenhouse-gas emissions or consider doing so. At least for an initial period, a number of countries appear to opt for industry-specific applications of tradable permit (TP) systems instead of systems covering all emitters. For instance, Denmark has established a TP system for carbon emissions—the single most important greenhouse gas—that only covers emissions from (large) electricity producers (Danish Parliament, 1999). Moreover, the Commission of the European Union has proposed a TP system for greenhouse gases that only would comprise a few industries (EU, 2001).[1]

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[1] Since greenhouse gases are fully mixed emissions (*i.e.*, the effect on the climate is given by the aggregate emissions level only (IPCC, 1996), there exist no environmental reasons to control the geographical distribution of these emissions.

Restricting the coverage of carbon TP systems in this way may be costly, not only because emitters will face different carbon prices depending on whether or not they are embraced by the emission cap—as discussed in *e.g.*, Babiker *et al.* (2000)—but also since limiting the number of traders may generate market power outcomes.

Most, if not all assessments of market power effects in emissions trading presume that the large seller (buyer)—or a group of sellers (buyers)—would exert market power by reducing the quantity it supplies (purchases), a behavior that inevitably would have a detrimental effect on the cost-reducing services of emissions trading. For example, see Westskog (1996), Burniaix (1999) and the studies reviewed in Tietenberg (1985). Hahn (1984) shows that such a quantity withholding is optimal for the dominant trader when permit trade is governed by an institution requiring all trade to be conducted simultaneously at a uniform price. However, such a market institution must not govern emissions trading.

Experimental economists have for long constructed so-called laboratory markets to investigate how various (existing) market institutions differ with respect to trade outcomes, see *e.g.*, Smith (1981). What seems to be a robust result is that, in particular, the so-called double auction (DA) institution[2] is able to attain high market efficiency also when the market is dominated by only a few firms and even when it is monopolized; see Plott (1989) and Holt (1995) for reviews of this literature. Recent emissions trading experiments based on the DA institution, *i.e.*, Carlén (2000) and Muller *et al.* (2001), confirm that the DA institution indeed is able to produce efficient trade allocations also when a single trader dominates the market. These results stand in sharp contrast to the standard theory of market power in emissions trading and suggest that the presence of dominant traders need not be detrimental to the cost-effectiveness of emissions trading, at least not as long as trade is governed by DA rules and inter-dependencies between markets are negligible. However, since production costs of some industries (*e.g.*, the power industry) to a large extent would depend on the permit price, the latter condition may not be at hand.

A dominant firm may exploit this type of market inter-dependencies; see *e.g.*, Williamson (1968) and Salop and Scheffman (1987). Misiolek and Elder (1989) analyze how a dominant firm by increasing its holdings of permits can raise its rivals' production costs and thereby gain more on the product market—see also von der Fehr (1993). Such so-called *exclusionary manipulation* may further distort the permit market and add potentially large distortions on the product market, as compared to the standard monopoly case. These additional distortions may outweigh aggregate cost-savings attained on the permit market. If so, allowing firms to trade emission permits would reduce overall efficiency.[3]

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2 In traditional (single) auctions buyers bid for an object or sellers offer an object to a buyer. In DAs these phenomena occur at the same time; sellers make offers and buyers make bids. The lowest outstanding offer and the highest outstanding bid is the market offer/bid. Sellers and buyers may make new offers/bids whenever they want. A transaction is struck whenever a seller's (buyer's) offer (bid) equals the market bid (offer). Trade under DA rules is sequential and different transactions can be conducted at different prices. Obviously, quantity withholding need not be optimal under DA rules. For instance, if buyers are sufficiently myopic, the dominant trader may be able to reap higher profit by conducting price discrimination in ways that give allocations near the efficient one. Versions of the DA institution govern trade on numerous exchanges throughout the world, such as the New York Stock Exchange and the major Chicago commodity exchanges. Despite its importance, no general theory regarding behavior on the DA institution has yet emerged.

3 The conditions under which exclusionary manipulation may arise are rather restrictive, but may be at hand for a carbon TP system covering only a single "carbon intense" industry, such as electricity production. Electricity is a product for which (i) trade between several European countries is restricted due to limited transmission capacity,

The case of exclusionary manipulation has been tested experimentally by Brown-Kruse, Elliott and Godby (1995), henceforth Brown-Kruse *et al*., and Godby (forthcoming). In these tests, emission permits were traded under DA rules and the final product on a market requiring all transactions to be conducted simultaneously at a uniform price.[4] Taken at face value, the outcomes in these experiments seem to "support" the theory of exclusionary manipulation. This has led some analysts to express skepticism about the ability of the DA-institution to limit the exercise of market power on emission permit markets and to conclude, "*Although the theory underlying exclusionary manipulation only suggests that welfare losses are possible, the behavioral results of the few laboratory studies that have been completed show dramatically that the threat is real.*" [italics added] (Godby *et al*., 1999).

It is here argued that this conclusion may be premature. One reason being that the studies underlying this claim treat emission permits as if being a physical input in production. Consequently, in these experiments firms had to acquire permits before they could produce. In addition, firms had to decide upon their final permit holdings prior to engaging in transactions on the product market, *i.e.*, before knowing the product price and, hence, their valuations of permits. As explained below (Section 3), on existing emission (and proposed carbon) permit markets firms may produce/emit and sell their output before they have to possess any permits.

The experiment presented here tests the case of exclusionary manipulation under conditions that more closely than earlier experiments parallel a trading situation likely for carbon markets. More precisely, the design includes (some) potentially important institutional and informational conditions likely to hold for real carbon permits trade amongst electricity producers, the perhaps most significant application of industry-specific carbon TP systems. In this context, both the permit market and the product market may be governed by DA rules. A few laboratory experiments have been carried out regarding trade on inter-related DA markets, often with high trade efficiency as the primary result; see Holt (1995) for a review of this literature. However, to the best of the author's knowledge, no experiment has been reported that tests the case of market power in inter-related DA markets, which is what the experiment reported here amounts to.

The experiment uses the aggregate costs and value schedules that were used in Brown-Kruse *et al.* and Godby (forthcoming). But, in contrast to these tests it focuses only on the case where the dominant firm holds a monopoly position on the permit market, the potentially worst case under exclusionary manipulation.

The paper is organized as follows. Section 2 briefly accounts for the two standard theories of market power on emission permit markets. In Section 3, the likely trading situation for electricity producers is outlined. The design of the experiment is described in Section 4. The experimental outcome is presented in Section 5. Some concluding remarks are given in a final section.

(ii) the concentration on domestic markets often is high, and (iii) the cost of substituting away from fossil fuels in the production may be high. Of course, exclusionary manipulation would not be an issue if firms could trade carbon permits internationally, as "suggested" by the Kyoto protocol, UN (1997). However, governments may choose to restrict firms' access to an international carbon market. In addition, several countries plan to implement TP systems prior to the first commitment period of the Kyoto protocol (should it enter into force), *i.e.*, before international trade with carbon emissions under an international climate treaty is likely to occur.

[4] A complete description of procedures and results of these experiments can be found in Godby (1997) Chapter 4 and Chapter 5, respectively. Moreover, the experiments are summarized in Godby *et al.* (1999), Godby (2000) and Brown-Kruse *et al.* (forthcoming).

2. TWO TYPES OF PERMIT MARKET MANIPULATION—THE MONOPOLY CASE

This section illustrates the principal effects of a firm that holds a monopoly position on the permit market and uses its market power (a) to maximize its profits from permits trade alone as compared to (b) maximizing its overall profits (profits from permit trade *plus* profits from transactions on a product market). The illustrations are based on theoretical contributions made by Hahn (1984) and Misiolek and Elder (1989). In line with these studies it is assumed throughout this section that trade in permits is (i) governed by an institution that requires all transactions to be conducted simultaneously at a uniform price, and (ii) only occurs at the beginning of the period over which emissions are regulated. Often these assumptions are made since they facilitate the analytical work and allow clear analytical predictions and not for the reason that such an institutional arrangement would be a good candidate for real emissions trading.

Consider the case where the government has put a cap on an industry's aggregate emission level and distributed tradable emission permits *gratis* to the firms therein in such a way that a single firm (firm D) holds a monopoly position on the permit market. All other firms are assumed to behave as price takers and are, for simplicity, treated as a competitive fringe (firm F). Such a permit market is illustrated in **Figure 1**, where:

(i) firm D's (F's) emissions are counted from the right (left) axis to the left (right) and the width of the open box represents the allowed aggregate emission level,

(ii) e^D (e^F) is firm D's (F's) emission level in the absence of any policy controlling emissions (for simplicity it is assumed that $e^D = e^F$),

(iii) MAC^D (MAC^F) shows firm D's (F's) marginal abatement costs,

(iv) Q denotes the initial permit allocation, and

(v) q denotes the firms' emission levels *ex post* permit trade.

If all firms act as profit-maximizing price takers, each firm would emit and sell/buy permits until its MAC equals the competitive price level, P*. Thus, competitive permit trade would equalize MAC across all firms at P*. Firm D would sell Q – q* permits and firm F buy q* – Q permits. Aggregate cost-savings from such competitive (efficient) permit trade equals the area *abc*.

However, when firm D is aware of the fact that it can influence the permit price level, it maximizes its profits on the permit market (minimizes its net-abatement costs) by selling $Q – q^M$ permits, the quantity at which firm D's marginal revenue (MR) and MAC are equal. Thus, compared to the competitive outcome, firm D withholds $q^M – q^*$ permits from the market. The resulting price equals P^M. Obviously aggregate cost-savings attained under this cost-minimizing manipulation case, *adec*, are smaller than the ones obtained under efficient trade. As shown by Hahn (1984) the government can, in principle, prevent this type of cost-minimizing manipulation by adjusting the initial allocation of permits. If the initial permit allocation were q* (*i.e.*, the vertical line would be at q*), firm D would no longer have incentives to trade permits or withhold permits from the market. However, to accomplish this the government must have rather detailed information about firm D's MAC and the MACs of the competitive fringe.

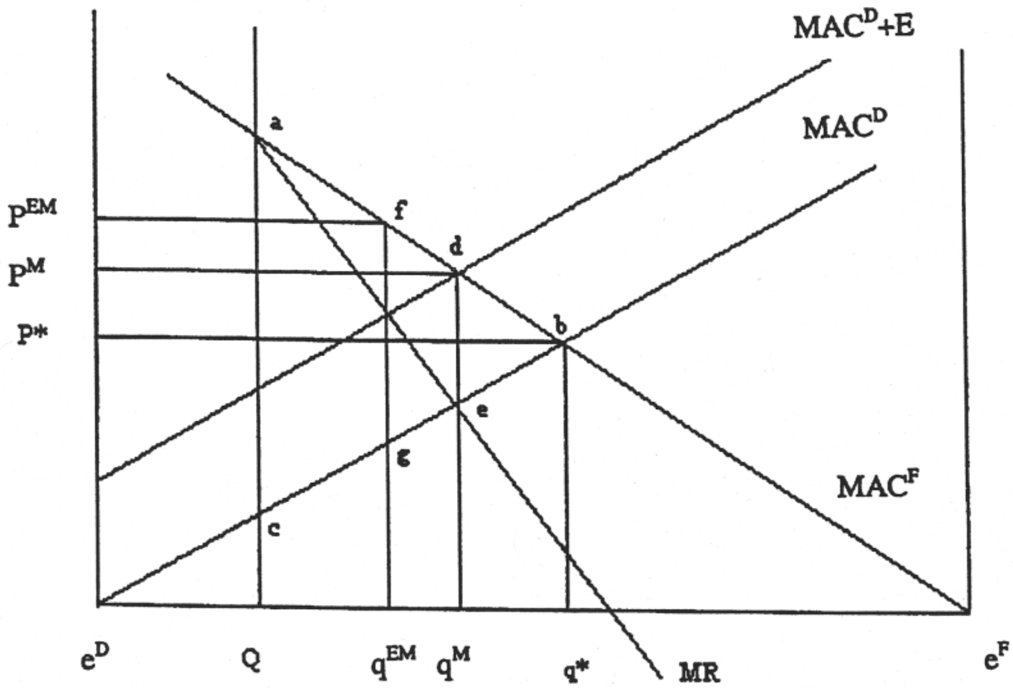

Figure 1. Illustration of a Permit Market

Consider now the case where firm D and firm F are the only competitors also on a product market and where also this market is governed by an institution requiring all trade to be conducted simultaneously at a uniform price level. Given this, firm D may find it profitable to increase its holdings of permits beyond q^M, although this implies lower profits from permit trade. The reason is that by doing so firm D increases the permit price and thereby firm F's costs, which could allow it to reap higher profits on the product market. Firm D finds it profitable to increase its permit holding as long as the resulting increment in the product price exceeds the increment in its average costs.[5] Although not needed for such behavior to be profitable, the outcome may be that all, or part, of some fringe firms' production capacity are excluded from the market. Therefore, this type of behavior by the dominant firm has been labeled *exclusionary manipulation* of permit markets.

Let E denote firm D's "exclusionary value" of additional permit holdings, assumed to be independent of firm D's current permit holdings. Given this, firm D's value of additional permit holdings equals MAC^D *plus* E, and it maximizes its overall profits by selling $Q – q^{EM}$ permits (the quantity at which the sum MAC^D *plus* E equals MR). That is, firm D now withholds $q^{EM} – q^*$ permits from the market, which yields a permit price equal to P^{EM}. Obviously, aggregate abatement-cost savings of emissions trading under exclusionary manipulation by a firm that holds a monopolist position on the permit market, *afgc*, are smaller than the savings attained

[5] Misiolek and Elder (1989) state that the rise in the product price is larger (i) the easier firm D can influence the permit price through its net purchase of permits, (ii) the more sensitive firm F's output is to changes in the permit price, (iii) the less elastic is the market demand for the final product, and (iv) the less elastic is firm F's supply with respect to the product price.

under cost-minimizing manipulation.[6] Moreover, the behavior of firm D prevents otherwise "low-cost" units from being supplied on the product market and/or implies a higher product price, *i.e.*, it may induce a potentially large additional distortion on the product market.[7] Whether this additional distortion outweighs the abatement-cost savings attained—whereby allowing firms to trade permits would reduce overall efficiency—depends crucially on the initial allocation of permits. The closer the initial allocation is to the cost-effective one, the smaller are the potential abatement-cost savings of permit trading and the more likely is it that exclusionary manipulation renders permit trading to reduce overall efficiency.

In contrast to the case of cost-minimizing manipulation, the government cannot eliminate the incentives for firm D to conduct exclusionary manipulation solely by the means of the initial allocation of permits.

3. THE TRADING SITUATION IN CARBON PERMIT SYSTEMS

A TP system requires a number of institutional arrangements that seldom are dealt with explicitly in theoretical work. The discussion below focuses only on a sub-set of these; (i) the length of the compliance period (*i.e.*, the period over which an emission objective is defined for a given set of firms), (ii) the point in time when firms have to show compliance (*i.e.*, when each firm has to surrender permits to the regulator in an amount that covers its actual emissions during the compliance period[8]), (iii) the consequences for firms that turn out not to be in compliance, and (iv) the trading rules. Other institutional arrangements, such as monitoring of emissions and enforcement of law-abiding behavior are presumed to be viable.

The length of the compliance period in a domestic carbon TP system is not likely to exceed the length of each compliance period of the international climate treaty already in place or expected to enter into force (*e.g.*, five years as in the Kyoto Protocol). In contrast, governments seem to opt for much shorter compliance periods in their domestic TP systems. For instance, in the Danish carbon permit system and in the proposals for carbon TP systems in Norway, Sweden and the UK, the length is one year; see *e.g.*, NOU (2000), SOU (2000) and UK Department of Environment (2000).

Firms can only be expected to be in compliance as long as this is less costly than the alternative. There are several ways in which the regulator can make the cost of non-compliance high. For instance, it may levy a penalty fee on firms that end up being in non-compliance or reduce the number of permits non-complying firms have at their disposal in a sub-sequent compliance period,

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[6] Since incentives for exclusionary manipulation work to increase the dominant firm's permit holding, they may, if not too strong, actually increase abatement-cost savings attained on a monopsonized permit market.

[7] Additional distortions are likely to arise also on other markets. For instance, an increased product price will raise the consumer-price level in the economy, which would lead to additional distortions on "pre-distorted" input markets where the supply depends positively on the real net reward, Browning (1994). In the literature on the so-called double dividend of environmental taxes this phenomena has been labeled the tax-interaction effect.

[8] In real TP systems, firms may be allowed to bank and possibly borrow (up to some limit) permits to/from the next commitment period. Then, a firm is not allowed to emit more than its permit holdings *plus* borrowing *minus* banking. Moreover, firms may have an opportunity to trade on futures markets, *i.e.*, trade permits valid for the next commitment period. None of these aspects are dealt with here.

or a combination thereof. Here, we focus on the case where there only is a penalty fee. Obviously, such a penalty fee implies that firms would not buy permits at prices over the level of fee.

In the literature of exclusionary manipulation, of which this study is a continuation, it has been assumed that firms only trade permits at the beginning of the compliance period. For instance, in Brown-Kruse *et al.* and Godby (forthcoming) the institutional landscape is such that firms first could trade emission permits on a DA market and then, after the closure of the permit market, they had to report to a "clearing-house" the number of units they wanted to produce and supply to the market. All units produced were sold simultaneously at the market-clearing price. The assumption of sequential markets may reflect the timing of input decisions and production decisions, but need not be valid for permit markets. In existing emission permit markets (*e.g.*, the Danish carbon permit system and the SO_2 allowance market in the US) as well as in many proposed carbon permit systems, each firm is obliged to surrender permits to the regulator at the end of the compliance period in an amount that at least covers the emissions it has generated during this period (the calendar-year). This implies *i.a.* that firms can produce (emit) and enter the product market and await better information about their valuations of permits before they have to decide upon their final permit holdings. Moreover, firms may be allowed to trade permits also during a so-called grace period, as on the SO_2 allowance market in the US (EPA, 2002). That is, firms only have to show compliance at some point in time after the compliance period. Hence, firms may trade emission permits before, during and after engaging in transactions on the product market.

Trade with permits is here taken to be governed by DA rules. This is by no means an awkward assumption. The DA institution is the prime candidate for developed tradable carbon permits systems; see *e.g.*, Sandor *et al.* (1994) and Bohm (1999). Moreover, wholesale trade with electricity in several countries is organized as DA markets, *e.g.*, the Scandinavian countries, Nordpool (2002). Thus, at least in the context of carbon TP system covering only electricity producers both the permit market and the product market may be governed by DA rules.

Given the high stakes in carbon permit trading amongst electricity producers, firms would have strong incentives to gather information about marginal production and abatement costs of their rivals before engaging in such trade. Since (a) the performance of different power-production technologies is well and commonly known, (b) power producers are competing (as buyers) on the same fuel markets, and (c) firms may acquire information by recruiting personnel from their rivals, such gathering is likely to be rather successful. In effect, electricity producers can be expected to have quite accurate information about each other's marginal production and abatement costs.

To summarize, the discussion above regarding carbon permits trading among electricity producers suggests:

(a) a compliance period of the length of one year,

(b) that firms may trade carbon permits not only during this compliance period but also during a so-called grace period of substantially length, say, three months,

(c) that firms may end up in non-compliance, in which case they have to pay a penalty fee,

(d) that both the permit market and the electricity market are governed by DA rules, and

(e) that information asymmetries regarding firms' costs are rather small.

An experimental design that parallels these institutional and informational conditions is outlined in the next section.

4. EXPERIMENTAL DESIGN

4.1 Experimental Procedures and Environment

The design of the experiment presented here draws heavily on the ones developed in Brown-Kruse *et al.* and Godby (forthcoming).[9] In particular, it uses the parameter set up and market structure that was used in the monopoly sessions in the Godby study. However, several potentially important design changes have been made to create laboratory markets that parallel the institutional and information conditions outlined above. Still other changes have been made to arrive at a design that better corresponds to, at least, the present author's beliefs—or prejudices—about what constitutes a functional experimental design.

One change of the latter category concerns the use of an explicit context. The standard procedure in experimental economics has been to create laboratory markets free of an explicit context. The ambition behind this seems to have been to avoid having subjects' behavior influenced (in ways that add noise to or bias the outcome) by knowledge about the context. However, as pointed out by *i.a.* Lowenstein (1999), also the absence of an explicit context may affect subjects' behavior. For instance, subjects may have difficulties grasping and solving abstract decision problems. Moreover, subjects may create their own contexts that may or may not be "productive." See also Hertwig and Ortmann (2001) and the responses to their "target" article, and Bohm (forthcoming) for discussions on this topic. In order to avoid a situation where subjects would not be able to perform their tasks properly because they lack experience of dealing with abstract decision problems, subjects were here given an explicit context, namely the one that has spurred the research question. Moreover, subjects were here exposed to pecuniary incentives stronger than those commonly used in laboratory market experiments, which implies a higher costs for a subject to let other considerations than the objective of maximizing his/her firm's profits influencing his/her decisions.

The laboratory markets comprise six electricity producers and four retailers of electricity.[10] All subjects act as traders on the permit market. On the (spot) market for electricity, subjects representing producers (retailers) act only as sellers (buyers). One producer (firm D) dominates the electricity market in that it can produce up to 10 electricity units while each one of the five fringe-producers has a production capacity of two units. In the absence of "abatement" activities (fuel switching) the production of one unit of electricity (GWh) generates one unit of CO_2 emissions (kton). The aggregate emission cap equals ten emission units. All permits are initially allotted *gratis* to firm D. Given the induced production costs, abatement costs and the demand for electricity, the permit allocation is such that firm D has incentives to conduct exclusionary

[9] Brown-Kruse *et al*. and Godby (forthcoming) use almost identical designs. The main differences are that in the former (latter) the number of fringe firms were 10 (five) and suppliers/demanders of permits could only sell/buy permits (act as traders). The two studies use the same aggregate production capacity, costs and demand schedules.

[10] In Brown-Kruse *et al.* and Godby (forthcoming) the demand for the final product was simulated. However, since here also the final product (electricity) is traded on a DA market, subjects with induced values of electricity—representing retailers of electricity—constitute the market demand for electricity. Retailers are here presumed to re-sell electricity bought to end-users at pre-contracted prices (equal to end-users' marginal value of electricity). Alternatively, firms here labelled retailers may be thought of as large end-users that substitute away from electricity at certain price levels and whose production levels are fixed.

manipulation of the permit market. No retailer of electricity has incentives to unilaterally withhold demand units from the market.

Subjects were recruited amongst students in Economics at the intermediary level at Stockholm University. Each subject participated in one session only. One day in advance of the session, subjects who were to represent producers (retailers) received instructions common to all producers (retailers).[11] These instructions (available in Appendix B) included information about:

(i) the climate change policy issue and tradable permit systems,

(ii) the market structure, expected production and abatement costs as well as the expected demand for electricity, and the competitive outcome calculated on basis of this information,

(iii) that the cost/value information could be updated but that only small information asymmetries were to be expected,

(iv) the trading rules,

(v) the show-up fee, and

(vi) a statement that they could earn considerable amounts of money by trading electricity and carbon emission permits.

At the outset of the session, before engaging in trade, subjects participated in the training program included in the Multi-Unit-Double-Auction (MUDA) program package (Plott, 1991). Thereafter, each subject received private information about which firm he/she would represent, that firm's updated production costs/values of electricity (see Table B1 in Appendix B) and his/her payoff factor.[12] No information was given about other firms' updating. Expected and actual production costs (values) of electricity were such that the "expectation error" regarding the competitive price level was close to zero. For individual producers (retailers) the expectation error ranged from zero to seven (19) percent in price terms.[13]

Each subject was paid a fraction of the profits he/she was able to negotiate on the behalf of his/her firm. Since both the market power outcomes and the competitive outcome imply rather unequal divisions of trade gains, individual pay-off factors were used.[14] At the beginning of a session, each subject was given a fixed payment of SEK 90 (over and above a show up fee of SEK 100 ≈ US$ 10 at the time the experiment was conducted). Any net-losses at the end of the session would be deducted from this fixed payment up to a maximum deduction of SEK 90. This was done in order to give subjects incentives to continue to maximize their firms' gains also in

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[11] At this point in time subjects did not know which firm they were to represent. Moreover, during the session they would be anonymous to each other. Therefore, the risk of collusive behavior was deemed low.

[12] To avoid that firm D (the firm crucial for the test of market power effects) would be represented by subjects having problems to implement their strategies because of insufficient skills in using MUDA, subjects representing this firm were randomly selected among those "producer subjects" that best seemed to assimilate the MUDA training.

[13] In Brown-Kruse *et al*. and Godby (forthcoming) very strong information asymmetries were induced. Subjects representing the dominant firm were informed about all firms' costs while subjects representing fringe firms only knew their own costs.

[14] For fringe firms 1–5, the pay off factors were 1.0, 5.0, 5.0, 5.0, and 2.0 SEK/1000 SEK in firm's profit respectively. For firm D it was 0.05. For all retailers it amounted to 0.1. These pay off factors are 5–28 (three) times higher than those used in earlier studies for the fringe firms (firm D).

case they would experience large losses in early trading periods. Thus, although subjects could not loose money by participating in the experiment they could loose money by engaging in trade transactions. Subjects' experimental earnings turned out to range from SEK 0 to 1000 (net of the show-up fee and income taxes).

When producing (selling) electricity producer-subjects had to decide what fuel to use, coal or biomass, *i.e.*, whether or not they should emit carbon.[15] To be in compliance, a subject had to possess, at the end of the grace period, one emission permit for each electricity unit he/she had produced using coal. A subject found to be in non-compliance had to pay a penalty fee for each overshooting emission unit. The penalty fee was set to SEK 250 thousand per emission unit, to be compared with a competitive (exclusionary manipulation) permit price equal to SEK 105 (185) thousand. (See **Table 1**, below.)

The electricity market and the permit market opened at the same point in time. The former held open for ten minutes (the length of the compliance period) and the latter was open during 13 minutes, yielding a grace period of three minutes. When both markets had closed, subjects were given two minutes to calculate their earnings and prepare for a subsequent trading period. No changes in the parameter setting were made between trading periods and each subject represented one and the same firm throughout the session he/she participated in.[16] Each session comprised six trading periods. However, the first period was used solely for training purposes and the outcome of this period is not reported below. Three sessions were conducted. So, this experiment produced three independent observations, each consisting of a series of five trading periods.

4.2 Benchmarks

When firms end up in non-compliance or "over-compliance" the measure of efficiency often used when evaluating laboratory market outcomes—*i.e.*, (Σfirm's realized profits)/(Σfirm's profit) under perfect competition—will, in general, be misleading. The reasons are two. First, the event of aggregate emissions exceeding (falling below) the target level implies a social cost (revenue—a negative cost).[17] If this were not the case, there would be no need to regulate carbon emissions in the first place. Second, penalties collected from non-complying firms allow the government to increase its spending or lower some distortionary tax, of which both options generate a positive social value. Here, an efficiency index is used that accommodates these consequences. The index is calculated as (Σfirm's realized profits)/(Σfirm's profit under perfect competition) *plus* (the social value of additional governmental spending due to Σpenalty *minus* the social value of overshooting emission units)/(Σfirm's profit under perfect competition), where overshooting units equal actual aggregate emissions *minus* the target level. The social marginal value of carbon

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[15] Combustion of both coal and biomass release carbon to the atmosphere. However, the current view is that biomass during its "growing phase" assimilates carbon to an extent such that the net-effect of biomass combustion is zero (IPCC, 1996).

[16] In Brown-Kruse *et al*. and Godby (forthcoming) subjects representing fringe producers switched firms with each other every fifth/third period without knowing this.

[17] Given the emission levels in other sectors, this cost may reflect a government's will to comply with an international climate treaty. In case there exists an international market for carbon emissions quotas to which only the government has access, the government's opportunity costs of additional emission quota holdings equal the international quota unit price.

Table 1. Benchmark Cases

Prices and Quantities (coal-based production within parenthesis) (SEK thousand, permit units and GWh)

	Permit holdings		Electricity production			Permit	Electricity
	Fringe	D-firm	Fringe	D-firm	Total	price	price
• PERMIT TRADING							
(1) competitive markets	3-4	6-7	5-6 (3-4)	9-10 (6-7)	15 (10)	105-110	120-125
(2) exclusionary manipulation	1	9	4 (1)	8 (8)	12 (9)	180	185
(3) competitive permit market, manipulated power market[1]							
i)	3	7	6 (3)	7 (7)	13 (10)	125-145	165
ii)	3	7	5 (3)	7 (7)	14 (10)	120-125	145
• NO PERMIT TRADING							
(4) competitive power market	0	10	3 (0)	10 (10)	13 (10)	–	150-165
(5) manipulated power market	0	10	3 (0)	9 (9)	12 (9)	–	150-185

Trade Surplus and Efficiency (SEK thousand and percent)

	Producers'	(D's)	Retailers' surplus	Total	Social gains[2]	Efficiency %[3]
• PERMIT TRADING						
(1) competitive markets	1299	(1220)	2100	3399	3399	100
(2) exclusionary manipulation	1744	(1540)	1320	3064	3169	93
(3) competitive permit market, manipulated power market[1]						
i)	1659	(1485)	1560	3219	3219	95
ii)	1554	(1435)	1820	3374	3374	99
• NO PERMIT TRADING						
(4) competitive power market	1449-1644	(1350-1500)	1560-1755	3204	3204	94
(5) manipulated pwr market	1314-1734	(1215-1530)	1320-1740	3054	3159	93

1. Two predictions are possible; see Godby (1997) for details. The outcomes presented under benchmark (3) presume (a) that the permit price equals the upper bound of the interval stated and (b) that the fringe does not produce and sell a zero-profit coal-based electricity unit. If not (b), D's production would be one coal-based unit lower and so would its permit holding, which yield a profit that is SEK 5 thousand lower.
2. Social gains = Total Surplus + ∑ penalty – 105 x (∑emissions – cap).
3. Efficiency of (j) = [Social gains of (j) / Social gains of (1)] x 100; j = 1, 2, 3, 4 and 5.

emissions is taken to be constant and equal to the fully competitive permit price, and the social value of increasing governmental spending with one SEK is taken to be constant and equal one SEK. These values are chosen not because they would be representative for any real economy, but since they, for the purpose of this study, constitute rather conservative values.[18]

The outcome is evaluated against a set of benchmarks, namely the cases of (1) competitive markets, (2) exclusionary manipulation and (3) a competitive permit market and a product market manipulated by firm D. In these benchmarks, market manipulation is equivalent to quantity withholding. To indicate the size of the potential gains from trading in these laboratory markets, two other benchmarks are also presented: (4) no emissions trading and a competitive product market and (5) no emissions trading and a manipulated product market. In benchmark cases (2) and (5) firm D holds one permit in excess of the amount required for being in

[18] A positive marginal deadweight loss of fiscal taxes would imply a higher social value of revenues from penalties for non-compliance, and, hence, would tend to increase the efficiency of such outcomes. A higher social value of emission reductions would tend to increase (decrease) the efficiency of outcomes where actual aggregate emissions fall short of (exceed) the emission target.

compliance. This implies that aggregate emissions in these cases fall short of the aggregate emission target by one unit. All benchmarks are presented in Table 1.[19]

As shown in Table 1 the outcomes in the benchmark cases are rather close to each other, especially in terms of production and efficiency. Two notes can be made of this fact. First, despite the extreme initial allocation of permits the chosen parameter set-up implies rather small potential gains from emissions trading—compare case (5) with (3) or case (4) with (1). Second, firm D's production level does not vary much across the three market power cases—(2), (3i) and (3ii). Moreover, (3ii) coincides with (1) with respect to permit holdings and D's and F's production, which implies that case (3ii) is rather close to the competitive outcome also in terms of efficiency. Thus, to discriminate between benchmarks (1) and (3ii) we have to study also the price outcome.

5. RESULTS

The experimental outcome is summarized in terms of prices and quantities in **Table 2** below. As mentioned above, the outcome in each session is an independent observation (consisting of a series of five trading periods). We may look at these observations in various ways, *e.g.*, giving the outcome in each period equal weight or focusing only on a subset of the periods within each session.

The mean of session averages (calculated over all periods), stated in the second last row in Table 2, reveals that in terms of quantities the outcome on the permit market is within the range of the competitive outcome—benchmark case (1). So is also the fringe's electricity production. Nevertheless, total supply of electricity is substantially below the competitive level. In fact, it lies between benchmarks (2) and (3i). This is due to the low production by firm D. Moreover, firm D's permit holdings and coal use indicate an outcome closer to case (1), (3i) and (3ii) than to case (2). In terms of closing prices the outcome resembles case (3ii) rather than (2) or (3i). In other words, the theory of exclusionary manipulation—benchmark (2)—does not do well in structuring data. Rather, the outcome seems to indicate that the permit market was fairly competitive but that firm D manipulated the electricity market by reducing the quantities it supplied.

In all sessions, production levels tend to increase and prices tend to decrease over periods (see Table 2 and **Figures 2–4**). A possible explanation for this is that subjects were "learning the game" during initial trading periods and became more sophisticated and informed traders in later periods. If so, it would be more relevant to focus on the outcome in later periods. The mean of session averages (calculated over periods 4–5) is presented in the last row in Table 2. As compared to the mean calculated on all periods, the mean outcome in <u>the last two periods</u> has moved closer to the case of competitive markets. Still, it is difficult to discriminate between benchmark cases (1), (3i) and (3ii). While permit holdings and closing prices on both markets are closer to (1) than to (3i) or (3ii), firm D's production, total production and mean prices are closer to (3i) or (3ii) than to (1). Looking at other dimensions of the outcome gives no clear guidance.

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[19] For derivations of these benchmarks the reader is referred to Godby (1997). The derivations therein do not take into account the social value of overshooting emission units. Therefore, SEK 105 thousand have been added to the social gains in benchmarks (2) and (5) in Table 1.

Table 2. Outcome: Prices and Quantities (coal-based production within parenthesis)

	Final permit holdings		Electricity production			Permit price		Electricity price	
	Fringe	D-firm	Fringe	D-firm	Total	Mean	End	Mean	End
Session 1									
Period 1	6	3[1]	7 (5)	3 (3)	10 (8)	210	150	211	200
Period 2	5	4[1]	5 (3)	8 (4)	13 (7)	208	170	207	150
Period 3	6	4	6 (3)	6 (3)	12 (6)	178	150	194	170
Period 4	4	6	6 (4)	10 (6)	16 (10)	146	100	173	140
Period 5	4	6	6 (3)	9 (5)	15 (8)	125	108	151	120
Average	**5**	**4.6**[1]	**6 (3.6)**	**7.2 (4.2)**	**13.2 (7.8)**	**173**	**136**	**187**	**156**
Session 2									
Period 1	2	6[1]	5 (3)	6 (5)	11 (8)	188	152	185	186
Period 2	1	8[1]	6 (3)	7 (7)	13 (10)	82	10	179	199
Period 3	1	9	4 (3)	10 (9)	14 (12)	135	135	166	161
Period 4	3	7	6 (5)	7 (7)	13 (12)	92	60	161	145
Period 5	4	6	7 (6)	8 (7)	15 (13)	92	100	150	100
Average	**2.2**	**7.2**[1]	**5.6 (4)**	**7.6 (7)**	**13.2 (11)**	**118**	**91**	**168**	**158**
Session 3									
Period 1	1	6[1]	5 (1)	3 (3)	8 (4)	171	130	177	150
Period 2	1	8[1]	5 (1)	6 (6)	11 (7)	140	120	144	150
Period 3	2	7[1]	6 (2)	7 (7)	13 (9)	137	130	138	145
Period 4	4	6	7 (5)	6 (6)	13 (11)	142	130	141	140
Period 5	3	7	5 (3)	7 (7)	12 (10)	130	100	144	135
Average	**2.2**	**6.8**[1]	**5.6 (2.4)**	**5.8 (5.8)**	**11.4 (8.2)**	**144**	**122**	**149**	**144**
Mean of session averages									
Periods 1-5	**3.1**	**6.2**[1]	**5.7 (3.3)**	**6.9 (5.7)**	**12.6 (9)**	**145**	**116**	**168**	**153**
Periods 4-5	**3.7**	**6.3**	**6.2 (4.3)**	**7.8 (6.3)**	**14 (10.7)**	**121**	**100**	**153**	**130**

1. Permit(s) held by retailer(s).

To sum up: The outcome seems to reject the case of exclusionary manipulation but it is not clear what benchmark is in favor, (i) fully competitive markets, or (ii) a competitive permit market and a manipulated electricity market.

Given that in later periods closing prices and trade volumes on both markets are quite close to competitive levels, the interpretation is that trade would be highly efficient. **Table 3** indicates that this indeed is the case. Session averages for the last two trading periods in Session 1, 2 and 3 equal 99%, 94.5% and 93.5%, respectively—all above the rates in benchmark case (5). So, allowing firms to engage in emissions trading seems to increase efficiency. However, although the mean rate (96%) is higher than in benchmarks (2) and (3i) it is substantially below the ones in (3ii) and (1).

Individual firms were in non-compliance in eight of the fifteen periods (*cf*. Table A1 in Appendix A). However, in several of these periods firm D or fringe firms held more permits than their emission levels required, and in some periods also retailers of electricity held permits at the end of the grace period. Therefore, aggregate emissions exceeded the target level of ten emission units only in four periods. In eight periods aggregate emissions fell below the target level. The efficiency implications of this are shown in the second and third columns in Table 3.

Compared to the case of perfectly competitive markets the dominant producer (firm D) gained more while fringe firms as well as electricity retailers gained less, especially in early periods (*cf.* Table 3 and Table A2 in Appendix A). In fact, the fringe firms' aggregate profits (= Producers' surplus *minus* firm D's surplus in Table 3) were negative in most periods, something that may have contributed to reduce the efficiency. A similar outcome was observed in Brown-Kruse *et al.*

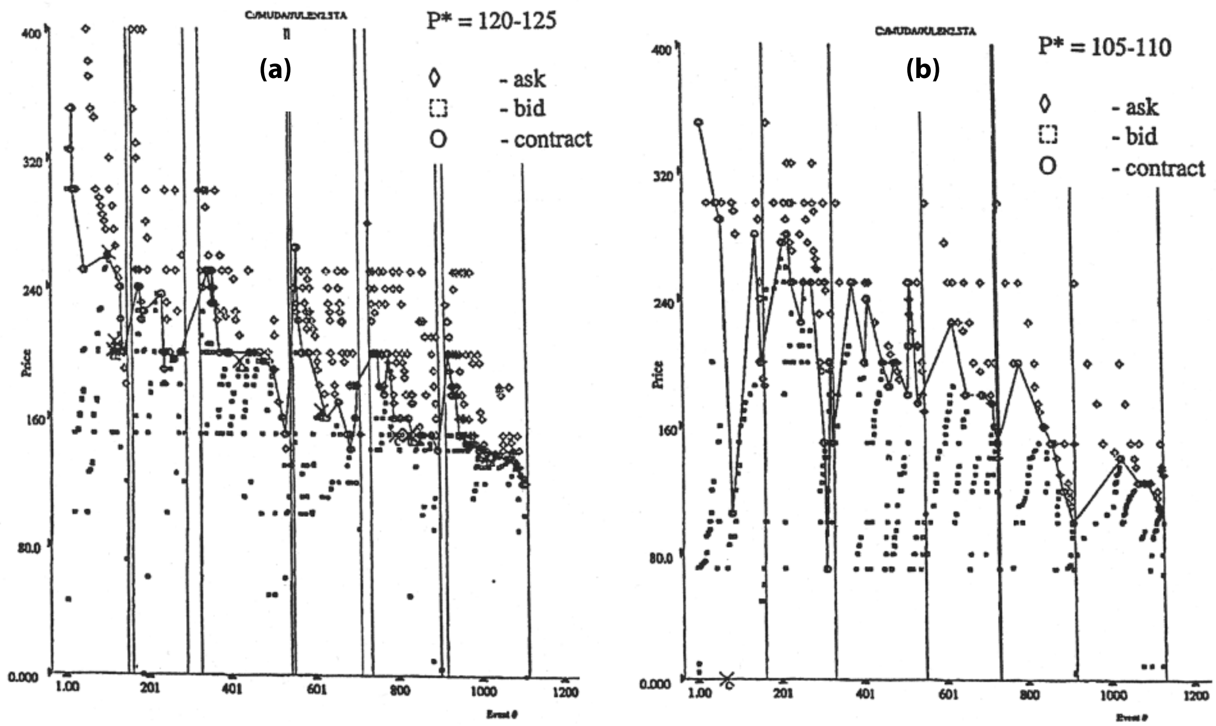

Figure 2. (a) Electricity Market Periods 0–5, **(b)** Permit Market Periods 0–5; Session 1 (first period for training purpose)[20]

and Godby (forthcoming), respectively. Thus, the hypothesis that the outcome of negative profits in earlier tests was due to the fact that firms/subjects there had to decide upon their permit holdings before knowing the product price seems to be rejected. Another, still living, hypothesis may be that some feature of the common parameter set up used in these experiments drives the finding of low fringe earnings. For instance, the costs and valuations are such that, for a wide range of price levels, several fringe producers had no opportunities to engage in profitable (net) trade. Lack of opportunities to undertake reasonable activities (profitable trades) in laboratory market experiments has been shown to provoke "irrational" behavior, see Lei *et al.* (2001).

5.1 Comparison with Outcomes in Earlier Studies

The outcome of the experiment presented here differs from the outcome observed in earlier exclusionary-manipulation experiments in several ways. For instance, here, total production seems to be higher while prices seem to be lower. As has been emphasized above, the design of the experiment presented here differs in several potentially important aspects from the design of earlier tests of exclusionary manipulation, whereby we cannot without further experiments

[20] The figures show asks, bids and transactions made on the market indicated. The vertical bars indicate the end of each trading period. (On the electricity market diagrams there are two vertical bars for each trading period, the first indicates the closure of the electricity market and the second the closure of the permit market.) The first period in the diagrams is the training period in which subjects did not face pecuniary incentives. The reader should not pay attention to the outcome in this period.

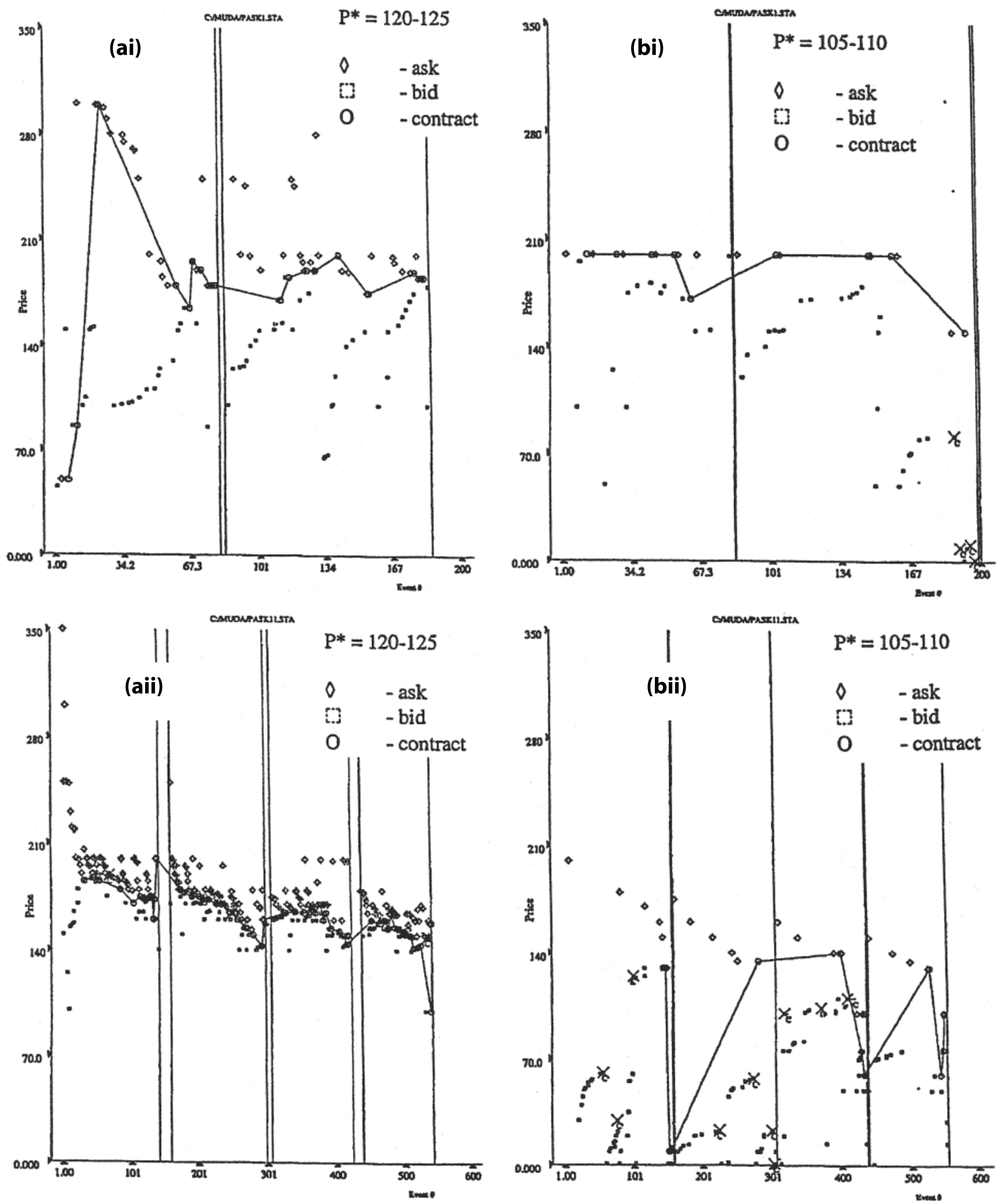

Figure 3. (ai) Electricity Market Periods 0–1, **(bi)** Permit Market Periods 0–1; Session 2 (first period for training purpose). **(aii)** Electricity Market Periods 2–5, **(bii)** Permit Market Periods 2–5; Session 2.[21]

[21] Due to network problems in Session 2, the MUDA program had to be restarted between periods 1 and 2. This explains why there are two figures for each market in Session 2.

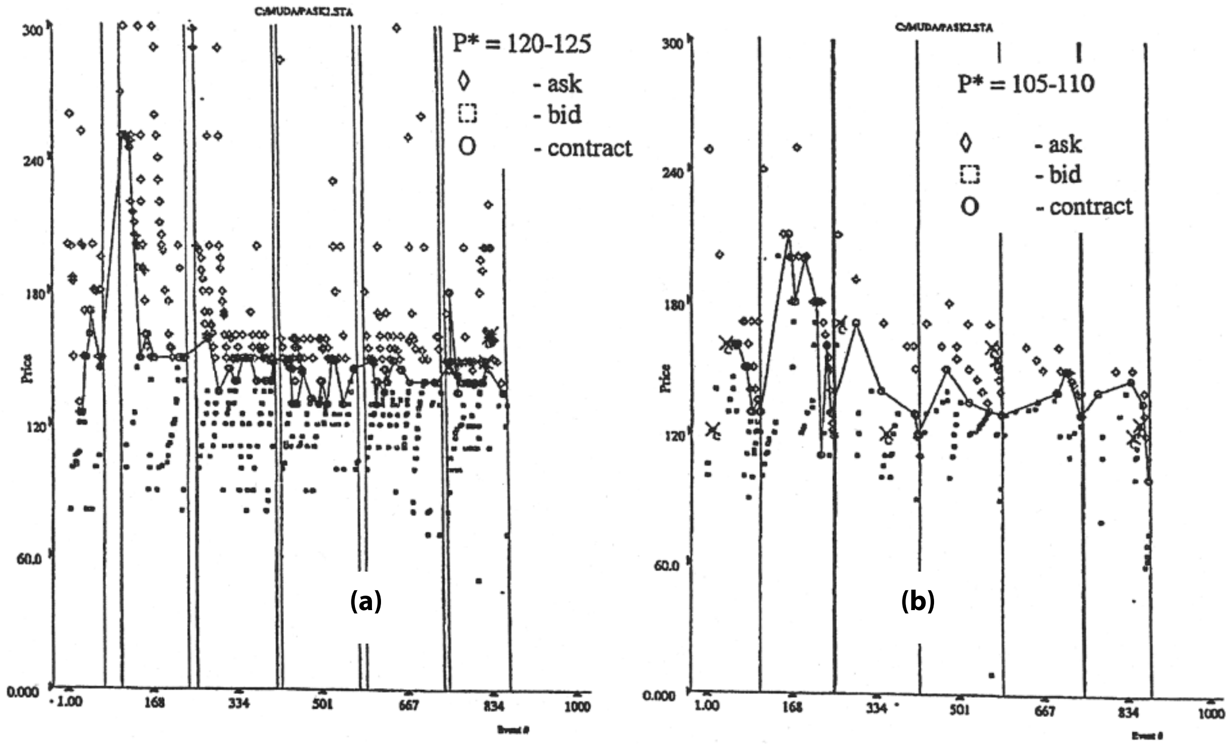

Figure 4. (a) Electricity Market Periods 0–5, **(b)** Permit Market Periods 0–5; Session 3 (first period for training purpose).

Table 3. Outcome: Trade Surplus and Efficiency (SEK thousand and percent)

	Sum penalty	Social value of over-shooting em's	Producers'	(D's)	Retailers'	Total Surplus	Social gains	Efficiency %
Session 1								
Period 1	0	–210	2251	(2245)	758	3009	3219	95
Period 2	0	–315	2189	(2400)	735	2924	3239	95
Period 3	0	–420	1674	(1870)	1215	2889	3309	97
Period 4	250	0	1859	(1965)	1265	3124	3374	99
Period 5	0	–210	1437	(1500)	1707	3144	3354	99
Average	**50**	**–231**	**1938**	**(2052)**	**1136**	**3074**	**3299**	**97**
Session 2								
Period 1	250	210	1743	(1740)	916	2659	3119	92
Period 2	500	0	1148	(1170)	1371	2519	3019	89
Period 3	500	210	1440	(1579)	1525	2965	3255	96
Period 4	500	210	1267	(1273)	1612	2879	3169	93
Period 5	750	315	1126	(1123)	1703	2829	3264	96
Average	**500**	**105**	**1345**	**(1377)**	**1425**	**2770**	**3165**	**93**
Session 3								
Period 1	0	–630	1278	(1124)	516	1794	2424	71
Period 2	0	–315	937	(1005)	1637	2574	2889	85
Period 3	0	–105	1111	(1232)	1783	2894	2999	88
Period 4	250	105	1207	(1275)	1872	3079	3224	95
Period 5	0	0	1319	(1250)	1815	3134	3134	92
Average	**50**	**–189**	**1172**	**(1177)**	**1525**	**2697**	**2934**	**86**
Mean of session averages								
Periods 1-5	**200**	**–105**	**1485**	**(1535)**	**1362**	**2847**	**3133**	**92**
Periods 4-5	**292**	**210**	**1369**	**(1398)**	**1662**	**3032**	**3253**	**96**

isolate the effect(s) any individual design change has had on the outcome. Still, since these changes were made to create an experimental situation that more closely than earlier tests parallels important features of carbon permit trade amongst electricity producers or to arrive at an experimental situation that subjects easily could understand and relate to, it is clearly of interest whether or not observed differences are statistically significant. Here, the mean of the (three independent) session averages produced by each one of Brown-Kruse *et al.*, Godby (forthcoming) and this study is compared by means of the Permutation test, see Siegel and Castellan (1988). The results of all tests made and the outcomes in the earlier tests are summarized in Appendix C.

A comparison based on the outcome in the last five periods tells us that (a) average and closing permit prices, (b) the closing electricity price, and (c) the dominant firm's hoarding of permits, observed here are statistically lower (at the 5 or the 10 percent level) than the levels observed in Brown-Kruse *et al*. Given this, it is surprisingly that differences in permit holdings and production volume are not statistically secured.

However, this comparison, based on the outcome in all periods in this experiment and the outcome in the last five periods in earlier tests in which each session consisted of at least 10 periods, may lead to biased conclusions since subjects in these earlier studies then have had (five) more periods to learn from and adjust there behavior in. Therefore, also the outcome in the last two periods in each study was subjected to a significance test. Now, several additional differences are deemed significant. Among these are that closing prices on the electricity market observed here is lower than the (uniform) price level observed in Brown-Kruse *et al.* and Godby (forthcoming). Moreover, total electricity production and efficiency are higher than the levels observed in the studies just mentioned.

So, barring the possibility that observed differences are due to the use of different subject pools, the conclusion is that the changes made in the experimental design have produced an outcome (in later trading periods) that is closer to the efficient one. In other words, the outcome of exclusionary manipulation and low efficiency observed in earlier tests is not robust to the changes made in the experimental design (a) that increase the parallelism between the laboratory and the field or (b) that aim at facilitating subjects understanding of the decision problem.

6. CONCLUDING REMARKS

The case of exclusionary manipulation of permit markets has here been tested in an experiment designed to parallel some important institutional and information conditions of real carbon permit markets, in particular those of carbon permit systems for electricity producers. Thus, firms (subjects) could here trade permits during not only the compliance period but also during a so-called grace period. Both permits and electricity were traded on so-called double-auction markets. The outcome seems to reject the case of exclusionary manipulation. But, even if the outcome on the permit market is close to the efficient outcome, the dominant firm withheld supply from the electricity market. So, although both markets were governed by double auction rules, a market power outcome seems to have emerged on the electricity market. The reasons for this asymmetry cannot be determined without further tests. However, given the parameter set-up used, the market power outcome obtained is close to the efficient (competitive) outcome. In later trading periods, permit holdings, closing prices on the permit and the electricity markets as well as total electricity production are close to the efficient levels. Consequently, high efficiency is observed.

These results stand in contrast to the findings of earlier tests and indicate that the outcomes of low efficiency observed in earlier tests are not robust to the changes made here in the design to increase the parallelism between the laboratory and the field or improve subjects understanding of the decision problem. Similarities were also found. For instance, subjects representing small producers often experienced negative gains (implying low subject's earnings), something that may have lead to a reduction in efficiency. A potential cause for this outcome lies in the parameter set up used (here and in earlier tests), which is such that for a wide range of prices several of the small producers have no opportunities to engage in profitable net-trade on any of the markets. Such lack of meaningful tasks may have provoked some subjects to make excessive speculations or simply to trade anyway. This calls for future tests with experimental designs that allow all subjects to have active roles as net-traders.

Although attempts were made to construct laboratory markets that quite closely parallel the likely case of real carbon permit trade among electricity producers, some overly simplified assumptions have been made. For instance, firms were not allowed to bank or borrow carbon permits to/from the next compliance period. This is another important route for future research to go.

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APPENDIX A. EXPERIMENTAL OUTCOME

Table A1. Production and Producers' Permit Holdings (the training period not included)

	Session 1 Period					**Session 2 Period**					**Session 3 Period**					**Benchmark**	
Firm #	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**(1)**	**(2)**
F_1																	
Coal	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0
Bio	2	2	2	2	1	1	1	0	1	1	2	2	2	2	2	2	2
Permits	0	0	0	0	0	1	1	0	1	1	0	0	0	0	0	0	0
Penalties	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F_2																	
Coal	2	1	1	2	0	0	0	0	1	1	0	0	0	0	0	0	0
Bio	0	0	1	0	2	1	2	1	0	0	1	0	0	0	0	0	1
Permits	2	1	1	2	0	0	0	0	1	1	0	0	0	0	0	0	0
Penalties	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F_3																	
Coal	1	1	0	0	0	0	0	0	1	0	1	0	0	2	2	0	0
Bio	0	0	0	0	0	0	0	0	0	0	1	2	2	0	0	0	0
Permits	1	1	0	1	0	0	0	0	1	0	1	0	0	2	2	0	0
Penalties	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
F_4																	
Coal	1	0	1	2	1	2	2	2	2	2	0	0	1	1	0	1-2	0
Bio	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Permits	2	2	4	1	2	1	0	0	0	0	0	0	1	1	0	1-2	0
Penalties	0	0	0	1	0	1	2	2	2	2	0	0	0	0	0	0	0
F_5																	
Coal	1	1	1	0	2	0	0	1	0	2	0	1	1	2	1	2	1
Bio	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Permits	1	1	1	0	2	0	0	1	0	2	0	1	1	1	1	2	1
Penalties	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
D																	
Coal	3	4	3	6	5	5	7	9	7	7	3	6	7	6	7	6-7	8
Bio	0	4	3	4	4	1	0	1	0	1	0	0	0	0	0	3-4	0
Permits	3	4	4	6	6	6	8	9	7	6	6	8	7	6	7	6-7	9
Penalties	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
Sum																	
Coal	**8**	**7**	**6**	**10**	**8**	**8**	**10**	**12**	**12**	**13**	**4**	**7**	**9**	**11**	**10**	**10**	**9**
Bio	**2**	**6**	**6**	**6**	**7**	**3**	**3**	**2**	**1**	**2**	**4**	**4**	**4**	**2**	**2**	**5-6**	**3**
Total prod.	**10**	**13**	**12**	**16**	**15**	**11**	**13**	**14**	**13**	**15**	**8**	**11**	**13**	**13**	**12**	**15**	**12**
Permits held by producers	**9**	**9**	**10**	**10**	**10**	**8**	**9**	**10**	**10**	**10**	**7**	**9**	**9**	**10**	**10**	**10**	**10**
Penalties	**0**	**0**	**0**	**1**	**0**	**1**	**2**	**2**	**2**	**3**	**0**	**0**	**0**	**1**	**0**	**0**	**0**

Table A2. Producers' and Retailers' Profits, SEK 1000 (the training period not included)

Firm #	Trading Period					Benchmark	
	1	2	3	4	5	(1)*	(2)
Session 1							
F_1	359	289	119	149	54	49	169
F_2	-35	-125	140	105	-25	0	35
F_3	21	0	0	-160	0	0	0
F_4	-305	-325	-490	-100	-130	5	0
F_5	-34	-50	35	-100	38	25	0
D	**2245**	**2400**	**1870**	**1965**	**1500**	**1220**	**1540**
R_1	245	330	210	105	395	540	360
R_2	210	130	195	305	355	520	340
R_3	-20	195	365	390	467	520	320
R_4	323	80	445	465	490	520	300
ΣF_i	**6**	**-211**	**-196**	**-106**	**-63**	**79**	**204**
ΣR_j	**758**	**735**	**1215**	**1265**	**1707**	**2100**	**1320**
Total ($=\Sigma F_i + \Sigma R_j + D$)	**3009**	**2924**	**2889**	**3124**	**3144**	**3399**	**3064**
Session 2							
F_1	38	137	0	144	99	49	169
F_2	40	29	10	56	48	0	35
F_3	0	0	0	0	0	0	0
F_4	-75	-188	-184	-210	-224	5	0
F_5	0	0	35	0	80	25	0
D	**1740**	**1170**	**1579**	**1273**	**1123**	**1220**	**1540**
R_1	360	356	392	415	452	540	360
R_2	350	345	430	430	440	520	340
R_3	126	345	371	387	415	520	320
R_4	80	325	332	380	396	520	300
ΣF_i	**3**	**-22**	**-139**	**-6**	**3**	**79**	**204**
ΣR_j	**916**	**1371**	**1525**	**1612**	**1703**	**2100**	**1320**
Total ($=\Sigma F_i + \Sigma R_j + D$)	**2659**	**2519**	**2965**	**2879**	**2829**	**3399**	**3064**
Session 3							
F_1	194	84	60	84	87	49	169
F_2	100	0	0	0	0	0	35
F_3	-140	-176	-194	-41	-48	0	0
F_4	0	0	3	4	0	5	0
F_5	0	24	10	-115	30	25	0
D	**1124**	**1005**	**1232**	**1275**	**1250**	**1220**	**1540**
R_1	350	495	525	500	495	540	360
R_2	-19	441	458	466	467	520	340
R_3	295	460	350	465	400	520	320
R_4	-110	241	450	441	453	520	300
ΣF_i	**154**	**-68**	**-121**	**-68**	**69**	**79**	**204**
ΣR_j	**516**	**1637**	**1783**	**1872**	**1815**	**2100**	**1320**
Total ($=\Sigma F_i + \Sigma R_j + D$)	**1794**	**2574**	**2894**	**3079**	**3134**	**3399**	**3064**

* These calculations assume (a) that the competitive product (permit) price equals the upper (lower) boundary of the interval possible equilibrium prices, 120-125 (105-110).

APPENDIX B. Induced Costs/Valuations and Instructions

BI. Costs/Valuation

Table B1. Production Costs and Retailers' Valuation (expected values within parenthesis)*

Firm	Unit	Production cost Coal	Production cost Bio	Extra cost of Bio (Bio – Coal)	Firm	Unit	Contract Price (Marginal Valuation)
F_1	1	45 (43)	81 (77)	36 (34)	R_1	1	405 (482)
	2	45 (43)	120 (114)	75 (71)		2	265 (315)
F_2	1	35 (33)	150 (142)	115 (109)		3	245 (292)
	2	40 (38)	195 (185)	155 (147)		4	105 (125)
F_3	1	25 (24)	220 (210)	195 (186)		5	85 (101)
	2	30 (29)	265 (252)	235 (223)	R_2	1	385 (458)
F_4	1	15 (14)	290 (275)	275 (261)		2	285 (339)
	2	20 (19)	335 (318)	315 (299)		3	225 (268)
F_5	1	5 (5)	360 (342)	355 (337)		4	125 (149)
	2	10 (10)	405 (385)	395 (375)		5	65 (77)
D	1	15 (14)	60 (57)	45 (43)	R_3	1	365 (434)
	2	15 (14)	80 (76)	65 (62)		2	305 (363)
	3	15 (14)	100 (95)	85 (81)		3	205 (244)
	4	15 (14)	120 (114)	105 (100)		4	145 (173)
	5	15 (14)	140 (133)	125 (119)		5	45 (54)
	6	15 (14)	160 (152)	145 (138)	R_4	1	345 (411)
	7	15 (14)	180 (171)	165 (157)		2	325 (387)
	8	15 (14)	200 (190)	185 (176)		3	185 (220)
	9	15 (14)	220 (209)	205 (195)		4	165 (196)
	10	15 (14)	240 (240)	225 (214)		5	25 (30)

* Actual values correspond to those used in Godby (forthcoming).

BII. Instructions

Subjects received written information on two occasions. One day before the experiment, subjects that would represent electricity producers (retailers) were given instructions common for all producer (retailer) subjects. At the beginning of the experiment, each subject received private information about which firm he/she was assigned to, that firm's actual costs (values) and his/her payoff factor. Below are reproduced the information common to all producer-subjects, and for illustration, the private information given to the subject representing the dominant firm, referred to as Firm 6 in these instructions. Text in bold within brackets are explanatory notes to the reader of the paper.

Common instructions to electricity producers [translated from Swedish]:

> *You will participate in an experiment about climate change policy. More precisely, the experiment aims at shedding some light on the possibilities to reduce a country's costs of reducing the emissions of so-called greenhouse gases, by the means of tradable emission permits. During the experiment, you will act as a decision-maker on markets for emission permits and electricity and have the opportunity to earn money. Read the following text carefully. You earnings will depend on the decisions you make during the experiment.*

B1. Background

Greenhouse gases allow solar radiation to be transmitted inward but restrict heat radiation from being transmitted outward from the earth. Carbon dioxide (CO_2)—the single most important greenhouse gas—is added to the atmosphere mainly through combustion of fossil fuels. Current global emission levels run the risk of leading to a rapid and substantial growth in the average global temperature. Such a climate change may give rise to changes in wind and sea currents, higher sea level and desertifications. The conditions for localization of settlements, farming and industries would thereby be affected, resulting in possible large population movements.

The international community has taken this threat seriously. In December 1997, representatives of the world's countries gathered in Kyoto, Japan, to negotiate about a reduction of the emissions of greenhouse gases. This meeting resulted in a proposal to a climate treaty comprising a set of quantitative emission targets for the industrialized countries, the so-called Kyoto Protocol. In November 2000 the countries gathered again in Haag, the Netherlands, to specify parts of the Protocol. These negotiations did not solve all problems and it is for the moment unclear whether the Protocol will be ratified by a sufficient number of countries to enter into force. However, although no binding international climate treaty yet exists, a number of countries have established unilateral targets for their emissions of CO_2.

Several countries have already decided to implement tradable permit systems (TP) to reduce their emissions of CO_2 or consider doing so, among them Denmark and Sweden. The European Union discusses the introduction of international trade with CO_2 emissions. At the national level, TP systems work in the following way. First, the government sets a limit for the aggregate emissions a group of firms are allowed to make. Then, the government allocates tradable emission permits to the firms, according to some formula. Different firms may be allocated different number of permits. Since the permits are transferable, the firms can trade permits with each other. Firms with high costs to reduce their emissions can buy permits from firms with lower cost. On a competitive permit market an equilibrium price will be established so that the firms' marginal abatement costs are equalized, *i.e.*, the cost-effective allocation of abatements is reached.

Here, we will focus on CO_2 emissions from fossil fuel based electricity production. For simplicity, it is assumed that all electricity production is of this type, a condition that more or less reflects the situation in Denmark.

<u>The objective of the experiment is to investigate how trade with CO_2 permits amongst firms on the electricity market evolves when it is conducted on an exchange.</u>

B2. The Experiment

On the electricity market simulated in the experiment there are <u>six producers/seller</u> and <u>four retailers/buyers</u> of electricity. <u>You will play the role of a producer.</u> On x-day you will be informed about which one of these six producers you will represent. Your payment consists of a fixed <u>participation fee that amounts to SEK 100</u> and an <u>incentive payment, the size of which depends on the profits you are able to negotiate on the behalf on your company. The size of the incentive payment cannot be stated in advance, but it is expected to amount to SEK 200-300 per person.</u>

B2.1 Market structure and expected costs

The electricity producers differ from each other in terms of *i.a.* production capacity and costs. Five firms have a production capacity of 2 electricity units while one firm can produce up to 10 units. (With an electricity-unit is meant 10 GWh, a common trade unit on electricity markets.) All six producers use fossil fuels (coal) to produce electricity, which give rise to CO_2 emissions. For the time being there exists no economically justified technology to separate and deposit carbon. Thus, to reduce the emissions of CO_2 the use of fossil fuels has to be reduced. By using biomass a firm can produce electricity without generating CO_2-emissions.[22] However, it is more costly to produce electricity with biomass than with coal. The size of this extra cost varies typically among producers (see below). (The extra cost depends largely on what type of production facilities the firms have but also on the localization and age of the facilities.)

One (1) kton CO_2 is the amount emitted when an electricity unit is generated using coal. The government is assumed to have decided that the six producers' aggregate CO_2 emissions is not allowed to exceed 10 kton per year and has chosen to distribute emission permits to these firms, according to some formula. A permit allows the holder to emit 1 kton CO_2 during the period (one year) the permit is valid. Tradable permit systems requires that firms' CO_2 emissions can be monitored, *e.g.*, by keeping track of their use of coal (purchase *plus* changes in inventory).

The government distributes 10 permits each year. Since these permits are transferable the firms can trade permits with each other. Thus, a firm can sell permits (if it received any in the initial allocation), buy, re-sell or re-buy permits. No firm is allowed to emit more than its permit holding (*ex post* trade) allows.

A firm that during a year has used coal to produce electricity must, at the end of that year, possess at least one permit for each electricity unit generated in that way. A firm's valuation of using a permit in the production equals the cost saving the firm is doing by using coal instead of biomass, to be compared with the alternative cost of the permit.

Firms that during a year emit more CO_2 than they hold permits for have to pay a penalty.

Penalty = SEK 250000 per overshooting kton CO_2

Electricity producers have good knowledge about each other's production technologies. In the field, it can therefore be assumed that they have quite accurate information about each other's costs of producing electricity with different fuels, albeit not perfect information. Estimates of the six firm marginal costs are shown in Table 1. **[The content of Table 1 is stated within parenthesis in columns 3-5 in Table B1 above.]**

On the electricity market there are four retailers who buy electricity from producers and resell it to households and firms. Here, the producers are assumed to be able to estimate the retailers' demand for electricity with quite good precision. The retailers' expected demand is presented in Table 2. **[The content of Table 2 is stated in the last column in Table B1 above.]**

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[22] Also combustion of biomass releases CO_2. But since CO_2 of the same amount are bounded in the trees when these are growing, the combustion of biomass is taken to not add to the concentration of CO_2 in the atmosphere. For simplicity, we say here that combustion of biomass does not generate any CO_2 emissions. We also abstract from the opportunity to reduce emissions by increasing the energy effectiveness (produced GWh electricity/GWh fuel). The reason being that for a given set of production units this potential is small.

Whoever wants to may trade emission permits, so also retailers of electricity, which thus can speculate in permits.

Given the total number of permits (10), the cost and demand data in Table 1 and Table 2 and given an assumption that the markets for electricity and permits are competitive, expected market supply of and demand for electricity would be as indicated by Figure A1. The figure shows that under these assumptions the expected electricity price would amount to approximately SEK 125 thousand. Similarly, it can be shown that the expected permit price on a perfectly competitive market would amount to approximately SEK 105 thousand. The volume of the permit trade and the distribution of trade surpluses depend on how the government distributes the permits initially amongst the electricity producers. When the experiment begins you will be informed about this initial allocation.

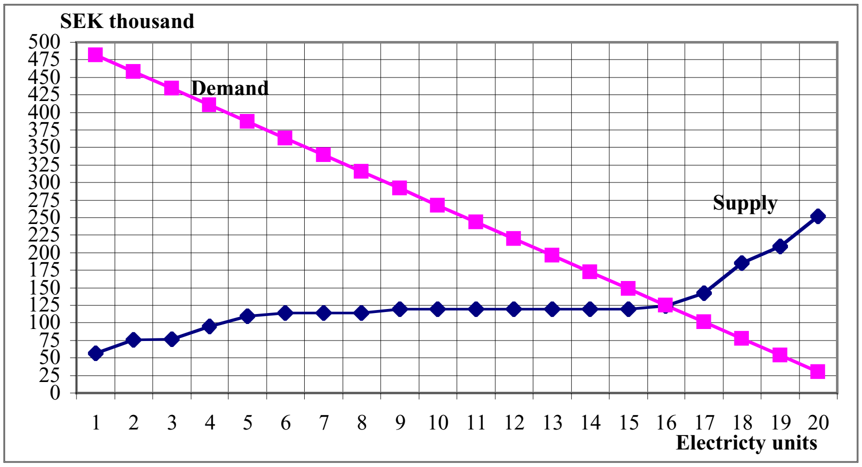

Figure A1. Supply of and Demand for electricity, given a competitive permit market

Observe! Even if, as we have said here, electricity producers have strong incentives to gather information about each others' production costs and the market demand for electricity, it has to be emphasized that no one can be 100 % certain that available information is correct or if it will guide market behavior. Although this uncertainty can be assumed to be small, given the incentives for information gathering, it may affect the conditions for trade. This uncertainty implies that the true production costs and demand for electricity may deviate from the data you have been given in Table 1, Table 2 and Figure A1. Before the trade begins you will receive private information about your firm's actual production costs.

B2.2 Market organization

Thus, as an electricity producer you trade on two markets. On the permit market you act as a trader, *i.e.*, you can both buy and sell permits. Also retailers of electricity may act as traders on the permit market. On the electricity market you can only sell electricity units and retailers can only buy electricity units. The permit market is open during the whole period the permits are valid (one year) *plus* some period thereafter. Thus, it is possible that a producer may purchase a sufficient number of permits before it produces electricity (and possibly causes CO_2 emissions) or chose to first produce electricity and thereafter—if need arise—via trade make sure that it holds a sufficient large number of permits.

Purchase and sales of permits and electricity

Trade with permits as well as trade with electricity is conducted on electronic exchanges. Purchase and sales of permits concern one permit at the time.

(1) You may submit one (or several) bid or ask on the market or remain passive in this regard.

(2) You may buy a permit either by accepting the standing ask (the lowest price anyone has announced willingness to sell to) or—if you have submitted a bid with the highest price anyone has announced willingness to buy to—if someone accepts your bid. The number of permits you can buy is limited only by your firm's budget. Thus, you may not buy permits on credit.

(3) You may sell a permit either if a buyer accepts your ask or by you accepting the standing bid on the market. You cannot sell more permits than your firm holds in its inventory.

Also on the electricity market one unit is traded at the time. You may sell electricity in two ways: (1) by accepting the standing bid or (2) if someone accepts the standing ask of yours. You can only sell electricity units that your firm has produced.

Bookkeeping of permit and electricity transactions

During the experiment you have to record all your transactions on a bookkeeping form. Attached you find such a bookkeeping form. Below are presented examples that illustrate how you should record your transactions.

Each time you buy a permit you shall record the price on the bookkeeping form. Ex.: If you buy your first permit for SEK *x* thousand, you shall write *x* on the first row in the Buy price column under Trade with permits. If you in your second transaction buy an additional permit for SEK *y* thousand you shall note that price on the second row in the Buying price column. When the market has closed you sum your expenditures on permits and write the obtained sum (x+y) on the row Total Permits in the Buy price column.

Each time you sell a permit you shall record the price on the bookkeeping form. Ex.: If you in your third transaction sell a permit to the price SEK *a* thousand, you shall write *a* on the third row in the Sale price column under Trade with permits. If you sell a second permit for SEK *b* thousand you shall write *b* on the fourth row in the Sale price column. Note that even if these transactions were your first and second sales of permits, they were your third and fourth transactions and shall therefore be recorded at row three and four, respectively. When the market has closed, you sum your revenues from permit sales and write the amount obtained on the row Total in the Sale price column. The large number of rows is to allow you to easy record any re-buy and re-sell permits.

Also the sales of electricity you make you have to record on the book keeping form. You also have to note your fuel choice. Ex.: If you first produce and sell one unit electricity, produced using biomass, for SEK *m* thousand you shall write this price on the first row in the price column below Sales of electricity and ”bio” in the Fuel choice column. If you produce a second unit with coal and sell this unit for SEK *n* thousand, you should write *n* on the second row in the price column and ”coal” in the Fuel choice column. When the market has closed you shall sum your revenues and write the figure obtained on the row marked Total.

Firm 2’s expected costs of producing electricity are shown in Table 1. For Firm 2 the production costs in the last mentioned example would be SEK 142 thousand for the first electricity unit produced using biomass and SEK 38 thousand for the second unit which was generated using coal. Thus, total production cost amounts to SEK 180 thousand. Possible costs for purchase of permits would be added.

Calculation of the firm’s profits

If Firm 2 would behave as in the examples given above, it profits would be calculated as follows:

Revenues from electricity sales	+*m*+*n*
Cost of electricity production	-180
Cost of purchase of permits	-(*x*+*y*)
Revenues from permit sales	+*a*+*b*
	= Profits SEK thousand

<u>On x-day at the outset of the experiment you will be informed about which of the six producers you will represent, the initial allocation of permits and how large share of your firm’s profits that is yours to keep.</u>

Bookkeeping form for electricity producers

Name: Period:
Firm number. Date:

Trade with permits			Sales of electricity		
Transaction	Sale price	Buy price	Unit	Sale price	Fuel choice
1	________	________	1	________	________
2	________	________	2	________	________
3	________	________	3	________	________
4	________	________	4	________	________
5	________	________	5	________	________
6	________	________	6	________	________
7	________	________	7	________	________
8	________	________	8	________	________
9	________	________	9	________	________
10	________	________	10	________	________
11	________	________			
12	________	________	Total	________	
13	________	________			
14	________	________			
15	________	________			

If you need more space continue on the backside.

Total Permits ________ ________

Calculation of your firm's period profits

Revenues from electricity sales	–	Costs of electricity production	–	Costs for purchase of permits	+	Revenues from sales of permits	–	Penalties (SEK 250 thousand per kton)	=	Profits
	–		–		+		–		=	

Private information to firm #6

You represent firm #6. Your assignment is to maximize this firm's—and thereby your own—gain. Your firm may produce up to10 electricity units. Your firm's initial production capacity, **initial inventory**, on market 2 (the electricity market) is thus equal to 10. Your firm's actual marginal costs are presented in Table 3. **[The content of Table 3 equals the parts of Table B1 that are valid for Firm D and not within parenthesis.]** You have already received information about expected marginal costs of other producers and the expected demand for electricity (Table 1, Table 2 and Figure A1). This information is also enclosed here. **[Tables 1 and 2, corresponds to the figures within parenthesis in Table B1.]**

The government has decided to give all 10 emission permits to your firm (Firm #6.) Your initial inventory on market 1 (the permit market) is therefore equal to 10. This unequal allocation of permits is explained by the fact that Firm #6 earlier where the single producer on the market and that the government has chose to allocate permits according to historical emission levels.

Your firm disposes an amount (= your firm's **cash on hand**) that initially equals SEK **500 thousand**. You may use the money to buy permits of other firms. You are not allowed to buy permits on credit. Your expenditures on permits can thus not exceed the amount of money that you dispose. If you sell an electricity unit or a permit your cash on hand will increase by the sales price. Your cash on hand will automatically be updated every time you engage in transactions on the markets for electricity and permits.

You cannot sell more electricity units than your firm can produce. Moreover, you may not sell more permits than your firm holds (= your firms inventory on market 1 which is automatically updated when you trade permits).

Your payment consists of a fixed part (SEK 100 which will be given to you after the experiment) and an incentive payment. The incentive payment is calculated according to the following formula: SEK **90** plus 0.05 × the sum of the gains/losses (in SEK 1000) you have negotiated for your company in each trading period. For each SEK 1000 in aggregate profit you have negotiated for your firm your incentive payment increases with SEK 0.05. If you would negotiate an aggregate loss for your firm your payment decreases with SEK 0.05 for every SEK 1000 in loss. Your incentive payment cannot be smaller than SEK 0.

APPENDIX C. Summary of Earlier Experiments and Significance Tests

Table C1. Outcome in Earlier Experiments: Session Averages

Prices and Quantities (coal based production within parenthesis)

	Permit holdings		Production				Permit price		Product price
	Fringe	D-firm	Fringe	D-firm	Total	(Em's)	Mean	End	Uniform price
Last five periods									
Brown-Kruse *et al*.									
Session 1	3.4	6.6	6.8	5.2	12	(8.6)	157	154	185
Session 2	1.6	8.4	6	6	12	(7.6)	243	236	185
Session 3	1.6	8.4	5.4	7.6	13	(9.2)	216	216	165
Mean	**2.2**	**7.8**	**6.1**	**6.3**	**12.3**	**(8.5)**	**205**	**202**	**178**
Godby (forthcoming)									
Session 1	4.8	5.2	5.4	6	11.4	(9.6)	108	105	201
Session 2	2.4	7.6	6.2	4.6	10.8	(7)	280	241	209
Session 3	4.2	5.8	5.4	8.2	13.6	(10)	118	121	153
Mean	**3.8**	**6.2**	**5.7**	**6.3**	**11.9**	**(8.9)**	**169**	**156**	**188**
Last two periods									
Brown-Kruse *et al*.									
Session 1	3	7	6.5	5.5	12	(8.5)	152	150	185
Session 2	1	9	5.5	6.5	12	(7.5)	245	245	185
Session 3	1	9	4.5	8	12.5	(9)	184	184	175
Mean	**1.7**	**8.3**	**5.5**	**6.7**	**12.2**	**(8.3)**	**194**	**193**	**182**
Godby (forthcoming)									
Session 1	5.5	4.5	6	6	12	(10)	102	102	185
Session 2	2.5	7.5	6	4.5	10.5	(7)	286	234	215
Session 3	4	6	5	9	14	(10)	118	118	145
Mean	**4**	**6**	**5.7**	**6.5**	**12.2**	**(9)**	**169**	**151**	**182**

Trade Surplus and Efficiency in the Last five periods (efficiency, not adjusted for emissions off target, within parenthesis)

	Social value of "overshooting" emission units[1]	Total Surplus[2]	Social gains[3]	Efficiency, %
Brown-Kruse *et al*.				
Session 1	147	2967	3114	91.6 (87.3)
Session 2	252	2692	2944	86.6 (79.2)
Session 3	84	3025	3109	91.5 (89)
Mean	**161**	**2895**	**3056**	**90 (85)**
Godby (forthcoming)				
Session 1	42	3029	3071	90.4 (89.1)
Session 2	315	2634	2949	86.8 (77.5)
Session 3	0	3151	3151	92.7 (92.7)
Mean	**119**	**2938**	**3057**	**90 (86)**

Source: Godby (1997): Final permit holdings, Figure 6 in Ch. 4 and Figure 6 in Ch. 5; Production, Figure 7 in Ch. 4 and Figure 7 in Ch. 5; Permit prices, Tables 5 and 10 in Appendix B; Product price, Figure 8 in Ch. 4 and Figure 8 in Ch.5.

1. That is: –105 x (actual emissions – 10).
2. Obtained by multiplying Total surplus in Benchmark case (1) with (unadjusted) efficiency rates given in Figure 10 in Ch. 4 and Figure 10 in Ch. 5 in Godby (1997).
3. Social gains = Total Surplus – 105 x (actual emissions –10).

Table C2. Permutation Tests of Differences in Mean Outcome

Explanatory notes: A ~ indicates that the null hypothesis of $\mu_x = \mu_y$ cannot be rejected and a > (<) that the null hypothesis is rejected in favor of the alternative hypothesis $\mu_x > \mu_y$ ($\mu_x < \mu_y$). BKEG indicates Brown-Kruse, Elliott and Godby (1995), Godby stands for Godby (forthcoming), and Carlén indicates this study. If not otherwise stated the 10%-level is used. A * indicates significance at the 5%-level.

Last five periods			
Permit price			
Mean	BKEG ~ Godby	BKEG > Carlén	Godby ~ Carlén
Marginal	BKEG ~ Godby	BKEG > Carlén*	Godby ~ Carlén
Electricity price			
Mean	BKEG ~ Godby	BKEG ~ Carlén	Godby ~ Carlén
Marginal	BKEG ~ Godby	BKEG > Carlén*	Godby ~ Carlén
Permit holding by the dominant firm	BKEG > Godby	BKEG ~ Carlén*	Godby ~ Carlén
Hoarding of permits by the dominant firm			
by frequency	BKEG > Godby	BKEG > Carlén*	Godby ~ Carlén
by # of permits	BKEG ~ Godby	BKEG > Carlén	Godby ~ Carlén
Production levels			
the dominant firm	BKEG ~ Godby	BKEG ~ Carlén	Godby ~ Carlén
fringe firms	BKEG ~ Godby	BKEG ~ Carlén	Godby ~ Carlén
Total	BKEG ~ Godby	BKEG ~ Carlén	Godby ~ Carlén
Efficiency	BKEG ~ Godby	BKEG ~ Carlén	Godby ~ Carlén
Last Two Periods			
Permit price			
Mean	BKEG ~ Godby	BKEG > Carlén*	Godby ~ Carlén
Marginal	BKEG ~ Godby	BKEG > Carlén*	Godby ~ Carlén
Electricity price			
Mean	BKEG ~ Godby	BKEG > Carlén*	Godby ~ Carlén
Marginal	BKEG ~ Godby	BKEG > Carlén*	Godby > Carlén*
Permit holding by the dominant firm	BKEG > Godby	BKEG > Carlén*	Godby ~ Carlén
Hoarding of permits by the dominant firm			
by frequency	BKEG > Godby*	BKEG > Carlén*	Godby ~ Carlén
by # of permits	BKEG ~ Godby	BKEG > Carlén*	Godby ~ Carlén
Production levels			
the dominant firm	BKEG ~ Godby	BKEG ~ Carlén	Godby ~ Carlén
fringe firms	BKEG ~ Godby	BKEG ~ Carlén	Godby < Carlén*
Total	BKEG ~ Godby	BKEG < Carlén*	Godby < Carlén
Efficiency[1]	BKEG ~ Godby	BKEG < Carlén*	Godby < Carlén*

1. In Godby (1997), from which data is collected, mean efficiency for BKEG and Godby is only reported for the last five periods. Therefore, we here use these means adjusted for the value of overshooting emission units.

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