et10_06.wpd
1998-07-27

Experimental Tests of Market Power in Emission Trading Markets

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July 1998

Abstract

Laboratory investigations of emissions trading markets in competitive environments generally confirm that emissions trading raises market efficiency and that simple markets converge rapidly to the competitive equilibrium. Little work, however, has been done to investigate emissions trading markets where one or more participants in have market power. Theory suggests that exploitation of market power could reduce or eliminate the gains from emission trading, particularly when the firms trading emission permits also compete in downstream markets. Experimental research into market power suggests that some trading institutions, especially the double auction, may be better than others in preventing market power from emerging. The most recent work has shown that even the double-auction may be susceptible to the influence of market power in emission permit markets, especially when participanats compete both in permit and downstream markets. These market power effects have been shown to reduce the performance of some laboratory markets, in some cases leading to outcomes inferior those from command-and-control regulation.

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1. Introduction

The welfare benefits of emission trading programs – the potential to minimize the aggregate cost of pollution control – seem clear. Several lines of research, however, cast doubt on the extent to which the benefits from emission trading can be realized. One line is represented by Oates (1995), who argues that introducing a market in emission rights might induce net welfare losses to the economy at large because exacerbation of pre-existing distortions in labour or capital markets could offset the gains in the emission markets alone. The second line of research addresses the effects of market power in the emerging markets for emission rights or in their related markets (Hahn 1984, Tietenberg 1985, Misiolek and Elder 1989). Market power may be of concern for at least two reasons. First, attempts to exploit market power will reduce the efficiency of emission permit markets, leading to lower gains than projected using theories of competitive markets.– It is even possible that emissions trading could lead to net welfare losses if imperfections in emission permit markets are exploited to gain monopoly power in related product markets. Second, the exploitation of market power may alter the distribution of gains from emissions trading in a way that would reduce political support for it. This research underlies some objections made to emission trading during policy debates.[1]

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[1] American markets have usually been large enough to avoid such concerns and therefore little attention has been given to market power. See for example the SO_2 market proposals (US Environmental Protection Agency, 1991). Even in Canada where markets could be much smaller and therefore more susceptible to such manipulation, however, little concern for market power has been shown in various policy documents (for example, see Nichols 1992, where even though in Ontario alone one firm, Ontario Hydro, accounts for over 45% of emissions, no mention is made of the potential for market power). If mentioned at all, it is usually assumed existing anti-competitive practices legislation will deter uncompetitive activity (see Recommendation #38, in

Discussions of emissions trading generally fail to consider the market institutions under which trade will be conducted. Theorists have identified a great variety of these institutions. In a posted-offer market, sellers each announce a single price/quantity combination and then buyers choose the quantity to purchase from each seller. In a posted-bid market the roles are reversed. In an English auction multiple buyers continuously offer rising bids for a single item until no further bids are forthcoming, at which point the single seller accepts the highest bid. In a Dutch Auction the single seller makes continuously falling offers (asks) until one of the multiple buyers accepts. In a double auction buyers and sellers continuously make rising bids or falling asks until one side of the market accepts the outstanding bid or ask. In a call market supply and demand schedules are determined from price/quantity combinations submitted by buyers or sellers. When the market is called, successful buyers and sellers are matched and the price determined by some rule. Many other variants are possible.

It is by now well established that market institutions can have a marked effect on the market's efficiency. A theory's predictions may be validated under one institution but not in another. Thus before deciding whether to implement an emissions trading system on the basis of theory alone, it is useful to investigate its performance in a more realistic, yet simple and controlled environment such as provided by laboratory experiments. Laboratory methods in economics have proven successful both in testing basic economic theories and in *testbedding*

Introduction, Summary of Recommendations, NRTEE 1993, p. 4, where no design responses are recommended to deter market power in the presence of existing legislation.). Greenhouse gas trading as envisaged under Kyoto Protocol to the United Nations Framework Convention on Climate Change could also be influenced by market power as the former Soviet Union is expected to be the principal seller in the proposed market (see IAT Draft Report on the Economic Effects of Global Climate Change Policies, June 1997, p. 20)..

specific policy proposals to determine those that appear best-suited for a particular application. Flaws in proposed designs can be uncovered and corrected before implementation in the field, where such adjustments may require much greater expense (see reviews by Plott 1989 and Holt 1995).

In this paper we review the considerable body of experimental literature which bears on the issue of market power in emissions trading markets. We begin with a brief introduction to laboratory methods and then review the results of a number of studies of market power in general. We then briefly review the economic theory of market power in emissions trading markets before finally turning to laboratory studies of market power in the specific context of emissions trading. We will focus on two issues. First, what is known about the effect of trading institutions on the *actual* emergence of market power in those cases where it is *theoretically* possible for market power to emerge? Second, will market power emerge behaviourally in a laboratory environment that captures critical features of an emission trading programme when a single firm dominates the industry? Our goal is to determine if there are known methods of organizing markets and designing trading institutions that will minimize the potential for exploitation of market power in emission trading markets and to provide direction for future research.

2. Laboratory Economics[2]

Over the past thirty years laboratory experimentation has emerged as a substantial and vigorous subdiscipline of economics.. Smith and Williams (1992) provide a non-technical

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[2] Parts of this section have been taken from Muller and Mestelman (1998). More details about conducting laboratory sessions can be found in Davis and Holt (1993) and Friedman and Sunder (1994).

overview of the field. The current state of the discipline is well presented in Kagel and Roth (1995) and Davis and Holt (1993).

Experiments are conducted with human subjects, usually university undergraduates. There are many types of laboratory experiments in economics; here we concentrate on market experiments. Typically about eight to twelve subjects are recruited for each market session. At the beginning of each session, participants are instructed about the rules of the experiment and assigned roles as buyers, sellers or traders. Usually they are told they will be participating in a market for an abstract product in which they are to act either as buyer or seller. The session is divided into decision rounds or periods. In each round, buyers purchase the product in the experimental market and redeem it from the experimenter in return for laboratory money (lab dollars). They are given a schedule indicating value of the each coupon redeemed in the given period. For example the first unit may be redeemed for 100 lab dollars, the second for 50 lab dollars, the third for 45 lab dollars, and so on. The buyer's profit on each unit is the difference between its redemption value and the price actually paid to the seller. Sellers incur a cost to acquire the product and gain revenue by selling it in the experimental market. They are given marginal cost schedules indicating what each unit they sell costs them and compute their profit as the difference between the selling price and the marginal cost of that unit. Trading may be done orally with manual record keeping or it may be mediated by computer programs of varying complexity and sophistication. In most of the experiments reported here, subjects entered bids and offers for units at a computer terminal. At the end of a session, subjects' earnings are converted from lab dollars to local currencies at a previously announced exchange rate and the subjects are paid privately in cash. A typical undergraduate may earn about $30 for a two-hour session, well above the minimum wage.

Trading institutions and the redemption and cost schedules can be manipulated to test various hypotheses or testbed performance of certain institutions. Price and quantity outcomes in laboratory markets can be compared to *a priori* predictions to determine the extent to which market performance conformed to expectations and the success of the traders in capturing gains from trade in the laboratory environment since if economic theories are truly generally applicable, they should also apply in the controlled laboratory environment.

One cardinal principle in experimental economics is to pay subjects sufficiently well to ensure their decisions are motivated by market payoffs. Usually this is interpreted as providing potential remuneration well above the opportunity cost of the subjects' time. This has promoted the use of student subjects, since the opportunity cost of their time is less than that of employed adults, especially senior decision makers. The use of student subjects has been criticized on the grounds that they are unlikely to participate in the market in the same way that participants in field markets would. Fortunately, the experimental evidence shows little effect of subject pool on the outcome of market experiments.(Davis and Holt 1993, 16-17). Moreover, if a particular hypothesis such as the emergence of market power is supported when using relatively unsophisticated student subjects it is reasonable to presume that actual market traders will exploit such opportunities that may arise.

A second cardinal principle in experimental economics is never to deceive the subjects. All the rules of the experiment are announced in advance and followed strictly. The experimenters' interpretation of the data, however, may be different from the subjects'. For example, subjects are not usually told that the units they are trading represent permits to emit pollutants. In this way experimenters hope to avoid biases induced by the nature of the commodity being traded.

3. Market Power in the Laboratory

Laboratory studies have shown that market power is severely constrained by market institutions. For example, in posted-offer markets a single seller is usually able to maintain prices well above competitive levels, while in double auction markets buyers quickly discover the monopolist’s willingness to sell some units at low prices. Consequently, they withhold demand to force price reductions, resulting in outcomes much closer to the competitive level. The effect of market institution on exploitation of market power has been demonstrated in two experimental contexts: pure monopoly or duopoly markets in which market power is created by limiting the number of sellers (or buyers) and dominant firm markets in which it is profitable for some sellers to reduce the number of trades they engage in, thereby driving prices away from competitive levels.

The leading experiments in pure monopoly and duopoly environments were conducted by Smith (1981) and by Smith and Williams (1989). Smith compared the outcomes of double auction, offer auction, and posted-bid markets with a single seller and posted-bid markets with two sellers using common demand and supply parameters. The efficient price (expected under perfect or Bertrand price competition) was $0.80, while the monopoly price (expected when market power is fully exploited) was $1.10. Standard economic theory suggests that the monopoly outcome should occur in single-seller markets, regardless of the trading rules used. Table 1 shows that this was not the case. In a single-seller posted-offer market the monopolist was able to raise prices until they converged to the monopoly price and to maintain them for the rest of the session.[3] In the double auction, offer auction and posted-bid sessions, however, the single seller could only realize a small fraction (12.8% to 30.9%) of the potential increase in prices. Prices in the two-seller posted-bid market, however, approached the single-seller outcomes under the other institutions. Clearly the pricing outcome depends on the type of trading institution used, with the double auction and posted-bid markets showing the most potential for constraining market power.[4]

Smith and Williams (1989) further investigated the sensitivity of market outcomes to the number of sellers by comparing monopoly and duopoly outcomes in double auction markets. Table 1 shows that all of their markets resulted in prices very close to the competitive price. Their work further demonstrates the resistance of double auctions to monopoly pricing. The mean final period market price calculated over five sessions implies that sellers were able to achieve only 6.6% of the potential price increase.[5] Increasing the number of sellers to two resulted in competitive outcomes in the final period.[6]

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[3] Experimental market outcomes often take time (typically up to four periods in market experiments) to converge as subjects become familiar with their task or the environment. No satisfactory theoretic descriptions exist to explain this process. Only the final period is reported to allow for this process, however, the general results presented in Table 1 do not change if one looks at the pricing results over the whole experiment or after some time is allowed for the convergence process to occur.

[4] Holt (1995, p. 381) summarizes a number of experiments that also find that monopolists are successful at keeping prices above the competitive price in the posted-offer environment.

[5] This result is computed by taking the data from the last two rows and last column of Table 1 and weighting the price results by the number of sessions.

[6] Using the data in Table 1, the average price deviation from competitive levels is -0.1% over the three duopoly markets.

A second set of experiments has investigated the emergence of market power in dominant firm markets. Holt, Langan and Villamil (1986) introduced a supply and demand configuration in which, due to their lower production costs, two of five sellers have the potential to realize market power by withholding output from buyers.[7] In effect, this action would shift the supply curve leftward , and result in an equilibrium price greater than the competitive level. Holt *et al.* observe this effect in three of five sessions in which sellers have market power. Over these three sessions, prices converged at about 8% above competitive levels, compared to a 9.6% increase predicted by theory. Davis and Williams (1991) replicate these results and also compare the performance of posted-offer and double auction institutions using the same market design. They replicate the Holt *et al*. finding of supra-competitive prices in all of their double-auction markets (across the double auctions, prices converged to levels approximately 12% higher than the competitive level). The prices in the posted-offer environments consistently converge to significantly higher levels than those found in the double auctions.[8]

Sbriglia and O'Higgins (1996) consider further the type of market power described by Holt *et al.* and Davis and Williams. They modify the Holt *et al.* design to sharpen the cost differences between sellers with and without market power and conduct four double auction and six posted-offer markets to determine if the market power outcomes indicated in the previous experiments are robust to this parameterization change whether the severity of such outcomes is

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[7] These authors also induce buyer market power of the same type in two session; if two of five buyers were to withhold purchases they could reduce the equilibrium market price. In these sessions, one observed competitive results while the other found prices below the competetive outcome.

[8] Davis and Williams also conducted a series of post-offer markets using computerized (non-human) buyers. These sessions are not reported here.

reduced by use of double auctions instead of posted offer markets. They found that the double auction appears to be more resistant to market power than the previous experiments of this sort indicated, with prices closer to the competitive level in three of four sessions. Using econometric analysis, they conclude that all of their double auctions appear to be converging to competitive outcomes.[9] Posted-offer markets, however, continued to exhibit strong market power pricing, comparable in degree to those found in Davis and Williams. Convergence analysis of the data from these markets indicated at least four of the six markets were converging to non-competitive outcomes.

The data presented in Tables 1 and 2 indicate that monopoly and duopoly sellers are usually able to raise prices above competitive levels, but that posted-offer markets regularly result in greater increases than are found in double auction markets. This appears especially true in posted-offer markets with a single seller. Most commentators ascribe the pro-competitive properties of the double auction to the extra power it delivers to the buying side. Thus Holt (1995, p. 398) concludes that "market power that results from capacity constraints or shopping costs can produce supra-competitive prices reliably in posted-offer auctions" and "sellers are sometimes able to exercise market power in double auctions, but the influence of seller market power is much weaker (in the double auction) because of the incentives to offer last-minute price concessions and the more active role that buyers have in this institution." Plott (1989) similarly argues that in the double auction there is a countervailing buyer's market power at work which (1991) attributes to the sequential nature of this trading institution. Since the monopolist cannot

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[9] One session exhibited price levels higher than the competitive levels in all periods, but, by both casual inspection and econometric analysis, prices appear to be converging on the competitive price.

pre-commit to the monopoly price as trading progresses , it lowers its price when gains from trade still exist at the end of a trading period. As these price reductions become public knowledge, in succeeding periods more buyers wait for the price reductions, causing the monopolist's market power to be eroded further, as it may be more profitable for the monopolist to make some sales at competitive prices than no sales at all. This behaviour is discussed further in Godby (1999).

In summary, experimental economic evidence clearly indicates the success with which market power opportunities are exploited depends on the trading rules employed in the market. Posted-price markets seem to allow the greatest opportunity to exploit market power. Double auction markets seem to resist the exercise of market power, whether the opportunity is created by a limited number of sellers in the market, or due to cost and capacity advantages of dominant firms. In general, it seems that market power is most successfully deterred in those institutions that do not allow firms to pre-commit to their price and quantity offerings.[10]

4. Simple Analytics of Market Power in Emission Permit Markets[11]

Experimental tests of market power in emissions trading markets have generally been based on the models of simple manipulation and exclusionary manipulation developed by Hahn (1984) and Misiolek and Elder (1989) respectively. We provide a simple graphical exposition of the two models before reviewing laboratory tests.

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[10] A possible test of the importance of pre-commitment is indicated by Smith's results. His results indicated that posted-offer markets were very susceptible to single *seller* market power pricing, yet posted-bib markets were not. The pre-commitment argument supports this results. As an extension one could compare the performance of these institutions in monopsony settings. If the pre-commitment hypothesis holds, the posted-offer market should outperform the posted-bid market. Such an experiment has not been reported in the literature.

[11] Parts of this section have been taken from Godby (1997).

We will distinguish between command-and-control regulation and emissions trading. There are, of course, many ways to implement command-and-control regulation. In our stylized model, however, we will consider only methods in which a regulator defines a total allowable discharge (a *cap*) for a specified group of firms and divides this target into discharge permits assigning the right to emit a specified quantity of emissions to individual polluters. Command-and-control regulation and market-based regulation will then differ only in whether or not the initial distribution of permits may be reallocated among firms through mutually agreed upon trades. Unless the initial assignment minimizes the system cost of abatement, firms with lower marginal abatement cost will have an incentive to sell their permits to those with higher marginal abatement costs. This will be permitted under emissions trading but not under command-and-control regulation.

When incentives to trade exist, some firms will be net sellers of permits while others will be net buyers. Since the cost-minimizing allocation of permits is independent of the initial distribution, a firm's role as seller or buyer is determined exclusively by this initial distribution. Market power can arise when the initial allocation results in only one or a few net sellers or one or a few net buyers. Note that this can only occur when the initial allocation of permits does not minimize system abatement costs. In the examples that follow, market power may be realized by only one firm, who may be either a monopolist or a monopsonist in the market for emission permits.[12]

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[12] In general, the results are applicable to a number of firms who might act in concert. Theoretically, a small number of firms could each have market power and act strategically and with respect to the other's actions. Such outcomes are not considered here, although, they are described in Sartzetakis (1992 and 1993). His results are comparable to those derived in the more simple environment described here.

4.2. Simple Manipulation (Hahn 1984)

Consider Figure 1, in which a single firm (the monopolist) is a net seller of permits. The vertical axis indicates the price of an permit and the horizontal axis indicates the quantity of permits purchased from monopolist by a group of small price-taking firms. The monopolist faces a derived demand for permits by the small firms indicated by the line DD. It also faces a marginal opportunity cost of permit sales equal to its own marginal abatement cost (given by the line MAC).

The efficient (competitive) solution occurs if the monopolist does not attempt to influence the market price and sells permits at the price at which DD and MAC intersect. In equilibrium, Q_C units are sold at the price P_C. The efficiency gain over the initial command-and-control assignment is given by the area of triangle HKL. For all firms, price equals marginal abatement cost. No additional gains from trade are possible.

If the monopolist recognizes that the price it receives for permits depends on the quantity it sells, it will select the quantity at which its marginal revenue schedule (MR in Figure 1) intersects its marginal abatement cost schedule MAC. The resulting price is P_S (greater than P_C) and the quantity of permits sold is Q_S (less than Q_C). The monopolist sells fewer permits to keep price and profit higher than in the efficient outcome. Relative to the efficient outcome, the monopolist is emitting too much pollution and the small firms are emitting too little. The loss to society, relative to the efficient outcome, is indicated by triangle HGF. Note, however, that relative to the command-and-control outcome, there remains a net welfare gain given by the area LKGF.

Figure 2 describes the simple manipulation outcome in the market if the firm with market power is a monopsonist in the permit market. Note the horizontal axis now describes the number of permits purchased by the monopsonist from the small firms. As before, the derived demand for permits is given by the line DD, however, it is now derived from the abatement cost each permit saves the monopsonist. The supply curve of permits (denoted MAC) is the horizontal summation of the marginal abatement cost curves of the small firms. The efficient equilibrium is at Q_C and price $P_{C,}$ with associated efficiency gain over the command-and-control assignment shown by the area HKL. If it recognizes that MFC reflects its marginal factor cost (associated with the average factor cost schedule MAC) the monopsonist can increase its profit by buying the monopsony output Q_S (where its marginal factor cost, MFC, equals its marginal benefit, DD) at the monopsony price P_S. Note that the both the monopsony price and quantity traded are less than the competitive levels. The monopsony equilibrium represents a welfare improvement of area KLFG relative to the command-and-control allocation and a welfare loss of area FGH relative to the efficient outcome.

4.3. Exclusionary Manipulation (Misiolek and Elder 1989)

Suppose a firm with market power in the permit market competes with the same small firms in the product market (the manufacture of this product creates the emissions whose permits are traded among the large and small firms). It is possible that the market-power firm can increase its profits by hoarding permits. This will force the small firms to abate more of their emissions than they would otherwise. In turn, this will increase the unit production costs for the small firms. Increased unit production costs force the small firms to reduce their quantity supplied at any given price. Given the quantity supplied by the market-power firm and the reduced supply from the small firms, the product market price will rise. Although hoarding behaviour may not maximize the market-power firm's profits from emission trading, total profit could be increased when considering profits from both the emission and product markets. Misiolek and Elder (1989) call this behaviour *exclusionary manipulation*.

Consider Figure 1. If the monopolist competes in the same product market as the small firms, the marginal opportunity cost of selling an permit will reflect not only the foregone abatement cost, but also the foregone opportunity of increasing a rival firm's costs and increasing the price in the product market. The effect of the exclusionary motive on the monopolist is shown by line EE, which is drawn as the vertical sum of the monopolist's marginal abatement cost and foregone exclusionary opportunity costs for each permit sold. The resulting equilibrium is characterized by even fewer permits sold (Q_e) at a higher price (P_e) than in the simple manipulation example. The additional efficiency loss in the emission market is measured by the area JGFI.

If the market-power firm is a monopsonist in the permit market (Figure 2), exclusion serves to raise the marginal gain from purchasing an permit by an amount equal to the marginal increase in profits obtained in the downstream market. The derived demand schedule for permits, DD, shifts upwards. With exclusionary manipulation, small firms may under-utilize or over-utilize abatement activities depending upon the incentive for the monopsonist to hoard permits due to their exclusionary effect in the product market. If permits have little effect on production costs for the small firms (including abatement costs), the incentive to exclude is weak, and the shift of DD is small (shown by line D_1D_1). The resulting equilibrium is shown at quantity Q_{e1} and price P_{e1}. Although small firms are still over-abating, both measures have increased from the simple manipulation outcome to nearer the competitive outcome, increasing the cost-effectiveness of the market. The resulting efficiency loss is also smaller (area HIJ). If the incentive to exclude is stronger, the shift in the derived demand line will be greater, as described by line D_2D_2. Equilibrium now occurs at Q_{e2} and price P_{e2}. Both quantity and price exceed the competitive values. The efficiency loss relative to competitive equilibrium is shown by area HMN. Pollution control costs to society increase as the monopsonist abates too much and the small firms abate too little relative to the competitive outcome. For a sufficiently strong downstream effect, the efficiency loss in the emissions market could exceed the efficiency loss under simple manipulation.

To be effective, exclusionary manipulation can be profitable only if the market-power firm can use permit prices to influence the costs of its rivals in the product market. For this to be true, it must be the case that a significant share of the output in the product market be produced in the geographic region covered by the permit market and that the permit market be susceptible to the simple manipulation of the type described in Hahn (1984). Provided this is the case, the effects of simple and exclusionary manipulation (by role of the market-power firm) on emission market cost-effectiveness relative to the competitive outcome are summarized in Table 3.

The combined effect of emissions trading and market power on economic efficiency depends on whether exclusionary manipulation is possible. The analysis above indicates that in the case of simple manipulation, any emission trading is welfare increasing.[13] In the case of exclusionary manipulation, the motive to exclude could result in increased or decreased emission

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[13] This assumes that the product markets remain relatively unaffected by any possible changes in production by firms in the permit market due to reallocation of their permit endowment and subsequent production decisions. It may be reasonable to assume such an outcome would occur if these product markets were competitive.

market efficiency relative to the case of simple manipulation. Overall efficiency is in question due to the effect of output restrictions in the product market. Once these are considered, Misiolek and Elder (1989) have shown that emission trading could reduce economic welfare relative to the outcome under command-and-control regulation.

5. Laboratory Investigations of Market Power in Emission Trading Markets

Although a considerable body of experimental investigation into emission trading markets exists, not much of it has explicitly addressed the issue of market power. Early research (Hahn 1988, Franciosi, Isaac, Pingry and Reynolds, 1993) focussed on the properties of different methods for auctioning permits. The earliest literature on emissions trading had envisaged the regulator auctioning off the total supply of permits, along the lines of a Treasury Bill auction. Because this plan would generate net revenue for the government and leave existing firms worse off than they would be under command-and-control regulation, many judged it politically infeasible. Hahn and Noll (1982) proposed a revenue neutral auction (RNA) in which existing firms would be *grandfathered* by distributing to them the entire initial stock of permits. Although this would create an incentive for trade, there was concern that it would be necessary to force firms to enter the market. Under the RNA, all firms would offer their entire supply of permits for sale in a call auction, in which they would simultaneously submit a series of sealed bid price-quantity combinations which would constitute their demand for permits. When the market was called the auctioneer would order the bids in descending order, match them with the available supply and set a uniform price at the lowest rejected bid. Permits would be distributed to the successful bidders and the revenue returned to the firms in proportion to their original supply of permits. Under this plan a firm could always maintain its initial allocation without any net cost while the regulator would maintain a thick market to ensure an efficient distribution of permits.[14] Franciosi *et al*. (1993) demonstrated that a laboratory implementation of the RNA generated high efficiencies, comparable to the equally high efficiencies of a naive double auction, in which permits were distributed to firms that were permitted but not forced to trade. Cronshaw and Brown-Kruse (1999) found excessive use of banking when this was permitted under rules similar to the US EPA. Ledyard and Szakaly-Moore (1994, see below) found comparable results in their competitive sessions.

Subsequent research has focussed on the efficiency properties of the rights conveyed by the emission permit and of alternative auction institutions in a competitive environment. Muller and Mestelman (1994) and Godby, Mestelman, Muller and Welland (1997) investigated the performance of markets with *coupons* (actual discharge permits) and *shares* (time streams of coupons), banking, and uncertainty in control of emissions. They found that markets with shares and coupons showed particularly high efficiency and confirmed a result of Carlson *et al.* (1993) that some intertemporal substitution of permits is necessary to prevent price instabilities in the permit market. Bjornstadt, Elliott and Hale (1995) describe a number of experiments conducted to investigate the properties of auctions proposed for the US EPA sulphur dioxide allowance market developed under the Clean Air Act of 1990. Cason (1995) and Cason and Plott (1996) conducted two experiments which show that the discriminative price call auction actually adopted by the EPA seriously biases both bids and offers downwards. Only Brown-Kruse and Elliott (1990), Brown-Kruse, Elliott and Godby (1995), Ledyard and Szakaly-Moore (1994) and Godby

[14] It could always submit a very high (and presumably successful) bid for its initial distribution and no bid for any additional permits. Regardless of the final price, the cost of the permits acquired would equal the revenues from the permits sold).

(1997, 1998, 1999) have conducted laboratory investigations directly addressing market power in emissions trading markets.

Ledyard and Szakaly-Moore argue that any politically feasible emissions trading plan must grandfather existing firms by distributing the initial stock of permits to them. They further argue an unorganized system in which firms privately negotiate trades of their initial allocation would be inefficient due to the lack of a central clearing house, high transactions costs in finding trading partners and lack of price information. Accordingly, they describe the ordinary double-auction and the Hahn and Noll RNA as the only efficient and politically feasible methods for trading emission permits. They compared these two institutions under monopoly and competitive market conditions. Under competitive market conditions, both institutions were very efficient, although the Hahn and Noll RNA was usually slightly out-performed by the double auction. Of more direct interest here is how these institutions compared in preventing the emergence of market power.

To investigate this issue, Ledyard and Szakaly-Moore provided the potential for market power by initially assigning ten permits to a single trader, who could then sell them through an auction market to five other subjects, each with abatement costs that exceeded the monopolist's. The seller's costs and buyer's resale values schedules were the same as those used in Smith (1981). The high cost subjects were assigned no permits. Seven sessions were conducted using an unchanging set of cost schedules and permit assignments. In four sessions the trading institution was the Hahn and Noll RNA; in three sessions the trading institution was the conventional double auction. Based on earlier laboratory work in which monopolists supplied output through a double-auction trading institution, the expectation was that market power would not be realized by the monopolist. The implications for the Hahn and Noll auction had not been explored. Since their experiment did not include downstream production markets, the more complex environment and predictions described by Misolek and Elder (1989) were not explored.

On average, prices and quantities in the Hahn and Noll RNA converged towards the monopoly predictions by the end of the session. Double-auction outcomes varied across sessions. One session converged towards the monopoly outcome, while another converged towards the competitive prediction. In the remaining session, prices and quantities were between the competitive and monopoly predictions. Summary price data for these sessions are found in Table 4. Overall, the monopolists achieved 78.3 and 47.8 percent of the potential price increase in the last period under the Hall and Noll RNA and double auction respectively.

Given that they used the same parameter set as Smith, it is surprising that Ledyard and Szakaly-Moore found the double auction less resistant to market power than Smith did. Two differences in the experimental design may explain this. Smith allowed subjects to buy or sell only, depending on their assigned market role. Ledyard and Szakaly-Moore allowed speculative trading, that is, they allowed buyers to resell units and sellers to re-buy them. Additionally, Ledyard and Szakaly-Moore conducted fewer market periods (10) per session than Smith. Godby (1999) reports on double auctions where speculation is possible. He observed that such experiments take longer to converge. Given these differences in experimental procedures and the fact that the double-auction price paths reported by Ledyard and Szakaly-Moore appear to be still in the process of converging to a price level nearer the competitive level than the monopoly outcome, it is possible that with more time their results would not differ significantly from Smith's.

The Ledyard and Szakaly-Moore results do support Hahn's simple manipulation predictions, especially when the Hahn and Noll auction was used. It appears that prices may be expected to diverge from competitive levels when this is predicted by theory, although under double auction trading rules the divergence is limited and perhaps temporary. The Hahn and Noll RNA is comparable to the posted-offer market in its relative inability to resist the exercise of market power. This is consistent with previous experimental findings, since both the RNA and the posted-offer markets allow sellers to commit themselves to a price schedule.

The work of Brown-Kruse *et al.* (1995) and Godby (1998) was designed to test both the hypotheses of simple manipulation and exclusionary manipulation.[15] The experimental designs incorporated a large firm and an industry *fringe* of small firms equal in aggregate to the size of the single large firm. All firms first participated in a double-auction market for permits and then made output decisions for their product market. Treatments varied in the nature of the product market and in the distribution of permits across subjects. In the simple manipulation condition, the price in the product market was fixed. In the exclusionary manipulation condition the product price was set at the price where the market demand for the product (defined by the experimenters) was equa1 to the aggregate output supplied by the firms in the industry. In the monopoly and monopsony conditions, all permits were distributed initially to the large firm and the fringe firms respectively. Godby (1998) introduced a third distribution condition in which the available permits were distributed proportionately to the large and small firms alike.

[15] The design was introduced by Brown-Kruse and Elliott (1992), who conducted one session per treatment cell. Brown-Kruse *et al*. (1995) report twelve additional sessions (3 per cell). Godby (1998) extended the design to test for additional effects.

In Brown-Kruse *et al.*, the laboratory environment comprised one firm capable of producing ten product market units and ten small firms, each capable of producing one product unit. Total production capacity of the market was 20 units. Production of one output unit created a unit of emissions. There were ten emission permits allocated in the market. Permits were called *coupons* and were described as an input which allowed subjects to avoid a part of each unit's production cost (called the *additional cost*) for each coupon held.[16] Direct production costs and additional costs (which together made up production cost) differed by firm, allowing gains to be made from trading coupons and reflecting the different production and abatement technologies in naturally occurring economies. These sessions also differed from the earlier monopoly double auction sessions in giving information regarding the cost structure of the other firms in the industry to the large firm, though it was not explicitly given their permit demand.[17]

In the simple manipulation condition subjects were informed that the product price would be 125 lab dollars. In the exclusionary manipulation condition each subject was given a table describing what the product market price would be for all possible levels of total product market output. Because the product market price was determined by the total production of all firms,

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[16] To avoid *framing* effects, subjects were not told that the market in which they were participating was a pollution emission market. By not referring to pollution, emission coupons, or abatement, actions by subjects in the markets observed should reflect only their desire to earn trading profits; it should avoid effects due to personal beliefs regarding pollution emission trading.

[17] This was done to reflect the implicit theoretic assumption made in Section 4 that the market power firm has the information available to exploit its power. In reality large firms could have the resources to discover their competitors costs and thus estimate the permit demand or abatement values. The market power firm was not given the demand information, only enough knowledge to construct such relationships if they chose to. In the actual experiments none did, with all market power subjects appearing to ignore the other firms' cost information contained in their experiment folders.

and firms made their production decision after engaging in coupon trade, the large firm had an opportunity to engage in exclusionary manipulation.

The combination of the two endowment conditions and two product market conditions created a 2x2 factorial design with each treatment testing for a unique type of coupon market manipulation.. The predicted prices, assuming that the large firm exploits its market power, are reported in Table 5. Although exclusionary manipulation is possible in the exclusionary manipulation with monopsony treatment, it actually leads to lower profits for the large firm than this firm would realize if it constrained its actions to simple manipulation of the coupon market.

Each session consisted of ten decision periods using the parameter values associated with one of the cells in Table 2. Each period started with a coupon assignment to firms corresponding to the treatment followed by coupon trading using the MUDA computerized double auction (Johnson, Lee, and Plott 1988). After the coupon market closed, each firm was asked to make a production decision. If the product market treatment in the session used a fixed market price, subjects then calculated their profits. If the product market price depended on total production of the industry, the decisions of the eleven firms were aggregated and the market price was announced. Subjects then computed their profits and the period ended. Note that coupons could not be banked – a new distribution of permits occurred in every period.[18] Three sessions were run for each of the four treatments. The resulting market prices and quantities were compared to

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[18] Banking refers to saving permits from one period to be used in the next. Allowing permits to be saved in this way, it is possible that market power could be exacerbated or mitigated in emission trading drawing upon the results found in theoretic futures markets for commodities (see Anderson 1991 for a survey of this literature). The interaction of market power and the possible properties of the permit traded have not been considered theoretically nor experimentally.

the market power predictions and to the competitive prediction (the outcome consistent with the large firm not exploiting its market power in either market).

In analysing the results, the initial assignment of coupons was identified as the command-and-control assignment and the surpluses realized in the trading environments were compared to the surplus that would be realized if coupons were not traded but firms made profit-maximizing production decisions. This made it possible to compare total market efficiency under alternative allocations of permits and alternative opportunities for simple or exclusionary manipulation.

Godby (1998) investigated the effect of permitting speculative trading and of distributing permits proportionately so as to eliminate the incentives for simple manipulation. A slightly modified parameter set was used. The ten small firms in the Brown-Kruse *et al*. design were reduced to five firms, each with a production capacity of two units. The production costs of these ten units were comparable to the production costs of the ten units from the small firms in use by Brown-Kruse *et al*.[19] Product market treatments were identical to those used in Brown-Kruse *et al*., however, an addition assignment treatment was included. The new treatment had each of the small firms initially receiving an endowment of one coupon while the large firm received five. This corresponds to an equal proportional reduction in pollution emission entitlements across all firms.[20]

In both experiments, market prices and quantities systematically deviated from the competitive equilibrium in the direction predicted by Hahn (1984) and Misiolek and Elder (1989).

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[19] Costs were modified to ensure each firm had increasing production and abatement costs.

[20] If the initial permit distribution is defined to be the command and control assignment, this new endowment treatment could be considered more representative of the type that would be expected under actual regulatory conditions than the extreme assignments used in previous experiments.

Table 5 reports the mean contract price in the last period of each treatment averaged over the 3 replications. In nine of the ten treatments the competitive and market power price predictions differ. In six of these nine treatments, the average coupon price more closely conformed to the market power prediction than to the competitive prediction. The exceptions occurred in the simple manipulation/monopoly treatment (both experiments) and in the exclusionary manipulation/monopsony treatment (Godby only). In one of the sessions of the latter case a severe speculative bubble (where prices remained above all rationally predicted levels throughout the session) drastically reduced the price deviation reported for the treatment. Ignoring this anomaly, the average coupon price in the last period was 55, implying a price deviation 67% greater than predicted by the market power hypothesis. In the remaining two cases there was only scope for simple manipulation, the difference between competitive and monopoly predictions was small, and the results were either intermediate between the market power and competitive predictions (Brown-Kruse *et al*.) or slightly below the competitive prediction. Since this treatment corresponds to the type of market power previously investigated in other experimental double auctions, it is not surprising that the competitive result should be realized.

Overall, the Brown-Kruse *et al.* and Godby results strongly suggest that manipulative behaviour will arise in emission markets that permit it. Moreover, the double auction institution was surprisingly unable to resist the exploitation of market power. Across all sessions where a market power prediction existed, the firm with market power achieved an average of 80% of the potential deviation from competitive price levels.

Such price deviations imply serious losses in efficiency. Table 6 shows this is the case. In this case efficiency is measured by the increase in aggregate profits (relative to the command-and-control allocation) as a fraction of the potential gain. Both Brown-Kruse *et al*. and Godby find similar patterns across treatments. Market efficiency is highest when the large firm receives all the permits and only simple manipulation is feasible (96% and 81% for Brown-Kruse *et al*. and Godby respectively). Efficiency falls somewhat when the large firm is the sole buyer (71% and 63% respectively). When exclusionary manipulation is feasible, the surplus realized by the subjects was less than that which they would have realized making profit-maximizing production decisions under command-and-control regulation. The loss is severe in the case of monopsony power (losses of 42% in both experiments) and even worse in the case of monopoly power, with losses of 140% and 119% of the potential gain, respectively. When permits are distributed to minimize the potential for market power, coupon trading allows subjects to realize nearly all (94%) of the available gains.

The poor performance of the double auction in these experiments seems surprising at first, given that previous market experiments indicated that this institution limits market power. On further consideration, however, some of the results do conform to previous interpretations of the success of the double auction. In particular, in the exclusionary manipulation environment the firm with market power can commit to a specific quantity in the product market. Commitment to initial strategies was advanced as an explanation for the success of monopolists in posted bid institutions. This does not, however, explain the poor performance of the double auction in the simple manipulation environments. Here the biggest surprise is the substantially poorer performance of the double auction in the monopsony case. Why should it be easier for a monopsonist to avoid purchasing marginal units at a high price than for a monopolist to avoid selling marginal units at a low price? This is fertile ground for future research. Godby's results show that the Brown-Kruse *et al.* findings are robust to changes in the number of fringe firms and opportunities for speculative trade. All of this suggests that the double auction may not be nearly as robust an institution for resisting market power pricing as had been previously thought.

6. Conclusions

The laboratory experiments reported in this paper suggest that regulators should take seriously the threat that market power may emerge in emissions trading markets, particularly ones which may affect competition in related markets. Trading institutions should also be carefully considered. Although the double auction has been shown to limit the exercise of market power, recent experiments suggest that it may not afford as much protection as previous work has suggested. In addition, the opportunity to engage in exclusionary manipulation poses serious concern for the social feasibility of a trading scheme. Although the theory underlying exclusionary manipulation only suggests welfare losses are possible, the behavioural results of the few laboratory studies that have been completed show dramatically that the threat is real.

A characteristic of the Brown-Kruse *et al*. and Godby experiments which is not necessarily characteristic of the field is that the firm with market power has complete information about its rivals' cost schedules. It is important to investigate whether this complete information is essential for market power to emerge. If market power results emerge even with less than complete information, it will be particularly important to develop alternative trading institutions to limit price distortions. Laboratory evaluation of these new institutions can provide useful insights into their validity.

Although needing replication and extension, laboratory experiments show that effects of market power predicted by economic theory tend to emerge in controlled environments, although their quantitative significance depends importantly on the institutions governing trading. They suggest that concerns regarding market power in emissions trading markets are well founded, especially when firms compete in both emissions and downstream product markets. They also validate the use of experimental methods in market design, especially in cases where no fully developed theory exists to guide policy-makers as they try to implement new regulatory methods that are both politically viable and increase the economic efficiency of an economy.

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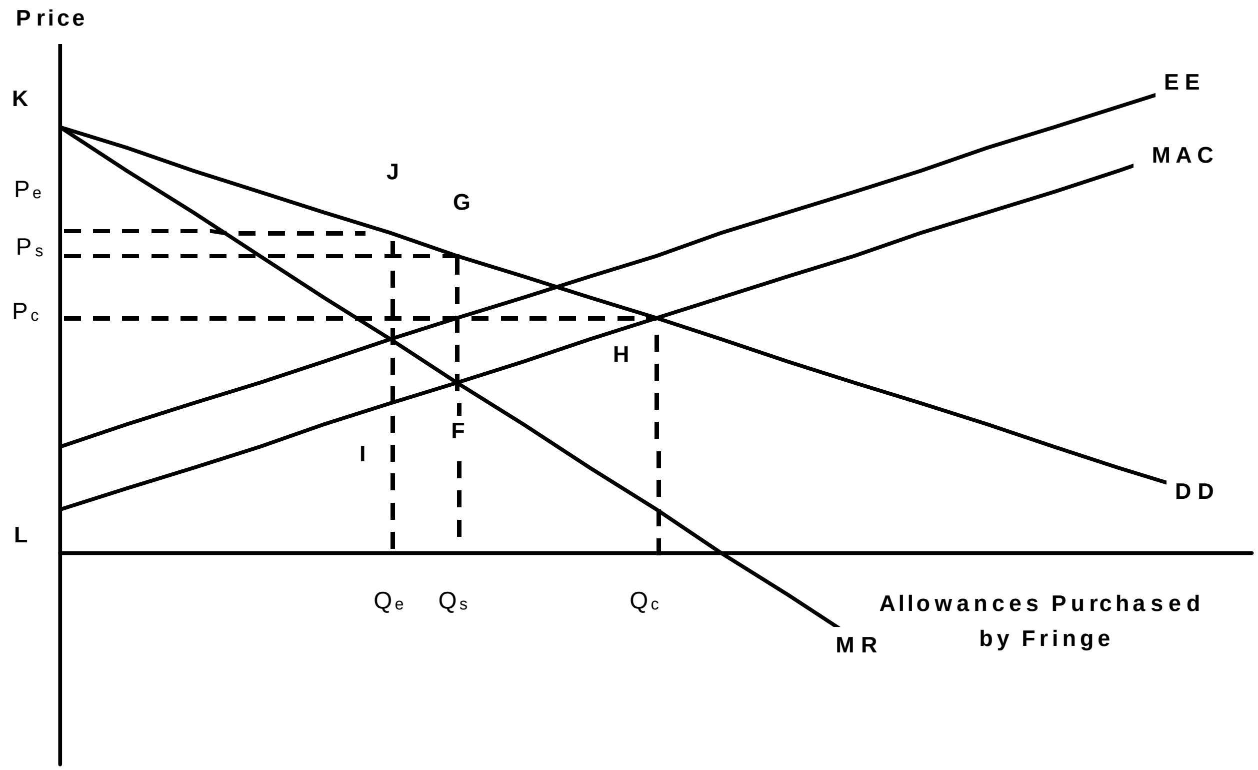

Figure 1 Simple and Exclusionary Manipulation by a Monopolist in the Allowance Market

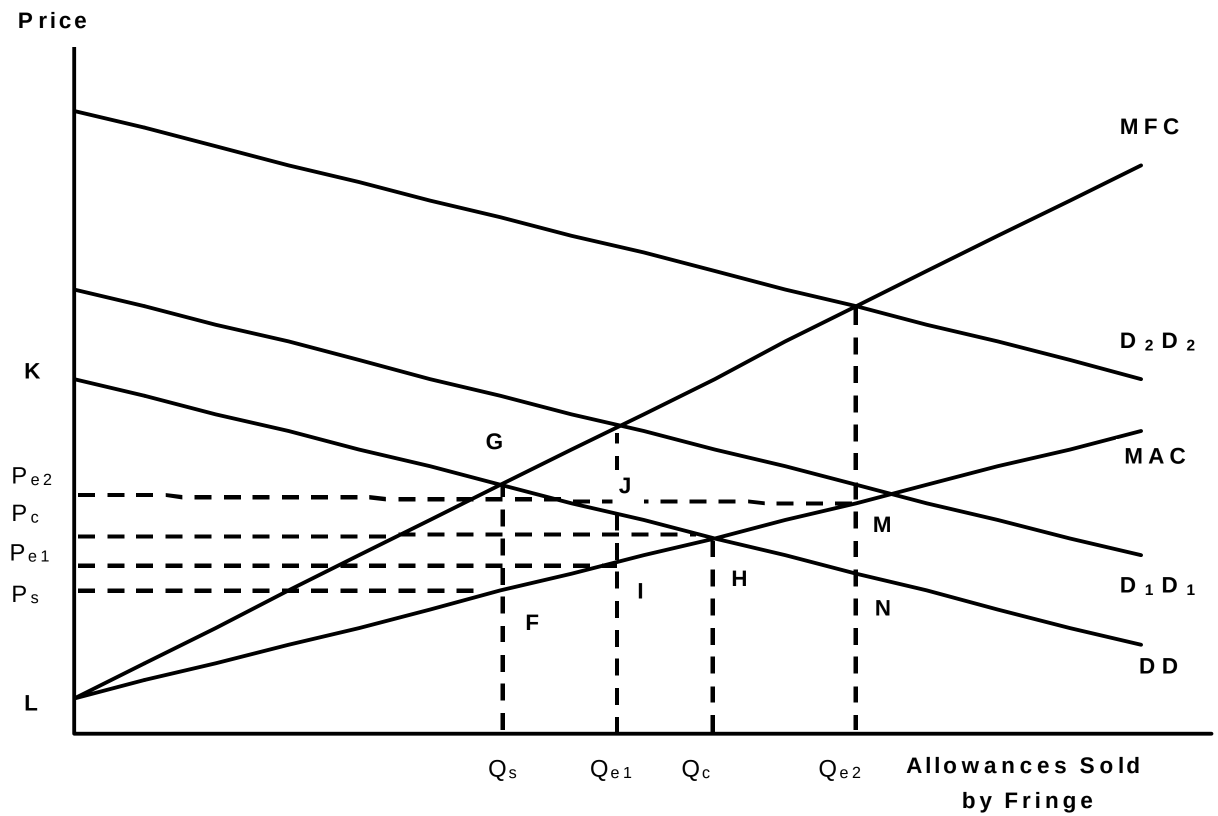

Figure 2 Simple and Exclusionary Manipulation by a Monopsonist in the Allowance Market

Table 1. Institutional Performance in Experiments Where Market Power is Caused by Limiting the Number of Sellers[1]

Author	Trading Institution	Number of Sellers	Number of Buyers	Number of Sessions	Percentage Deviation Between Competitive and Monopoly Price Predictions[2]	Percentage of Mean Price Deviation from Competitive Price (last period)[3]	Percentage of Monopoly Price Increase Attained (last period)[4]
Smith (1981)	Double Auction	1	5	3	37.5	9.3	24.8
	Posted Offer	1	5	1	37.5	37.6	100.2
	Posted Offer	2	5	1	37.5	8.5	22.7
	Posted Bid	1	5	3	37.5	4.8	12.8
	Offer Auction	1	5	1	37.5	11.6	30.9
Smith & Williams (1989)	Double Auction	2	5	1	7.9	0.8	10.2
	Double Auction	2	6	1	9.1	0	0
	Double Auction	2	10	2	4.8	-0.5	-10.4
	Double Auction	1	5	1	7.9	0	0
	Double Auction	1	5	4	4.8	0.4	8.3

[1] All data taken from original articles.

[2] The absolute deviations between competitive and monopoly price predictions are the same in the Smith (1981) and Smith and Williams (1989) papers. In the latter experiment, redemption and cost schedules were displaced by a constant amount to create different nominal equilibrium prices across sessions. This is reflected in the different percentage deviations.

[3] Percentages reported have been calculated using the mean of the average prices reported for the last period in cases where more than one session was conducted.

[4] Calculated using previous data from previous two columns.

Table 2. Institutional Performance in Experiments Where Market Power is Caused by the Incentive for Sellers to Restrain Trading Activity

	Number of Double Auction Sessions	Number of Posted Offer Sessions	Difference Between Competitive and Monopoly Prices (Percentage)	Number of Sessions with Supra-Competitive Prices	Mean Price Deviation from Competitive Level (Percentage)	Number of Sessions with Supra-Competitive Prices	Mean Price Deviation from Competitive Level (Percentage)
				Double-Auction Markets		**Posted-Offer Markets**	
Holt *et al.* (1986)[1]	5	0	9.6	3	7.7	0	Not Applicable
Davis and Williams (1991)[1, 3]	4	4	9.6	4	12	4	21
Sbriglia and O'Higgins (1996)[2, 3]	4	6	0-200 30	4	5	4	19

1 Competitive price is 260, monopoly price is 285. Davis and Williams use the same design as Holt *et al*. but displace the redemption and cost schedules to vary the equilibrium price across sessions. The results are normalized and reported to be comparable.
2 Authors used two designs, both with a competitive price of 500, one with monopoly price range from above 500 to 1500, the other with monopoly price of 700.
3 Estimated final period average price deviation from competitive price using charted data included in the original article.

Table 3. Effect on Market Price by Market Power[1]

Dominant Firm's Market Role	Cost Minimizing Manipulation	Exclusionary Manipulation	Net Effect
Net Seller	decreasing	decreasing	decreasing
Net Buyer	decreasing	increasing or decreasing	undetermined

[1] Relative to efficient (competitive) prediction.

Table 4. Market Power Pricing Results from Ledyard and Szakaly-Moore (1994)

Trading Institution	Number of Sessions	Number of Sessions with Supra-Competitive Prices[1]	Percentage Deviation Between Competitive and Monopoly Price Predictions	Percentage Mean Price Deviation from Competitive Price (last period)[2]	Percentage of Monopoly Price Increase Attained (last period)
Double Auction	3	2	37.5	17.9	47.8
Hahn and Noll Auction	4	4	37.5	29.4	78.3

[1] As determined by average price in the last period of the experiment.
[2] Estimated using chart data in original article.

Table 5. Average Price Performance in Market Power Environments[1]

Experiment		Simple Manipulation			Exclusionary Manipulation		
		Monopsony	Monopoly	Proportional Assignment[2]	Monpsony[3]	Monopoly	Proportional Assignment
Brown-Kruse *et al*. (1995)	Number of Sessions	3	3		3	3	
	Competitive Price	105	105		105	105	
	Market Power Price	90	110		75	180	
	Mean Price[4]	**75**	**107**		**75**	**192**	
	Percentage of market power price change attained[5]	166	40		100	116	
Godby (1998)	Number of Sessions	3	3	3	3	3	3
	Competitive Price	105	105	105	105	105	105
	Market Power Price	90	110	105	75	180	127
	Mean Price	**83**	**102**	**108**	**102**	**155**	**134**
	Percentage of market power price change attained[5]	147	-60	Does Not Apply	10	66	132

[1] Mean coupon prices in the final period are reported in **bold** characters. The equilibrium coupon price is 105 lab dollars regardless of the initial assignment of coupons if market power is not exercised. The market power prediction is less than 105 when the assignment is to the small firms and greater than 105 when assignment is to the large firm. Under proportional assignment, the market power and competitive predictions differ only if exclusionary manipulation is possible. In this case, the market power prediction is within the range of 125 and 127 lab dollars.

[2] There is no market power prediction in this treatment.

[3] In Godby (1998), one session experienced what could be called a "speculative bubble" where prices remained above rational levels throughout the experiment. If this session is ignored, the average price of the other two session's last periods is 55, or 167% of the predicted market power price change predicted.

[4] Mean of final period prices across three sessions in each treatment.

[5] The percentage of the market power price increase attained is calculated using price data from the last period of the experimental sessions only.

Table 6. Efficiency of Laboratory Emission Trading Markets by Market Power Treatment and Assignment of Coupons[1]

Experiment	No Market Power	Simple Manipulation			Exclusionary Manipulation		
	Proportional Assignment	Monopsony	Monopoly	Proportional Assignment	Monopsony	Monopoly	Proportional Assignment
Godby, *et al*. (1997)	0.94						
Brown-Kruse *et al*. (1995)		0.71	0.96		-0.42	-1.4	
Godby (1998)		0.63	0.81	0.32	-0.42	-1.19	-0.33

[1] Efficiency reported in this table represents the proportion of the potential gains from coupon trading in a competitive environment that is realized.