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Strategic Manipulation of Pollution Permit Markets: An Experimental Approach

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Abstract

In this paper we employ experimental economic methods to examine the effect of market structure on the use of marketable emissions permits. In particular, we ask whether firms can strategically manipulate a product market using marketable emissions permits. Subjects participate in two markets, a permit market and a product market. They use permits to reduce the cost of production of the final goods that they sell in the product market. Four treatments are used to test the effects of initial permit allocation and market structure. The first two treatments explore "simple" manipulation. In this case firms are all price takers in the product market but must compete for permits. In the second two treatments the experiment is expanded so that firms compete both in the permit and in final product markets, thus opening the potential use of permits as a form of market predation. Results show that in a market with one dominant firm and a number of fringe firms, strategic manipulation occurs repeatedly in the laboratory as the dominant firm uses licenses in an inefficient manner in order to minimize its costs, increase its profits and exclude rivals in the product market. Further these findings indicate, that far from improving market efficiency and decreasing the cost to society of pollution control, implementation of tradable permit markets where there are firms in a position of market power may decrease efficiency.

Strategic Manipulation Of Pollution Permit Markets: An Experimental Investigation

By J. Brown Kruse, S. R. Elliott and
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I. Introduction

Recent environmental policy initiatives in the United States and Canada have incorporated decentralized market mechanisms to achieve desired results. In the area of pollution control, markets for transferable pollution rights have been used in varying forms in the United States since the late 1970's, and were an integral part of the Acid (rain) Deposition Control of the Clean Air Act of 1990[1]. In Canada regulators frequently express concerns about the exercise of market power in such programs since proposed markets are often expected to be thin or dominated by few firms. In particular, in a proposed market for nitrogen oxides (NO_X) in southern Ontario, one firm currently accounts for over 50% of total emissions[2].

The theoretical benefits of transferable pollution rights markets are well known[3] Overall pollution control costs to society are minimized when permit trading institutions are employed. The theoretical benefits of decentralized methods however, are all based on the assumptions of perfect competition in the permit market.

"Command and control" mechanisms, based on legislated maximum emission levels by site, can only minimize control costs if the legislated levels are within the set of market solutions arrived at after trade in a decentralized system. Simply put, if a command and control mechanism were minimizing control costs, and the mechanism changed to a

[1] H R. 3030. Title V
[2] See Nichols (1992)
[3] See Dales (1968). Montgomery(1972)

decentralized method such as an emission permit market, there would be no incentive for those emitters involved to trade.

A number of researchers have investigated the outcome of permit systems when one or more participants have market power. This research has focused on market efficiency and pollution abatement effort across firms when a buyer or seller manipulates permit markets to minimize its pollution abatement costs, thus minimizing the financial burden of pollution regulation[4]. A number of researchers have argued market power in such markets, although detrimental to system efficiency, is not of great concern because the monopoly or monopsony solutions would still generate outcomes with efficiency well above those generally found in centralized systems (see for example Tietenberg, 1985). Misiolek and Elder (1989) formally analyzed emission rights markets and distinguished two types of possible manipulation: cost minimizing manipulation, where the dominant firm seeks to minimize control costs, and exclusionary manipulation where the dominant firm acts to lessen competition in a vertically related product market. Their results showed that in the presence of either type of manipulation, the outcome is dependent on the initial distribution of permits and may lead to serious efficiency effects, including decreasing efficiency relative to centralized methods.

The ability to exercise market power may also depend on market institutions. Laboratory evidence has shown that the double auction institution appears especially resistant to such manipulation Smith (1981) demonstrated that in a laboratory environment with one seller, the double auction institution repeatedly resulted in convergence in price to the competitive level. These results have led to the suggestion that this institution may be useful as a means of monopoly restraint

[4] See Lyon (1982), Eheart et al (1980), Hahn (1984), Tietenberg (1985), Misiolek and Elder (1989), Sartzetakis (1992, 1993)

We use a market experiment to investigate whether concern regarding market manipulation in permit markets is well-founded. Specifically, we design an environment which comprises one dominant firm and a number of smaller "fringe" firms. Within this context we maximize the market power of the dominant firm through one-sided permit allocation. Permit trading takes place in a double auction market. We analyse price, quantity and efficiency data to search for indications of manipulation in either of the forms postulated by Misiolek and Elder. If manipulation occurs, this is a clear warning to regulators. Market structure should be seriously considered to determine whether market power may be potential problem in proposed markets, even those utilizing institutions thought hostile to this type of conduct. If such behaviour does not appear we cannot conclude the link between structure and conduct in such markets merits little concern, as we may have only found further evidence to support the contention that double auction institutions are an effective method of insuring against market power.

II. Theoretical Foundations

The consequences of monopoly and monopsony power in permit markets have been analyzed in the literature. Misiolek and Elder (1989) assert outcomes of emission trading in monopolized and monopsonized markets may be even less effective than traditional forms of regulation in reducing the social cost of pollution control, especially if there exists vertically related product markets. These results have been largely ignored in policy documents where authors have dismissed market power as unlikely to have much effect in permit markets.

Cost minimizing manipulation, (hereafter "simple" manipulation), refers to manipulation of the permit market by an agent with market power They act to minimize expenditures on emission permits if they are a net buyer (monopsony case) or maximize revenues from permit sales if they are a net seller (monopoly case). The consequences of such actions on other firms in the market are incidental and not considered by the those influencing the market. The price-setting firms act only to minimize their own costs or maximize their own profits.

A dominant firm may also use its influence in the *permit* market to gain monopoly power in a *product* market by influencing rival's costs. If rivals have sufficiently high abatement costs, permits may also be considered exclusionary rights of the kind described by Krattenmaker and Salop (1986). This behaviour can only occur when a firm believes it can influence the costs of rivals *in the same industry*, defined by specific final product (and pollutant by-product) *and* a geographic location, as rivals in the industry must belong to the same permit market. It must also be the case that a significant share of the product market output be produced in the geographic region covered by the permit market of interest and that the permit market be susceptible to *simple manipulation* before a firm can engage in this activity. Clearly an implied pre-condition is production in a specific region creates a cost advantage, thus pollution permits give firms access to this location (i.e. in order to produce in the area one needs permits since production causes pollution and permits are required to pollute). Further, to be profitable, the gains in profit in the product market accrued by such manipulation *must outweigh* the lost profits in the permit market of not pursuing *simple manipulation* alone[5] This type of manipulation may be more attractive than predatory pricing, as it does not require the "deep pocket" of such activity. Further, predatory pricing must count on a sufficient discounted flow of future profits to compensate for immediate

[5] See the Appendix for derivation of this condition See Misiolek and Elder (1989) for a similar derivation.

losses of such actions. Predation through exclusionary rights yields immediate profit gains.

To simplify the exposition of both types of manipulation we present a graphical analysis The formal mathematical problem is provided in the Appendix. The analysis assumes an initial endowment of permits which leaves the market participants in particular role, either net sellers or buyers of permits. For reference we define this as the command and control allocation. Efficiency loss for these allocations is dependent on initial allocation, as are trading results if market power is utilized by a dominant firm. If initial allocation were at the competitive allocation[6], no gains from trade would be possible.

Consider Figure 1 in which the dominant firm is a net seller of permits. The vertical axis indicates the price of permits and the horizontal the quantity of permits purchased from the dominant firm by a "fringe" of smaller price-taking firms. The dominant firm faces a derived demand for permits by the fringe, indicated by curve DD The dominant firm, aware of the effect of its sales on permit price, derives a marginal revenue function MR. The firm faces a marginal opportunity cost of permit sales, curve MAC, equal to the marginal cost of abatement. The efficient solution occurs at the intersection of DD and MAC, resulting in quantity, Q_c being sold at price P_c. The efficiency gain over command and control is shown as the area below curve DD and above curve MAC from the vertical axis to point H. For all firms, price equals marginal abatement cost. No more gains from trade are possible.

If the dominant firm acts as a monopolist the solution occurs at Q_S and P_S. Permit price is higher and quantity purchased lower than the efficient outcome. Additionally, efficiency is not maximized in the market as marginal abatement costs across firms are

[6] For simplicity we assume the competitive allocation is unique

not equal. The deadweight loss to society relative to the efficient allocation is indicated by triangle FGH. Relative to the efficient solution the dominant firm sells too few permits and experiences lower marginal abatement costs, while the fringe marginal abatement costs are too high.

Now consider how the motive to exclude rivals in a common product market through permit manipulation affects Figure 1. If the dominant firm is a net seller of permits, and competes in the same product market as the fringe, the marginal value of another permit sale will reflect not only the abatement cost that permit avoids, but also the opportunity cost of excluding a rival unit of production in the related product market. The dominant firm has an incentive to hoard permits and increase rival's costs to increase their product market dominance. The mathematical formulation of this problem is outlined in the Appendix. The effect of exclusionary motive on the dominant firm is shown in Figure 1 by curve EE, which is drawn as the sum of marginal abatement and exclusionary opportunity costs of each unit sold. The resulting equilibrium is characterized by even fewer permits sold (Q_e) to the fringe than under *simple* manipulation, at a higher price (P_e) and with an increased efficiency loss relative to competitive equilibrium, indicated by area JKH. The motive to hold more permits caused by *simple* manipulation is reinforced by exclusionary incentives[7].

Figure 2 describes the simple manipulation outcome in the market if the dominant firm is a net buyer of permits[8]. In this case, the firm acts as a monopsonist. Note the horizontal axis now describes the number of permits *purchased* by the dominant firm from the

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[7] It is worthwhile to note that outcomes shown in Figure 1 suggest allowing permit trading after initial allocation increases efficiency This is the underlying basis for many authors' contentions that market power in permit markets is of little concern. If the value of exclusion shifted curve EE above the reservation price for permits of the fringe the dominant firm would become a net buyer of permits

[8] This could result from a free initial allocation of permits, known as *grandfathering* or due to an auction of permits occurring prior to trade.

fringe. As before the derived demand for permits is shown by curve DD, however it is now derived from the abatement costs each permit defrays for the dominant firm. MC denotes the horizontal summation of the marginal abatement costs of the fringe. This can also be considered the average factor cost of permits to the dominant firm if we view permits as an input in production. Competitive equilibrium occurs at Q_c and price P_c, with associated efficiency gain over initial allocation as defined for Figure 1[9]. If the dominant firm recognizes the effect of its permit purchases on permit price, its marginal factor cost is shown as curve FC. Solving this as a simple monopsony problem, yields the outcome at quantity Q_s and price P_s, with resultant efficiency loss FGH relative to the competitive outcome.

If *exclusionary manipulation* is considered by the dominant firm, and is profitable, two possible outcomes may occur. Exclusion serves to increase the value of a permit to the dominant firm, thus shifting the derived demand curve DD outward. If the incentive to exclude is weak, this shift is small, as shown by curve D_1D_1. Resulting equilibrium is shown at quantity Q_e^1 and price P_e^1. Both measures have increased from the *simple manipulation* levels to nearer the competitive ones. Resultant relative efficiency loss is also much smaller (area JKH)[10]. If the incentive to exclude is stronger, the shift in the derived demand curve will be more significant, as described by curve D_2D_2. Equilibrium now occurs at Q_e^2 and price P_e^2. Both measures are higher than competitive levels. Efficiency loss relative to competitive equilibrium due to the dominant firm's excessive permit holdings is shown by area HIL. Pollution control costs increase to

[9] However the gain is now defined as area below curve DD and above curve MAC from the vertical axis to point H

[10] Total efficiency in the economy however may have increased or decreased relative to competitive equilibrium in both markets due to the corresponding manipulation perpetrated by the dominant firm in the related product market which is not shown. Since comparison of efficiencies arising from *simple* and *exclusionary* manipulation is an exercise in second-best outcomes, the total effect would depend on the relative sizes of the distortions in each market. Decrease in social cost of pollution control due to an almost efficient allocation of abatement may or may not be outweighed by the welfare losses in the product market due to increased monopolization by the dominant firm.

society as the dominant firm abates too much and the fringe abate too little. Note the difference in outcomes due to *simple* and *exclusionary* manipulation. *Simple* manipulation leaves the fringe abating "too much". Differing incentives act in opposition to one another, thus final outcome is dependent on the exclusionary value of each permit.

III. Laboratory Implementation

The method of laboratory experimentation in economics[11] is utilized here. In laboratory economics experiments, subjects trade fictitious units with specific redemption values or acquisition costs to the subjects. The trading institution and subjects parameters can be manipulated for the purpose of the experiment, and are denominated in lab dollars. Subjects were paid in Canadian dollars an amount which depended upon their performance in the experiment, calculated using their lab dollar earnings at an announced exchange rate.

Firm Cost: Sessions utilized subjects acting as firms producing identical goods within an area governed by a transferable pollution permit market, referred to as the coupon market, or "C-Market". To avoid framing effects, subjects were told the permits were "coupons" and explicit references to pollution permits were not used. One firm enjoyed a production capacity of ten units (hereafter referred to as the dominant firm). The remaining ten firms could each produce one unit. All firms had two types of costs, production and abatement. These costs are shown in Table 2.

Abatement costs were referred to as "additional costs" in the experiment and were incurred to control for any external effects (pollution) caused by production. Fringe firms holding a coupon were not charged the additional costs of production. The

[11] See Friedman and Sunder (1994)

dominant firm was not charged the highest additional costs on production units it held coupons for. Heterogeneity of the fringe firms in production and abatement costs created a downward-sloped derived demand curve and upward sloped derived supply curve for pollution permits.

Laboratory Markets: In the experiments, each session ran for ten trading periods Each trading period began with the allocation of ten permits to either the dominant firm or the fringe firms. Two markets operated sequentially during the course of a trading period: the C-Market (permit market), and the P-Market (production market).

The C-Market was organized using MUDA[12] on eleven networked personal computers. The dominant firm subject was situated in a one room while the fringe subjects traded in another. Firms possessing permits, could either keep the permits or sell them in the C-Market. Firms without permits could buy them in the C-Market[13]. Since the number of permits available was fixed at 10 per period, all transactions in the C-Market involved redistribution of the existing permits. Firm payoffs were governed by their respective production and abatement (additional) costs and the primary market price for the firm's product. Speculation was not possible as permits could not be saved from period to period.

After the close of the C-Market, all firms submitted the quantity they wished to produce for the P-Market (subject to production capacity). All units produced were sold at a uniform market price. This price was determined by the market relationship utilized in the particular treatment being conducted.

[12] Multiple Unit Double Auction, California Institute of Technology 1991

[13] Each subject participated in an interactive instruction session before the session began to ensure each understood the operation of the computer trading program.

Experimental Design: A complete 2x2 factorial design was employed. This created four possible treatments, with three replications being conducted of each. Initial allocation of permits in two treatments distributed all ten coupons to the dominant firm, while the remaining two treatments delegated one coupon to each fringe firm. To control for the presence of exclusionary motive, the ability to utilize market power in the P-Market was controlled for by P-market price. Two treatments fixed the P-Market price at the "competitive" level of 125. Subjects were aware of the fixed product price. Remaining treatments had P-Market price determined by the aggregate production of the eleven firms using a predetermined P-Market demand curve (found in Figure 3), known by all firms. In this way, treatments with fixed price forced all subjects to be price-takers in the product market, thus the exclusionary incentive for the dominant firm was absent. The other treatments allowed this vertical relationship to be exploited. Subjects were given no advice or coaching concerning how this could be achieved. After the P-Market ended, subjects calculated earnings, and the next period began with an initial reallocation of permits according to treatment. Table 3 describes each treatment conducted.

Information: The dominant firm was given information about the other ten firms' costs, and productive capacity, however it was not told which firms had which costs. Fringe firms were given information dealing with their own private production and additional costs. Fringe costs were shuffled after the fifth trading period to equalize potential laboratory earnings and minimize boredom Each firm also had information regarding P-Market price or market demand in the P-Market, depending again on the treatment of market relationship

III.1 Laboratory Predictions

The socially efficient distribution of licenses is shown in Figure 3. This outcome would minimize total production and additional cost while providing the total surplus maximizing quantity of production in the product market (15 units: 5 by the fringe and 10 by the dominant firm). Socially efficient distribution of permits places three licenses with the fringe firms (F8, F9, F10) and seven to the dominant firm. This competitive outcome is fully described in the first row of Table 4. Under pure price taking behaviour, permit price and final holdings are independent of initial permit allocation.

The efficient solution was found setting supply equal to demand in the P-Market and identifying product price, then using this price to determine each firm's valuation for permits and calculating a derived demand curve. Setting this derived demand curve for permits equal to the supply of permits, resulted in the predictions found in the first row of Table 4. Predictions by treatment are calculated, using experiment parameters by treatment and using the methodologies outlined in the Appendix. Also included is the result if the dominant firm is monopolistic in the product market but a price taker in the permit market. The predictions by treatment described in Table 4 are for reference only. Mathematical methods describe static equilibrium, full information equilibria. The auction market result is the aftermath of a dynamic process not explicitly considered in these predictions. Since previous experiments have indicated institutions matter as equilibrium in laboratory markets is approached, the calculated predictions serve as benchmarks only Also, implementation of the laboratory markets causes some uncertainty for subjects in Treatments 3 and 4 as product market price is unknown. Results observed can be expected to be affected by the formation of expectations by a process or processes not considered in the calculations

III.2 Procedures

All sessions were conducted in the McMaster University Experimental Economics Laboratory over a three week period in January 1995. Each session took approximately two hours to run, of which 45 minutes were used for instruction Full instructions for each treatment are to be found in Appendix II, as are all worksheets and tables subjects received Four treatments, each with three replications were run using 132 subjects (11 per session). Rules of trade and costs of production and abatement were identical across all treatments. Subjects earned $25.00 CDN on average, with some variation depending on treatment.

Due to the complexity of the dominant firm's decisions, a discriminating selection process was used to select the dominant firm subject from the eleven subjects randomly selected for each session. The twelve subjects chosen to play this role were drawn from those subjects in the session who had experience in previous, unrelated laboratory experiments. This was done in an attempt to ensure this subject would not be overwhelmed with the decision they faced, having shown previously that they were able to understand and act independently upon instructions. Two sessions did not include such subjects (Sessions 5 and 8) and the dominant firm subject was drawn at random from the group of subjects involved. All subjects were recruited using advertising across campus and announcements in lower year undergraduate economic classes. None had prior experience using MUDA or the protocol used in the P-Market.

IV. Results

Laboratory results by treatment are compared to efficient predictions using one-tailed hypothesis tests We do so for two reasons. Firstly, the primary purpose of this investigation is to determine whether market manipulation should be of concern when designing pollution permit markets. Given this goal, results are compared to the competitive baseline in an attempt to determine whether significant deviations occur away from this benchmark under the different market structures in each treatment. Table 5 summarizes the findings of all sessions by treatment. Included for convenience are the predicted outcomes under perfect competition and simple or exclusionary manipulation as outlined earlier.

Figure 4 charts by treatment, the mean sequential C-market prices observed[14] in each session, with medians connected by solid line. Data points are labeled by treatment and session[15]. Predicted prices using the competitive market (105) and market power assumptions are labeled for each treatment on the vertical axes.

Result 1: In all treatments, observed permit prices deviate significantly and in the predicted direction from competitive predictions.

From Table 5, the mean prices found for Treatments I-IV were 86.64, 124.75, 64 43 and 206.68 respectively. These differences are large and in the direction of the theoretic strategic predictions. Further, inspection of Figure 4 indicates that in general, observed mean prices by session deviated from the competitive outcome in all treatments. Significantly, median mean permit price observed in all treatments never equals or crosses the efficient market prediction. These observations are quantified using a Wilcoxon Signed Ranks test[16]. Looking only at the last five periods of all treatments, observed prices reject the hypothesis that they are equal to the competitive prediction at

[14] Note mean price observed in Treatment II are coded "cmprice2", or "corrected mean price, treatment 2". Session II-1 recorded 4 observed prices greater than 150 These have been plotted at 150 to allow better scaling on the diagram

[15] Roman numerals indicate the treatment and replication number of the session within that treatment For example "III-2" indicates a mean observed price for one period of the second replication of Treatment 3

[16] See Wilcoxon (1945)

the 1% level[17]. Figure 4 and mean prices reported in Table 5 indicate observed prices were often higher than predicted by manipulation of any sort.

Inspection of the mean price paths of permits over time by treatment and session indicates convergence toward the strategic prediction. Further, in Session I-1, the dominant firm is so successful in depressing permit price, the mean price for the session is 39.7. Such behaviour is excessive as had the dominant firm allowed permit price to increase and if it purchased more coupons it could have increased profits. Session I-2 indicates convergence to the strategic prediction *from above*, indicating coupons did trade at or near the efficient price during period 3, however prices continue down towards the predicted strategic price, resulting in a mean price of 97.5. Mean permit price in Session I-3 is 87.3 Treatment II price paths indicate similar behaviour, converging to the strategic prediction in two sessions. In Sessions II-1 and II-2, prices appear to converge from above to 110, while in session II-3 price appears to converge on the efficient price of 105 from below. In Treatment III, Sessions III-1 and III-3 show convergence from below, indicating permit prices rising over time. Session III-3 however appears to converge to the competitive price prediction. Treatment IV price paths all indicate convergence to the predicted strategic price, all from above.

Result 2: Observed permit quantities deviate significantly, and in the predicted direction, from competitive levels in all treatments where competitive and market power predictions differ.

From Table 5 mean final license holdings observed for Treatments I and III indicate the dominant firm purchased fewer permits per period than the efficient prediction (7)

[17] Only the last five periods are used as the early periods of sessions recorded much higher deviations in observed prices than later periods Using all periods only strengthens findings reported above Results of the Wilcoxon tests reported are $z=-5.37$, $z=4.39$, $z=-4.13$, $z=5.09$ for Treatments I-IV respectively

Moreover, in Treatment IV this firm purchased more than the efficient level on average. Treatment II observed permit holdings differ little from the efficient prediction, however it should be noted that both competitive and strategic predictions are equal in this case. Where these quantities differ, they are in the direction of the strategic prediction. Wilcoxon Signed Ranks tests verify permit holdings after trade by the dominant firm (and therefore by all fringe firms) are significantly different from the efficient prediction at the 5% level over the last 5 periods of each treatment[18].

Figure 5 graphs sequential quantities of permits held at the end of the C-Market for all treatments. Median period values are connected by the solid line. Inspection of Figure 5 indicates convergence of permit holdings toward strategic predictions in all treatments, including Treatment 2 where strategic and efficient predictions are equal. Apart from those in Treatment II, only one session appears to converge to the efficient prediction, Session IV-1.

Result 3: Observed efficiencies differ across treatments.

Two measures of efficiency are used. The first and simplest asks whether permits are applied to the "correct" production units. The competitive allocation would apply seven permits to the dominant firm and three with the fringe. This would minimize abatement control costs in the laboratory economy if it were achieved and production occurred as predicted under competitive assumptions. Sixteen periods exhibit this allocation out of 120 over the course of the experiment Only Session II-2 regularly attained this permit allocation (in 5 of 10 periods).

[18] Results of the Wilcoxon tests reported are $z=-3.41$, $z=-3,41$ $z=2.02$ for Treatments I, III and IV respectively If the test is expanded to all periods, the efficient prediction is rejected at the 15% level for these treatments

To determine quantitatively the impact of possible strategic manipulation on market efficiency, an efficiency index is constructed. This index is the ratio of the difference between total surplus obtained by treatment and that which would occur in the command and control allocation if trade were not permitted[19], and the difference between that obtainable if the competitive results were obtained and that found given the initial allocation and product market assumptions by treatment[20]. Simply, this is the ratio of the improvement in efficiency found and that possible. These are calculated for the last five periods of each session[21]. They are reported in Figure 7. Average efficiencies found by treatment are found in Table 6.

There are obvious differences in efficiency observed by treatment. Figure 7 verifies this finding when looking at efficiencies recorded by session and extends it to

Result 4: Exclusionary treatments yield negative efficiency gains over command and control.

Exclusionary treatments (III and IV) yield negative efficiency gains, those in Treatment IV on average had efficiency gains of -1.40. Trade in this treatment caused efficiency to decrease by 1.4 times the amount it could have increased had the efficient outcome

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[19] Initial allocation baseline efficiencies (before trade) are: Treatment I=91%, Treatment II=83%, Treatment III=94%, Treatment IV=94%. It should be noted that the low efficiency baseline of Treatment II is due to the market parameters of the session. The P-Market price is set at 125, leaving excess demand in the market of 3 units which reduces consumer surplus achieved Treatment I also has this problem. however excess demand is only one unit, thus loss in consumer surplus is minimized Treatments III and IV assume a dominant firm in the product market.

[20] The efficiency index reported here is $\frac{TS_{6-10} - TS_{6-10}^{CC}}{TS_{6-10}^{PC} - TS_{6-10}^{CC}}$ The command and control baseline is calculated assuming no trade is allowed to take place in permits The product market price is determined either as P=125 (Treatments I and Treatment II) or assuming dominant firm pricing Total surplus (*TS*) is calculated as total consumer surplus and total profits realized by subjects

[21] Again the last five periods only are considered to ensure that early periods where observations exhibit higher variability, perhaps due to subjects becoming familiar with the environment, do not affect these measures

arisen. Treatment III also recorded negative efficiency gains, however the loss in efficiency was on average 0.42 times the gain possible.

From Figure 6 and Table 5 we see production in the exclusionary treatments was on average much lower than the efficient prediction Further, using a Wilcoxon Signed Rank test, both treatments reject the null their production results are described by the efficient prediction at the 1% level.

V. Discussion

Our results contrast strongly with earlier experiments which found a double auction institution restrained market power Using a Wilcoxon Signed-Ranks test, all treatments do not reject the null that permit prices are equal to those predicted under market power assumptions listed in Table 5[22]. We also test another hypothesis. Suppose all firms had acted as price-takers in the C-market but the dominant firm, recognizing its market power in the P-market acted in a dominant manner The theoretical prediction in this case is found in the second row of Table 2. If this behaviour were the case, P-market predictions and final permit price should be independent of the initial allocation, thus Treatments III and IV should yield identical results. The null hypothesis that quantities and prices observed from these treatments arise from the same distribution is tested using a Wilcoxon Signed Rank test for matched samples. Only the mean observed P-Market price does not reject this hypothesis, thus we reject the hypothesis that strategic behaviour is limited to the product market as high P-Market prices observed in Treatment III appear to be an artifact of systematic underproduction by the fringe.

[22] For Treatments I-IV, the respective calculated statistics were $z = -1.53$, $z = -0.42$, $z = -0.43$ and $z = 1.11$. All statistics do not reject the null at any level

It would seem that the trading institution has little effect in restraining market power. It should be noted however that Smith (1981) did not provide monopolists with the amount of information the dominant firm has here. It may be that without this level of information, the double auction will not disseminate the information required by a monopolist quickly enough to allow manipulation before a sort of tacit resistance develops among the buyers to resist such behaviour[23].

In Treatments III and IV the dominant firm has an exclusionary incentive to hold permits which was not present in the earlier treatments. Product market price in these treatments is determined as a function of total output produced by the eleven subject firms. This allows a more complex vertical relationship to link the two markets than in Treatments I and II. Although the opportunity exists for simple manipulation, these treatments allow the dominant firm another option: using the permit market to affect downstream market outcome. Decisions to produce, however are made in a state of uncertainty. All subjects still face a sequential decision, first whether to purchase or sell in the permit market and then to produce in the product market. Values of permits depend on the product price that can be received for the final product. Since the dominant firm has more information on other firm's costs, as well as a greater ability to manipulate the product market outcome, this information asymmetry make work to its advantage.

Some fringe firms consistently earned negative profits in these sessions. This may not have been due to irrational behaviour as much as expectations The marginal producers, those with mid-range production costs may have realized that they required a permit to produce at any foreseeable price. If their expectations were of slightly higher product prices than those realized (mean product price observed in Treatment IV=178), they may

[23] Smith comments " buyers appear to have a capacity for tacit collusion against the seller that has not appeared in non monopolistic experiments" (p 90) when describing observed buyer resistance to a monopolist's attempts to restrict sales and increase price

have purchased permits even at the seemingly unprofitable mean observed price of 207 (that for Treatment IV) From the market demand information provided to them, the difference between profit and loss would require a decrease in market production of only 2 units. Given the standard deviations of the observed product market price of 29 and total production of 1.45, this behaviour may have been justifiable. The uncertain product market price allows the possibility of losses for firms who are otherwise rational. This uncertainty could lead to firms dropping out of the permit market completely to avoid such risk, especially in naturally occurring economies. Losses due to production without permits or producing at all may be an acceptable risk premium for such firms to pay, especially those without access to capital markets. or other opportunities to diversify their risks.

To further the dominant firm's power over the product and permit market, at least one dominant firm subject suggested they used the product market to discipline fringe firms. If permit prices were difficult to maintain at the dominant firm's preferred level, the product market could be used to provide incentives to the fringe firms to accept the permit prices they were presented in the double auction. Operationally this could be accomplished by the dominant firm intentionally over-producing, thus lowering product prices and influencing perceived permit valuations downward in the case of Treatment III, or under-producing to create the opposite effect in Treatment IV. Such dynamic strategies are difficult to predict in static theoretic frameworks which describe only equilibrium but do not describe adjustment

In the full-information, static framework used to calculate the predictions for Treatment III in Table 2, any attempt to exclude is so costly, given initial allocation, that the dominant firm's predicted profit maximizing action is to pursue simple manipulation only, and acting as a monopsonist in the permit market, purchase only two coupons at 75 lab dollars for each . Treatment IV initially allocates all coupons to the dominant firm thus avoiding the costs of permit purchase if it attempts to exclude By reducing sales to the fringe, the dominant firm can maintain high permit prices *and* exclude rivals from the product market, reduce production and increase profits. This is seen in the strategic prediction of only one coupon sale to the fringe, while using eight to produce and defer abatement costs and idling the last. The exclusionary value of the last permit is so high that it is worth more to the dominant firm idle than it can obtain if sold or used in production.

Treatment III results suggest that exclusionary motive will not arise mistakenly. The dominant firm did not appear to attempt to exclude (only Session III-1 found mean permit holdings by the dominant firm greater than that predicted, and final holdings were at the predicted level in all periods after period five) and instead behaved in the predicted monopsonistic manner. Observed treatment permit market sales and prices indicate the dominant firm was either successful or excessive in pursuing the strategic behaviour expected.

The exclusionary manipulation sessions do not indicate such behaviour can be easily accomplished. In Treatment IV, although permit prices are maintained at high levels by the dominant firm, the fringe still purchased too many for effective exclusion, leading to systematic over-production by the fringe relative to strategic prediction. This behaviour by the fringe was often unprofitable (mean permit holding price was almost 25 lab dollars higher than mean product price), however the understanding that not having permits excluded them from production may have caused some fringe subjects to buy to avoid the risk they would miss a possible profit opportunity if the P-market price were high In the environment created in this experiment, subjects may have realized that withdrawing from the permit market excluded them from the production market and this deterred the restraining influence of the double auction institution. If hoarding of permits by them dominat firm is an indicator of exclusionary behaviour, it does not appear. The dominant firm on average, sold more permits than predicted under exclusion, however in the face of the high prices found in the permit market, lower holdings by the dominant firm may have been profit maximizing. The dominant firm did idle at least one permit in 22 of the 30 sessions observed, verifying that qualitative prediction, and in nine sessions idled more than one, possibly to compensate for fringe over-production (relative to strategic prediction). The dominant firm appears to have under-produced to maintain high product prices in the face of over-buying of permits and corresponding over-production by the fringe.

The efficiency results for Treatments I and II indicate that most of the potential efficiency gains have been achieved. This encouraging result indicates the social cost of simple manipulation is small, at least for the parameters used in this experiment. The loss in efficiency is strictly caused by the "wrong" firms holding permits, shifting the supply curve upward and lowering producer surplus available and achieved.

Treatments III and IV do not set an artificial price level in the product market. This allows maximal impact on efficiency as consumer surplus is effected by reduced output due to monopoly activity in the product market, in addition to the impact on producer surplus of the "wrong" firms producing. Treatment III results indicate efficiency loss is minimized if the fringe firms are allocated all permits In this treatment, the allocation of permits to the fringe deters the dominant firm from attempting to exclude the fringe in the product market The direct cost incurred in obtaining the number of permits required to exclude and the indirect effect such purchases would have on the price of permits combine to make such activity unprofitable, thus the dominant firm concentrates on cost minimizing behaviour The majority of the resulting loss in efficiency is caused by losses in potential producer surplus when social cost of abatement increases as the "wrong" firms produce and abate. The results also indicated underproduction which also reduced efficiency.

When exclusionary manipulation is attempted in Treatment IV, reductions in system efficiency are substantial, as indicated by the efficiency ratios reported. Further, the efficiency indices reported show that resultant loss in efficiency due to such behaviour is between 0.77 to over twice the potential gain the adoption of a competitive permit and product market could obtain over the command and control circumstances. Institution of a tradable permit market in this circumstance leads to results *worse than those initially present under the command and control allocation*. The fear some policy-makers have about market power distortions on potential permit institutions seems to be supported here.

VI. Conclusion

This experiment indicates that emission permit trading markets may be more susceptible to market power effects than previously believed. We used a trading institution with a strong history of competitive outcomes in the laboratory. Instead of reinforcing this result, we were repeatedly able to identify opportunistic behaviour by firms with market power. This seems to have been achieved by adding details common to naturally occurring economies: uncertainty and information asymmetries. The uncertainty arises from the existence of the sequential environment in which actions must be taken requiring information of the future and therefore expectations to be formed about future events. Further, the dominant firm has been furnished with information about rival's costs and market demand Such information may be available to firms in naturally occurring economies Experimentalists have been hard-pressed to identify successful use of market power by a dominant firm in the laboratory predicted by the simplest models given the double auction institution used here. Prior to this study, no evidence has been found of more complex forms of strategic behaviour in the laboratory. The structure of pollution permit markets would seem to facilitate predation through exclusion. Exclusionary behaviour was identified when the experimental firm was faced with this opportunity as a profit maximizing strategy (Treatment IV). Simple manipulation of the permit market by a dominant firm was also identified in a number of treatments. Further, the subject firm was able to determine which type of behaviour was more profitable in both cases when either strategy could have been pursued (Treatment III).

The theoretical benefits of transferable emission permit markets have been espoused for years. The reductions in the social costs of pollution control and their inherent effects on market efficiency promised by such programs are very appealing. The method of allocation of permits has not often been discussed since under the assumption of perfect competition it doesn't matter. Admitting the possibility of simple (cost minimizing) or exclusionary strategic manipulation of permit markets however causes the independence between initial allocation and final holdings to break down. With a causal link between initial holdings and final allocation, efficient permit allocation by market mechanisms cannot be guaranteed.

From our results it would appear that strategic manipulation of markets was most damaging to system efficiency when the dominant firm was in a vertically related market (those in Treatments III and IV) and allocated with more permits than it needed (Treatment IV) In the latter case, the dominant firm was able to hoard permits to profitably exclude its rivals This initial allocation reduced market efficiency on average by almost one and a half times the efficiency gain such markets could achieve in competitive conditions In this experiment, the dominant firm's competitors were other existing yet smaller firms. They could just as easily have been new entrants to the market. When permits are grandfathered to large existing firms the ability to exclude rivals and new entrants would seem a very real problem. Such allocation mechanisms have been used for existing programs and suggested for a number of others[24]. The evidence here suggests before such schemes are adopted the structure of the existing product markets affected should be scrutinized. Further, even when the dominant firm was allocated none of the available permits, there was no instance of an efficiency gain in vertically related environments. Simply put, this evidence suggests that the effect of market power is not minimal to system efficiency as some authors have suggested but on the contrary, could be very serious. Policy-makers worried about the effect of thin markets or market power may not be being overly cautious. These concerns may indeed be well-founded.

Acknowledgements

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[24] Such was the case in the Clean Air Act of 1990 in the emission market for sulfur dioxide and it has been suggested in a plan for the control of NOx in Southern Ontario (Nichols (1992))

Appendix

Simple Manipulation

Consider the case of J polluters located in a particular region emitting a uniformly mixed assimilative pollutant. Let $\overline{A}$ describe the total amount of emissions allowed in a specific region in a given period and let N be the supply of permits in the market. Each firm is initially endowed with q_j^o permits which can be traded at a market clearing price P The number of permits actually used by the firm after trade can be defined as

$$q_j = q_j^o + n_j \ .$$

Note net quantity demanded of the firm, n_j, may be positive or negative.

Abatement costs are a function of pollution reductions made by the firm, where the level of reductions required is determined by the number of permits held after trade. Therefore we define abatement costs as a function of the number of permits held after trade

$$C_j(q_j) \ .$$

Marginal abatement costs are assumed positive and increasing in abatement effort, thus they are decreasing in q_j Marginal benefit to the firm of a permit is the effect it has on abatement costs

If trading occurs in a perfectly competitive manner, efficient allocation of reductions and minimized social cost have been shown to arise for a given level of aggregate pollution reduction mandated by a central authority The efficient solution results when marginal abatement costs across all firms equals P. The market induced allocation changes however, if one or more firms realize that the market price P is a function dependent on their actions in the market and act using this knowledge to maximize profit (minimize costs). Specifically, the price function is the supply (demand) function of the price-taking firms in the market. Assume that there is only one price setting firm,[25] firm 1, that recognizes market price is sensitive to the total number of permits it buys (or sells). Firm 1's total cost (or revenue if a net seller) from permit transactions is

$$n_1 P = (q_1 - q_1^o) P(q_1),$$

therefore its marginal cost (revenue) of buying (or selling) another permit is

$$\frac{\partial n_1 P}{\partial q_1} = P(q_1) + (q_1 - q_1^o) P'(q_1)\ .^{26}$$

Setting this function equal to marginal benefit the dominant firm receives from permit acquisitions, that is the marginal cost of abatement, we find that the market solution will differ from the result found when markets are competitive. Marginal abatement costs will not be equal across firms. Marginal cost (revenue) exceeds price when $q_1 > q_1^o$ (firm 1 is a net buyer) and is less than price when $q_1 < q_1^o$ (firm 1 is a net seller) since $P'(q_1)$ is positive with respect to firm 1's holdings.[27] Firm 1 is buying too few (selling too few) permits and spends too much (little) on abatement.

[25] Alternatively, this firm could be a group of smaller firms, each with minimal market power acting as a cartel

[26] Note that when the initial allocation is the cost effective allocation, that is, when this firm has no incentive to trade, the marginal value of a permit to this firm is equal to the price, thus market power will have no effect only when the initial allocation is efficient

[27] Price is increasing in the market with respect to the number of permits firm 1 buys as total market demand increases when firm 1's demand for permits increases, while supply of permits remains fixed at N

Finally, it should be noted that a firm need not have complete monopoly or monopsony power to reap the benefits of market manipulation of the type described here. Sufficient conditions for such manipulation to be practicable are only that $P' > 0$ and the firm's marginal cost of abatement differ from the market price at the initial allocation of permits.

Exclusionary Manipulation

Consider the firm from the previous analysis, which has power in the permit market because it is the largest firm in an industry in which it and a competitive fringe of smaller firms are the major source of pollutants. Assume there is a clear cost advantage to producing in the region that is regulated by the permit market in question for reasons mentioned above. Because the large firm believes it can influence permit prices, it also must believe it can influence its rival's production costs through these prices.

This firm's optimization problem, following Misiolek and Elder (1989), is

$$\max_{\{P_p,\, q_1\}} \quad \pi = P_p Q_1 - C_p^1(Q_1, q_1)$$

$$\text{st.} \quad Q_1 = D(P_p) - S(P_p, P)$$
$$P = P(q_1)$$

This is the standard dominant firm model problem where here P_p is the market price of the product produced in the industry under consideration, Q_1 is the output level of the dominant firm and denoted, as in the previous section, by the subscript 1 Q_1 is determined by the residual demand of the industry, found by horizontally subtracting the supply of the fringe $S(P_p, P)$ from market demand. Supply of the fringe is upward sloped with respect to product market price and shifted inward by increases in permit prices P, implying an outward shift of the residual demand curve. Total costs the dominant firm incurs in production, C_p, include abatement costs which are negatively related to permit holdings after trade, as described previously.

A sufficient condition identified by Salop and Scheffman (1987) for the dominant firm to profit from raising rival's costs is that the upward shift in the residual demand curve be greater than the increase in its average costs C_p^1 / Q_1, evaluated at some given output level in the product market[28]

Since a permit purchase is spread over the total output of the dominant firm and decreases abatement costs, the effect on average costs may be very small. The sufficient condition under which a dominant firm could influence rival's costs may be easily met, especially if product market price is sensitive to permit purchases by this firm.

[28] Misiolek and Elder (1989) provide the conditions for this model

REFERENCES

Bjornstad, D.J , Elliott, S.R., Hale, D.R., "Understanding Experimental Economics and Policy Analysis in a Federal Agency: the Case of Marketable Emissions Trading," Typescript.

Cronshaw, Mark B.; Brown Kruse, Jamie. (1992). An Experimental Analysis of Emission Permits with Banking and the Clean Air Act Amendments of 1990 University of Colorado, Department of Economics.

Dales, J. H , *Pollution, Property and Price,* University Press, Toronto, 1968.

Eheart, J. W., "Cost Efficiency of transferable discharge Permits for the Control of BOD Discharge," *Water Resources Research,* 1980, Vol. 16, pp. 263-270.

Eheart, J.W., Joeres, E.F., David, M.H., "Distribution Methods for Transferable Discharge Permits," *Water Resources Research,* 1980, Vol 16, pp. 833-843.

Franciosi, R.; Isaac, R. Mark; Pingry, David E ; Reynolds, Stanley S. (1993a). An Experimental Investigation of the Hahn-Noll Revenue Neutral Auction for Emissions Licenses. *Journal of Environmental Economics and Management* 24, 1-24

Friedman, D. and Sunder, S., Experimental Methods: A Primer for Economists , Cambridge University Press, 1994.

Godby, R., Mestelman, S., Muller, R. A., Welland, D , "An Experimental Analysis of Emissions Trading with Shares and Coupons in the Presence of Effect of Market Uncertainty," forthcoming in *Environmetrics,* (1994)

Hahn, R.W., "Market Power and Transferable Property Rights," *Quarterly Journal of Economics*, 1984, Vol. 99, pp. 753-765.

Hahn, R.W., "Economic Prescriptions for Environmental Problems: How the Patient followed the Doctor's Orders," *Journal of Economic Perspectives*, 1989, Vol. 3, No. 2, pp 95-114

Holcombe, R.G , and Meiners, R.E., "Corrective Taxes and Auctions of Rights and Control of Externalities," *Public Finance Quarterly*, 1980, Vol. 8, pp 345-349.

Holcombe, R.G , and Meiners, R.E , "Corrective Taxes and Auctions of Rights and Control of Externalities A Reply," *Public Finance Quarterly*, 1981, Vol 9, pp. 479-484

Isaac, R.M , and Smith, V L., "In Search of Predatory Pricing," *Journal of Political Economy*, 1985, Vol 93, pp 320-345

Krattenmaker, T.G., and Salop, S.C., "Competition and Cooperation in the Market for Exclusionary Rights," *American Economic Review Papers and Proceedings,* 1986, Vol. 76, pp. 109-113.

Lyon, R.M., "Auctions and Alternative Procedures for Allocating Pollution Rights," *Land Economics,* 1982, Vol. 58, pp. 129-152.

Mestelman, S.; Moir, R.; Muller, R.A. (1994). Emissions Trading With Shares And Coupons: A Laboratory Test Of Canadian Proposals. McMaster University, Department of Economics. Forthcoming in A Volume on Emission Permit Trading, C. Holt and R. M Isaac, editors Westview Press: Boulder.

Misiolek, W.S. and Elder, H.W., "Exclusionary Manipulation of Markets for Pollution Rights," *Journal of Environmental Economics and Management,* 1989, Vol. 16, pp. 156-166.

Muller, R. Andrew; Mestelman, Stuart (1994) Emission Trading with Shares and Coupons: A Laboratory Test. *Energy Journal* 15(2), May 1994.

Montgomery, W. David, Markets in Licenses and Efficient Pollution Control Programs, *Journal of Economic Theory,* 1972, vol. 5, pp. 395-418.

Nichols, Albert L. (1992). Emissions Trading Program for Stationary Sources of NOx in Ontario. Cambridge, MA: National Economic Research Associates.

Oates, W.E., "Corrective Taxes and Auctions of Rights in the Control of Externalities: Some Further Thoughts," *Public Finance Quarterly,* 1981, Vol. 9, pp. 471-478.

Plott, C.R., "Externalities and Corrective Policies in Experimental Markets," *the Economic Journal,* Vol. 93, 1983, pp. 106-127.

Sartzetakis, E.S., "Emissions Trading Under Imperfect Competition in Both the Emission Permit and the Product Market," Carleton Industrial Organization Research Unit, Department of Economics, Carleton University. 1992.

Sartzetakis, E.S , "The Use of Emission Permits in Deterring Entry in the Product Market," Carleton University and GREEN, Department of Economics, Carleton University 1993

Salop, S.C , and Scheffman, D T., "Raising Rival's Costs," *American Economic Review Papers and Proceedings,* Vol 73, 1983, pp 267-271

Smith, V L , "An Empirical Study of Decentralized Institutions of Monopoly Restraint," from Essays in Contemporary Fields of Economics, edited by Horwich, G and Quirk, J , Purdue University Press, 1981, pp 83-106

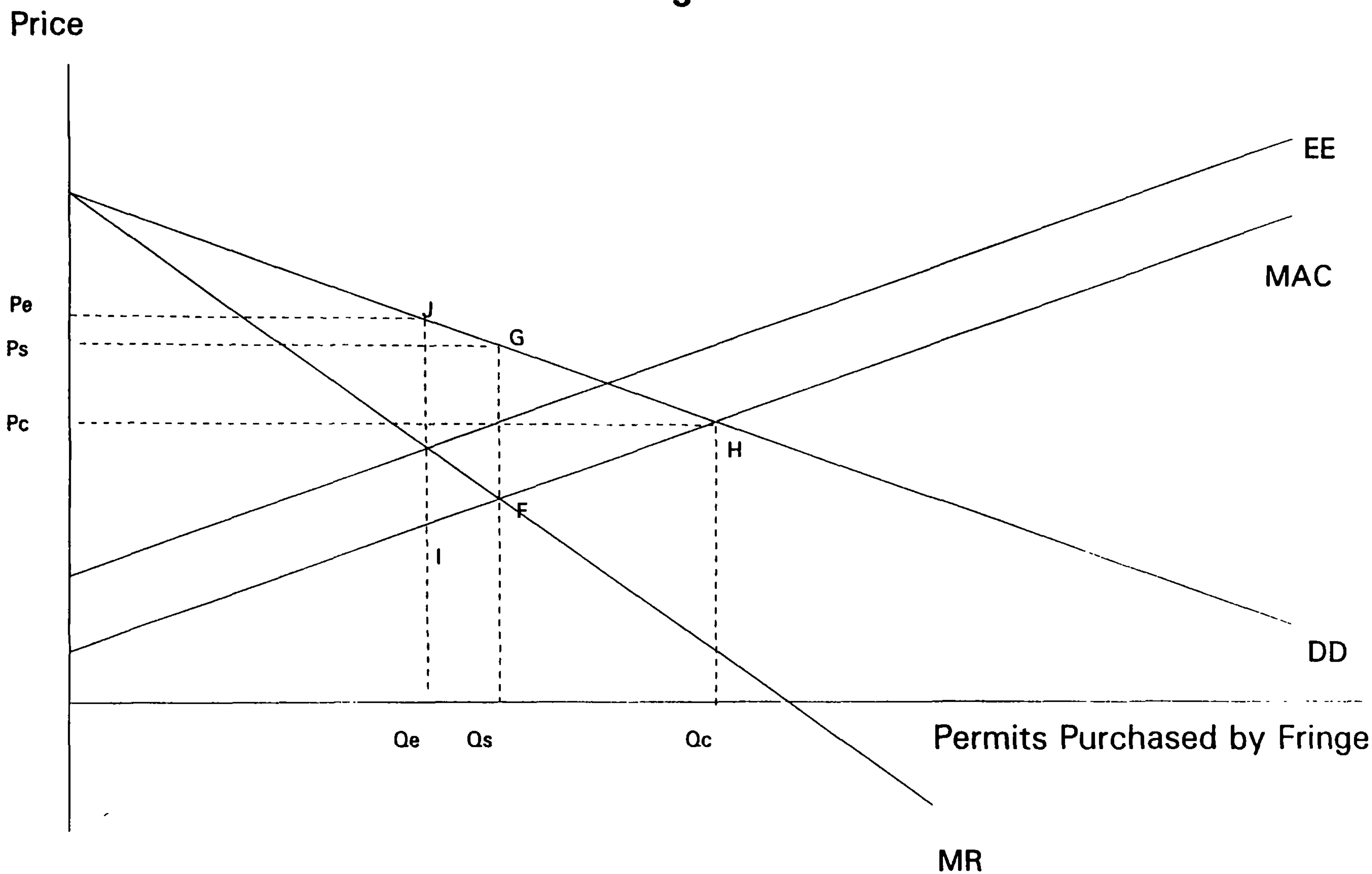
Tietenberg, T., "Transferable Discharge Permits and the Control of Stationary Source Air Pollution: A Survey and Synthesis," *Land Economics*, 1980, Vol. 56, pp. 391-416.

Tietenberg, T. (1985). *Emissions Trading: An Exercise in Reforming Pollution Policy.* Washington, D.C.: Resources for the Future.

Williams, A.W., "Computerized Double Auction Markets: Some Initial Experimental Results," *Journal of Business*, 1980, Vol. 53, pp. 235-258.

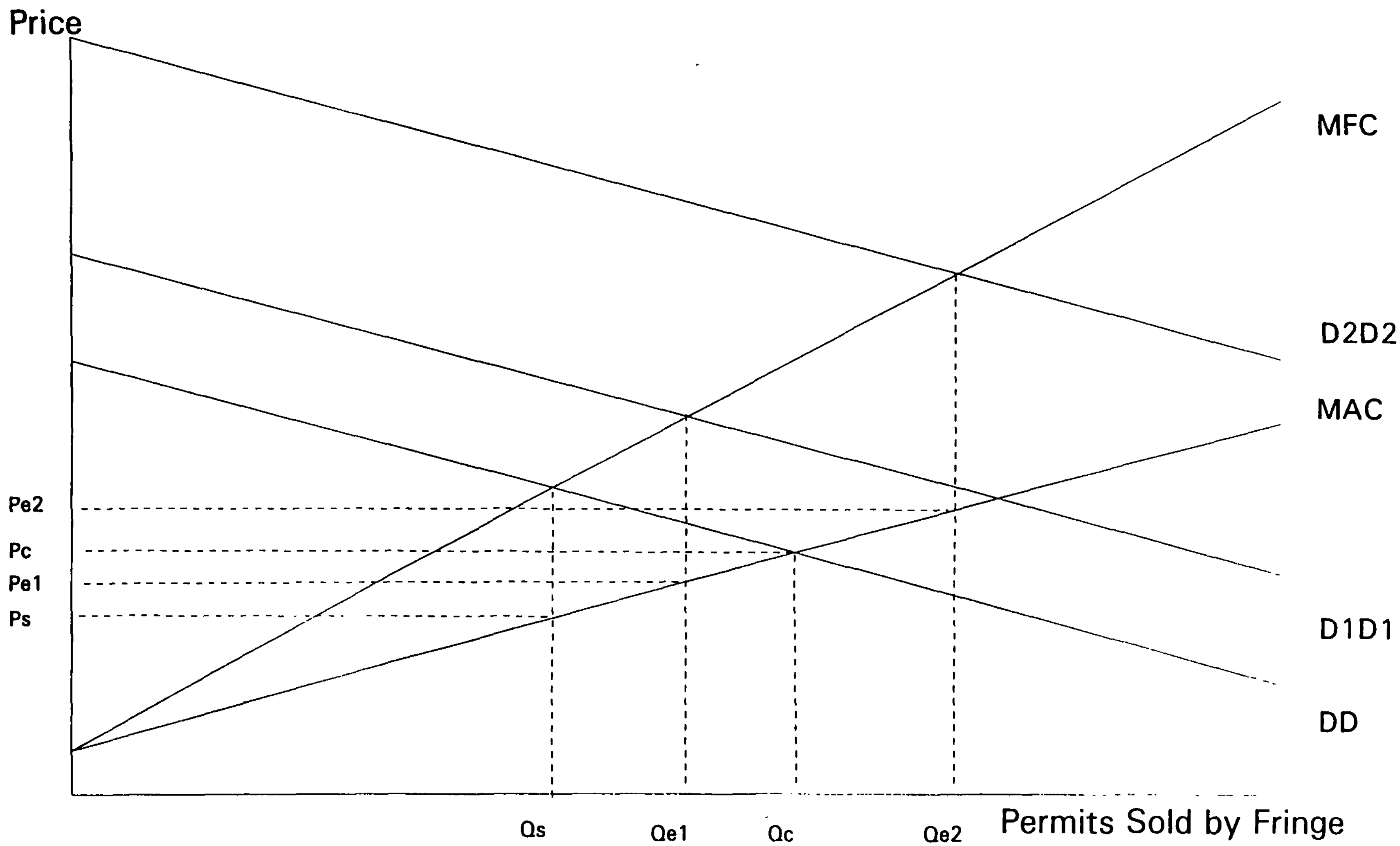
Wilcoxon, F., "Individual Comparisons by Ranking Methods," *Biometrics*, 1945, Vol. 1, pp. 80-83.

Figure 1



Price
EE
MAC
Pe
J
Ps
G
Pc
H
F
I
DD
Qe
Qs
Qc
Permits Purchased by Fringe
MR

Figure 2



Price
MFC
D2D2
MAC
D1D1
DD
Pe2
Pc
Pe1
Ps
Qs
Qe1
Qc
Qe2
Permits Sold by Fringe

Table 1: Summary of Predicted Effects on Permit Market Price Due to Strategic Manipulation*

Dominant Firm: Market Role	Cost Minimizing Manipulation	Exclusionary Manipulation	Net Effect
Net Seller	increasing	increasing	increasing
Net Buyer	decreasing	increasing	undetermined

* Relative to efficient (competitive) prediction.

Table 2: Laboratory Firm Costs

	Marginal Production Costs	Marginal Abatement Costs
Fringe Firms		
Firm 1	45	36
Firm 2	45	75
Firm 3	40	115
Firm 4	35	155
Firm 5	30	195
Firm 6	25	235
Firm 7	20	275
Firm 8	15	315
Firm 9	10	355
Firm 10	5	395
Dominant Firm (Production Unit)		
1	15	45
2	15	65
3	15	85
4	15	105
5	15	125
6	15	145
7	15	165
8	15	185
9	15	205
10	15	225

Table 3: Experimental Design

		Allocation: Fringe	Allocation: Dominant
P-Market Price	P=125	Treatment 1	Treatment 2
	Market Determined	Treatment 3	Treatment 4

Figure 3: Competitive Product Market with Efficient Permit Allocation

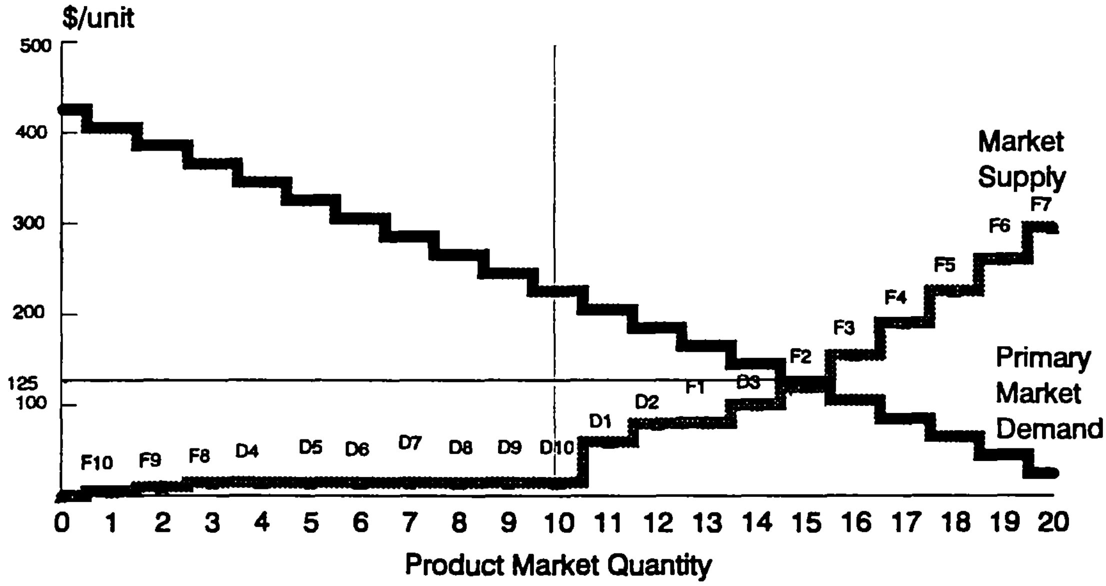


Table 4. Theoretical Predictions

	Permit Price* (C-Mkt.)	Final Permit Holding Fringe: Dominant	Production Fringe: Dominant: Total	Product Price* (P-Mkt.)
Efficient Outcome	105	3:7	5:10:15	125
Efficient Coupon Mkt. Dominant Firm P-Mkt.	120	4:6	6:8:14	145
Treatment I Allocation: Fringe	90	6:4	8:8:16	125
Treatment II Allocation: Dominant	110	3:7	5:10:15	125
Treatment III Allocation: Fringe	75	8:2	10:4:14	145
Treatment IV: Allocation: Dominant	180	1:9	4:8:12	185

* all prices are given in Lab Dollars

Table 6: Calculated Efficiency Indices by Treatment

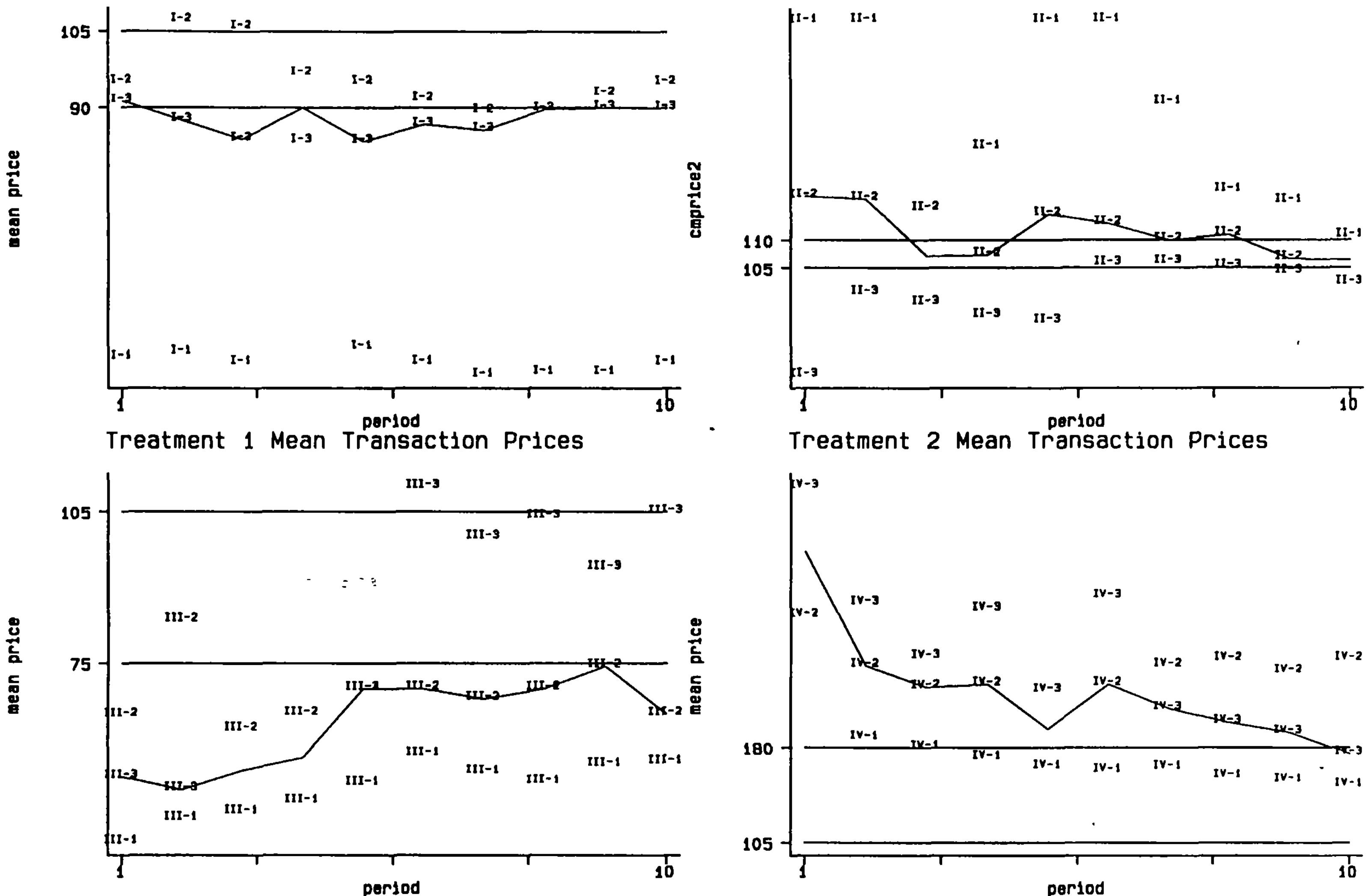
Treatment	Calculated Efficiency Index
I	0.71
II	0.96
III	-0.42
IV	-1.40

Table 5 **Experimental Results by Treatment**

	License Price	Final License Holding: Fringe	Final License Holding: Dominant	Production Fringe	Production Dominant	Total Production	Product Price
Treatment 1							
Prediction*	105	3	7	5	10	15	125
Prediction**	90	6	4	8	8	16	125
Mean Observation	86.64	7.133	2.867	8.533	6.500	15.033	
Standard Deviation	19.534	1.756	1.756	1.279	1.961	1.189	
Treatment 2							
Prediction*	105	3	7	5	10	15	125
Prediction**	110	3	7	5	10	15	125
Mean Observation	124.75	2.833	7.167	5.033	9.500	14.533	
Standard Deviation	55.83	1.440	1.440	1.273	0.900	1.008	
Treatment 3							
Prediction*	105	3	7	5	10	15	125
Prediction**	75	8	2	10	4	14	145
Mean Observation	64.43	8.065	1.935	8.871	3.483	12.354	177.903
Standard Deviation	19.927	1.124	1.124	0.806	1.313	1.427	28.542
Treatment 4							
Prediction*	105	3	7	5	10	15	125
Prediction**	180	1	9	4	8	12	185
Mean Observation	206.68	2.233	7.767	6.000	6.367	12.367	177.667
Standard Deviation	61.698	1.569	1.569	1.287	1.712	1.450	28.998

*** Prediction under perfectly competitive assumptions**
**** Prediction under market power assumptions**

Figure 4



Treatment 1 Mean Transaction Prices

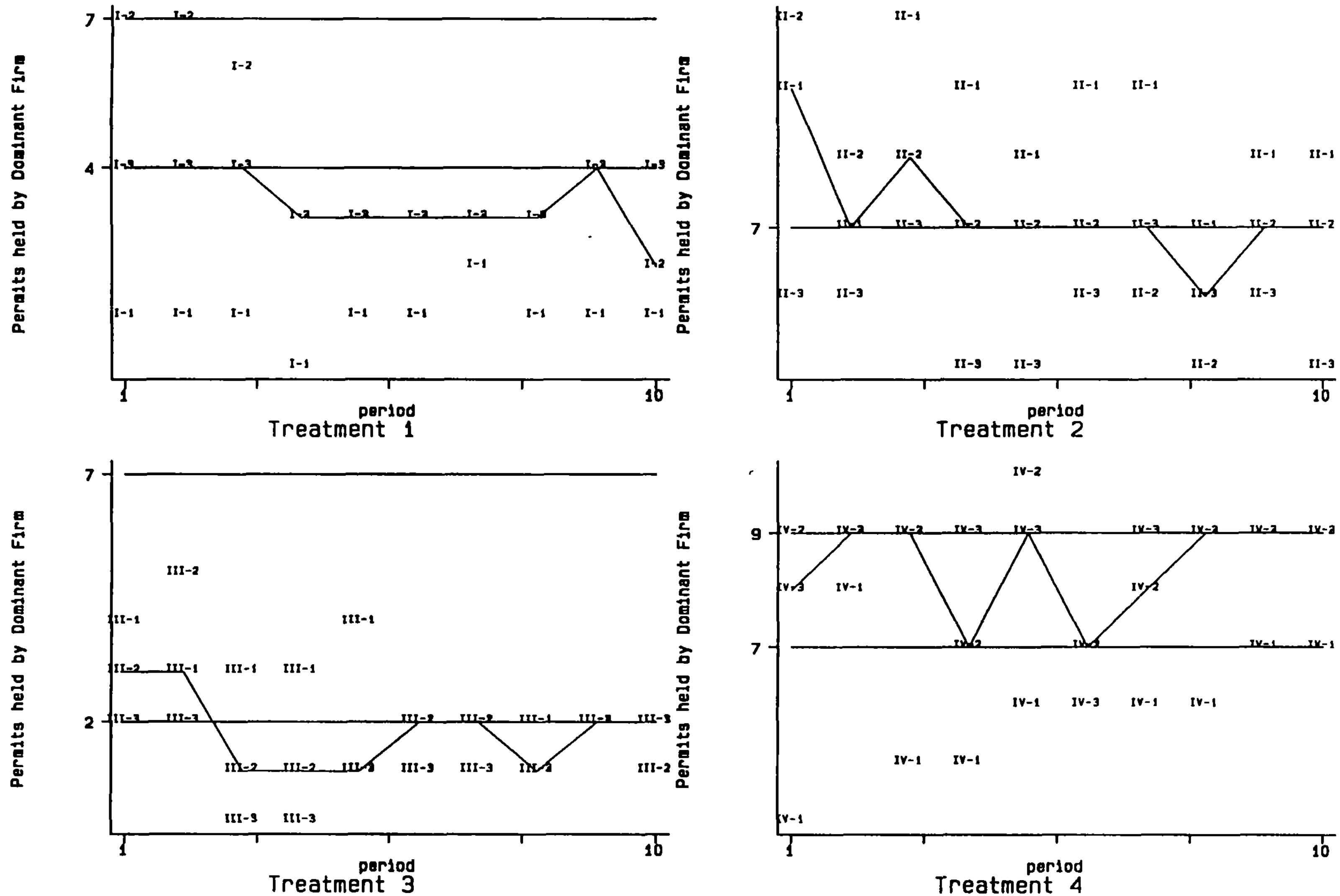
Treatment 2 Mean Transaction Prices

Treatment 3 Mean Transaction Prices

Treatment 4 Mean Transaction Prices

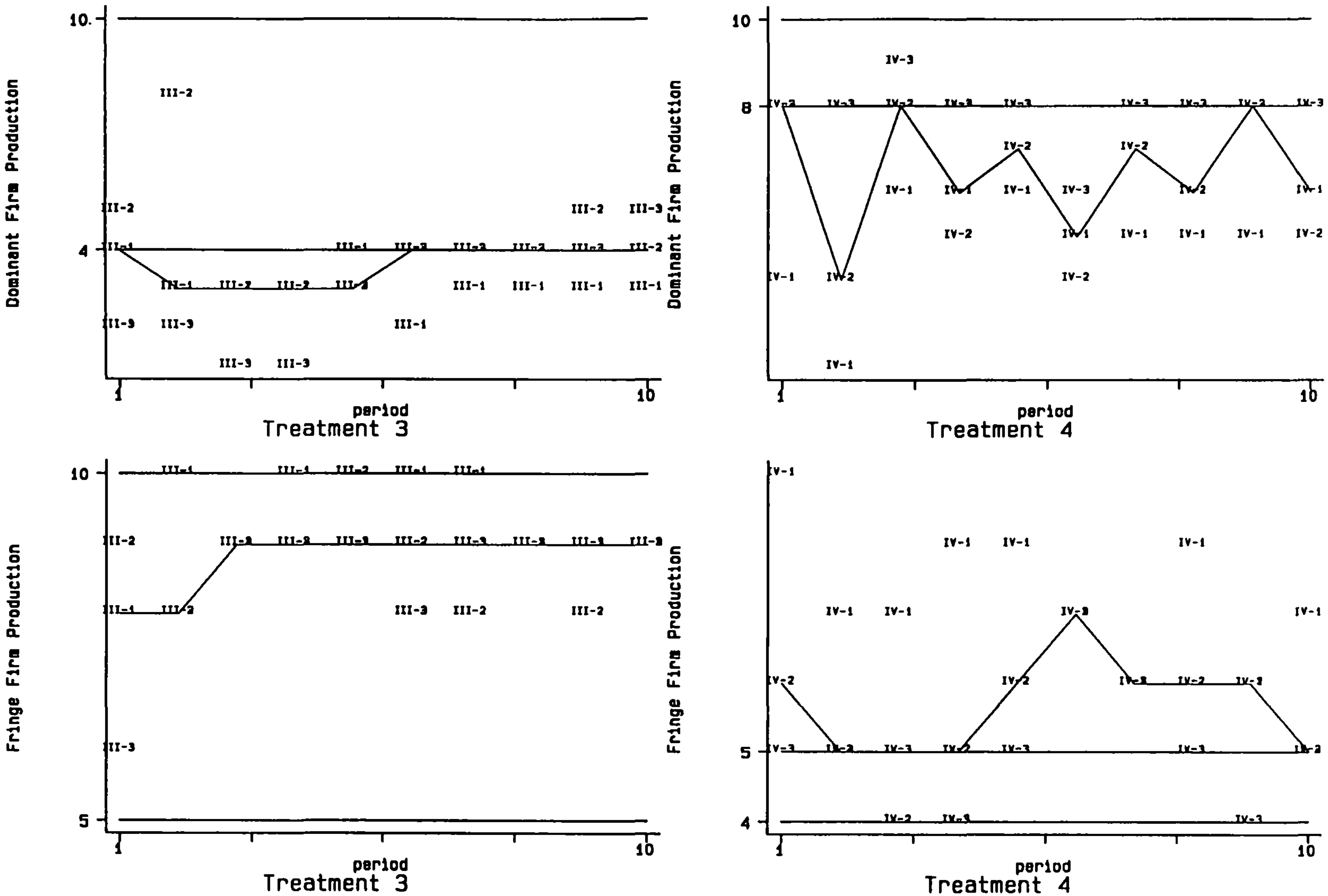
Mean Transaction Prices by Treatment

Figure 5



Permits held by Dominant Firm (Post-trade)

Figure 6



Production by Firms, Treatments 3 and 4

Figure 7 **Calculated Session Efficiency Indices**