THE EFFECT OF MARKET POWER IN EMISSION PERMIT MARKETS

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Abstract

Emission permit markets are being actively implemented as a regulatory method to control various types of pollution in the United States because of the potential efficiency improvements they offer. In Canada, regulators have been more cautious, frequently citing concern that proposed Canadian markets are expected to be thin and/or dominated by a single firm. In these circumstances, such a firm could manipulate prices to reduce its own emission control costs while increasing the total cost of pollution control across the market. Such activity might also cause emission permit markets to be viewed as unviable on efficiency and equity grounds. This thesis investigates the potential problems such markets might experience if one firm (or a group of firms) has the ability to manipulate market prices to their advantage. Given the lack of empirical data, experimental economic methods are used in an attempt to determine whether it is reasonable to assume violations of the basic competitive market assumptions should be expected to seriously undermine the efficiency benefits emission permit markets offer in a controlled setting.

The experiments reported here show that in double auction markets with one dominant firm and a number of fringe firms, strategic manipulation occurs repeatedly in the laboratory. The dominant firm uses emission permits in a socially inefficient manner in order to reduce its costs, increase its profits and exclude rivals in downstream product markets. Far from finding increased market efficiency and decreased cost of pollution control, this study confirms that implementing permit markets when there are firms with market power may decrease efficiency. The resultant loss in gains from trade could also reduce the political viability of emission trading programs.

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A number of people made this thesis possible. Each was responsible in their own way for ensuring I had the support, guidance and reassurance necessary to finish this work over the four years it took to complete. My supervisors were often patient when they need not have been and generous when generosity was not deserved. I disappointed them more than once by choosing to ride my bicycle instead of working, yet when I needed their help they were always available. My parents provided me with the means to hide from the real world long after they needed to. I hope by finishing this I have made them proud. Jenn was always there when I needed someone. I know the personal sacrifices she made to see this through were equal to mine.

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Chapter 1

Introduction

Markets for transferable pollution rights have been used in varying forms and with varying degrees of success in the United States since the late 1970's. They are an integral part of the Acid (rain) Deposition Control of the Clean Air Act Amendments of 1990. More recent environmental policy initiatives in the United States have further incorporated decentralized market mechanisms as a means of achieving regulatory goals while minimizing social costs. In Canada, regulators have been more cautious, frequently citing concerns regarding the exercise of market power because proposed Canadian markets are often expected to be thin and/or dominated by a few or single firms. In these circumstances, a single firm could manipulate prices to reduce its own emission control costs while increasing the cost of pollution control across the market. Such fears may cause emission permit markets to be viewed as unviable on efficiency and equity grounds. In one proposed market for nitrogen oxides (NO_X) in southern Ontario, this concern is especially relevant as a single firm is estimated to account for over half of total emissions.[1] Further, emission markets may also be regarded as riskier than traditional methods of pollution control because they do not specifically regulate polluter behaviour.

The question of pollution regulation as a social and economic issue is not new. In the past two decades economists have focused increasing attention on market based forms of regulation as a possible alternative to those historically used, although the origins of markets as a means of controlling market externalities date back to the 1920's.[2] Dales

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[1] See Nichols (1992). Ontario Hydro is estimated to account for 56% of total NO_X emissions.

[2] The idea of using the market to control for externalities dates back to at least Pigou (1920).

(1968) first considered tradable rights as a means of pollution control. Montgomery (1972) formally characterized such markets in a competitive environment. In general, little adoption of these ideas has taken place.[3] The majority of pollution regulation world-wide is done using more traditional "command and control" methods which legislate compliance by source to government imposed standards. As noted above, recent environmental policy initiatives in the United States and Canada have incorporated or suggested decentralized mechanisms.[4] The most obvious of these in the United States have been the SO_2 trading program implemented by the Clean Air Act and the RECLAIM market in the Los Angeles Basin.[5] In Canada, an emission trading market for control of methyl bromide was to be implemented January 1st, 1995, and recent provincial and federal government proposals have suggested the adoption of emission markets for a variety of other pollutants.[6]

The theoretical benefits of using transferable pollution rights markets are well known and extend beyond minimizing control costs.[7] They are predicted to reduce informational burdens for regulators and provide potential incentives to those involved to adopt cleaner technologies. Additionally, by leaving to firms the decision of when, where and how to reduce emissions, the bureaucracy required to administer, monitor and enforce pollution regulations is reduced relative to traditional methods. "Command and control", based on source-specific legislated maximum emission levels using acceptable or desired environmental benchmarks, will only minimize control costs if these levels are within the

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3 For a description of programs up to the mid 1980's, see Hahn (1989).

4 In Europe, charges or taxation has been used as a decentralized means of controlling pollution. See Grafton and Flanagan (1995) or Hahn (1989).

5 See Millington Campbell and Holmes (1994) for a description of the EPA market and Carlson and Sholtz (1994) for description of markets in Southern California.

6 See CCME (1992), NRTEE (1993), and Nichols (1992). The market for methyl bromide is described in the Ozone Depleting Substances Regulations-Amendment, Canada Gazette, Part 1, August 27, 1994. No information was available on the actual implementation at the time of writing.

7 See Tietenberg (1985) for a complete overview.

potential set of market solutions after competitive trade. Put another way, if a market-based regulatory method were instituted in place of command and control, there would be no economic incentive for any of the emitters involved to trade if the previous system had been minimizing system-wide pollution control costs. Traditional regulatory methods also often employ incentive-incompatible mechanisms for information revelation, increasing the cost of regulation and provide few incentives for the adoption of "cleaner" technologies.[8] They also involve considerable bureaucratic constraint of the potential pollution reduction alternatives available to firms. Using such regulatory means could also come into conflict with economic growth, as assignment of source specific standards requires a tradeoff between economic growth and aggregate emissions ceilings.[9]

The potential control cost benefits of emission permit markets are very difficult to establish while under command and control. After implementation of permit trading programs, such estimates are also open to debate for a number of reasons. Among these, the most significant is uncertainty.[10] Perfect foresight is impossible and hindsight is not always clear. Estimates of future cost savings can at best provide only possible cost saving ranges, while estimates of past program successes require knowledge of the opportunity costs of the possible alternative actions and those taken. Potential and realized cost savings estimates may be inflated as they do not account for the increased

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[8] For example, in Ontario's CAP program, three types of standards were applied depending on the pollutant type. Class 1 pollutants had to achieve "lowest achievable emissions rates" (LAER). Class 2 pollutants had to achieve "best available control technology economically achievable" (BACTEA) requirements, while Class 3 pollutants were required to meet "new source performance standards" (NSPS). It was up to the applicant to provide all information on available control technologies, their cost and cost effectiveness. Competitive output markets and sufficient penalties for non-compliance created incentives for firms only to meet imposed standards and none to exceed them as there were no benefits the firm could capture for doing so outside of intangibles such as better public image. See Nichols (1992).

[9] Assuming new sources do not require existing sources to reduce their emissions. Early EPA standards, introduced in 1975, allowed new sources locating in areas not meeting emissions standards (non-attainment areas) the opportunity to negotiate reductions at other sources, or "offsets", greater than that which they planned to emit. Such opportunities allowed economic growth to occur in conjunction with reduced emissions. Such programs could be viewed as a very limited form of emissions right trading. See Hahn (1989).

[10] See Carlson and Sholtz (1995) for a discussion.

uncertainty due to imperfect future knowledge faced by firms in a trading environment. If trading imposes an uncertainty cost that was not present prior to trade implementation, the actual benefits of trading will be lower than those estimated.[11] Nevertheless, and even with consideration of such cautions, published control cost reduction estimates, both possible and realized, have been substantial. Cost savings estimates made by Tietenberg (1985) for the re-allocation of emission rights offered by emission trading were as high as 90% in some of the potential markets he considered.[12] Actual cost saving estimates for early programs in the United States which allowed limited forms of emission rights trading ranged from $525 million to $12 billion.[13] Estimates for the RECLAIM market prior to its implementation in southern California claimed potential annual emission reduction costs savings of 42%, saving $57.9 million per year.[14] Current EPA estimates indicate SO_2 trading under the Clean Air Act rules have reduced control costs by 50%, saving $2.5 billion.[15] While such estimates may cause some to view emission permit markets with considerable optimism, they should be regarded as estimates only. The Fox River Program in Wisconsin was estimated to offer potential annual cost savings of up to $7 million per year yet only one trade was ever made.[16]

The theoretical case for emission trading in competitive markets is well understood. It is less well established when markets are less than perfectly competitive for structural or other reasons. Two potential (and related) problems are posed by market power and thin

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[11] Adjustment for such uncertainty is impossible in the practical sense. Uncertainty may also be present in markets where "backstop provisions" made at the time of implementation allow for adjustments to be made in the program after introduction as deemed necessary by regulators. Markets without such backstop provisions may have even greater uncertainty risk if, for example, it is believed by some or all participants some non-zero probability exists that the market could be terminated on relatively short notice.

[12] See Tietenberg (1985), pp. 43-44.

[13] These were generated from programs allowing limited trade. See Hahn (1989) for a description of the trading allowed, and a tabulation of various savings estimates attributed to these trades.

[14] South Coast Air Quality Management District (AQMD), see Carlson and Sholtz (1995).

[15] *The Financial Post*, May 7, 1996, pg. 14.

[16] Hahn (1989).

markets. The first is the problem of market power and its potential effect on cost-savings. Distortions from market power may arise solely from conditions in emission permit markets, or may be the result of strategic manipulation by some participants in an attempt to secure market power in output markets where they and other emission market participants also compete.[17] As noted above, market power is (or should be) of considerable interest to Canadian policy-makers. The second problem is that of thin markets. A market may be termed "thin" if there are few participants and/or if there are few gains from trade available. Thin markets may be the cause of market power by allowing one firm in the market a dominant position and may be the symptom of an attempt to curb market power.[18] Existing American market experience sheds little light on these problems as programs have included many more participants than proposed Canadian markets would include, although the Fox River program may be the exception. It had relatively few potential traders given its design and those involved may have been part of an oligopolistic industry. Only one trade ever took place, but whether this was the result of the types of problems just mentioned or due to unusually restrictive trading rules is open to debate. Unfortunately, although its characteristics were relevant to Canada, the very limited insight available from only one transaction leaves its predictive value limited.

Institutions may be very important in determining whether market outcomes are influenced by the use of market power. It has been shown by Smith (1981) that utilizing different trading institutions can reduce the potential for the exercise of market power to occur in controlled markets. Thin markets may also increase transactions costs due to search if certain trading institutions are employed. The implications of market power and

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[17] See Misiolek and Elder (1989).

[18] If for example, initial trading right allocations are made to limit such a potential, they may result in only small gains from trade remaining in the market.

choice of trading institution have been considered by few in the emission trading literature.[19]

Given the lack of empirical data, experimental economic methods are used in an attempt to determine whether the violations of the basic competitive market assumptions, outlined above, seriously undermine the efficiency benefits emission permit markets offer in a controlled setting. Experimental methods are valuable complements to theoretic analysis and numerical simulation because theoretic methods may not be able to address certain questions and because mathematical and computer simulations of potential markets and possible trade outcomes are strongly dependent on the initial assumptions used to program them.[20] One aspect of laboratory experiments which is especially useful is their ability to investigate the relationship between market institutions and outcomes. Smith (1981) and Plott (1989) outline how several alternative market institutions can influence market outcome when investigated in a laboratory environment, a result for which no adequate theory exists. For example, experimental double auctions with only one seller have been shown often not to attain their predicted monopoly equilibrium and sometimes converge to competitive outcomes, while posted-offer markets usually result in the attainment of the monopoly prediction.[21] Since markets exhibit convergence processes which lack confident theoretic explanations, general economic theory can only describe resultant equilibria occurring after all trade takes place. Laboratory experiments allow observation of markets out of equilibrium and allow the researcher the ability to simplify markets to capture their salient features.

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19 See Ledyard and Szakaly-Moore (1994) for the only example.

20 In the context of emission trading, one recent simulation was completed by Mallory and Wilman (1995).

21 See Smith (1981).

Experiments, however, have their critics. A defense of experimental methods is not included here as examples can be found in numerous other sources and because their use has become accepted as a valid form of economic research.[22] Laboratory markets are real and economic principles should apply there as elsewhere. They are simple and special cases designed to capture only specific details of naturally occurring markets. If general theories are found not to apply in these special cases, their relevance in the field may be challenged or require additional modification. In the extreme, some theories may have to be rejected outright. Experiments may also provide an arena where competing theories may be compared to determine which appears more relevant. Lastly, the ability to explore the sensitivity of market outcomes to structural and institutional changes in the environment can be used to refine the design of proposed markets which do not yet exist.[23]

This thesis investigates the influence of market power on the performance of emission trading markets using a double auction trading institution. The central question investigated asks "Can market power be repeatedly detected in laboratory based emissions markets?". The structure of the thesis is as follows. Chapter 2 briefly outlines the general theory of externalities and how it applies to pollution regulation. It also indicates in general terms how three methods of pollution regulation; command and control, emission taxes and emission permit markets approach this problem and describes their resulting outcomes and efficiency properties. Chapter 3 mathematically characterizes the problem of market power in emission markets, both when it is pursued

[22] The reader may find the theoretic underpinnings and resultant defenses in Smith (1976), Plott (1989), Davis and Holt (1993), Friedman and Sunder (1994).

[23] Experiments have been used to evaluate market design in the allocation of airport landing slots, the EPA and RECLAIM emission markets among others. For descriptions of such experiments or their use, see Bjornstadt, Elliott and Hale (1995), Cronshaw and Brown Kruse (1992), Franciosi, Isaac, Pingry, and Reynolds, (1993a and 1993b), Godby, Mestelman, Muller and Welland, (1995), Hahn, (1988), Ledyard and Szakaly-Moore, (1994), and Muller and Mestelman (1994).

as a means of minimizing emission abatement cost and when it is used as a means of strategically manipulating competitor's costs in a common product market by a dominant firm. The general efficiency properties resulting from both types of manipulation are also described. This analysis extends that of Misiolek and Elder (1989) and also provides an outline of the solution method used to calculate the outcome in a specific market environment used in the following chapters. Chapter 4 describes a market experiment in which the implications of both types of manipulation described in Chapter 3 are tested to ascertain whether they have strong predictive power in a market characterized by a single dominant firm using the parameter set developed in Brown Kruse and Elliott (1990). A double auction trading institution is utilized, in which participants may only buy or sell, depending on their pre-defined market role. Although the double auction institution has shown some resistance to monopoly power outcomes in previous experimental settings, significant market power as predicted by the theories outlined in the previous chapters is detected.[24] Chapter 5 tests the sensitivity of the results reported in Chapter 4 to a structural change in the market. The smaller firms used in Chapter 4 (referred to as fringe firms) are doubled in size and their numbers cut in half. The double auction is also modified to allow all market participants to buy or sell at any time, provided they have the inventory to do so. Again market power is repeatedly found. Chapter 6 investigates the effect of substantially reduced potential trade gains in the trading environment used in Chapter 5 on the efficiency outcome; do the efficiency properties promised by a trading system in pollution rights emerge when there are thin markets? The thin market circumstances described in this chapter are generated by an initial trading rights endowment which allocates emission permits based on firm productive capacity (or historic emissions). The endowment process also creates no market power incentives for the dominant firm. Results indicate that in such circumstances, few of the potential

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[24] See Smith (1981) and Smith and Williams (1989).

trading gains are achieved. Chapter 7 summarizes the results of the three experiments and their implications for emission permit market design in circumstances where market power may be a potential problem.

Chapter 2

Pollution as an Externality

I. Introduction

In economics, pollution regulation and control can be viewed as a response to a form of market failure. Specifically, if actions are taken by agents engaged in market activities without proper consideration of the effects these activities have on other agents external to them, then the socially optimal amount of such activities may not occur. The "side effects" of market activity causing changes in utility, consumption or production are termed by economists as "externalities" and may be positive or negative.[1] Market failure occurs when the lack of consideration for these effects results in transactions and resultant resource allocations which do not reflect their highest use value. The existence of externalities, however, is not sufficient to generate market failure, as this result depends upon the type of externality encountered.

Externalities may be of two forms, pecuniary or technological.[2] A pecuniary externality is said to occur when market activity affects others outside that market yet still results in allocation based on willingness to pay. For example, increased demand for oil caused by a cold winter could cause oil prices to increase and result in higher gasoline prices. The higher gasoline price would likely be reacted to negatively by its purchasers, however, the resulting gasoline allocation would still be determined by the willingness of buyers to pay

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[1] An externality is said to be positive if it generates a net benefit to those external to the transaction which creates it. An externality is said to be negative if it generates a net cost to those external to the transaction which creates it.

[2] This follows the definitions used by Grafton and Flanagan (1995).

for it. A technological externality on the other hand, prevents the allocation of resources to their highest use value and therefore the ability of markets to allocate resources efficiently. Consider the use of coal as fuel at electrical generating stations. If utilities attempt to maximize profit, they will supply electricity to the market until the marginal revenue of the last unit of electricity sold is equal to its marginal cost of production.[3] In the absence of regulation, coal-fired power plants could pollute too much, relative to the social optimum and result in a mis-allocation of resources in the economy. This level of emissions is often termed the "uncontrolled level of emissions" and is the maximum amount of pollution such a plant would produce given current market conditions. The marginal cost recognized by the firm of producing electricity does not reflect the actual marginal cost to society because the well-being of those negatively affected by resultant emissions is not considered in the firm's production decision.

Often the problem of externalities is termed as one of "missing markets". If there existed mechanisms, such as additional markets, they could be used to induce reallocation of resources with consideration (implicitly or otherwise) of the impact of externalities. When allocation is made with the necessary consideration of these impacts, the externality is said to be fully "internalized" and the marginal social benefit of the activity generating the externality is equated to its marginal social cost.[4]

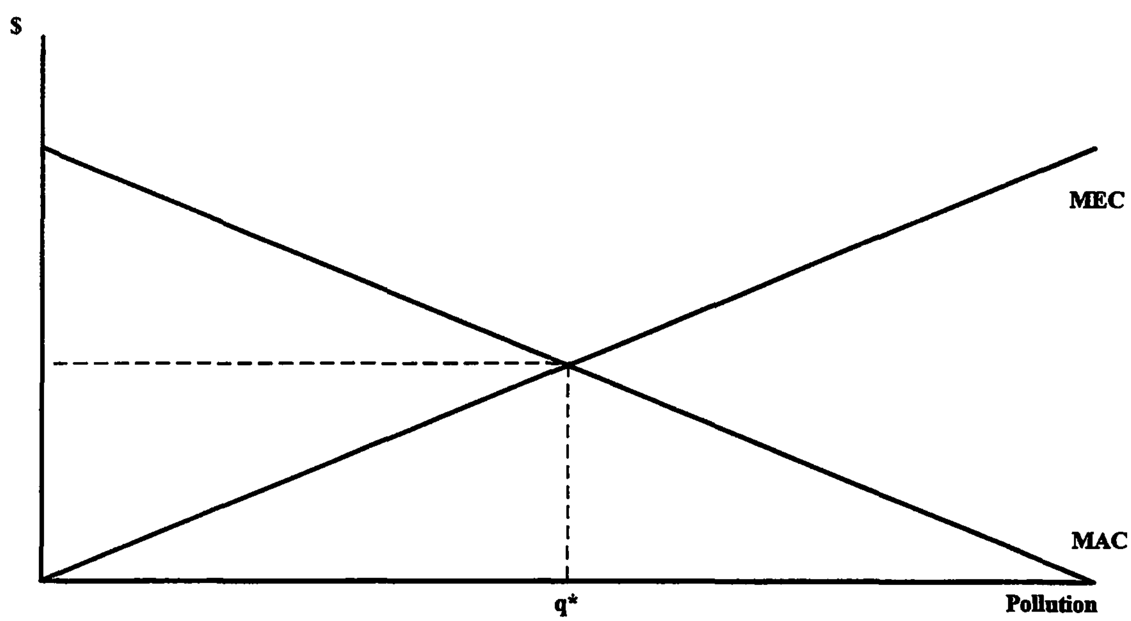
The socially optimal allocation of emissions may not be one which completely eliminates pollution, due to the benefits of the production activity responsible for them. It is defined as that occurring when the marginal externality cost (MEC) of a unit of pollution, equals the marginal cost of pollution abatement (MAC). This is illustrated in Figure 1. The

[3] Assume such utilities are not publicly regulated and for simplicity, though it isn't necessary, also assume markets for electricity are competitive.

[4] If an externality is positive, its marginal social benefit exceeds its marginal private benefit. If an externality is negative, the marginal social cost of the activity exceeds its marginal private cost

level of pollution occurring at this condition is efficient because resources are allocated to their highest use values and net benefits are maximized. This solution is also Pareto efficient as, given the initial wealth distribution, no re-allocation of resources is possible which makes any agent better off without making another worse. The MEC function may be constant or increasing with the level of pollution in the environment.[5] The marginal abatement costs (MAC) are considered because they measure the reduced benefit or increased cost in production per unit to control the emissions which cause the externality.[6] MAC is assumed to be increasing as level of pollution emitted is reduced, and equal to zero at the uncontrolled level of emissions. The optimal level of emissions is **q***.

Figure 1



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[5] MEC is derived as the vertical summation of all agent's individual externality costs associated with the pollutant. Note the MEC function is not decreasing with quantity because pollution is assumed to impose at least a constant cost per unit emitted.

[6] MAC is derived as the horizontal summation of all firm's marginal abatement cost functions (provided they are involved in producing the pollutant).

The conditions required to attain the socially optimal level of emissions using market mechanisms include zero transactions costs, complete and well-defined property rights and no other market failure. If these conditions hold, there will be no impediment to exchange allocating resources toward their highest use value. An externality which causes an inefficient allocation implies one of these conditions has been violated.

Reparation such that the externality is internalized can be done in numerous ways. Possibilities include mergers allowing those affected by externalities to be involved in the production decision which creates them, Coasian bargaining between the parties affected by externalities and those creating them, regulated standards like those used in command and control regulation, taxes, or the creation of new markets. For pollution, only the latter three methods are usually used. Mergers are often impossible due to the numbers of people affected by externalities and the numbers of firms emitting, while Coasian bargaining often carries very high transactions costs in negotiation. In the following, standards, permit markets and taxes are presented and their solutions compared.

II. The Regulation Problem

II.1 Source Specific Standards

Assume a policy maker would like to control the level of some airborne pollutant. For simplicity, assume this pollutant is a uniformly mixed assimilative pollutant.[7] This

[7] Such a pollutant has the following characteristics (as defined by Tietenberg (1985): (i) the environment has a large enough natural capacity to assimilate the pollutant such that the pollution level measured at any given time is a function of present emissions only and independent of emissions in previous periods, and (ii) ambient concentrations of emissions depends only on total emissions into the environment, not the distribution of emissions among sources. Where emissions sources are located does not affect pollution concentrations at any particular "receptor", or measurement location. This reduction greatly simplifies the problem. See Montgomery (1972) or Tietenberg (1985) for cases when the pollutant considered does not

allows the solutions presented to ignore any potential problems caused by accumulation of pollutants in the environment over time, and also assumes away problems of high ambient concentration in local areas within the regulated airshed. Making such an assumption is not out of place if the pollutant considered is something like greenhouse gas emissions.[8] The following borrows some notation from Tietenberg (1985).

Letting A be the steady-state level of emissions in a period, e_j the uncontrolled emission rate of the jth source, where j runs from 1 to J, and a the background or naturally occurring level of pollution present, the level of pollution in a given airshed can be expressed as

$$A = a + \sum_{j=1}^{J} e_j \qquad (1).$$

The regulator wishes to restrict the pollution level in the environment by limiting the pollution rates of all sources, such that total emissions are no greater than $\overline{A}$. This may or may not be equal to the socially efficient level of emissions as defined in Figure 1. The policy maker has some choice of methods at their disposal with which to bring reductions about. The usual method employed is commonly called the command and control approach, where non-transferable reductions are imposed upon every source within the airshed. These reductions are expressed as r_j, again with subscripts running from 1 to J. Restrictions are set such that the following condition holds:

$$\overline{A} \geq a + \sum_{j=1}^{J} (e_j - r_j) \qquad (2).$$

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have such characteristics. In general, more numerous, smaller markets are required instead of one for the entire airshed.

[8] See *The Financial Post*, May 7, 1996, pg. 14 for a description of one proposal.

Society would prefer the means employed to achieve a pollution reduction is of least cost. In the command and control context, the aggregate reduction is

$$A-\overline{A}=\sum_{j=1}^{J} r_j \quad (3).$$

If we assume costs of abatement (pollution control) effort to be a positive, increasing function of the level of abatement attempted and continuous, the abatement cost function at each source *j* to society is defined as

$$C_j(r_j), \text{ where } \frac{\partial C_j}{\partial r_j} \geq 0 \quad (4).$$

The abatement cost function to society of abatement effort is therefore defined as

$$C_S=\sum_{j=1}^{J} C_j(r_j) \quad (5).$$

The regulatory solution achieves minimum control cost if and only if sources with the lowest costs of abatement are assigned the pollution reductions. The minimum cost solution will have the property that there is no way to reallocate legislated emission requirements among sources such that total abatement cost could be lowered while maintaining the required ambient standards defined by $\overline{A}$.

Formally the problem for the regulatory planner is defined as

$$\min_{r_i} C_S = \sum_{j=1}^{J} C_j(r_j) \tag{6}$$

$$\text{st.} \quad \overline{A} \geq a + \sum_{j=1}^{J} (e_j - r_j) \tag{7}.$$

The planner minimizes total abatement costs to society by choice of reductions at each source such that, at most, the desired level of emissions in the environment is achieved through the legislated reductions. If abatement costs are strictly positive, and positive reductions are desired, it is the case that the constraint will hold with equality, since by definition of the problem, minimum costs are attained with minimum abatement effort (when the industry abatement cost function equals zero across firms at the uncontrolled emission level). Using the method of Lagrange to solve results in *J+1* first order conditions:

$$\frac{\partial C_1(r_1)}{\partial r_1} - \lambda = 0$$

$$\vdots \tag{8}$$

$$\frac{\partial C_J(r_J)}{\partial r_J} - \lambda = 0$$

$$\overline{A} - a + \sum_{j=1}^{J} (e_j - r_j) = 0 \tag{9}.$$

since pollution costs are positive and the constraint binding

Clearly, marginal costs of abatement at each source will be equalized at the cost minimizing solution and will be equal to the marginal cost to society (the marginal increase in damage to society) of relaxing the constraint by one unit, λ.[9] The planner must allocate reductions across all sources such that after implementation there is no other combination or reallocation of reductions which could lower the total cost of abatement required to achieve the legislated aggregate level[10]. To find the cost-effective allocation, the planner requires perfect information regarding pollution abatement costs at each source. This is not a trivial condition because cost information is difficult to obtain as it is often private. There would also likely be an incentive mis-match among program participants and the regulator. Private individuals may find it in their interest to attempt to lower the reductions imposed on them by upwardly biasing the regulator's beliefs regarding their true abatement cost functions. If these attempts were successful, reduced reductions relative to those under perfect information would be imposed, reducing the costs incurred in abatement to the firm.[11] Often regulatory agencies obtain cost information directly from firms.[12] A basic principal-agent problem may exist, which imposes an additional constraint on the planner's problem. The resulting solution may be constrained to be inefficient if information is gathered by the regulator from the regulated firms.[13]

Command and control regulation may also reduce incentives to adopt cleaner technologies. A firm with the opportunity to adopt a new, cost reducing technology would also recognize doing so would cause increased required reductions. There would

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[9] λ is positive when the constraint is binding

[10] For simplicity, assume the solution is unique across sources, as it would be if all sources have different marginal abatement costs.

[11] This assumes the upward bias achieved is substantial enough to alter the solution described and that other firms aren't equally successful in achieving such deceptions. Reduced reductions would only occur if the bias created shifted the marginal abatement cost function upward.

[12] See footnote 9, Chapter 1.

[13] Such an outcome is seen often in problems involving moral hazard.

be no gain to the firm for adopting the technology, thus it would not do so.[14] In effect, firms must be punished with reduced emission allowances for such socially redeeming behaviour if command and control standards are truly cost-minimizing.

The informational burden on the regulator is further increased if the level of emissions allowed in the problem must also be socially optimal. In this case the regulator requires perfect information about the externality costs imposed by pollution across the environment. Achieving a socially efficient level of emissions may be viewed as a two-step problem. The first is to determine the optimal level of the constraint. This requires perfect information regarding the aggregate marginal abatement cost and aggregate marginal externality cost functions to society. The second is solving the minimization problem just outlined above, which further requires perfect information regarding individual source abatement cost functions.[15] The ability to impose the cost-minimizing solution under command and control would imply the ability to impose the socially optimal emissions ceiling.[16] The fact the regulator cannot usually calculate the socially efficient solution implies it cannot find the cost-effective one either as a rule.

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[14] The firm might adopt new technologies however, if it believed doing so would result in intangible benefits such as a better public image, if the firm preferences included a cleaner environment as would be the case if it were publicly owned and shareholders were directly affected by emissions, or if the new technology were costless to adopt.

[15] It may be the case that estimation of the aggregate marginal abatement cost function requires less information than that at each source.

[16] This assumes the ability to identify exactly each individual firm's marginal abatement costs at each level of pollution also allows the regulator the ability to aggregate and find the economy MAC function.

II.2 Permit Markets

Instead of utilizing the command and control approach in the regulation of pollutants, the regulator could employ a market-based means. A decentralized approach would allow market participants to act in their own interests and avoid the incentive mismatch and informational problems outlined above by letting those with the best information available determine how emissions are reduced. In the command and control approach, it has been argued that the decision making ability of the regulators is handicapped by the information conditions they face. For the manager of a pollution source, information about control technology and abatement costs is readily available thus decisions pertaining to source emission levels could potentially be made by them in a cost-effective manner to society. Plant managers lack only the proper incentives to act on information at hand in a manner consistent with a cost-effective solution, a problem the creation of a new market can theoretically solve.

To internalize the incentive problem, one could begin by explicitly defining property rights over emissions allowed. If these rights were made transferable, a market in emissions rights could be designed which could assist in the allocation of allowable emissions by firm based on a willingness to pay for them. Theoretically, the identical cost minimizing solution to that outlined above can be achieved by allowing the exchange of these rights among individual emitters acting in their own self-interest and without the incentive problem previously described or informational burden required of the regulator. It should be recognized the liquidity of these emissions permits creates new wealth. The distributional and equity effects this creates for society are not considered here but would be of concern to regulators.

The total number of permits *N*, would be set at

$$N = \overline{A} - a = \sum_{j=1}^{J}(e_j - r_j^*) \tag{10}$$

where r_j^* is the market determined emission reduction at source *j*. Each unit of the pollutant emitted would require the polluter to submit a permit showing that they held the right to emit that unit. Emitting without permits would be punishable with a penalty severe enough to warrant such behaviour unprofitable. It will be true that the aggregate level of emissions achieved under this method must be equal to that in the command and control case. Although point source emissions may differ between methods, in aggregate

$$\sum_{j=1}^{J} r_j = \sum_{j=1}^{J} r_j^* \qquad (11).$$

Since permits allow the polluter to avoid costs of abatement or punishment (as abatement is the only alternative if production levels are to be positive and the polluter does not hold permits), if polluters face different marginal abatement costs there may exist gains from trade between those with high abatement costs and those with lower costs of abatement effort.

If each firm is endowed permits initially by the regulator of

$$q_j^o \geq 0 \quad \text{where} \quad \sum_{j=1}^{J} q_j^o = N \tag{12}$$

the cost minimization problem faced by each firm can be written as

$$\min_{r_j} C_j(r_j) + Pn_j \tag{13}$$

$$\text{st.} \qquad n_j \geq e_j - q_j^o - r_j \tag{14}$$

where n_j is the number of permits the firm requires net of its initial endowment to ensure that all emissions produced have a permit to cover their production. P is the market determined price of a permit. If all abatement in the economy is costly, and no banking of permits is allowed such that they could be carried into the next period (therefore we explicitly assume here that the permits are only valid in a given period), the constraint will be satisfied with equality.[17] Because permits are a scarce input in production, none will be wasted in the cost-effective solution. The price for the excess permits required (or sold) by polluters given their pollution levels is determined by the market.[18] First order conditions for each individual source minimization problem imply

$$\frac{\partial C_j}{\partial r_j} = P \qquad \text{for all } j \tag{15}$$,

thus each polluter chooses its abatement effort r_j such that the marginal cost of abatement is equal to the price of a permit. Demand for permits by each firm is determined by the constraint that each unit of pollution emitted must have a permit to avoid penalty. Therefore individual demand for permits by firm is described as

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[17] Assuming no market power.

[18] It is explicitly assumed that the demand polluters face for the goods they produce and whose production process creates emissions is constant, and that individual sources have no market power. Output levels of the firm are determined competitively given output market considerations.

$$n_j^* = (e_j - q_j^o - r_j^*) \tag{16}$$

where r_j^* denotes the abatement level chosen by the source to satisfy the cost minimization problem. Demand may be positive or negative depending on whether, after initial allocation of permits, the source is a net seller or buyer of permits. Market demand for permits is found as the sum of source demands for permits and given total supply of permits in the market, *N*, equilibrium in the permit market implies

$$\sum_{j=1}^{J} n_j^* = N = \overline{A} - a = \sum_{j=i}^{J} (e_j - r_j^*) \tag{17}.$$

Given that the total supply of permits in the market allows an emissions level identical to that in the command and control case, $\overline{A}$, total reductions must be equal using either command and control or permit markets. In the command and control case, r_j is set such that

$$\frac{\partial C_j(r_j)}{\partial r_j} = \lambda \tag{18}$$

while in the decentralized problem the solution is found to satisfy

$$\frac{\partial C_j(r_j)}{\partial r_j} = P \tag{19},$$

thus

$$\lambda = P \tag{20}.$$

From the above, it must be the case that the market price for emission permits when market equilibrium is attained and trading is allowed is equal to the marginal value to society of relaxing the emission cap $\overline{A}$ by one unit. The cost-effective solution to society for a given reduction in total emissions is also achieved with competitive emission permit markets.

The intuition for this result is easy to see. Trade will occur until all possible gains from trade are exhausted, thus each polluter's marginal cost of abatement is equal to the price of a permit in equilibrium. There is no possible reallocation of pollution reductions that could lower the total cost to society of the enforced aggregate reductions, therefore the decentralized solution must equal the cost-effective solution. Theoretically, as long as the regulator provides the incentives and the appropriate restrictions under which polluting can take place, and provides the permit to be traded, the decentralized result should be able to achieve the cost-effective solution under the assumptions used here. The incentive problem that exists for firms to misrepresent their true abatement costs under command and control is eliminated by allowing those best informed to make abatement level decisions. The regulator's role is reduced to that of providing the institutions required to support the market. The disincentive to adopt new lower cost technologies is also eliminated as firms with the option to do so can capture the benefits from such adoptions.[19]

The prohibitive informational costs required to ensure cost-effectiveness in the command and control case need not exist if competitive permit markets are established. Note that in the command and control case, information costs are also ongoing. The planner must continually update abatement cost information as the menu of control possibilities

[19] Malueg (1989) suggests this is not always true and may depend on the position of the firm in the industry before and after such an adoption.

expands at each source. A transferable permit system avoids this by shifting the information burden to the regulated. Furthermore, the permit system creates an incentive for the regulated to continually update their control information as they search for profitable new technologies which lower their abatement costs, allowing them to sell the permits once required to cover previous emissions levels. This would result in an increased speed of compliance to reduced emission ceilings over time relative to command and control.[20] Current regulation will often announce a time path of ceilings reductions, in the form of proportionately equal reductions across emitters. As described above the emitter has no incentive to adopt cleaner technologies until the date of the increased reduction standard arrives. In a trading system, such adoptions may immediately begin to capture both present and future benefits.

A transferable permit system also offers a method of easing the conflict between pollution reduction and economic growth. Under command and control, new sources are usually assigned an allowed emission level as employment often dominates environment as a social issue. Historically other sources have not had to reduce their emission levels to compensate for this increase in total emissions, thus economic growth would decrease the air quality of a regulated airshed.[21] A transferable permit system would not require standards to be reduced, as any firm could purchase its required permits. Supply of permits need not increase. Growth would be accommodated in the permit market by a shift outward in the demand for permits and result in increased prices. This increase in

[20] Such a benefit was claimed as one of the reasons for the adoption of lead trading market for oil refiners in the US. from 1982-1988. It was claimed that the cost savings from this program over command and control was $228 million. It has also been credited with resulting in a faster phase out than would have been possible had command and control standards been used as reduced source by source reductions would have been implemented over a longer time period to allow refiners more time to adopt newer technologies without adversely affecting gasoline market prices.

[21] Although this is generally true, offset policies in the US. circumvented this problem in areas of non-attainment. As noted before, this is just a very controlled case of a transferable permit system and such policies were only used where emissions already did not meet mandated levels. In areas where emissions were below the allowable ceiling, growth without offsets would reduce air quality, thus the tradeoff would still exist. See Nichols and Harrison (1990) and Nichols (1992).

price would induce an adjustment to the market allocation of abatement levels accordingly such that the result in equation (19) would be again true across the market.[22]

Adoption of permit markets however does not reduce the informational burden required to determine the socially optimal level of emissions. For the permit market described above, the regulator would set the level of emissions allowed by firms to q^* in Figure 1 (assuming Figure 1 is drawn net of background emissions). The benefit of a permit system comes in the decreased information requirement in the second stage of the command and control problem outlined for the socially efficient case. If the information required to allocate individual source reductions is greater than that required to determine the socially optimal level of emissions, then the decentralized permit market will reduce the regulator's information costs required to achieve a cost effective allocation of abatement effort at the social optimum.[23] If the socially efficient outcome cannot be determined, emission markets still allow the regulatory goal of cost-effectiveness to be achieved.

[22] In the United States, permit trading programs have resulted in environmental groups purchasing permits as well for the purpose of retiring them.

[23] As long as it is the case that estimation of the aggregate marginal abatement cost function entails less information than that at each source.

II.3 Emission Charges

An alternative decentralized method of pollution regulation available is to impose a Pigouvian tax on emissions. Such regulatory methods are common in Europe.[24] A tax solution can be cost effective as all emitters in an efficient market will emit until their marginal abatement costs equal the level of the tax. The drawback of such a program is that without sufficient information regarding the aggregate marginal abatement cost schedule, the regulator will not be certain of the level of abatement and therefore the pollution levels occurring for a given tax rate. As before, using a tax does not reduce the informational requirement needed to establish the socially optimum level of pollution. If such a solution can be calculated however, then the optimal level q^* of emissions in the environment implies the per unit tax needed would be levied at the level implied at the level corresponding to q^* in Figure 1.

III. Overview of Regulatory Methods

If the regulatory goal is to achieve the socially optimal level of pollution in the environment, given technology in the economy and cost functions as defined above, there is no difference in the amounts of information required using any of the three regulatory methods described.[25] Command and control and tradable permit markets differ from taxation in that they are quantity based, establishing a cap on emissions, while taxation is

[24] See Hahn (1989). In North America, subsidies to adopt cleaner technology or reduce emissions function like Pigouvian subsidies. See Grafton and Flanagan (1995).

[25] Again it is assumed the ability to estimate the MAC function implies an ability to determine source specific marginal abatement cost functions.

price-based, allowing the response to a tax to determine the emission level in the airshed. All three can achieve cost effectiveness at any level of emissions, however the centralized command and control method requires the regulator have greater information to achieve this criterion.[26]

If the regulatory goal is cost-effectiveness for a given emission level, then either decentralized method can potentially achieve it at substantially lower cost. Which method is adopted depends on the preferences of the regulator, as well as the general applicability of either method to certain situations. There may be situations where the tax is the only realistic alternative. Additionally, whether taxes or permit markets are preferable when both are possible may depend on other criteria, such as uncertainty. If the slope of the MAC curve is very flat, a small mistake in the appropriate level of the tax needed to achieve a certain emissions level will result in a very large difference between the goal and the actual emissions level occurring. Competitive permit markets should always meet their emissions goal while being cost effective provided monitoring is done to avoid cheating. If technology changes cause shifts in the MAC curve, permit markets will adjust without intervention. A tax-based system would require an adjustment in the tax rate by the regulator for every technology shift.

Given the large information requirements of the socially optimal solution, cost-effectiveness for a given emission standard may be the only possible goal for a regulator. Restricting the regulatory goal to cost-effectiveness due to imperfect information implies that only decentralized methods have the ability to attain the regulatory goal. If abatement costs are very elastic with respect to pollution levels, or technology changes

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[26] This level in fact is equivalent to that required to solve for the socially efficient solution.

are expected to occur frequently, permit markets will be the most appropriate method to use.

The analysis presented here has explicitly assumed that no market power exists for any participant or group of participants in an emission permit market. The following describes the permit market problem in the face of market power. Taxes are not considered further, however in situations where permit markets face problems due to firms being able to affect market prices and resulting allocations, taxes may be the only alternative, since they remove the ability of market power firms to use price to their advantage.

Chapter 3

Permit Markets and Market Power

I. Introduction

The discussion and analysis of the preceding chapter was conducted under the assumption that permit markets are competitive. A number of researchers have investigated the theoretical outcome of permit systems when one or more participants have market power.[1] Most research has focused on market efficiency and pollution abatement effort across firms when a buyer or seller manipulates permit markets to reduce its pollution abatement costs and minimize the financial burden of pollution regulation. Some researchers have argued that market power in such markets, although detrimental to system efficiency, need not be of great concern because monopoly or monopsony solutions still generate outcomes with cost-effectiveness well above those generally found in centralized systems (see for example Tietenberg, 1985). Hahn (1984) and Misiolek and Elder (1989) formally analyzed emission permit markets under two types of manipulation. Hahn considered cost minimizing manipulation, where the dominant firm seeks to minimize control costs, and found market outcome and cost-effectiveness are dependent on the initial distribution of permits. Misiolek and Elder extended the analysis to include exclusionary manipulation, where the dominant firm acts to lessen competition in a vertically related product market, and describe potential efficiency effects. They noted decreased efficiency could occur for certain initial endowments, relative to centralized methods.[2]

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

[2] Tietenberg (1985) considers exclusionary manipulation briefly but concludes that such manipulation is highly unlikely (pp. 139-141). Sartzetakis (1992, 1993) analyzes such manipulation in the context of a

Ledyard and Szakaly-Moore (1994) have also considered the issue of political viability and permit markets. It is often not enough that system cost effectiveness gains can be shown to accrue to market-based methods for them to be adopted as a policy tool. It must also be the case that the distribution of gains and ensuing redistribution of wealth caused by changing the regulatory regime is such that no affected group or sector which can veto the regime is disadvantaged. Often it is this second consideration that is more important in the determination of regulatory method. Manipulation of emission permit markets due to market power may not only cause efficiency gains to be lowered, but cause such methods to become politically unviable due to the distribution of wealth they could create.

II. Implications and Graphical Description of Market Power in Permit Markets

Cost minimizing manipulation, or "simple" manipulation, occurs when an agent acts to minimize expenditures on emission permits if it is a net buyer (monopsony case) or maximize revenues from permit sales if it is a net seller (monopoly case). Hahn (1984) showed if such an agent exists and initial permit allocation does not equal that in competitive equilibrium, total expenditure on abatement in the system will not be minimized after trading. Further, the inefficiency created by the "incorrect" distribution of permits after trade increases with the difference between the initial allocation and the competitive solution. The market power firm does not consider the consequences of its actions on other firms in the market and acts only to maximize their own profits.

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duopoly. Hahn (1984) showed the dependence of outcome and initial distribution of permits in the case of cost minimization but did not consider exclusionary manipulation.

Exclusionary manipulation occurs when the dominant firm uses its influence in the permit market to gain market power in a product market by influencing rivals' costs, in a manner similar to that described by Krattenmaker and Salop (1986). This behaviour will only occur if a dominant firm believes it can influence competitors costs in the same output market industry. It must be the case that a significant share of the product market output 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) before a firm can engage in this activity. An implied pre-condition is that production in a specific region creates a cost advantage, thus pollution permits give firms access to this location. Further, to be profitable, the gains in profit in the product market accrued to the manipulating firm must outweigh the lost profits in the permit market of not pursuing simple manipulation alone.[3] This type of manipulation may be more attractive than predatory pricing to a firm attempting to increase its dominance in an output market as it does not require a "deep pocket".[4] Further, rational predatory pricing requires a sufficient discounted flow of future profits to compensate for the immediate losses of such actions. Predation through exclusionary rights yields immediate profit gains. Misiolek and Elder (1989) show outcomes of emission trading in such cases may be even less cost-effective than command and control in reducing the social cost of pollution control. These results have been largely ignored in policy documents where authors have dismissed market power as unlikely to have much effect in permit markets.[5]

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[3] Exclusionary manipulation requires a firm to buy more permits than it might otherwise attempt to acquire (if the market power firm is a net buyer) or sell fewer permits than it would otherwise (if it were a net seller) when attempting simple manipulation only. See the Appendix for derivation of this condition or Misiolek and Elder (1989) for a similar derivation.

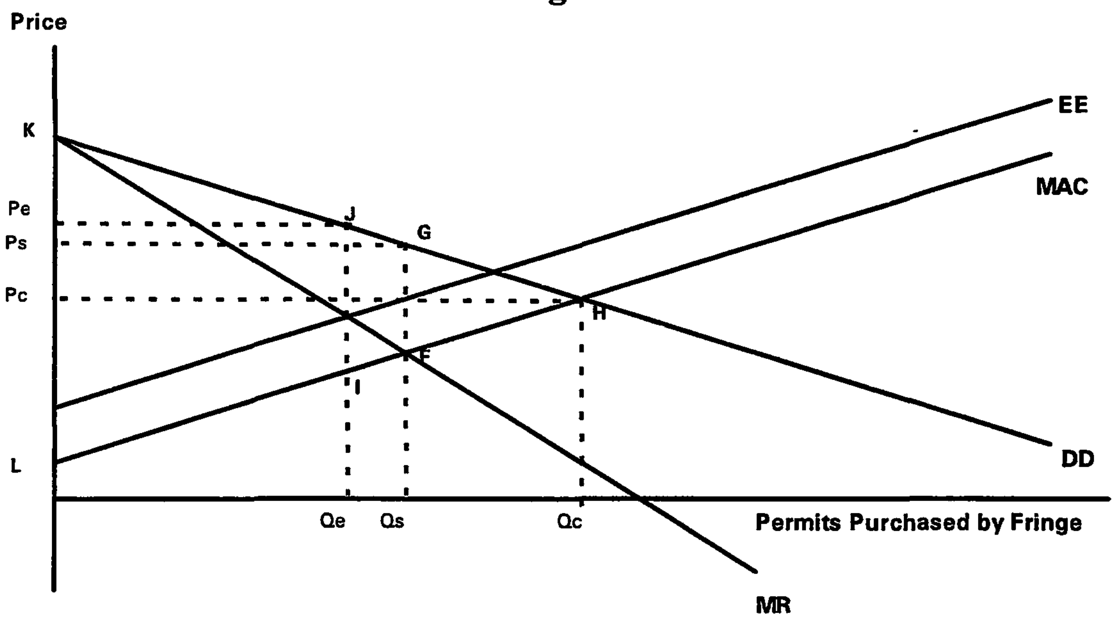
[4] Predatory pricing implies the firm attempting such predation be willing and able to sustain losses, at least in the short-run.

[5] Note Nichols (1992), CCME (1992), and the NRTEE Economic Instruments Collaborative (1993) pay scant attention to market power as a potential problem, and when considered, assume existing competition legislation will curb such activity.

To simplify the exposition of both types of manipulation a graphical analysis is used with formal mathematical presentation following. As before, assume a uniformly mixed pollutant and specific initial endowment of permits which leaves market participants as either net sellers or buyers of permits. For comparison, we define the initial distribution of permits as the command and control source allocation. Assume the regulatory goal is cost-effectiveness for a given emissions ceiling. Cost-effectiveness, or efficiency, is measured by the gains from permit trading, namely the observed reduction in system abatement costs and the gain in consumer surplus achieved through trade relative to the command and control. If the initial allocation were at the competitive allocation, no gains from trade would be possible and efficiency of the system would be maximized without trading, as shown in the last chapter.[6] It will be shown here that unlike the competitive markets, cost-effectiveness achieved is dependent on the specific initial allocation, as are the trading results if market power in a permit market is utilized by a dominant firm.

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

Figure 1



Consider Figure 1, in which the dominant firm is a net seller of permits.[7] 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 its marginal abatement cost. The competitive solution occurs at the intersection of DD and MAC, resulting in quantity, Q_C being sold at price P_C.[8] The efficiency gain over command and control is shown as the area of triangle HKL. For all firms, price equals marginal abatement cost. No more gains from trade are possible.

If the dominant firm acts as a simple monopolist, the solution occurs at Q_S and P_S. Permit price is higher and quantity purchased by the fringe lower than in the efficient outcome.

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

[8] Assuming a competitive product market.

Additionally, efficiency is not maximized in the market as marginal abatement costs across firms are 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 firm's 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 opportunity cost of another permit sale will reflect not only the foregone abatement cost, but also the foregone opportunity of increasing a rival firm's costs and possible exclusion of a rival unit of production in the related product market. The dominant firm has an incentive to hoard permits and increase rivals' costs to increase its product market dominance. The effect of the exclusionary motive on the dominant firm is shown by curve EE, which is drawn as the sum of marginal abatement and exclusionary opportunity costs of each unit sold.[9] The resulting equilibrium is characterized by even fewer permits sold (Q_e), at a higher price (P_e), and an efficiency loss, area JGFI relative to the case of simple manipulation. The motive to hold more permits caused by simple manipulation is reinforced by exclusionary incentives.[10]

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[9] Curve EE may be parallel to curve MAC, implying a constant exclusionary value of permits, or may have a different slope, depending on whether increasing marginal exclusionary value of permits is increasing or decreasing.

[10] It is worthwhile to note that both exclusionary and simple manipulation outcomes shown in Figure 1 indicate 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.

Figure 2

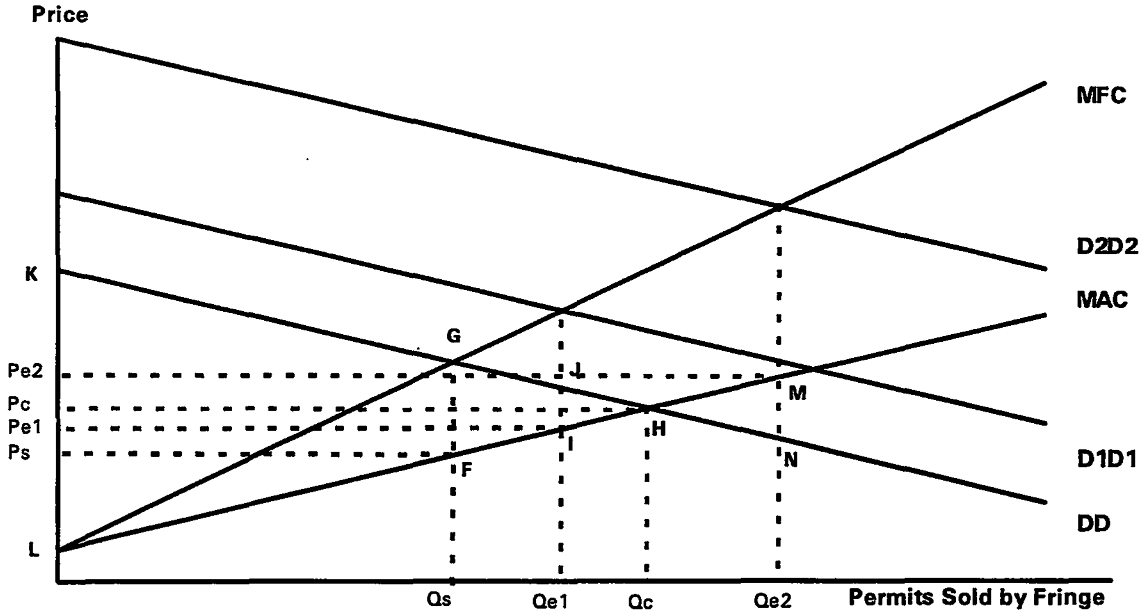

Figure 2 describes the simple manipulation outcome in the market if the dominant firm is a net buyer of permits.[11] In this case, the firm acts as a monopsonist. Note the horizontal axis now describes the number of permits purchased by the dominant firm from the fringe. As before the derived demand for permits is shown by curve DD, however, it is now derived from the abatement costs each permit defrays for the dominant firm. MAC 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.[12] If the dominant firm recognizes the effect of its permit purchases on permit price, its marginal factor cost is shown as curve MFC. Solving this as a simple monopsony problem yields the outcome at quantity Q_S and price P_S, with resultant efficiency loss FGH.

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11 Again this could result from a free initial allocation of permits or an auction of permits occurring prior to trade.

12 The gain is now defined as the area below curve DD and above curve MAC from the vertical axis to point H.

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. The resulting equilibrium is shown at quantity Q_e^1 and price P_e^1. Both measures have increased from the simple manipulation outcome to nearer the competitive ones. The resulting efficiency loss is also smaller (area HIJ).[13] 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. The efficiency loss relative to competitive equilibrium due to the dominant firm's excessive permit holdings is shown by area HMN. Pollution control costs increase to 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", while exclusionary manipulation may cause this abatement effort to be diminished, and benefit permit market efficiency. If the benefits from excluding rivals in the product market are great, however, the dominant firm hoards permits and thus abates "too little". Differing incentives act in opposition to one another, thus final system outcome is dependent on the exclusionary value of each permit.

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[13] 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 due to cost-minimizing or exclusionary manipulation involves comparing 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.

III. Formal Presentation of the Problem

III.1 Simple Manipulation

Consider the case of J polluters located in a particular region emitting a uniformly mixed assimilative pollutant. As in Chapter 2, $\overline{A}$ is the total amount of emissions allowed in a specific region in a given period and N is the supply of permits in the market. Each firm is initially and costlessly endowed with c_j^o permits which can be traded at a market clearing price P_C. Again, the number of permits actually used by the firm after trade can be defined as

$$c_j = c_j^o + n_j \qquad (1).$$

The 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 reduction 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

$$C_j = C_j(c_j) \qquad (2).$$

Marginal abatement costs are assumed positive and increasing in abatement effort, thus they are decreasing in c_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 in Chapter 2.[14] The efficient solution results when marginal abatement cost across all firms equals P_C. The market induced allocation can be changed, however, if one or more firms realize that the market price P_C is a function dependent on their actions in the market and act using this knowledge to maximize profit (or minimize costs). Specifically, the permit price function, $P_c = P_c(c_1)$, is derived from the marginal abatement cost function of the price-taking firms in the market. Assume that there is only one price setting firm, Firm 1, that recognizes market price is sensitive to the total number of permits it sells (or buys).[15] Firm 1's total cost (revenue) from permit transactions is

$$n_1 P_c = (c_1 - c_1^o) P_c(c_1) \qquad (3).$$

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

$$\frac{\partial n_1 P_c}{\partial c_1} = P_c(c_1) + (c_1 - c_1^o) P_c'(c_1) \qquad (4)^{16}.$$

Equating this function to Firm 1's marginal benefit, that is, its marginal cost of abatement, yields the market solution which differs from the result found when markets are competitive. Marginal abatement costs will not be equal across firms. Marginal cost (revenue) exceeds price, P_C, when $c_1 > c_1^o$ (Firm 1 is a net buyer) and is less than P_C when $c_1 < c_1^o$ (Firm 1 is a net seller) since $P_c'(c_1)$ is positive with respect to firm 1's holdings.[17]

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[14] See Montgomery (1972) for greater detail.

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

[16] 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 not be used when the initial allocation is efficient.

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

Firm 1 is buying too few (selling too few) permits and spends too much (too little) on abatement.

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 profitable include $P_c' > 0$ and the firm's marginal cost of abatement differ from the market price at the initial allocation of permits.

III.2 Exclusionary Manipulation

Consider the firm from the previous analysis, which has market power in the permit market, possibly because it is the largest firm in a single industry in which it and a competitive fringe of smaller firms are the major source of pollutants being regulated.[18] Assume there is a clear cost advantage to producing in the region that is regulated by the permit market in question. Because the large firm believes it can influence permit prices, it must also believe it can influence its rival's production costs through these prices.

This firm's optimization problem becomes

$$\max_{\{P_p,\, c_1\}} \pi = P_p Q_1 - C_p^1(Q_1, c_1) \tag{5}$$

$$\text{st.} \quad Q_1 = D(P_p) - S^f(P_p, P_c) \tag{5a}$$

$$P_c = P_c(c_1, P_p) \tag{5b}$$

[18] This market power may be a result of relative size of this firm relative to competitors and an initial endowment which leaves its excess demand large.

This is an extension of the standard dominant firm problem. P_p is the market price of the product produced in the industry under consideration, and Q_1 the output level of the dominant firm. Q_1 is determined by the residual market demand of the industry, given the market demand function, $D(P_p)$, and the supply function of the competitive fringe, $S^f(P_p, P_c)$. Supply of the fringe is upward sloped with respect to product market price and shifted inward by increases in permit prices P_C (implying an outward shift of the residual demand curve faced by the dominant firm). The total cost the dominant firm incurs in production (including abatement costs) is described by C_p, and assumed to be negatively related to permit holdings after trade. Total cost is also increasing in production, Q_1.

Equation (5b), the permit price function, indicates permit prices depend on the price taking fringe's valuation of permits.[19] Permit prices increase as the dominant firm increases its permit holdings after trade, resulting in choice c_1. The permit price may also depend on product market price P_p. The marginal impact on fringe profit of holding an additional permit is determined by either (i) the marginal abatement costs the permit avoids in the case the firm would produce with or without a permit or (ii) the increase in profit the permit creates by allowing the firm to produce, where production is only profitable when it occurs without abatement cost. This second determinant is not considered by Misiolek and Elder (1989), who consider the permit price only as a function of the dominant firm's permit holdings. For example, it may be the case a fringe firm's abatement costs are so large that without permits, production is unprofitable. The value of a permit is the change in profit it creates by allowing production to be profitable. The value of a permit to a fringe firm is its marginal impact on profit. This analysis

[19] The permit price function represents the horizontal summation of fringe firm (inverse) permit input demand functions, derived from each firm's profit maximization problem, given initial endowment of permits.

recognizes the potential discreteness of the fringe firm's production decision. Firms may choose to produce or not produce. After this decision is made, output level is assumed to be a continuous, increasing function of permit holdings. Permit holdings are assumed to be a continuous and decreasing function of permit price.

Consider another simple example. Suppose a fringe firm is capable of producing only one unit of output. Also suppose this firm has been endowed with one permit at no cost. Production may occur without abatement costs only if the firm continues to hold the permit. Assume the firm has a unit production cost of 15, and abatement cost (if incurred) of 200. If the product market price is 125, the value of the permit to the firm is 110 (the increase in profit the permit allows over not producing since production is unprofitable without a permit). Suppose the product price rises to 205. The value of the permit to this firm increases to 190. If all fringe firms face abatement costs as prohibitive as the firm in this example, the change in the permit price function with for a marginal change in market price is $\partial P_c / \partial P_p = 1$. If product price rises to 325, the valuation of the permit is 200, thus $\partial P_c / \partial P_p < 1$. Any further increases in product market price have no effect on permit valuation.

A sufficient condition identified by Salop and Scheffman (1987) for the dominant firm to profit from raising its 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 the output level in the product market prior to attempting exclusionary manipulation, Q_1^0.

Inverting the market demand curve $D(P_p)$ to obtain $P_p=P_p(Q_p)$, where $Q_p = Q_1 + S^f$, we obtain

$$P_p = P_p(Q_1 + S^f(P_p, P_c)) \qquad (6).$$

Holding Q_1 constant and totally differentiating (6), the change in product market price for a change in the price of emission permits is found as

$$\left.\frac{dP_p}{dP_c}\right|_{Q_1^o} = \frac{dP_p}{dQ_p}\frac{\partial S^f}{\partial P_c} \bigg/ (1 - \frac{dP_p}{dQ_p}\frac{\partial S^f}{\partial P_p}) \qquad (7).$$

Obtaining $\frac{dP_p}{dP_c} = \frac{\partial P_c}{\partial c_1}\frac{dc_1}{dP_p} + \frac{\partial P_c}{\partial P_p}$ from (5b) and substituting into (7) yields the change in the product market price for a change in firm 1's permit holdings

$$\left.\frac{dP_p}{dc_1}\right|_{Q_1^o} = \frac{\partial P_c}{\partial c_1}\frac{\partial S^f}{\partial P_c} \bigg/ (\frac{dQ_p}{dP_p} - \frac{\partial S^f}{\partial P_p} - \frac{\partial S^f}{\partial P_c}\frac{\partial P_c}{\partial P_p}) \qquad (8).$$

Misiolek and Elder (1989) define the above equation as *necessarily* positive if the following conditions are true:

- permit price increases with the holdings of the dominant firm,
- fringe output decreases with permit price increases,
- residual demand is downward sloped, and
- fringe supply increases in response to product price increases.

Misiolek and Elder did not consider the case where the permit price is a function of coupon holdings of the dominant firm and product market price. Including the possibility that the permit price is a function of the product market price challenges their conclusion. If the permit price is increasing with respect to the product price, the effect on the residual demand of an increase in the dominant firm's permit holdings at a given output level may be larger, or negative relative to findings if permit price is not a function of product market price.

The conditions under which the dominant firm's purchases of pollution permits have a greater impact on residual demand, increasing the profitability of exclusionary manipulation include

(i) the more responsive the permit market price is to the dominant firm's permit purchases,

(ii) the more sensitive the fringe supply in the product market is to increases in permit price,

(iii) the more inelastic is the residual market demand for the product of the dominant firm, and

(iv) the less elastic is the fringe firm supply to changes in product market price.

All these conditions were identified by Misiolek and Elder. The negative effect of exclusionary manipulation on residual demand, however, was not and increases the more responsive fringe supply is to increases in product market price and the more insensitive it is to permit prices.

The result is a knife-edge response to attempts to exclude through increased permit holdings. The feedback effect of increasing product market prices on permit price increases the likelihood of profitable fringe production even without permits. Exclusion may shift residual demand upward, or efforts to exclude through hoarding of permits and restricted output by the dominant firm may cause product market price to increase enough to induce increased fringe supply. In some circumstances it may be unprofitable to pursue exclusion as a strategy, if the sensitivity of permit prices to product price is positive and fringe supply too insensitive to permit price.

As Misiolek and Elder note, the increase in the dominant firm's average total costs by buying one more permit is written as

$$\frac{dC_p^1(Q_1,c_1)}{dc_1}\cdot Q_1^{-1} = \frac{1}{Q_1}\cdot\frac{dC_p^1}{dc_1}\bigg|_{Q_1^o} \qquad (9).$$

The increase in total costs associated with purchasing an additional permit in an attempt to exclude, is spread over the total output of the dominant firm while abatement costs are reduced, thus the effect on average costs may be very small. The sufficient condition under which a dominant firm can influence its rival's costs (that Equation (8) is greater than Equation (9)) may be easily met, especially if conditions (i-iv) apply and increased product market price benefits to the dominant firm do not increase fringe output.

IV. Allocation, Trading Institution, and Regulatory Implications

From the analysis above it is clear that initial allocation is an important determinant of potential manipulation. Suppose the dominant firm attempts simple manipulation. The initial allocation determines the net-demand function of the dominant firm. Referring back to Figures 1 and 2, the height of curve DD, and therefore the distance from the origin along the horizontal axis to quantity Q_C (the number of permits the dominant firm must buy or sell to move to the efficient allocation) is determined by the initial allocation the dominant firm receives. If the origin were moved to the right such that the dominant firm's initial allocation were the competitive one, it is clear no simple manipulation is possible which can improve the costs of the dominant firm.[20] The ability to influence the permit market is determined not only by the size of the dominant firm relative to the market, but by the net demand after initial allocation. Unlike models of permit markets which assume perfect competition, once market power is considered, allocation determines the final outcome.

Exclusionary manipulation serves to increase both the value of holding a permit and to increase the benefit accruing to the dominant firm from obtaining another. Clearly Figures 1 and 2 indicate allocating at the efficient level may not offset this incentive to manipulate. It is clear, however, that the initial allocation does change the total benefit such manipulation generates. In the case where the dominant firm is a net seller of permits, hoarding may not increase the loss in efficiency in the market relative to source specific standards (the initial allocation in this context). Although exclusion might cause rival firms to leave the product market, this is also not necessarily the case. Hoarding is undertaken here for its effect on rival's production decisions, and it is possible that exclusion may not be complete and that a trading outcome may improve on an alternative command and control allocation.

Grandfathering, or basing initial allocation of emission permits on historic emissions levels or past holdings of permits, could cause a bias against new entrants. New entrants may need to acquire permits to allow profitable production. If the initial allocation of permits by firm does not change over time (in a manner to be decided upon by the

[20] Note that the MR (Figure 1) and MFC (Figure 2) curves cross line DD at the point of initial allocation if the axis is moved in the described manner. If the dominant firm is a net seller, when initial allocation is equal to the competitive allocation, marginal revenue of any permit sold to the fringe is less than its abatement cost value. Similarly, if the dominant firm is a net buyer the marginal factor cost of another permit is greater than the marginal benefit accrued.

regulator) new sources will suffer a "new-source bias". An apparent benefit of a tradable permit system is its flexibility to allow economic growth without increasing pollution. If future allocation patterns are dependent on present after-trade allocations, then acquisition values of permits in a new entrant's start-up period may reflect the value of gaining a share of future allocations. Existing firms could exploit this advantage to charge prices which capture a location rent. If new entrants are rivals in the existing dominant firm's product market, then the exclusionary value to the dominant firm of permits would include the possibility of entry deterrence. Neither of these cases is explicitly considered here, however, they could be of concern. Design of the optimal instrument traded is considered elsewhere by other authors, although in the context of market power, work remains to be done.[21]

The ability to exercise market power may also depend on the market trading institution utilized. Laboratory evidence has indicated the double auction institution may be resistant to such price manipulation[22]. Smith (1981) demonstrated that in a laboratory environment with one seller the double auction institution repeatedly resulted in price convergence nearer to the competitive level than that found for a variety of other

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[21] One method of controlling an allocational bias may be to allow permit allocation to be determined by auction. In a simple auction, the ability of a dominant firm to manipulate the market is not overcome. In such a case every firm is a net buyer of permits and the previous analysis still applies. If the auction is revenue generating, it will not be politically viable (Ledyard and Szakaly-Moore, 1994). To overcome viability problems and possibly manipulation incentives, the Hahn-Noll auction mechanism has been suggested. Firms submit their bids for each unit, a market demand curve is derived from the bids, and market price is set at the first rejected bid (the first step in the derived demand curve below the intersection of the demand curve and the total permits available). The mechanism is revenue neutral in that rights to a certain number of permits are grandfathered to firms before the auction. After the market price is determined, existing firms would either pay the value of any additional permits acquired or be paid the value of the rights they have sold. Again the new source bias is not overcome. Ledyard and Szakaly-Moore (1994) argue that given current knowledge of auction theory, the Hahn-Noll revenue neutral auction can be expected to exhibit less than full efficiency since bidding is done over multiple units. It can also be influenced by market power, as the dominant firm could skew the derived demand curve to their advantage by submitting some infinitely high bids (in the net-buyer case) or zero bids (the net-seller case) without penalty since their bid vector could be constructed such that none of these submitted bids could hurt profits.

[22] Smith found however that this did not translate into resistance to the quantity effects or efficiency losses such activity creates. Buyers would "counter-speculate" against the monopolist, waiting for lower prices, and this waiting lowered traded quantities and market efficiency.

institutions. Smith and Williams (1989) also found convergence to the competitive outcome in a majority of their experimental monopoly markets. Ledyard and Szakaly-Moore (1994) found the double auction superior to the Hahn-Noll revenue neutral auction when comparing efficiency in competitive laboratory markets and less sensitive to price increases, in laboratory monopoly markets. These results have led to the suggestion that this institution may be useful as a means of monopoly restraint.[23]

For regulators, the effects of market power could be severe, both due to cost-effectiveness losses as previously described, or in combination with the impact distributional gains due to such manipulation could have on the program's political viability. Identification of markets in which market manipulation is possible, however, should be a relatively simple task. In cases where cost minimizing manipulation is presumed a possibility, information regarding previously assigned emissions standards (assuming source specific regulation was previously in place) or technological information concerning production process and scale (information often gathered to assign source specific standards) could be gathered to evaluate the potential for market manipulation. Hahn (1984) provides one such example. Nichols (1992) provides information for a proposed market in southern Ontario which might indicate potential for such activity.

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[23] There does not exist a consensus whether double auctions can defeat market power in single seller environments however a large amount of literature leans toward this result. Davis and Holt (1993) characterize the double auction as very successful in the control of monopoly pricing. They describe the only non-competitive double auction price result (at their time of writing) due to market power as an experiment by Holt, Langan, and Villamil (1986), and later replicated by Davis and Williams (1991). This experiment had two sellers with large sales capacity, relative to three other sellers, who also held the marginal units, which when traded only generated commission revenue but no unit profit due to high unit costs. Additionally, at the competitive price there is excess capacity of one unit. If both large firms withhold their last high cost unit the supply curve will shift leftward and result in an increased price and increasing sales revenue over their lower cost units. Such a result occurred in a majority of sessions. Plott (1989) argues this result may have been due to market power or an alternative model of convergence developed by Easley and Ledyard (1993). Which model applies is unclear as both are capable of explaining the result. The results of both Holt, Langan and Villamil and Davis and Williams are not directly relevant to the type of problems we will consider, which concern a single dominant firm whose market power does not occur only due to influence over only the last units traded.

Identification of markets where exclusionary manipulation is a concern could be accomplished by checking for two further necessary conditions: whether there is a firm which is dominant in product markets common to many of the polluters in the air or watershed regulated and whether location in the region must be required to compete in these product markets.[24] As an example, Tietenberg (1985) notes that the Piceance Basin in Colorado is the only region in the United States where shale oil production has been attempted or planned in the recent past. Since it has also been argued that in some industries smaller firms find pollution regulation more burdensome than larger competitors, firm specific cost structures could also be considered with respect to allocation method used. Denial of cost-saving pollution rights may be especially critical to some firm's viability and therefore make exclusion a very cost effective method of controlling competition in product markets for larger predatory firms.[25]

V. Conclusion

The analysis described here has defined the types of manipulation a market power firm could pursue in a permit market. It also described how the manipulation attempted depends on the competitive conditions found in the product market and whether competitors in that market are also common to the permit market. Whether such manipulation is possible depends on a number of other factors, such as initial allocation of permits and trading institution used. The costs of such manipulation could outweigh the efficiency gains trade creates. The redistribution of gains from trade created in the

[24] Otherwise competitors in the product market could move to regions where such exclusionary activity would not affect them.

[25] Misiolek and Elder also note this potential.

presence of market power could also undermine the political viability of emission trading programs if the firms without market power or the consuming sector are made worse off. The consequences and implications outlined above, however, are made on the assumption that manipulation will occur whenever a firm has the opportunity. This assumption has yet to be tested. Although theoretically such manipulation could be worrisome, if it does not arise naturally, then it presents little reason for concern or regulatory reaction. The following chapters attempt to determine whether such behaviour should be expected, and whether market outcomes should be expected to be as severe as theory suggests.[26] If this is found to be the case, then regulators might find reason to seriously consider the possibility and consequences of such activity in permit markets.

[26] Predatory pricing is a good example of a behaviour which is expected to occur naturally in markets where it is possible, and regulation exists to control it. Experimental evidence, however, is mixed as to whether it is a naturally occurring form of market behaviour. See Isaac and Smith (1985) and Harrison (1988) for description of experimental results investigating this question.

Chapter 4

Strategic Manipulation of Pollution Permit Markets: An Experimental Approach

I. Introduction

This chapter presents an economic experiment that attempts to determine whether the market power predictions of the last chapter occur in laboratory markets. The experimental permit markets reflect the explicit sequence of firm input and production decisions of naturally occurring economies. Few emission permit market experiments have included this characteristic in their design, but given the results presented in the preceding chapter, production decisions may be an important determinant of permit market outcome.[1] The experimental design follows that used in Brown-Kruse and Elliott (1990), whose initial results indicated some evidence of market power in a limited pilot study.[2] Market power implies permit and product markets may not be separable. The structure of the exclusionary manipulation problem indicates distortions in one market will have repercussions in another. Including both the permit and product markets allows analysis of both types of possible market manipulation and allows direct comparison of impacts on overall system cost efficiency. The predicted effects of market manipulation on permit price were established in Chapter 3 and are reviewed in Table 1.

The experiment proceeds using the following assumptions: a permit market has been chosen as the means of pollution regulation with overall cost-effectiveness as the

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[1] Godby, Mestelman, Muller and Welland (1995) also include an output decision in their market experiment.

[2] They were only able to conduct one experiment in each treatment cell of the experiment, limiting the statistical inferences possible from the data generated.

regulator's goal. The airshed or watershed has been suitably defined, and the allowable emissions cap determined. An emission permit is defined as a one period allowance to emit a specified level of the pollutant being regulated. Complete abatement for any emissions over and above the amount covered by permit holdings after trade is required of all firms. Suitable monitoring and enforcement is carried out to induce this behaviour. Initial permit allowances are distributed at no charge to the participating firms ("grandfathered") and in quantities determined by the regulator. Permit trade is conducted using a double auction as it is a natural type of market to expect in such circumstances.[3] Two direct questions are asked of the observed results: (i) is market power successfully exploited when a dominant firm is given the opportunity to do so and (ii) if so, is the resulting outcome serious enough to merit special consideration by regulators?

Opportunity for either cost minimizing manipulation, or exclusionary manipulation, is allowed, depending on market treatment. Specifically, the laboratory market is comprised of one dominant firm and ten smaller "fringe" firms. Within this context, the market power of the dominant firm is maximized using initial permit allocation. Unlike previous market power experiments, monopoly and monopsony conditions are both considered.

Price, quantity, efficiency and earnings data are analyzed to search for (i) indications of manipulation, (ii) system efficiency improvements and (iii) the final distribution of the gains from trade. If market manipulation of the types predicted is observed, and low or negative efficiency gains result, and/or seriously inequitable outcomes arise, then these

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[3] The Chicago Board of Trade has been developing such an institution for the EPA SO_2 trading market in the United States. Ledyard and Szakaly-Moore (1994) have also argued that such an allocation method and trading institution are politically viable and most previous emission trading work has considered this type of allocation method and institution. Godby, Mestelman, Muller and Welland (1995), Muller and Mestelman (1994), Franciosi, Isaac, Pingry and Reynolds (1993) and Cronshaw and Brown-Kruse (1992) are other examples using such an allocation method and trading institution.

results may serve as a warning to regulators to carefully consider whether monopoly or monopsony power is a potential problem in proposed markets. Anti-competitive exploitation of market power or inequitable trade gains may not only inhibit the gains offered by emission permit markets, but may also make them politically unviable. If, however, serious market manipulation does not appear in the experiments reported, it may be premature to assume market power in permit markets is not a serious concern. Such results then may be only further evidence that double auction institutions are effective in controlling market power. Implementation of alternative trading institutions may not be so robust in the presence of market power incentives.

Results reported are also relevant to the experimental literature of market power in double auctions. The market conditions used here will be shown to be significantly different to those used in previous market power experiments and therefore the results offer increased insight regarding the relationship between market structure and this institution.

II. Previous Experiments in Market Power

A number of authors have examined the effect of a single seller's market power in laboratory markets using various institutions.[4] In the case of the double auction, Smith's (1981) results of three monopoly sessions indicated the institution appears somewhat robust to monopoly pricing effects, although observed efficiency was lower than most other trading institutions when considering monopoly circumstances.[5] Smith found one session converged to the competitive price prediction with all closing trade prices below

[4] Often these authors also considered duopoly markets (Smith, (1981) and Smith and Williams (1990)), however those results are not reported here. They generally appear to achieve competitive outcomes.

[5] Session lengths were eleven periods in the first, nineteen in the second and sixteen in the third.

the monopoly prediction by the fourth period. A second session exhibited similar behaviour until period eight when prices abruptly rose to near the monopoly price, and remained high for the rest of the experiment. The third session exhibited stable prices within periods, declining throughout the experiment to end at slightly above the competitive price.

Smith and Williams (1989) reported similar results over five monopoly double auction markets.[6] In three sessions, prices converged quickly to the competitive price prediction or below it. By the fourth period all trade prices were below the monopoly price prediction. In two other sessions however, convergence to competitive price was not clear. In one session the monopolist was able to maintain prices at or near the monopoly prediction for the whole session. In the other, trading prices converged completely to competitive prediction by period seven, in period nine jumped to near to the monopoly price and then slowly fell again, ending at competitive levels by session's end.

Both articles' findings indicate double auction monopolists may temporarily lift prices above the competitive level, however, maintenance of high prices is difficult and often unachievable. Negotiation of prices above the competitive level was often accompanied by significant loss in efficiency as buyers appeared to under-reveal demand. The double auction appears to allow perfect price discrimination as a possible outcome, however the negotiation of different transaction prices produces signals to all buyers (since transaction data is available to all participants), including those with higher valuations, that the monopolist is willing to sell some units at low prices. Such information may induce under-revelation or "counter-speculation". Drops in observed market efficiency appear to result. It is not unusual, however, to observe price oscillations or persistently high prices.

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6 These sessions lasted from twelve to fifteen periods.

Oscillations may occur when the seller refuses to concede lower prices and for the few trades observed, prices are high. Afterward prices may drop as the seller's resolve begins to soften.

Ledyard and Szakaly-Moore (1994) argue only two types of trading institution are politically viable for emission trading markets: the double auction and the Hahn-Noll revenue neutral auction. Their laboratory setting found mixed pricing results in monopoly markets. One session appeared to converge to competitive equilibrium while another appeared to converge to the monopoly equilibrium. Which outcome the other session achieved is unclear as prices were generally between both predictions. Comparison of the monopoly double auction to the Hahn-Noll revenue neutral auction (with only one seller) in the laboratory indicated the double auction achieved lower observed prices and comparable efficiencies. Both institutions achieved lower efficiencies in monopoly settings than those observed in competitive markets.

III. Laboratory Implementation

In economics experiments subjects trade fictitious units with specific redemption values. The trading institution and subject redemption values, denominated in lab dollar and specific to them, can be manipulated for the purpose of the experiment. In the following experiment, 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.[7]

[7] To ensure that earnings for each subject were not too dissimilar, a different exchange rate was used for the dominant and fringe firms, and also depended on the treatment. Subjects were not aware that individual exchange rates might differ. Exchange rates were as follows (value of 1 Lab Dollar in $CDN):

Treatment 1		Treatment 3	
dominant firm:	0.015	dominant firm:	0.01

III.1 Parameters and Procedures

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 not told they were trading pollution permits, but instead traded "coupons" which represented a scarce input and could reduce cost of production. One subject (hereafter referred to as the dominant firm) enjoyed a production capacity of ten units. The remaining ten subjects could each produce one unit. All firms had two types of costs: production and abatement. These costs are shown in Table 2.

Production costs were defined to reflect why one firm might gain a dominant position in an industry. The dominant firm had (relatively) low constant marginal costs over all production. The fringe firms each had different costs, with most having production costs for their single unit higher than the dominant firm's marginal cost. Such cost structures might be expected for example, between an electricity generating utility and a number of smaller producers respectively.

Abatement costs were referred to as "additional costs" in the experiment and were incurred to abate discharges. Fringe firms holding a coupon were not charged their additional costs of production. The dominant firm's permits were applied to production units in descending order of additional costs. Heterogeneity of firm's production and

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fringe firm: 0.015
Treatment 2
dominant firm: 0.0025
fringe firm: 0.024

fringe firm: 0.013
Treatment 4
dominant firm: 0.0025
fringe firm: 0.03

abatement costs created a downward-sloped derived demand curve and upward sloped derived supply curve for pollution permits.

Laboratory Markets: Each session ran for ten trading periods. Every trading period began with the allocation of ten permits to 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 the MUDA computerized double auction on eleven networked personal computers.[8] Permits could be traded only one at a time, thus the results are applicable to single unit double auctions in general. The dominant firm subject was situated in one room while the fringe subjects traded from 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.[9] The C-Market lasted up to four minutes.[10] As the number of permits available was fixed at 10 per period, all transactions in the C-Market involved redistribution of the existing permits. Firm's earnings were governed by their respective production and abatement (additional) costs and the primary market price for the firm's product. Permit market speculation was not possible as permits could not be saved from period to period and subjects were limited to either buying or selling, depending on initial endowment.

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 treated as if sold at a uniform market price determined by the market relationship utilized in the particular treatment being conducted.

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[8] See Plott (1991) for a description of MUDA.

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

[10] Some early periods of sessions T2-2, T3-1, and T3-3 were longer than the standard three minute period length used. Subjects, however, did not have control over the length of the sessions

Experimental Design: A complete 2x2 factorial experiment design was employed as described in Table 3. This created a block of four possible treatment combinations which was replicated three times. The order of treatments was randomized in each block. 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. Potential for market power in the P-Market was controlled using P-market price. In two treatments, the P-Market price was fixed at the "competitive" level of 125. Subjects were aware of the fixed product price. In the remaining two treatments, the P-Market price was determined by the inverse demand curve (found in Figure 1) and aggregate production of the eleven firms. The treatments with a fixed price forced all subjects to be price-takers in the product market and removed the dominant firm's exclusionary incentives. The remaining 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.

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, minimize boredom, limit inertia in decisions, and to ensure any subject's confusion about the task at hand became apparent and could be corrected. Each firm also had information regarding P-Market demand in those treatments in which the P-Market price was not fixed.

Procedures: All sessions were conducted in the McMaster University Experimental Economics Laboratory over a three week period in January 1995 using 132 subjects (11 per session). Rules of trade and costs of production and abatement were identical across all treatments. Care was taken to properly randomize treatments and session participants. Subjects earned approximately $25.00 CDN on average, with some variation depending on treatment.[11] Each session took approximately two hours to run, with forty-five minutes used for instruction. No communication was allowed among subjects once the session had begun. Subjects read their instructions and were then given a demonstration and chance to use the double auction software. After this demonstration, subjects were given an example of how to do the record-keeping the experiment required. Finally, two practice periods for which subjects were not paid were run to allow them to become familiar with the complete task. Full instructions, tables and worksheets for each treatment are found in Appendix C.

Due to the complexity of the dominant firm's decisions, the twelve people chosen to play this role were drawn from those subjects in the session who had experience in previous, unrelated competitive double auction experiments. This was done in an attempt to ensure these subjects would not be overwhelmed with the decision they faced. Two sessions did not include subjects with this type of experience (Sessions 5 and 8) and the dominant firm was drawn at random from the group of subjects involved. All subjects were recruited using advertising across campus and announcements in introductory and intermediate undergraduate economic classes. None had prior experience using MUDA or the protocol used in the P-Market.

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[11] Mean payoff $25.43, high $42.75, low $12.00, standard deviation $6.93.

III.2 Differences in Procedure from Previous Market Power Work

Smith (1981), Smith and Williams (1989) and Ledyard and Szakaly-Moore (1994) have tested the results of limiting the number of sellers in double auction markets. All experiments tested monopoly markets only, allocating all units to one seller. All experiments had five buyers. Smith utilized a double oral auction, while Smith and Williams and Ledyard and Szakaly-Moore used PLATO and MUDA computerized double auctions. All experiments allowed only single unit trading. None of the experiments provided the monopoly subject with competitors' valuations. Ledyard and Szakaly-Moore and Smith and Williams, used undergraduate students experienced in the computerized environment. Smith used graduate and advanced undergraduate students only, whose experience with the oral double auction was not explicitly stated. Smith (1981) and Smith and Williams (1989) assigned specific roles (buyers or single seller) to subjects, while Ledyard and Szakaly-Moore allowed trade (subjects could buy or sell). Smith and Williams and Ledyard and Szakaly-Moore used Smith's valuation parameter set. Smith and Williams paid a $0.10 per trade commission. In this experiment, mainly undergraduate subjects traded permits using a computerized environment like that of Ledyard and Szakaly-Moore without commissions. The dominant firm was provided a list of fringe firm production and abatement costs, without reference to corresponding firm identities in the auction.

III.3 Laboratory Predictions

The socially efficient distribution of licenses given the costs in Table 2 is shown in Figure 1.[12] This outcome would minimize total production and additional costs while providing

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[12] Assuming competitive product market.

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 and exhaustion of all trading opportunities of permits in treatments where the fringe firms are endowed with all permits places three licenses with the fringe firms (F8, F9, F10) and seven to the dominant firm. Endowing all permits to the dominant firm, the efficient allocation places four permits with the fringe (F7, F8, F9, F10) and six with the dominant firm after trade. Note these predictions assume the last permit traded trades at a price of 105. These competitive outcomes are described in the first row of Table 4. Under pure price taking behaviour, permit price is independent of initial permit allocation.

Market power predictions by treatment are also calculated, using experiment parameters and the methodologies outlined in Appendix A, and are reported in Table 4. Treatments 1 and 2 limited strategic behaviour to the permit market and are treated as simple monopsony and monopoly problems respectively. Also included in Table 4 are the predictions for Treatments 3 and 4 if the dominant firm is monopolistic in the product market but a price taker in the permit market. In Treatment 3 any attempt to exclude is so costly that the dominant firm's profit maximizing action is to pursue simple manipulation only, to act as a monopsonist in the permit market, and to purchase only two coupons at 75 lab dollars for each. Treatment 4 initially allocates all coupons to the dominant firm thus avoiding the costs of permit purchase if the firm attempts to exclude. By reducing sales to the fringe, the dominant firm can maintain high permit prices *and* exclude rivals from the product market, thus reducing production and increasing profits. This is seen in the strategic prediction of only one coupon sale to the fringe, while using eight to produce with defrayed abatement costs and idling the last. Note the exclusionary value of the last permit is so high that it is worth more to the dominant firm idle than if sold or used in production.

IV. Results

Two competing models might describe the outcomes of this experiment. The first is the competitive model. If market power is not used, or if the double auction trading institution is robust to such manipulation, the competitive predictions described in Table 4 are expected, at least for Treatments 1 and 2. If, however, market power is exploited in all markets, the market power predictions relevant to each treatment apply. To determine which theoretic model best describes observed outcomes, session permit prices, permit holdings observed, quantities produced, and product market prices are compared to the predictions in Table 2. The principal results of the experiment are summarized by Results 1-7 below.

Table 5 summarizes the mean observation of all market variables by treatment. Time series of observed market variable outcomes are found in Figures 2 to 8. Permit market prices are shown in the order they occurred in real time by squares, with elapsed time measured in seconds on the horizontal axis and lab dollar prices on the vertical axis.[13] Vertical lines indicate the end of each trading period, while the competitive and market power model predictions are indicated by horizontal lines. Sequential observations of permit holdings and production level outcomes observed by period in each treatment are shown with median observations connected by solid line. Data points are labeled by reference to session. Production market price time paths are shown for Treatments 3 and 4 by session. Predicted levels using the competitive market and market power assumptions are labeled for each treatment on the vertical axes for all figures.

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[13] Session ETC T2-1 in Figure 3 recorded some very high observed permit prices in periods 1, 2 , 5 and 6 which have been plotted at 180 to improve the clarity of the figure.

Useful impressions are generated by the summary statistics and simple figures. Table 5 indicates that the means of all market variable outcomes are closer to the market power predictions than to their corresponding competitive model predictions. This impression is reinforced by time paths of market variables. From the figures it is clear the observed data do not automatically cluster at either prediction. This is not an unusual feature of experimental market data, because not all market trades in double auctions are expected to be at the predicted equilibrium values when equilibrium models are used in market outcome specification. Over time, however, the time series appear to tend toward the market power predictions.

Double auction permit prices in all treatments tended to have significantly higher variance in early periods. Over the experiment, prices appear to converge toward the market power prediction. It is significant that few of the sessions indicate a convergence path which crosses the competitive prediction. To those who feel the competitive equilibrium is a stable "attractor" point, these examples may indicate otherwise.[14] Only two sessions indicated strong evidence of price convergence to the competitive prediction, Sessions T2-3 and T3-3, while Session T2-2 exhibits two final contracts at the competitive prediction in the last period after a run of fifteen contracts at or close to the market power prediction. Permit holdings and production level median observations across treatments appear to track toward the market power model predictions with declining variance toward the end of the experiment. None of the observed production market price paths suggests a convergence toward the competitive outcome. Although it does not do so exactly, the market power model appears to better predict the direction of market convergence for all variables, even in the double auction market. The formal statements of results to follow make more precise these general impressions.

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[14] At least for the time lengths we consider.

Analysis and interpretation of experimental market data is often made difficult because markets exhibit a convergence process which is not theoretically understood. Individual sessions or replications of experimental treatments will often exhibit heteroscedasticity, while serial correlation may be indicated over time in the price adjustment process. Such statistical properties make any attempts to summarize patterns in the data using standard statistical methods difficult. Non-parametric methods often provide results which are too imprecise to differentiate between competing models. Given these concerns, the effect of time on the observed outcome of market variables is analyzed using a model found in Noussair, Plott and Riezman (1995), which in turn was motivated by the model of Ashenfelter et al. (1992).

Analysis of the effect of time on observed market variables is accomplished econometrically using the following specification:

$$Y_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{1i} D_i \frac{1}{t} + \ldots + \beta_{1n} D_n \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_{it}$$

where i indicates the particular experimental session, running from one to n=3, t represents the market period in the experiment in which the particular value of the dependent variable was observed, D_i is a dummy with value 1 for observation of the dependent variable in session i and zero otherwise, β_{1i} is the starting point of the convergence process for session i, while β_2 is the asymptote. When t=1, β_{1i} takes the value of the dependent variable for session i. At large values of t the influence of β_{1i} is small, while the influence of β_2 is large as $(t-1)/t$ approaches one. Since both the competitive and market power models make specific predictions of the value of the end point of the market adjustment process, β_2 should be common across experiment sessions within treatment if market convergence occurs. There is no such restriction on the starting point. u indicates a random disturbance term distributed normally with mean zero. Since the model attempts to quantify a dynamic adjustment process, we allow for first-order autocorrelation and also allow for heteroscedasticity across sessions within treatments. The specification imposes linearity to estimate an unknown convergence process occurring in experimental markets. Accordingly, it is open to criticism, however changes in the functional form did not alter the results reported.[15]

Since the model attempts to capture the dynamic adjustment process, it is also capable of answering questions of convergence direction. The definition used by Noussair, Plott and Riezman (1995), is adopted to describe "weak convergence" as occurring when the starting point of the estimated process is further from model prediction than the estimated asymptote, β_2.[16] The model was estimated by treatment using ordinary least squares for closing prices in the double auction, permit holdings, production prices and levels, firm earnings and market efficiency measures. These results are reported in Tables 6 to 13, as

[15] As in Noussair et. al. (1995), two other functional forms were tested. The first alternative functional form allowed the end point of the convergence process to vary with each session while maintaining a linear specification

$$Y_{it} = \beta_{11}D_1\frac{1}{t} + ... + \beta_{1i}D_i\frac{1}{t} + ... + \beta_{1n}D_n\frac{1}{t} + \beta_{21}D_1\frac{t-1}{t} + ... + \beta_{2i}D_i\frac{t-1}{t} + ... + \beta_{2n}D_n\frac{t-1}{t} + u \ .$$

This yielded similar coefficient estimates to the specification reported in the text. A non-linear test equation was also used,

$$Y_{it} = \beta_{11}D_1(\frac{1}{t})^{\alpha 1} + ... + \beta_{1i}D_i(\frac{1}{t})^{\alpha i} + ... + \beta_{1n}D_n(\frac{1}{t})^{\alpha n} + \beta_2(\frac{t-1}{t})^{\gamma} + u$$

where coefficient and exponent terms were estimated. As in Noussair et al. (1995) this did not improve goodness of fit, while generating standard errors which did not allow either model to be rejected, thus the results are not reported. As is the case for much econometric work, correct model specification is never certain. Any inferences gained from the results reported must be interpreted with this caution, however, given the lack of any confident theoretic foundations of market convergence, further investigation of such concerns is outside the scope of the paper. Even to the most hostile reader, the following reported results can be interpreted as mere refinements to those summarized in Table 5 and Figures 2 to 8. The econometric work attempts to further quantify results which are clearly indicated using ocular inspection.

[16] Weak convergence is defined to occur when the following conditions are true: (i) estimated β_2 is closer the model's prediction than β_{i1} when both estimated values are significantly different from the model predictions (ii) if the p-value of β_2 less than the p-value on β_{i1} (iii) or if both estimated p-values are greater than 0.05, indicating neither is significantly different from the model prediction at the 0.05 level, therefore the series is said to have already converged at its starting point and the series did not deviate away.

are the significance levels of the various hypothesis tests conducted. Standard errors were corrected for heteroscedasticity using White's method (White, 1980) and serial correlation where appropriate.

The first result formalizes a general experimental result previously noted. Data generated in the laboratory will appear to be moving toward a final equilibrium level, however, it often will not attain it until late in the experiment, if at all. This characteristic is observed in Figures 2 through 8. The first question asked of the data is whether either model accurately predicts actual observed outcomes. Both models can be statistically rejected using the equation above, even though it has been adjusted to account for different adjustment rates and time paths across experimental treatments and sessions. Since dynamic behaviour occurs in all markets as adjustment takes place, the following result indicates that, in general, any point predictions of market outcome made using static models should not be expected with certainty. Dynamic disequilibrium processes are at work in these markets which cannot be described by these simple static models.

Result 1: In all treatments, the competitive and market power models can be rejected. Neither model accurately describes all market outcomes observed.

Support:

Since both competing models make numerous specific predictions regarding outcomes of market variables, to reject either model requires only one prediction to be in error, however, many of the observed outcomes do not support either model. As noted before, due to statistical problems encountered in experimental data, testing outcomes relative to predictions is accomplished by asking whether the predicted asymptote of the estimated convergence process, β_2, is significantly different from that predicted by either model. Estimated starting points, asymptotes and standard errors are reported by treatment for prices, production levels and permit holdings in Tables 6 through 10. A summary of the p-values generated by the significance tests of each model's predictions is also included, with those exceeding the 0.05 level of significance indicated in bold type.

Competitive predictions are rejected at a significance level of at least 0.05 in two of four treatments for closing permit prices and fringe firm production levels, three of four treatments for permit holdings, and in all treatments for dominant firm production levels and production market prices.[17] The market power model fails to predict any of the fringe production levels, three of four treatment outcomes for permit holdings, and half of the treatment outcomes for dominant firm production levels and production market prices. It does, however, accurately predict all permit market closing prices across treatments.

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In a second, less strict pass of the data, it is apparent from Figures 2 to 8 that both models often appear to predict the direction of convergence even though actual predicted levels are not attained. Table 5 and the above-mentioned figures indicate observed market variables were often more extreme than predicted assuming manipulation of any sort. This impression is further validated by comparison of the estimated time paths of market variable starting points to predicted asymptotes. Comparing β_{1i} to β_2, convergence of the data, is, in general, in the direction of the predictions given by either model. Across permit price, permit holdings, production prices and production levels by firm type, forty-three of fifty-four instances occur where "weak convergence", as previously defined, is observed toward at least one of the two model predictions. Of these weakly convergent series, the direction of twenty-four fit both competitive and market power model

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[17] Note that if dominant firm permit holding predictions are rejected, so too are fringe firm permit holding predictions given the fixed number of permits available.

predictions. Of the remaining nineteen series, the majority are described by the market power model, therefore the competitive model is rejected as an adequate description of the general tendency of observed outcomes.

The following results summarize this observation with respect to the market variables observed. The first two results outline the double auction permit market outcomes. The predictive power of the market power model was significant and unexpected given previous work. A brief discussion of the possible reasons for this departure from previous market power work outlines some potential reasons for these findings.

Result 2: In all treatments, observed permit prices are accurately described by the market power model.

Support:

This is the only market variable accurately predicted by the market power model in the strictest sense. Summary statistics, and simple observation of time series results alone provide adequate support for this statement. The result is also strongly supported using the results of the estimated permit price time series. From Table 5, mean permit prices found for Treatments 1 to 4 were 86.64, 124.75, 64.43 and 206.68 respectively. We reject the hypothesis that observed permit prices arise from the identical sampling distribution, which would have indicated an efficient trading result, at the 1% level for all periods and from period six on.[18] Differences from the competitive outcome were large and in the direction of strategic predictions.

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[18] Previous market power experiments have shown that it may take four to five periods for the observed prices to converge. For all periods and the last five we reject the null hypothesis that all treatment coupon price samples are identical using a Kruskal-Wallis Rank-sum, also known as a Wilcoxon test for the two-variable case (calculated chi-square statistic of 84.196 (with 3 df.)). For a description of this test, see Kohler (1994). Nonparametric testing is used to limit the number of distributional assumptions needed and also due to the fact sessions exhibit autocorrelation from period to period.

Inspection of all price paths of permits by treatment over time in Figures 2 to 5 indicate convergence toward the strategic prediction. In Session T1-1, the dominant firm is so successful in depressing permit price, the mean price observed is 39.7. Such behaviour is excessive. Had the dominant firm purchased more coupons, even at higher prices, it could have increased profits. Session T1-2 indicates price path convergence to the strategic prediction from above, indicating coupons did trade at or near the efficient price during period 3, however prices continued downward toward the predicted strategic price, resulting in a mean price of 97.5. Mean permit price in Session T1-3 is 87.3. Treatment 2 price paths indicate convergence to the strategic prediction in two sessions. For Sessions T2-1 and T2-2, prices appear to converge from above to 110, while Session T2-3 appears to converge to the efficient price of 105 from below. In Treatment 3, all sessions indicate convergence from below over time with only Session T3-3 appearing to converge to the competitive price prediction. Treatment 4 price paths all indicate convergence to the predicted strategic price from above. From Table 6, the estimated asymptote β_2, is not significantly different from the market power prediction for any treatment. The competitive model predicts only two of the four treatment outcomes and the significance of the prediction is always lower. All series are seen to be weakly convergent to the market power predictions while the competitive model is weakly convergent in ten of twelve.

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The market power model proved less able in predicting permit quantities, however the following result further reinforces Result 2.

Result 3: Observed permit quantities deviate significantly and in the predicted direction from competitive levels in all treatments where competitive and market power predictions differ.

Support:

Figure 6 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. Figure 6 and summary statistics provided in Table 5 indicate convergence of permit holdings toward strategic (market power) predictions in all treatments, including Treatment 2 where strategic and efficient (competitive) predictions overlap. Mean permit holdings of the dominant firm after trade for Treatments 1 through 4 were 2.667, 7.167, 1.935 and 7.767 respectively. For Treatment 2, Sessions 1 and 2, at least seven permits were held by the dominant firm in most periods. Apart from Session T2-3, only Session T4-1 appears to indicate permit holdings converging to the efficient levels. All others are best described by the strategic predictions.

From Table 5, the mean final permit holdings observed for Treatments 1 and 3 indicate the dominant firm purchased fewer permits per period than the efficient prediction (implying the fringe held too many). Moreover, in Treatment 4, this firm purchased more than the efficient level on average. Observed permit holdings in Treatment 2 differ little from the efficient prediction, however, both competitive and strategic predictions are equal in this case. Where these holdings were observed to differ from efficient levels, they were in the direction of the strategic prediction. From the estimated time series results in Table 7 all predicted asymptotes exceed the competitive prediction in the direction of the predicted market power outcome. Seven of the twelve series weakly converge toward the market power prediction. The estimated time series confirm all of the impressions gathered noted above from the summary measures. In general permit holdings deviate in the direction of market power predictions, while the competitive model is firmly rejected as an accurate description of the data observed.

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These results contrast with earlier competitive permit market experiments. Previous experiments have generally found the competitive model to predict observed market prices. This contradiction may suggest that differences in this experiment's environment could have caused the strong market power pricing outcomes. Earlier experiments did not provide monopolists with the amount of information the dominant firm had here. Without this extra level of information, the double auction may not disseminate the necessary information a monopolist needs quickly enough to allow manipulation. Tacit resistance may then develop among the fringe toward such manipulation, and the successful counter-speculation observed by fringe firms in earlier work would then emerge.[19] It is not hard to imagine monopolists in previous experiments giving up high price strategies after making the (wrong) assumption the prices they have offered are unprofitable for their buyers, especially when faced with a fringe that is not buying.

Sessions in which monopoly power was previously observed may have occurred because the monopolist acquired fringe cost information indirectly through repeated high priced trades in early periods. These conjectures, however, might cause one to expect sessions in the earlier work which did result in non-competitive outcomes to be characterized by higher initial prices when compared to those that resulted in competitive, or near-competitive outcomes. The results of Smith (1981) and Smith and Williams (1989) do not support this conjecture.[20] In Smith's work, the one monopoly double auction session

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[19] 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.

[20] Ledyard and Szakaly-Moore do not provide individual transaction data.

that clearly converged to competitive equilibrium also exhibited the highest early trade prices. Smith and Williams' price data did not exhibit significantly different early transaction prices between sessions that converged to competitive price and those that did not.

Alternatively, the extra information provided to the market power firm in the environment here may have served to harden the market power firm's response to counter-speculation. In Treatments 3 and 4 the dominant firm had an exclusionary incentive to hold permits which was not present in the other permit experiments and allowed a more complex vertical relationship to link the two markets than in Treatments 1 and 2. Although opportunity existed for simple manipulation. Treatments 3 and 4 allowed the dominant firm another option: using the permit market to affect downstream product market outcome. Decisions to produce, however, were made in a state of uncertainty. All subjects faced a sequential decision, first whether to purchase or sell in the permit market and then to produce in the product market. Permit values depended on the product price received for the final product. Since the dominant firm had more information regarding other firm's costs, as well as a greater ability to manipulate the product market outcome, this information asymmetry could have worked to its advantage.

An asymmetric information hypothesis would seem very attractive in explaining differences between our results and earlier work, however observation of the market power subjects during sessions and informal questioning afterward indicated they did not generally use the fringe cost information provided. No formal or informal instruction was given regarding how these costs could be used and there were no sessions which exhibited transaction patterns suggesting an attempt at price discrimination. Although subjects did not indicate they used the additional information, it could have been used to some advantage. Naturally occurring economies could often include larger firms with large information advantages over smaller rivals. Conversely, although smaller firms might also be able to acquire competitor cost information, without market power the usefulness of such information may be limited. These results might indicate if such an information asymmetry effect exists, real world applications of double auctions may not be as resistant to monopoly pricing as otherwise. Clearly experiments regarding asymmetric information could be informative here.

Another explanation for our results may be an experience asymmetry previous work did not include. Fringe subjects in these experiments had never participated in a double auction experiment before while market power subjects had. The market power firm in two sessions though, had to be chosen at random from a pool of inexperienced subjects.[21] These sessions also achieved predicted strategic outcomes, and did not exhibit strikingly different results from other sessions.

Previous market power work has attempted to explore the boundaries of competitive price theory by limiting the number of sellers. They did not consider the alternative boundary limit, the number of buyers, and also only considered only the special case of a "small" fringe. Smith (1981) offers a theory that the double auction is more resistant to monopoly price manipulation than other trading institutions specifically because it is possible to demand withhold, or counter-speculate. Monopoly is welfare reducing due to the lower quantity traded. This may be represented experimentally by all subjects buying less, as earlier authors have modeled their markets, or by some buyers being excluded from the market if the strategic predictions arise. Designing these markets to reflect the second possibility may explain the strong market power results observed.[22] Increasing the

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[21] Sessions 2-2 and 4-2.

[22] Researchers must consider the bias certain methodological techniques may introduce to their work. It is much easier to design an experiment in which all subjects generate a positive return for themselves, avoiding the possibility of uncomfortable situations in which subjects do not earn a reward for their effort.

number of buyers to allow the possibility of market exclusion may nullify the effectiveness of counter-speculation. If the reason the competitive market outcome was observed so often in monopoly environments was due to counter-speculation, adding more buyers to the market and allowing such activity to risk market exclusion and zero profits might reverse the finding. Our results support this argument.[23] Increasing the number of buyers (and not increasing the number of predicted trades to match) may have undermined the incentive to counter-speculate.

Permits may be viewed as an input required in the production of an output which may or may not be common across firms. The market power model suggests that output in the production market will deviate from competitive predictions. Since the market power model predicts permit market outcomes well in Treatments 3 and 4, Result 4 follows.

By not allowing trade to exclude subjects when the strategic outcome occurs, previous authors may have introduced bias. Our methodology may create bias in the opposite direction.

23 In previous work the parameters used generate predicted market power outcomes which still allow a purchase by each fringe firm, thus none risks being left without a unit by counter-speculating. Such parameter sets rule out any uncertainty for demand withholding behaviour. Counter-speculation is in the fringe sector's best interest when the monopoly prediction still generates enough sales to cover all fringe firms, and excludes none from earning a return in the experiment. Such activity forces lower prices and benefits all buyers, even if quantity traded does not increase. In fact, such behaviour might be reinforcing. A firm buying too early and at a high price in any period, might after observing the lower price others obtain by waiting, also withhold its demand in ensuing periods. Periods would exhibit later and later trades at lower and lower prices. In response, the monopoly firm would be better off offering lower prices sooner in an attempt to increase volume, with competitive result being the final outcome. Counter-speculation would not be expected to be self-sustaining behaviour if demand withholding resulted in the exclusion of some firms from trade, as the excluded firms would stop counter-speculating to trade earlier and include themselves in the market. Smith (1981) observed only 12 periods of 46 in which one or more fringe firms were clearly excluded from sales. All exclusions except two (both in different sessions) took place very early in the session. Smith and Williams (1990) observe even fewer exclusions as defined, with six occurring over 43 periods. Since Ledyard and Szakaly-Moore (1994) use Smith's parameters, they too may have used a design that, by its nature, induces counter-speculation. Our strong market power results are consistent with the incentive explanation proposed. Treatments 1 and 3 endow all fringe firms with a permit. Strategic predictions would leave four and two fringe firms without permits after trade in each period and for each treatment respectively. Treatments 2 and 4 would inhibit the incentive to counter-speculate due to the risk of exclusion from the market resulting in zero profits for the affected fringe firms. Strategic predictions would leave five and six fringe firms without a permit and the means of earning a profit in each period, by respective treatment.

Result 4: Initial allocation of permits determines system outcome.

Support:

Market power outcomes in permit markets imply distortions in vertically related product markets, as seen in the predictions in Table 4. Differences in initial allocation in the presence of market power are felt throughout the economic "system". Consider a situation where all firms in the permit market compete in a common product market, such as in Treatments 3 and 4. If all firms acted as price-takers in the C-market but the dominant firm, recognizing its market power, acted in a dominant manner in the P-market, the resultant theoretic outcomes would be described by the second row of Table 4. Results could be identical across treatments, or could differ due to distortions caused by the use of market power in the product market only. Given the estimated values and standard errors from Tables 6 and 7, the efficient permit market predictions of this model are firmly rejected for Treatments 3 and 4, even after allowing that observed prices and permit quantities may differ from the competitive system outcome due to the distortions caused by the dominant firm's use of market power in the P-market. In fact, all implications and predictions of this model are firmly rejected, for both permit and product markets. Results 1 and 2 indicate the use of market power in the permit market. Permit market outcomes of all treatments are also found significantly different from one another, suggesting an non-competitive permit market result. The uncompetitive permit market outcomes observed result in are significantly different outcomes in all product markets by treatment. Result 4 therefore follows: in the presence of market power, initial allocation determines total system outcome.

The repercussions of the use of market power in the permit market can been seen in Table 5. Treatments 1 and 2 induced price-taking behaviour in the P-Market. The production results for these treatments were close to efficient levels, though output levels by sector were not. The effect of market power in these treatments mostly impacts firms' earnings. Allowing P-market price to be market determined allowed market power to be used to influence product market outcomes. Observed production levels by sector changed significantly, as did total production relative to treatments with fixed P-market price. Sectoral production levels by period for Treatments 3 and 4 are plotted by session in Figure 7. Treatment 3 mean and median production levels are very close to the strategic prediction and five units below that expected from the dominant firm in an efficient market. Fringe production was also closer to the strategic prediction of ten units than the efficient level of six. Treatment 4 exhibited excessive underproduction by the dominant firm relative to the strategic prediction. This may explain the fact that the observed mean fringe production level of six units in Treatment 4 is better described by the efficient production level of five units than by the market power prediction of 4. Excessive product market prices caused the fringe to increase production though on average they held very few permits.

Econometric analysis of the data verifies these results. Four of six P-market price paths in Treatments 3 and 4 are found weakly convergent toward the market power prediction. Of those that are not, ignoring the standard error of the starting point estimate suggests another series also weakly converges. Eight dominant firm and six fringe production series weakly converge to the market power prediction. Of those that do not, one dominant firm series only rejects due to the large standard error of the starting point estimate. Point estimates alone suggest weak convergence. Three others are rejected due to excessive under-production, where under-production is predicted in the market power model relative to the competitive one. In general, the direction of output market outcomes is successfully predicted by the market power model predictions.[24]

■

The combination of Results 2, 3 and 4 have important implications theoretically. For policy-makers, however, the fact that market power is an important determinant of permit market outcome and the fact that distortions caused in permit markets may cause significant distortions elsewhere should also be of serious concern. This result could influence both the political viability of permit markets and the magnitude of efficiency benefits they offer. Efficiency and equity considerations are the focus of the remaining results.

Production decisions impact directly in earnings results. Earnings results could affect the political viability of permit trading programs. Ledyard and Szakaly-Moore (1994) argue institution of a tradable emission permit system will not be politically viable if one firm or sector participating in the market is made worse off after its inception. If the permit trading program is "sold" politically by the promised gains the institution of trade will create, it is important to determine how market power could undermine these gains. Additionally, if consumer surplus is reduced due to manipulation of the product market through use of the permit market, the concept of political viability must be expanded to include the consuming sector's constituency. Result 5 describes the earnings outcomes observed.

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[24] To further their power over the product and permit markets, one dominant firm subject suggested they used the product market to discipline fringe firms. When permit prices were difficult to maintain at the dominant firm's preferred level, the product market was used to provide incentives for the fringe firms to accept the permit prices presented in the double auction. 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 3, or under-producing to create the opposite effect in Treatment 4. Sessions T3-1, T3-3, T4-1 and T4-2 support such predictions and might further explain the observed under-production found for the pooled data of Treatment 4. Modeling such behaviour is outside the scope of this paper but would be an interesting avenue of future research.

Result 5: Successful market power manipulation results in significant changes to the distribution in gains from trade.

Support:

Table 11 presents the results of estimated earnings convergence functions for the dominant firm by treatment. The market power predictions indicate successful manipulation of markets by the dominant firm will transfer potential profit gains of trade away from the fringe. Treatments 2 and 3 do not reject the hypothesis that earnings time series have converged to the market power predictions. Treatments 1 and 4, as reflected by the general finding of Result 1, reject this hypothesis. Six of the twelve series weakly converge to the market power prediction, and of the four series that do not, it is the large standard errors of the starting point estimates that cause weak convergence not to be indicated. Weak convergence is indicated if only point estimates are considered. Table 12, the estimated time path of fringe sector total earnings further reinforces the findings noted above. All treatments and all estimated series for fringe earnings indicate weak convergence to the market power prediction.

Tables 14 to 17 describe mean earnings outcomes across sectors for the last five periods of each session. The strategic prediction for Treatment 1 indicates a loss of half of the possible efficient market profit gains for the fringe, with 73% of that loss transferred to the dominant firm. The strategic prediction for Treatment 2 indicates a 50% loss to the fringe with 100% profit transfer. Analysis of final distribution of total profits by treatment indicates the dominant firm successfully captured or exceeded predicted gains in both treatments. Negative profit gains for Treatment 2 were caused by trading "mistakes", purchases at excessive coupon prices or by inappropriate firms, the largest of which occurred in Session T2-1.[25]

Treatments 3 and 4 allowed opportunity for both the fringe and dominant firm to increase profits over efficient levels if the dominant firm restrained production levels. Treatment 3 results indicate both sectors earned higher gains than the strategic prediction allowed. Distribution of total profits reflected successful manipulation by the dominant firm, allowing it to capture over 20% of total profits on average, and exceeding the highest share predicted. In Treatment 4, 97% of the total profit earned by both sectors was captured by the dominant firm. When losses occurred due to trading errors, average loss experienced by the fringe was 50% higher than that incurred by the market power firm. Sessions T4-2 and T4-3 indicate the dominant firm was generally the only firm to earn a profit.

■

From the predictions presented in Tables 14 to 17, no firm in this study should have been made worse off by participating in trade. Firms were free to buy or sell endowed rights in the C-market and then produce in the P-market afterward. Simply not participating would not incur loss. In the absence of risk or trading "mistakes", trade should only have occurred if it were mutually beneficial through increased profits. Sessions which allowed product price to be determined by the market, however, introduced risk and the potential for losses, if "price surprises" occurred.

[25] Here we define trade mistakes to be those trades which cannot be expected to be profitable. In treatments with fixed P-market price any permit trade made at a price greater than (125 - the firm's production cost). In Treatments 3 an 4, determination of mistakes is more difficult. We define a mistake as any trade occurring at prices which result in a loss after the P-market takes place (observed P-market price - firm production cost). "Unexpected mistakes" are further defined as those trades which were unprofitable after P-market price was announced but would have been profitable for P-market prices (given market demand is a step function) one std. deviation above the observed P-market price. (Observed P-mkt. price + std. deviation) was rounded to nearest P-market price possible. The standard deviation was calculated using the observations of product market price over the three previous periods.

Treatments 1 and 2 resulted in no consumer surplus loss since P-market price was fixed at the competitive level of 125. Losses due to market power would only be reflected in the distribution of profits among producers. From Tables 14 and 15, session results indicated a larger than predicted share of the benefits of permit market institution were captured by the dominant firm. Further, exactly half of the sessions led to fringe losses. These sessions corresponded to the sessions in which the dominant firm came closest to the earnings predicted using strategic manipulation. It would appear when market power is exercised, the distribution of potential gains from trade are skewed toward the market power firm. Smaller potential gains are left for fringe firms compared to the efficient market prediction. When trade errors occurred, their potential impact on fringe firms was proportionately much larger than had competitive market circumstances been present, and often eliminated any chance of any trade gains.

If uncertainty or risk in markets is present, the possibility of unexpected outcomes could increase the probability of losses so large that could not be offset by later gains for fringe firms. In Treatments 3 and 4, profits earned by sector were compared to those that would accrued had no trade occurred and the dominant firm used its market power only in the P-market. Treatment 3 results indicate that on average per period profit gains earned by the dominant firm exceeded the strategic prediction while the fringe realized losses after trade. The dominant firm exceeded earnings implied by the market power model in all sessions. Treatment 4 predictions allowed only small gains available to either sector for permit trade, even if market power were used. Significantly, all sessions in this treatment indicated losses in one or both sectors relative to a no-permit trade outcome. When the dominant firm's earnings came closest to the market power prediction, fringe losses were highest. When uncertainty was present (in Treatments 3 and 4) and trade risk increased, combined with smaller potential trade gains available, losses occurred more often across all firms. Market power predictions generally describe actual outcomes and earnings time paths, but in two of three cases in Treatment 4, the dominant firm incurred loss instead of gain by participating in trade. Although the dominant firm appeared successful in the direction of its market manipulation, it was not successful enough to see a gain from it. This may indicate it is difficult to gain from market power in markets where little gain is available to be made and risk exists. When market power outcomes are expected in downstream markets, permit trade increased risk without realizing any gain (on average) for fringe firms, and often resulted in losses. This would imply the political viability of markets in such circumstances may be questionable, as firms may choose not top trade at all. Both treatments realized a net loss in total earnings relative to the no-trade prediction. In such circumstances, participating firms might prefer the no-trade environment to that with trade.

A further impediment to political viability might be the reaction of the consuming sector in cases where permit market participants also compete in product markets. Treatments 3 and 4 allowed consumer surplus to be negatively impacted by manipulation in one or both markets due to production market production level and price changes. Although not apparent from the tables, realized consumer surplus was reduced in two sessions of Treatment 3 and Treatment 4 respectively, relative to the no-trade outcome.[26] Consideration of consumer sector gains also does not obtain a politically viable result.

The combined effects of consumer surplus and firm earnings imply changes in efficiency observed across the economic system. Permit markets are implemented or suggested by

[26] Had trade not been allowed and the dominant firm used its market power in the production market, expected P-market price would have been 145 in Treatments 3 and 4. Mean observed P-market price for Treatment 3 was 177.903 with session means of 177.0, 163.0, and 192.3. Treatment 4 mean price was 177.667 and session means were 179.0, 189.0 and 165.0. These prices imply on average consumer surplus was less than (Sessions T3-1, T3-3, T4-1 and T4-2) or equal to (Sessions T3-2, T4-3) than that possible without permit market trade.

policy-makers for their potential to increase system efficiency relative to more traditional regulatory methods. Market power in permit and product markets could undermine these results. The following discussion describes how the observed use of market power affected system efficiencies.

Result 6: Efficiencies differ across treatments.

Support:

If competitive results had been achieved across treatments there should have been no significant difference in treatment efficiencies. The fact that efficiencies do differ reinforces the earlier results indicating successful use of market power. Three measures of efficiency are used. The first and simplest asks whether permits are applied to the "correct" production units. The competitive result would allocate six or seven permits to the dominant firm and three or four to the fringe, depending on initial endowments. These allocations would minimize abatement control costs and maximize efficiency. Only fifteen periods of 120 exhibit the efficient allocation over the course of the experiment. Session T2-2 attained the efficient permit allocation in as many as half of its periods, while Sessions T2-1 and T2-3 reached it in two of ten periods. Mean observation for Treatment 2 was 7.167, but the market power prediction is also the efficient one. For Treatment 1, the efficient allocation was found in only one of thirty periods, while Treatment 3 never arrived at an efficient allocation. Efficient allocation occurred in five of thirty periods in Treatment 4.

The second efficiency measure compares observed market surplus with that achievable in competitive circumstances. To determine quantitatively the impact of strategic manipulation on market efficiency relative to initial allocation efficiency, an efficiency index is constructed. This index is the ratio of the actual observed improvement in efficiency and the maximum possible improvement, given initial allocation.[27] These are calculated for the last five periods of each treatment and reported in Figure 9. Figure 10 illustrates a third measure, efficiencies ratios, defined as the efficiency observed relative to that possible by session. For reference, the efficiency ratio that would occur if no trade taken place (command-and-control allocation) is also indicated. Both efficiency measures indicate a dead weight loss in the laboratory economy for all sessions with the exception of session T2-3. Obvious differences appear in efficiency observed by treatment.

Table 13 reports the estimated time path of efficiency indices observed across treatments. The market power model accurately predicts the asymptote in treatments which allocate toward the dominant firm. In the other two treatments, the estimated time series appears to be converging to an efficiency worse than that predicted by the market power model. Nine of twelve series are found weakly convergent to market power predictions, with the remainder indicating excessively low efficiency at the asymptote point estimates.

■

Efficiency results for Treatments 1 and 2 indicate most potential trading gains were achieved. This encouraging result implies the social cost of simple manipulation is small, at least for the parameters used here. Loss was caused only by the "wrong" firms holding permits, shifting the supply curve upward and lowering producer surplus available and

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27 The efficiency index reported here is $\frac{TS_{6-10} - TS_{6-10}^{CC}}{TS_{6-10}^{PC} - TS_{6-10}^{CC}}$. Note the indices in the figure are reported for periods 6 to 10, to allow the market time to approach convergence. In the regressions described later, the indices are calculated based on the results of each period. 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 1 and Treatment 2) or assuming dominant firm pricing. Total surplus (*TS*) is calculated as total consumer surplus and total profits realized by subjects.

achieved for intra-marginal units traded. P-market trade was conducted in these treatments at a price unaffected by manipulation in the C-market and generally no loss in consumer surplus was observed. The higher efficiencies observed in Treatment 2 reflect the more efficient initial allocation of permits. In a dynamic context, however, the allocational efficiency of these markets may be over-stated by these results. Permit price signals are used as an incentive for technological innovation but are also influenced by market manipulation. Treatment 1 observed prices could lead to lower innovation than dynamic efficiency would require while Treatment 2 prices would cause excess innovation relative to a competitive market outcome.

Treatments 3 and 4 did not set an artificial price level in the product market, allowing potential consumer surplus to be reduced by market power activity. This loss, in addition to the impact on producer surplus of the "wrong" firms producing, had serious implications for system efficiency. Treatment 3 observed efficiencies exceeded those in Treatment 4. As predicted, the allocation of permits to the fringe deterred 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 these purchases had on the price of permits combined to make such activity unprofitable, and the dominant firm concentrated on cost minimizing behaviour. Limiting the extent of profitable strategic manipulation in Treatment 3 in the product market by the dominant firm appears to have increased observed efficiency relative to Treatment 4. The latter treatment's results reflect lower observed efficiencies as the dominant firm attempted to exclude fringe firms from the product market by hoarding permits and restraining production. On average, two permits were retired in each period throughout these sessions. Reduced total production caused lower consumer surplus relative to Treatment 3. In Treatment 3, relatively more of the observed efficiency losses were caused by trade mis-allocations. Monopsony in the C-market did influence the P-market, with restricted permit holdings by the dominant firm leading to lower output and inducing higher prices and reduced consumer surplus. Systematic underproduction by fringe subjects also reduced observed efficiency in this treatment.

The effect on dynamic efficiency and rate of technological innovations caused by uncompetitive prices observed in the Treatments 1 and 2 would continue to be present. Contrary to strategic predictions, however, the excessive permit prices observed in Treatment 3 would have caused excessive technical innovation, as would the prices observed in Treatment 4, relative to a dynamically efficient environment.

The efficiency results found here indicate the circumstances where market power might be most distorting. Clearly, cases in which permit market competitors compete in separate product markets results in higher efficiencies achieved. Further, in circumstances where the competitors only compete in the permit market, initial allocations which are closer to the competitive one result in higher efficiency achieved. This result was theoretically shown by Hahn (1984) and verified in experimental markets here. Treatment 2 observed efficiency is higher than that found in Treatment 1, where the initial allocation in the former treatment is closer to the competitive allocation than it is in the latter. In some cases, as already indicated by the earnings results presented, systems are more efficient without permit trade.

Result 7: Institution of permit markets when emitters competed in common product markets yielded negative efficiency gains with respect to command and control allocative efficiency.

Support:

On average Treatment 4 exhibited efficiency losses of 1.4 times the possible gain had the efficient outcome arisen. Treatment 3 also recorded negative efficiency gains, with an average efficiency loss of 0.42 times the possible gain. Note, the asymptote of the estimated convergence process for Treatment 4 in Table 13 is identical to the average value, while in Treatment 3 is -0.32, indicating almost complete convergence had been achieved in both treatments. Treatments 1 and 2 indicate efficiency improvements over initial allocation were obtained when exclusion was not permitted, even in the presence of the market power. Comparison to estimated asymptotes (in Table 13) also indicates almost complete convergence had been achieved in this treatment. Fixed prices at the competitive level forced high efficiency in the production market while trade in the permit market increased allocative efficiency in these treatments. Treatments 3 and 4 results indicate most efficiency loss comes from the dead-weight loss caused by the exercise of market power.[28] Both predicted asymptotes for these treatments are negative.

■

Results from Treatment 3 do not indicate exclusion was attempted by the dominant firm. Efficiency losses, however, were observed, which was not predicted. One possible reason for this occurrence may have been risk. If the fringe firms, who were endowed with all permits in this treatment, chose to hold onto permits instead of selling them, the dominant firm would be forced to reduce its output, resulting in lower consumer surplus. Such

[28] Some of the efficiency loss recorded also occurs due to trading losses, however these account for a very small proportion of the total.

behaviour on the part of the fringe may have been an attempt by low abatement cost fringe firms to ensure an ability to produce profitably at any product market price, thereby reducing the risk of production losses in this uncertain environment. The types of firms that would engage in such behaviour would more likely be the predicted sellers in the permit market, firms F1 or F2. In the last five periods of the three sessions in Treatment 3, only three periods occurred where the predicted firms, F1 and F2 actually sold permits to the dominant firm. Resultant efficiency outcomes therefore might reflect this problem, with the majority of efficiency loss occurring due to reduced consumer surplus, because of reduced dominant firm output levels.

When exclusionary manipulation was attempted in Treatment 4, reductions in system efficiency were substantial. The institution of a tradable permit market in these circumstances led to results worse than those possible had no trade permit occurred. The dominant firm idled at least one permit in 22 of the 30 sessions observed, and in nine sessions idled more, possibly to compensate for fringe over-production (relative to strategic prediction), under-producing to maintain high product prices. Session efficiency indices indicate the magnitudes of the observed efficiency losses were between 77% and 200% of the potential gain competitive permit and product markets could have obtained over initial allocation.[29] The fear some policy-makers have regarding market power distortions on planned permit institutions appears supported here.

Initial allocations "closer" to efficient outcome were not always "better". If one believes regulators need only have enough information to institute an initial allocation which is "close" to the efficient allocation to reduce market power effects, the vertical relationship of markets should be troubling. Treatments 1 and 2 would support such a contention.

[29] The efficiency indices calculated for Treatment 4 are -1.05, -2.36 and -0.77 for sessions T4-1, T4-2 and T4-3 respectively.

Treatments 3 and 4 clearly indicate market power incentives across markets cause efficiency to fall after permit trade despite initially high allocative efficiencies.[30] Initial distribution of permits *and* vertical relationship effect final outcomes. Clearly the relative concept of "close" must be redefined if vertically linked market manipulation is possible. The observed efficiency improvement in Treatment 3 caused by initial endowment suggests distribution of permits away from firms expected to have market power could minimize the effect of such vertical relationships, even if this results in a less efficient initial allocation. The opposite would be true if no such vertical relationship exists.

V. Conclusions

The exercise of market power in these permit markets (Results 2 and 3) stand in opposition to results in previous market power experiments using double auctions. Result 3 reflects the earlier finding that quantity traded is reduced by allowing a single subject monopoly power in a double auction. The significant effect that initial permit allocation has on market outcomes (Result 4) should only occur if market power is exercised in the permit market or all trade opportunities are not exhausted. The data suggests the reason initial allocation determines outcome in both markets is due to market power and not uncompleted trades. Given the extreme initial permit allocation and Results 2 and 3, this finding is not surprising. Manipulation by the dominant firm is so successful (Result 5) that total profits possible, given Result 4, are sometimes exceeded by the market power firm. The variation in efficiency across treatments (Result 6) is determined by Results 4 and 5 while the negative efficiency measures found in cases of exclusionary manipulation (Result 7) provide an example of how implementation of a

[30] Both treatments have initial allocation efficiencies of 94% assuming a dominant firm result occurs in the P-market.

permit trading system will not always increase overall system efficiency. Although the occurrence of trading in single markets for competitive economies must be welfare increasing, barring trading errors, distortions in vertically related markets due to market power can cause system efficiency losses. Results 2 through 4 offer insights regarding previous author's experimental market power findings. Outcomes found here are discussed with respect to those results and explanations suggested for the strong manipulation observed.

Two research questions were posed of the results. The first asked if there was consistent evidence of market power being successfully exploited when the opportunity was present. The response is affirmative, this experiment indicates emission permit markets may be very susceptible to a variety of market-power effects. The predictions of Misiolek and Elder are strongly supported by the results. Even using a trading institution with a history of competitive outcomes in the laboratory, it was possible to repeatedly able to identify opportunistic behaviour by firms with market power. This behaviour may have resulted by adding details not considered in previous market power work concerning double auctions: uncertainty and information asymmetries, experience, or the possibility of excluded price-taking firms in equilibrium. Further research is required to determine which, if any, of these effects is actually responsible for the repeated results found here.

Uncertainty arises from the existence of the sequential environment in which actions must be taken which optimally would require information of the future, generating the need for expectations to be formed regarding future events. This uncertainty seems especially harmful to fringe firms and seems to have been manifested in observed "mistakes" in the sessions in which they faced the highest risk of earning a zero or negative profit for unwise decisions (Treatment 3 and 4). In these treatments fringe firms repeatedly experienced profit losses. The sequential market structure of pollution permit markets also seems to facilitate predation through exclusion when firms compete in common product markets. Exclusionary behaviour was identified when the dominant firm was allowed this opportunity as a profit maximizing strategy (Treatment 4). Simple manipulation of the permit market by a dominant firm was identified in all other treatments. Further, the market power subject was able to determine which type of behaviour was more profitable in the case where either strategy could have been pursued (Treatment 3).

The theoretical benefits of transferable emission permit markets have been espoused by many critics of current regulatory methods. The reductions in the social cost of pollution control and their inherent effects on market efficiency, as well as the policy compatibility of pollution control with growth 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. Identification of markets where market power is likely to be used should not be too difficult after consideration of market structure in both the permit and product markets.

The second question asked whether resultant market power outcomes were serious enough to require special consideration by regulators. From the results reported here, it appears that although market power is repeatedly observed, relative to "command-and-control" only specific circumstances lead to inferior outcomes. It would appear from these experiments that strategic manipulation of markets is most damaging to system efficiency when the dominant firm is part of a vertically related market (those in

Treatments 3 and 4) and allocated with more permits than it needs (Treatment 4). In the latter case, the dominant firm could hoard permits to profitably exclude its rivals. Such an initial allocation reduced market efficiency on average by almost one and a half times the efficiency gain our markets could have achieved had competitive outcomes occurred. If the initial allocation were considered to be the "command-and-control" allocation, imposition of emission permit markets in these treatments led to inferior outcomes over centralized regulatory methods, even when the initial allocation was grossly skewed in favour of the dominant or fringe firms. When permits are grandfathered to large existing firms the ability to exclude rivals and new entrants appears to be a significant potential problem. 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. Grandfathering as an allocation mechanism has been employed in existing programs and suggested for a number of proposed markets.[31] The evidence here suggests before emission markets using such an allocation method are adopted, the structure of affected product markets should be scrutinized.

In this experiment, the dominant firm's competitors were other existing yet smaller firms. These could just as easily have been new entrants to the market. Larger firms would be expected to find exclusion more profitable than predatory pricing when facing small rivals as the latter strategy is costly. Predatory pricing was not a reasonable option here given the fringe subject's lack of an exit opportunity. The evidence here suggests the effect of market power is not minimal to system efficiency and could be very serious, especially with respect to entry. Simply allocating permits away from firms suspected to have market power in the permit market would not solve the problem. Policy-makers worried about the effect of market power may not be being overly cautious. These

[31] Such was the case in the Clean Air Act Amendments 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)).

concerns may indeed be well-founded. It may be very difficult to determine an initial allocation which would defeat market power opportunity.

The political viability of proposed emission permit markets also deteriorates when such market power is present. These results indicate the potential for manipulation of markets by a dominant firm could have serious effects on the distribution of gains such a program could generate, both to producers and consumers. Such distortions could leave some sectors worse off after such a program is implemented, and make such a system politically unacceptable. Common product markets maximize this potential.

Ironically, had these been actual markets, the lowest uncontrolled emissions would have occurred when the combined effect of market power and common product markets was most serious and resulted in the most distortionary outcomes from an efficiency and equity point of view. If a dominant firm chose to exclude firms by retiring permits, lower emissions would result. Generally, portions of the environmental movement have opposed implementation of market mechanisms for pollution control for philosophical, often anti-market reasons. The strongest indication of the severe distortions market power may have on market systems is the possibility to generate favour and support for markets from such an unlikely group.

Figure 1: Competitive Product Market with Efficient Permit Allocation

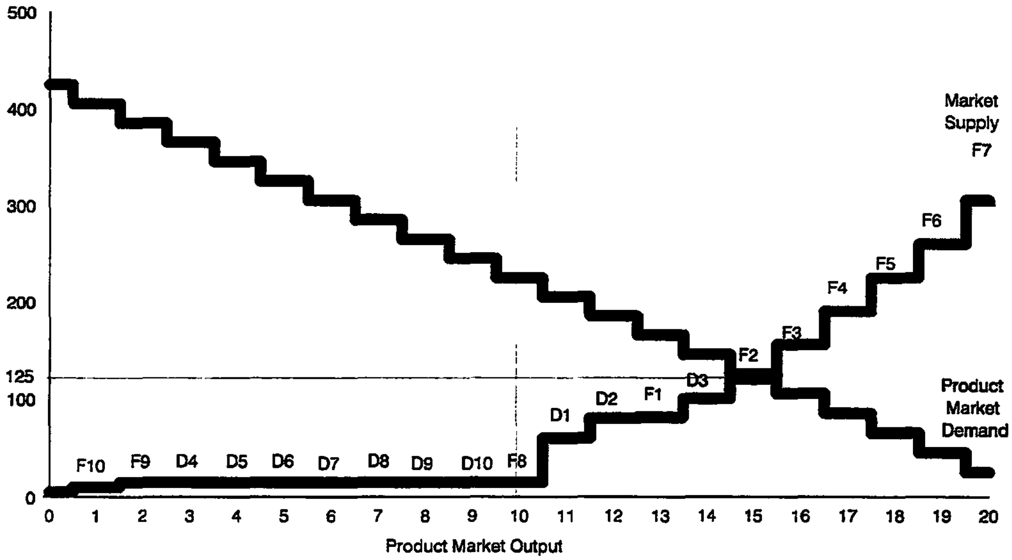
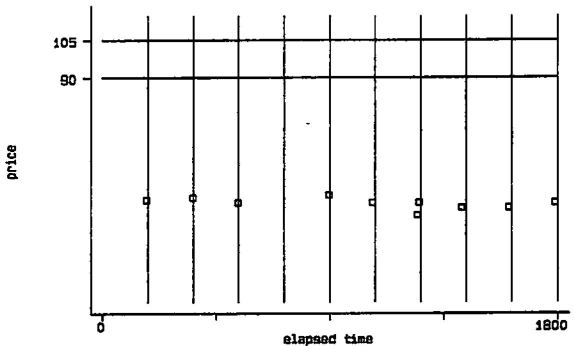
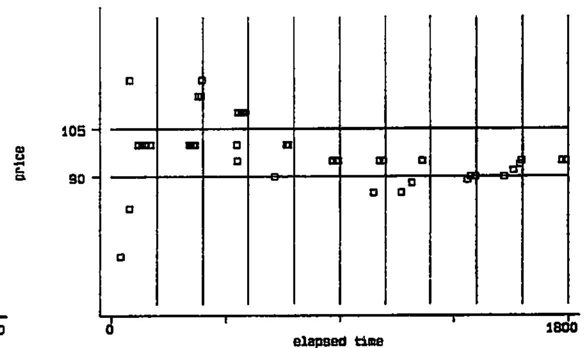


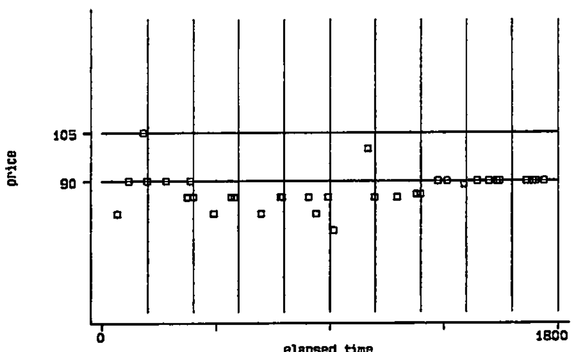
Figure 2: Permit Prices Over Time: Treatment 1



Session ETC 1-1: Transaction Prices

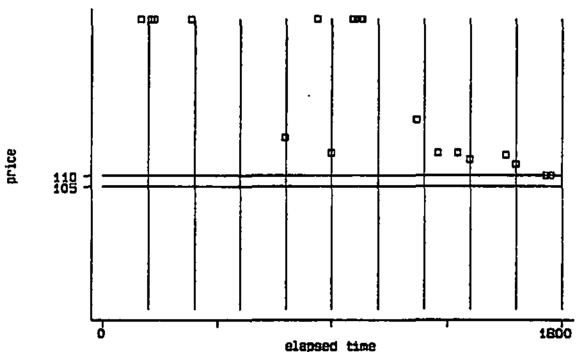


Session ETC 1-2: Transaction Prices

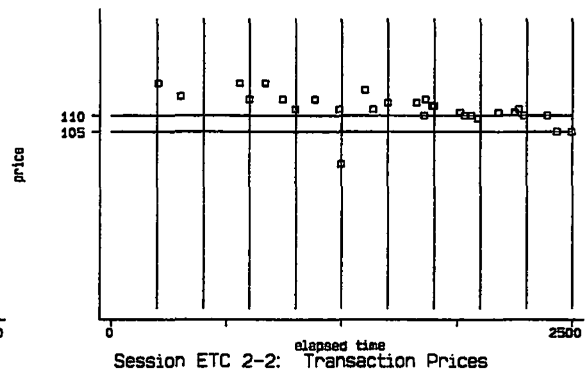


Session ETC 1-3: Transaction Prices

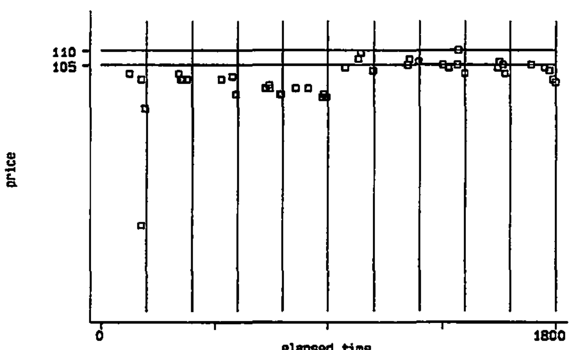
Figure 3: Permit Prices Over Time: Treatment 2



Session ETC 2-1: Transaction Prices

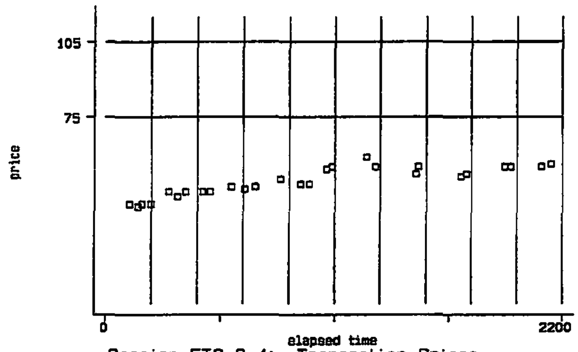


Session ETC 2-2: Transaction Prices

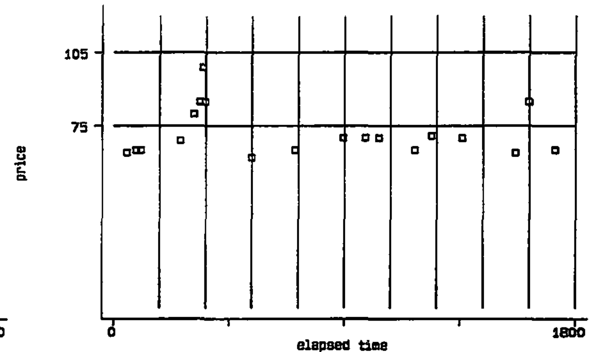


Session ETC 2-3: Transaction Prices

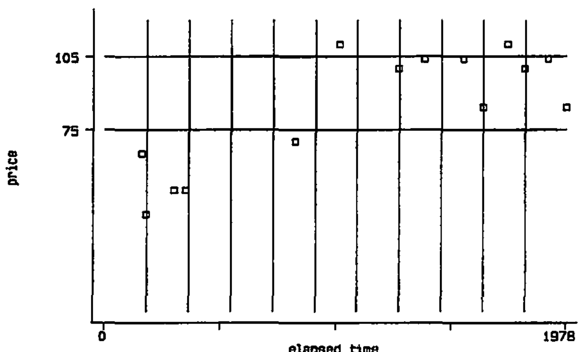
Figure 4: Permit Prices Over Time: Treatment 3



Session ETC 3-1: Transaction Prices

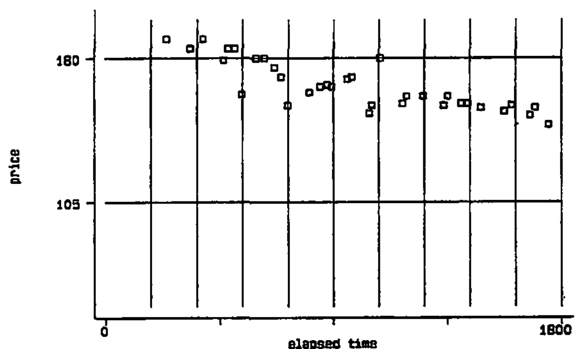


Session ETC 3-2: Transaction Prices

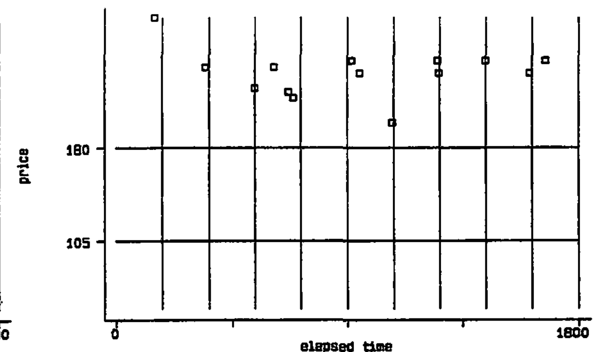


Session ETC 3-3: Transaction Prices

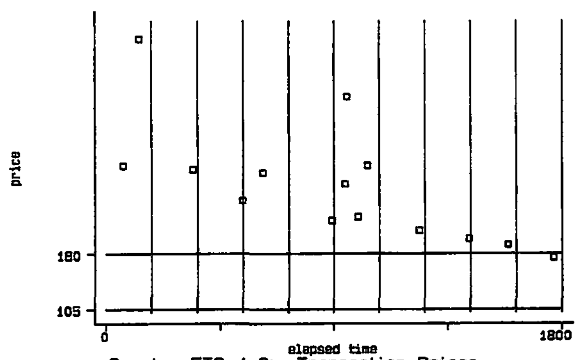
Figure 5: Permit Prices Over Time: Treatment 4



Session ETC 4-1: Transaction Prices

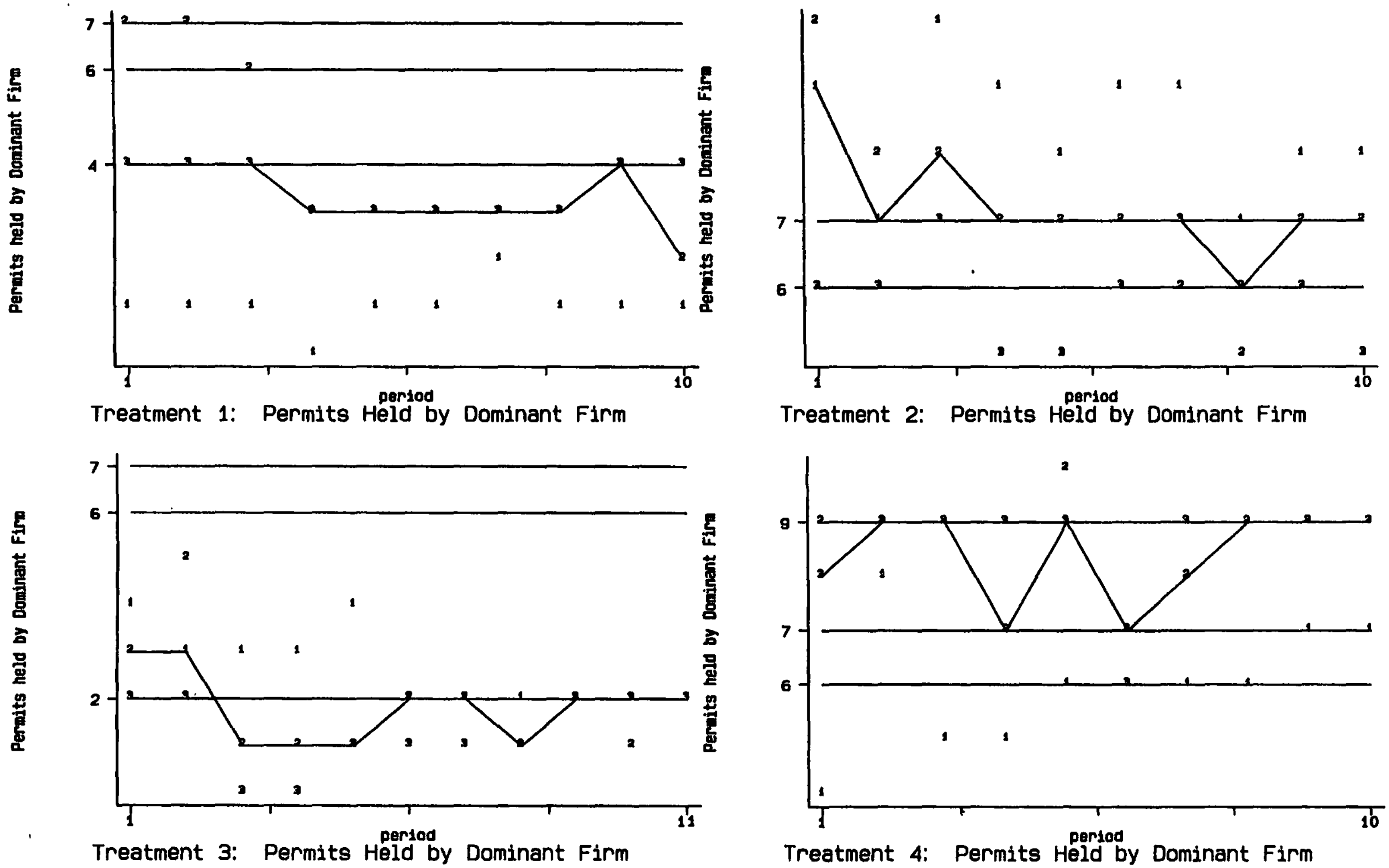


Session ETC 4-2: Transaction Prices



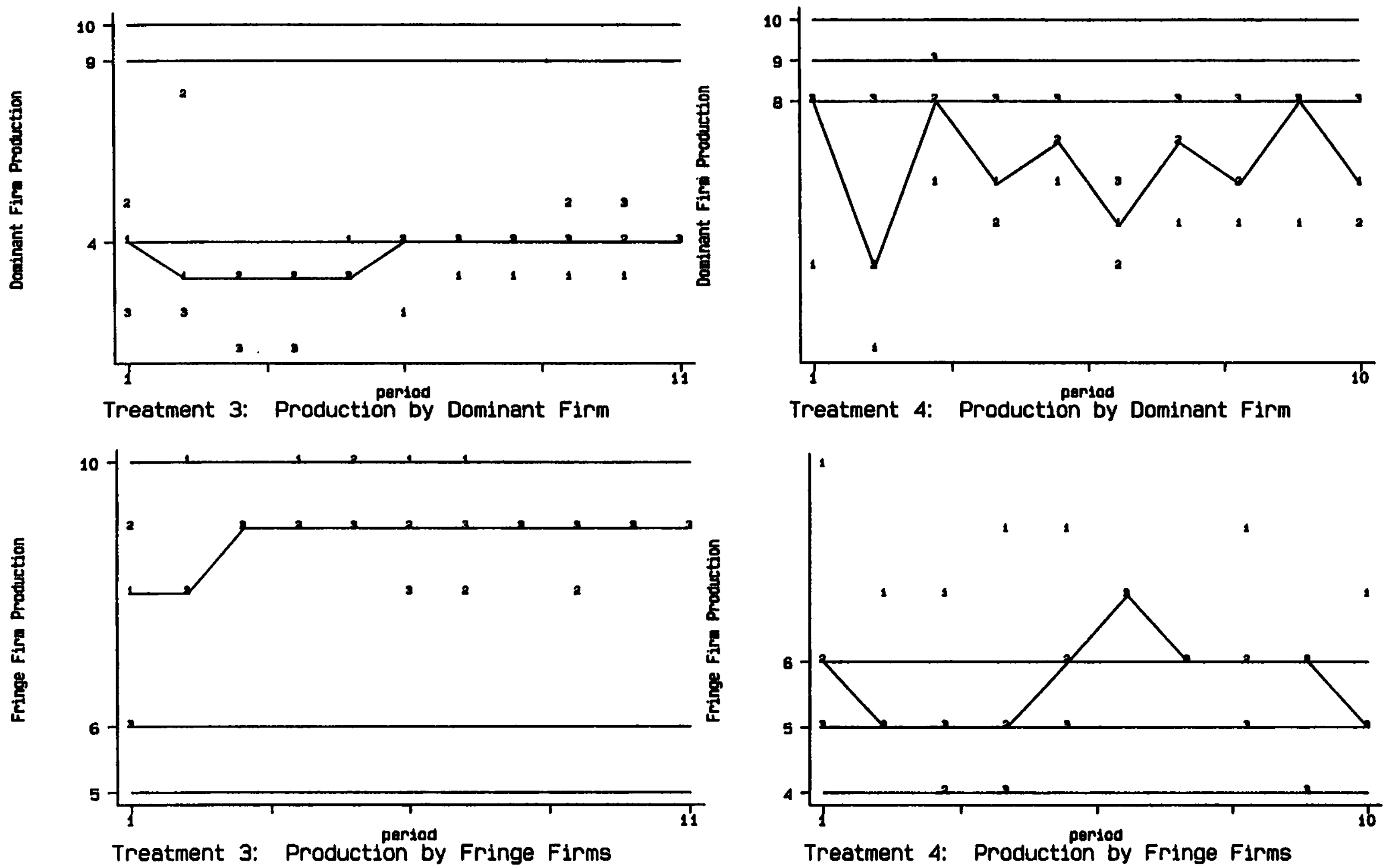
Session ETC 4-3: Transaction Prices

Figure 6: Permits Held by Dominant Firm After Trade



Notes: Digits 1, 2, and 3 refer to the session within treatment. The solid line connects median values.

Figure 7: Production by Firms, Treatments 3 and 4



Notes: Digits 1, 2, and 3 refer to the session within treatment. The solid line connects median values.

Figure 8: Production Market Prices, Treatments 3 and 4

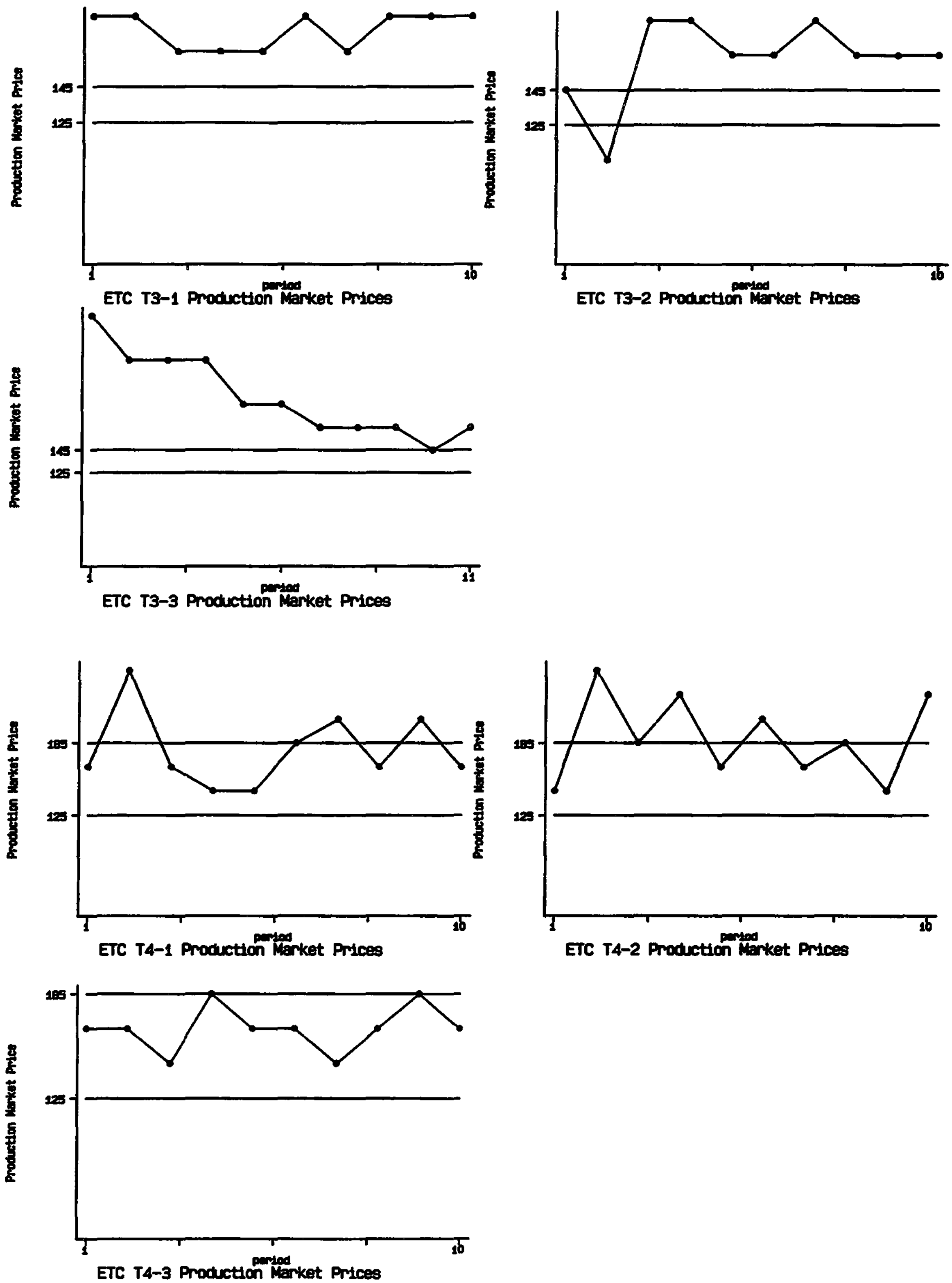


Figure 9: Efficiency Index by Treatment

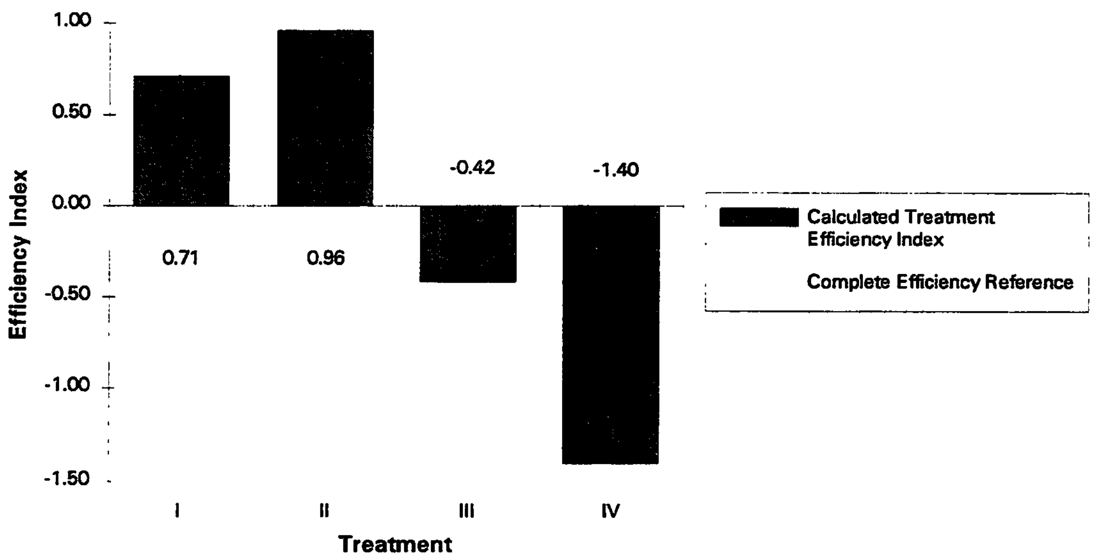


Figure 10: Efficiency Ratios by Session

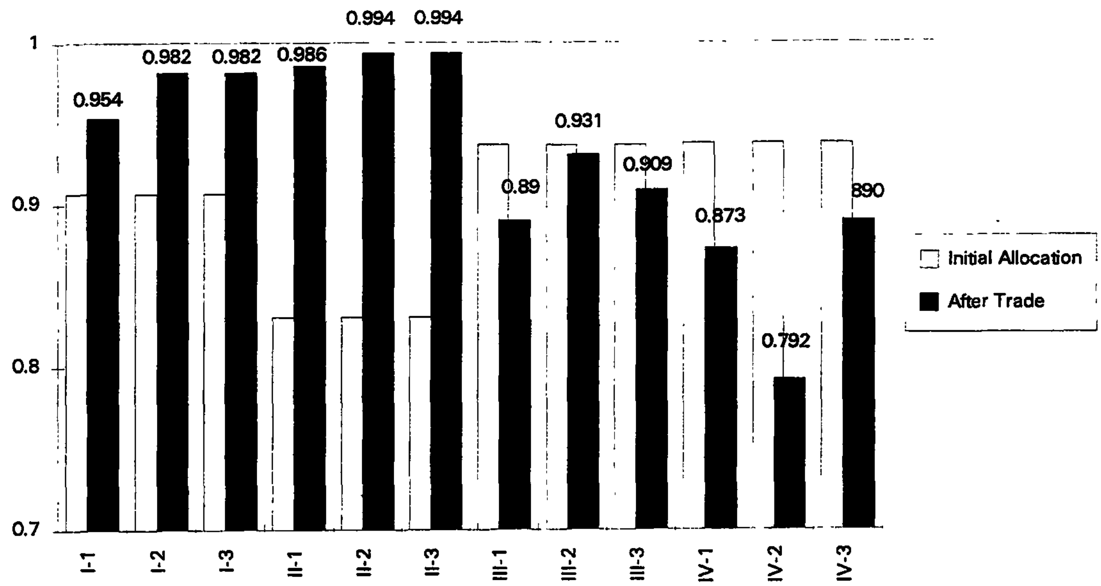


Table 1: Predicted Effects on Permit Market Price Due to Strategic Manipulation[1]

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

Notes: [1] Relative to efficient (competitive) prediction.

Table 2: Laboratory Firm Costs

Firm	Marginal Production Costs	Marginal Abatement Costs
F1	45	36
F2	45	75
F3	40	115
F4	35	155
F5	30	195
F6	25	235
F7	20	275
F8	15	315
F9	10	355
F10	5	395
D1	15	45
D2	15	65
D3	15	85
D4	15	105
D5	15	125
D6	15	145
D7	15	165
D8	15	185
D9	15	205
D10	15	225

Note: F_i indicates fringe firm i, D_i indicates production unit i of the dominant firm.

Table 3: Experimental Design

Product Market Price	Allocation	
	Fringe	**Dominant**
P=125	Treatment 1 (T1)	Treatment 2 (T2)
Market Determined	Treatment 3 (T3)	Treatment 4 (T4)

Table 4. Market Predictions

	Permit Price[1] (C-Mkt.)	Final Permit Holding Fringe: Dominant	Production Fringe: Dominant: Total	Produc Price[1] (P-Mkt.
Efficient Outcome	105[2]	3:7[4] or 4:6[3]	5:10:15[4] or 6:9:15[3]	125
Efficient Coupon Mkt. Dominant Firm P-Mkt.	120-125[5] or 125-145[6]	4:6[5] or 5:5[6]	6:8:14[5] or 8:5:13[6]	145[5] or 165[6]
Treatment 1 Allocation: Fringe	90	6:4	8:8:16	125
Treatment 2 Allocation: Dominant	110	3:7	5:10:15	125
Treatment 3 Allocation: Fringe	75	8:2	10:4:14	145
Treatment 4: Allocation: Dominant	180	1:9	4:8:12	185

Notes: 1 All prices are given in Lab Dollars.
2 Assuming marginal unit is traded (see text).
3 Treatment 2 and 4 allocation assuming marginal unit trades.
4 Treatment 1 and 3 allocation assuming marginal unit trades.
5 Treatment 3 or Treatment 4 (see Appendix).
6 Treatment 4 only(see Appendix).

Table 5: Experiment Results by Treatment

	License Price	Final License Holding: Fringe	Final License Holding: Dominant	Production: Fringe	Production: Dominant	Total Production	Product Price
Treatment 1							
Prediction[1]	105	3	7	5	10	15	125
Prediction[2]	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[1]	105	4	6	6	9	15	125
Prediction[2]	110	3	7	5	10	15	125
Mean Observation	124.75[3]	2.833	7.167	5.033	9.500	14.533	
Standard Deviation	55.83[3]	1.440	1.440	1.273	0.900	1.008	
Treatment 3							
Prediction[1]	105	3	7	5	10	15	125
Prediction[2]	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[1]	105	4	6	6	9	15	125
Prediction[2]	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

Notes: [1] Competitive Prediction.
[2] Market Power Prediction.
[3] One observation dropped due to subject error (see text).

Table 6: Convergence Patterns of Period Closing Coupon Prices Over Time

$$P_{it} = \beta_{11}D_1\frac{1}{t} + \ldots + \beta_{13}D_{13}\frac{1}{t} + \beta_2\frac{t-1}{t} + u_t$$

Treatment 1[1]
$R^2 = 0.888$ Number of Obs. = 29 Rho = 0.91
Adjusted $R^2 = 0.875$ SSE = 2131.7 Std. Err of Rho = 0.08

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	58.54	18.65	105	0.02	90	**0.10**
β_{12}	113.67	16.82	105	**0.61**	90	**0.17**
β_{13}	75.03	16.98	105	**0.09**	90	**0.39**
β_2	73.55	15.16	105	0.05	90	**0.29**

Treatment 2
$R^2 = 0.615$ Number of Obs. = 28
Adjusted $R^2 = 0.566$ SSE = 32459

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	310.50	31.93	105	0.00	110	0.00
β_{12}	111.91	56.86	105	**0.90**	110	**0.97**
β_{13}	82.08	31.14	105	**0.47**	110	**0.38**
β_2	111.15	11.08	105	**0.58**	110	**0.92**

Treatment 3[1]
$R^2 = 0.645$ Number of Obs. = 29 Rho = 0.736
Adjusted $R^2 = 0.603$ SSE = 3822.8 Std. Err of Rho = 0.13

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	44.68	17.28	105	0.00	75	**0.09**
β_{12}	73.05	13.70	105	0.03	75	**0.89**
β_{13}	47.69	13.84	105	0.00	75	**0.06**
β_2	74.48	8.74	105	0.00	75	**0.95**

Treatment 4
$R^2 = 0.818$ Number of Obs. = 28
Adjusted $R^2 = 0.795$ SSE = 23252

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	107.32	48.26	105	**0.96**	180	**0.15**
β_{12}	304.84	26.47	105	0.00	180	0.00
β_{13}	457.58	26.39	105	0.00	180	0.00
β_2	187.67	9.49	105	0.00	180	**0.43**

Notes: [1] Estimates corrected for AR1 using Cochrane Orcutt technique.
Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 7: Convergence Patterns of Dominant Firm Permit Holdings Over Time

$$Q_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1
$R^2 = 0.716$ Number of Obs. = 30
Adjusted $R^2 = 0.683$ SSE = 25.395

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	-0.20	0.83	7	0.00	4	0.00
β_{12}	8.18	0.83	7	**0.17**	4	0.00
β_{13}	4.97	0.83	7	0.02	4	**0.25**
β_2	2.27	0.27	7	0.00	4	0.00

Treatment 2[1]
$R^2 = 0.522$ Number of Obs. = 30 Rho = 0.20
Adjusted $R^2 = 0.465$ SSE = 27.082 Std Err of Rho = 0.18

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	12.14	1.84	6	0.00	7	0.01
β_{12}	9.62	0.95	6	0.00	7	0.01
β_{13}	5.60	0.95	6	**0.67**	7	**0.15**
β_2	6.47	0.65	6	**0.20**	7	**0.14**

Treatment 3
$R^2 = 0.414$ Number of Obs. = 31
Adjusted $R^2 = 0.349$ SSE = 22.206

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	4.75	0.76	7	0.01	2	0.01
β_{12}	3.46	0.76	7	0.00	2	**0.06**
β_{13}	1.37	0.76	7	0.00	2	**0.42**
β_2	1.44	0.24	7	0.00	2	0.03

Treatment 4
$R^2 = 0.489$ Number of Obs. = 30
Adjusted $R^2 = 0.430$ SSE = 36.485

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	3.47	0.99	6	0.02	9	0.00
β_{12}	9.42	0.99	6	0.00	9	**0.68**
β_{13}	8.95	0.99	6	0.01	9	**0.96**
β_2	7.97	0.32	6	0.00	9	0.00

Notes: [1] Estimates corrected for AR1 using Cochrane Orcutt technique.
Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 8: Convergence Patterns of Product Market Prices Over Time

$$P_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_{13} \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 3

$R^2 = 0.637$ Number of Obs. = 31

Adjusted $R^2 = 0.597$ SSE = 8864.7

	Coeff.	Std. err.	Competitive Model: Prediction	Competitive Model: *p* value of H_0	Market Power Model: Prediction	Market Power Model: *p* value of H_0
β_{11}	186.98	15.18	125	0.00	145	0.01
β_{12}	138.24	15.18	125	**0.39**	145	**0.66**
β_{13}	270.25	15.21	125	0.00	145	0.00
β_2	169.35	4.83	125	0.00	145	0.00

Treatment 4

$R^2 = 0.053$ Number of Obs. = 30

Adjusted $R^2 = -0.056$ SSE = 23096

	Coeff.	Std. err.	Competitive Model: Prediction	Competitive Model: *p* value of H_0	Market Power Model: Prediction	Market Power Model: *p* value of H_0
β_{11}	180.62	25.01	125	**0.04**	185	**0.86**
β_{12}	187.14	25.01	125	0.02	185	**0.93**
β_{13}	150.42	25.01	125	**0.32**	185	**0.18**
β_2	179.71	8.14	125	0.00	185	**0.52**

Note: Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 9: Convergence Patterns of Dominant Firm Production Levels Over Time

$$Q_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1[1]
$R^2 = 0.797$ — Number of Obs. = 30 — Rho = 0.70
Adjusted $R^2 = 0.773$ — SSE = 21.292 — Std Err. of Rho = 0.13

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	2.82	2.65	10	0.01	8	**0.06**
β_{12}	10.90	0.98	10	**0.37**	8	0.01
β_{13}	8.38	1.00	10	**0.12**	8	**0.71**
β_2	6.30	0.62	10	0.00	8	0.01

Treatment 2
$R^2 = 0.53$ — Number of Obs. = 30
Adjusted $R^2 = 0.48$ — SSE = 11.05

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	10.33	0.55	9	0.02	10	**0.55**
β_{12}	10.33	0.55	9	0.02	10	**0.55**
β_{13}	6.92	0.55	9	0.00	10	0.00
β_2	9.63	0.18	9	0.00	10	0.05

Treatment 3
$R^2 = 0.320$ — Number of Obs. = 31
Adjusted $R^2 = 0.245$ — SSE = 35.180

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	3.25	0.96	10	0.00	4	**0.44**
β_{12}	5.97	0.96	10	0.00	4	0.05
β_{13}	1.38	0.96	10	0.00	4	0.01
β_2	3.47	0.30	10	0.00	4	**0.09**

Treatment 4
$R^2 = 0.416$ — Number of Obs. = 30
Adjusted $R^2 = 0.348$ — SSE = 49.64

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	2.70	1.16	9	0.00	8	0.00
β_{12}	6.63	1.16	9	0.05	8	**0.25**
β_{13}	9.41	1.16	9	**0.73**	8	**0.24**
β_2	6.42	0.38	9	0.00	8	0.00

Notes: [1] Estimates corrected for AR1 using Cochrane Orcutt technique.
Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 10: Convergence Patterns of Fringe Firm Production Levels Over Time

$$Q_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1
$R^2 = 0.665$ Number of Obs. = 30
Adjusted $R^2 = 0.627$ SSE = 15.888

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model p value of H_0	Market Power Model Prediction	Market Power Model p value of H_0
β_{11}	9.35	0.66	5	0.00	8	0.05
β_{12}	4.04	0.66	5	**0.15**	8	0.00
β_{13}	8.25	0.66	5	0.00	8	**0.70**
β_2	9.08	0.21	5	0.00	8	0.00

Treatment 2
$R^2 = 0.577$ Number of Obs. = 30
Adjusted $R^2 = 0.528$ SSE = 19.868

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model p value of H_0	Market Power Model Prediction	Market Power Model p value of H_0
β_{11}	2.14	0.73	6	0.00	5	0.00
β_{12}	2.20	0.73	6	0.00	5	0.00
β_{13}	6.37	0.73	6	**0.62**	5	**0.07**
β_2	5.64	0.24	6	**0.14**	5	0.01

Treatment 3
$R^2 = 0.486$ Number of Obs. = 31
Adjusted $R^2 = 0.429$ SSE = 10.010

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model p value of H_0	Market Power Model Prediction	Market Power Model p value of H_0
β_{11}	8.78	0.51	5	0.00	10	0.02
β_{12}	8.39	0.51	5	0.00	10	0.00
β_{13}	6.38	0.51	5	0.01	10	0.00
β_2	9.29	0.16	5	0.00	10	0.00

Treatment 4
$R^2 = 0.508$ Number of Obs. = 30
Adjusted $R^2 = 0.451$ SSE = 23.615

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model p value of H_0	Market Power Model Prediction	Market Power Model p value of H_0
β_{11}	9.52	0.80	6	0.00	4	0.00
β_{12}	5.27	0.80	6	**0.37**	4	**0.13**
β_{13}	4.32	0.80	6	**0.05**	4	**0.69**
β_2	5.85	0.26	6	**0.56**	4	0.00

Note: Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 11: Convergence Patterns of Dominant Firm Period Earnings Over Time

$$\pi_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1

$R^2 = 0.107$ Number of Obs. = 30

Adjusted $R^2 = 0.004$ SSE = 16448

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	208.93	21.11	165	0.05	220	**0.60**
β_{12}	194.63	21.11	165	**0.17**	220	**0.24**
β_{13}	239.13	21.11	165	0.00	220	**0.37**
β_2	200.89	6.87	165	0.00	220	0.01

Treatment 2[1]

$R^2 = 0.474$ Number of Obs. = 30 Rho = -0.50

Adjusted $R^2 = 0.413$ SSE = 254080 Std Err of Rho = 0.16

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	1567.20	66.23	1220	0.00	1235	0.00
β_{12}	1164.80	63.90	1220	**0.40**	1235	**0.28**
β_{13}	1090.00	64.04	1220	0.05	1235	0.03
β_2	1225.1	20.35	1220	**0.80**	1235	**0.63**

Treatment 3

$R^2 = 0.209$ Number of Obs. = 31

Adjusted $R^2 = .121$ SSE = 156170

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	486.32	63.70	165	0.00	260	0.00
β_{12}	304.51	63.70	165	0.04	260	**0.49**
β_{13}	324.31	63.83	165	0.02	260	**0.32**
β_2	301.79	20.27	165	0.00	260	0.05

Treatment 4[1]

$R^2 =$ Number of Obs. = 30 Rho = -0.47

Adjusted $R^2 =$ SSE = Std Err. of Rho = 0.16

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	1429.50	144.50	1220	**0.16**	1540	**0.45**
β_{12}	1268.70	140.10	1220	**0.73**	1540	**0.06**
β_{13}	1847.80	140.40	1220	0.00	1540	0.04
β_2	1428.10	44.61	1220	0.00	1540	0.02

Notes: [1] Estimates corrected for AR1 using Cochrane Orcutt technique.
Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 12: Convergence Patterns of Fringe Firm Period Earnings Over Time

$$\pi_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1[1]

$R^2 = 0.586$ Number of Obs. = 30 Rho = 0.69

Adjusted $R^2 = 0.538$ SSE = 38318 Std Err. of Rho = 0.13

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	979.18	51.10	1129	0.01	1054	**0.16**
β_{12}	1075.90	40.74	1129	**0.20**	1054	**0.60**
β_{13}	1052.30	41.00	1129	**0.07**	1054	**0.97**
β_2	1009.70	23.49	1129	0.00	1054	**0.07**

Treatment 2

$R^2 = 0.411$ Number of Obs. = 30

Adjusted $R^2 = 0.343$ SSE = 328530

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	-320.73	94.34	79	0.00	64	0.00
β_{12}	29.23	94.34	79	**0.60**	64	**0.72**
β_{13}	197.00	94.34	79	**0.22**	64	**0.17**
β_2	48.51	30.72	79	**0.33**	64	**0.62**

Treatment 3

$R^2 = 0.220$ Number of Obs. = 31

Adjusted $R^2 = 0.133$ SSE = 1266000

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	1282.20	181.40	1129	**0.41**	1219	**0.73**
β_{12}	953.04	181.40	1129	**0.34**	1219	**0.15**
β_{13}	1629.20	181.70	1129	0.01	1219	0.03
β_2	1314.50	57.72	1129	0.00	1219	**0.11**

Treatment 4

$R^2 = 0.161$ Number of Obs. = 30

Adjusted $R^2 = 0.065$ SSE = 1399200

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	-131.00	194.70	79	**0.29**	199	**0.10**
β_{12}	7.01	194.70	79	**0.71**	199	**0.33**
β_{13}	-367.32	194.70	79	0.03	199	0.01
β_2	112.34	63.39	79	**0.60**	199	**0.18**

Notes: [1] Estimates corrected for AR1 using Cochrane Orcutt technique.
Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 13: Convergence Patterns of Period Efficiency Indices Over Time

$$EI_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1[1]
$R^2 = 0.630$ Number of Obs. = 30 Rho. = 0.65
Adjusted $R^2 = 0.587$ SSE = 0.365 Std. Err. of Rho = 0.14

	Coeff.	Std. err.	Competitive Model Prediction	 *p* value of H_0	Market Power Model Prediction	 *p* value of H_0
β_{11}	0.52	0.1515	1.00	0.00	0.94	0.01
β_{12}	1.07	0.1237	1.00	**0.55**	0.94	**0.28**
β_{13}	0.96	0.1233	1.00	**0.77**	0.94	**0.85**
β_2	0.70	0.065	1.00	0.00	0.94	0.00

Treatment 2
$R^2 = 0.504$ Number of Obs. = 30
Adjusted $R^2 = 0.447$ SSE = 0.1822

	Coeff.	Std. err.	Competitive Model Prediction	 *p* value of H_0	Market Power Model Prediction	 *p* value of H_0
β_{11}	0.66	0.0703	1.00	0.00	1.00	0.00
β_{12}	0.67	0.0703	1.00	0.00	1.00	0.00
β_{13}	0.89	0.0703	1.00	**0.12**	1.00	**0.12**
β_2	0.99	0.0229	1.00	**0.81**	1.00	**0.81**

Treatment 3
$R^2 = 0.694$ Number of Obs. = 31
Adjusted $R^2 = 0.660$ SSE = 6.0021

	Coeff.	Std. err.	Competitive Model Prediction	 *p* value of H_0	Market Power Model Prediction	 *p* value of H_0
β_{11}	-0.64	0.3949	1.00	0.00	0.52	0.01
β_{12}	0.32	0.3949	1.00	0.02	0.52	**0.23**
β_{13}	-3.55	0.3957	1.00	0.00	0.52	0.00
β_2	-0.32	0.1257	1.00	0.00	0.52	0.00

Treatment 4
$R^2 = 0.129$ Number of Obs. = 30
Adjusted $R^2 = 0.028$ SSE = 45.192

	Coeff.	Std. err.	Competitive Model Prediction	 *p* value of H_0	Market Power Model Prediction	 *p* value of H_0
β_{11}	-1.48	1.107	1.00	0.03	-0.68	**0.48**
β_{12}	-2.38	1.107	1.00	0.01	-0.68	**0.14**
β_{13}	0.46	1.107	1.00	**0.63**	-0.68	**0.31**
β_2	-1.40	0.360	1.00	0.00	-0.68	**0.06**

Notes: [1] Estimates corrected for AR1 using Cochrane Orcutt technique.
Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 14: Treatment 1 Total Period Profits to Producers and Total Profit Gains

		MP Firm		Fringe			
		Profit Realized	Gain	Profit Realized	Gain	Total Gain	Percent Gain
Predictions							
No Permit Trade/ Efficient P-Mkt.	**Profit**	140	0	980	0	0	0.0%
	% of Total	12.5%		87.5%			
Efficient Outcome	**Profit**	165	25	1129	149	1294	15.5%
	% of Total	12.8%		87.2%			
Strategic Prediction	**Profit**	220	80	1054	74	154	13.8%
	% of Total	17.3%		82.7%			
Outcomes (Mean outcome in last 5 periods)							
Session 1	**Profit**	216	76	929	-51	25	2.2%
	% of Total	18.8%		81.2%			
Session 2	**Profit**	195	55	1042	62	117	10.4%
	% of Total	15.8%		84.2%			
Session 3	**Profit**	213	73	1021	41	114	10.2%
	% of Total	17.2%		82.8%			
Treatment Means	**Profit**	208	68	997	17		
	% of Total	17.3%		82.7%			

Table 15: Treatment 2 Total Period Profits to Producers and Total Profit Gains

		MP Firm		Fringe			
		Profit Realized	Gain	Profit Realized	Gain	Total Gain	Percent Gain
Predictions:							
No Permit Trade/ Efficient P-Mkt.	**Profit**	1100	0	49	0	0	0.0%
	% of total	95.7%		4.3%			
Efficient Outcome	**Profit**	1220	120	79	30	150	13.1%
	% of total	93.9%		6.1%			
Strategic Prediction	**Profit**	1235	135	64	15	150	13.1%
	% of total	95.1%		4.9%			
Outcomes (Mean outcome in last 5 periods)							
Session 1	**Profit**	1248	148	7	-42	106	9.2%
	% of total	99.5%		0.5%			
Session 2	**Profit**	1241	141	41	-8	133	11.5%
	% of total	96.8%		3.2%			
Session 3	**Profit**	1204	104	79	30	134	11.7%
	% of total	93.8%		6.2%			
Treatment Means	**Profit**	1231	131	42	-7		
	% of Total	96.7%		3.3%			

Table 16: Treatment 3 Total Period Profits to Producers and Total Profit Gains

		MP Firm		Fringe			
		Profit Realized	Gain[1]	Profit Realized	Gain[1]	Total Gain[1]	Percent Gain[1]
Predictions							
No Permit Trade/ Efficient P-Mkt	**Profit**	140	-115	980	-400	-515	-46.0%
	% of total	12.5%		87.5%			
Efficient Outcome	**Profit**	165	-90	1129	-251	-341	-26.4%
	% of total	12.8%		87.2%			
No Permit Trade/ Dom. Firm P-Mkt (No-trade prediction)	**Profit**	255	0	1380	0	0	0.0%
	% of total	15.6%		84.4%			
Strategic Prediction	**Profit**	260	5	1219	-161	156	-11.3%
	% of total	17.6%		82.4%			
Outcomes (Mean outcome in last 5 periods)							
Session 1	**Profit**	319	64	1350	-30	549	49.0%
	% of total	19.1%		80.9%			
Session 2	**Profit**	373	118	1291	-89	544	48.6%
	% of total	22.4%		77.6%			
Session 3	**Profit**	306	51	1193	-187	378	33.8%
	% of total	20.4%		79.6%			
Treatment Means	**Profit**	333	78	1278	-102		
	% of Total	20.3%		79.7%			

Notes: [1] Gain is measured relative to the no-trade prediction indicated.

Table 17: Treatment 4 Total Period Profits to Producers and Total Profit Gains

		MP Firm Profit Realized	MP Firm Gain[1]	Fringe Profit Realized	Fringe Gain[1]	Total Gain[1]	Percent Gain[1]
Predictions:							
Efficient Outcome	**Profit**	1220	-280	79	-60	-340	-20.7%
	% of total	12.8%		87.2%			
No Permit Trade/ Efficient P-Mkt	**Profit**	1500	0	139	0	0.0%	0.0%
	% of total	91.5%		8.5%			
No Permit Trade/ Dom. Firm P-Mkt [2] (No-trade Prediction)	**Profit**	1500	0	139	0	0.0%	0.0%
	% of total	91.5%		8.5%			
Strategic Prediction	**Profit**	1540	40	199	60	100	6.1%
	% of total	88.6%		11.4%			
Outcomes (Mean outcome in last 5 periods)							
Session 1	**Profit**	1417	-83	233	94	11	0.7%
	% of total	85.9%		14.1%			
Session 2	**Profit**	1368	-132	-18	-157	-289	-17.6%
	% of total	101.3%		-1.3%			
Session 3	**Profit**	1536	36	-72	-211	-175	-10.7%
	% of total	104.9%		-4.9%			
Treatment Means	**Profit**	1440	-60	48	-91		
	% of Total	97.4%		2.6%			

Notes: [1] Gain is measured relative to the no-trade prediction indicated.
[2] Dominant firm P-mkt outcome identical to efficient P-mkt outcome with no permit trade.

Chapter 5

Further Investigation of Market Power in Emission Permit Double Auctions

I. Introduction

Clearly emission permit markets, like most, could be manipulated by firms with market power. Although this insight is not new, the fact such manipulation might lead to inferior efficiency outcomes relative to alternative forms of pollution regulation, has appeared in the academic literature only in the last decade.[1] The market experiment of the last chapter examined an environment where the introduction of an emission permit market could theoretically reduce overall system efficiency, if a dominant firm used its market power.[2] The results of that experiment (hereafter referred to by the experiment code ETC) indicated inferior efficiency outcomes arise behaviourally when they are theoretically possible (Treatments 3 and 4 of ETC). Average efficiency loss occurring in the last five periods of Treatment 4 was 1.4 times the gain possible had competitive trade arisen. In Treatment 3, which theoretically, even in the presence of market power, should have observed a small efficiency gain after trade, also recorded an efficiency loss.[3]

Of surprise was the poor performance of the double auction in limiting the extent to which the dominant firm was able to manipulate the permit market price. The double auction results of the ETC experiment indicate that the previously observed competitive

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[1] See Misiolek and Elder (1989), Sartzetakis (1992, 1993) for examples.

[2] The initial endowment and product market conditions of Treatment 4 allowed a predicted efficiency loss of 4.5 % if market power were used, or, after trade, an efficiency loss equivalent to 68% of the potential gain available relative to competitive market predictions.

[3] Treatment 3 indicated an average efficiency loss in the last five periods of three sessions equivalent to approximately 40% of the trading gain possible under competitive conditions.

convergence properties of the double auction may not be as robust to market power pricing as earlier experiments might suggest.[4] Double auction pricing results, in both monopoly and monopsony markets, converged to levels equal to or exceeding market power predictions. This result was observed when auction unit valuations were both certain and uncertain. In a rather thin body of existing experimental literature, the ETC results appear to be the first to find strong and repeated market power outcomes in double auctions with standard demand and supply parameters.[5] Since the underlying market structure of the ETC experiment was fundamentally different from that of previously cited experiments, the ETC findings present an important theoretic question: can structural differences in double auction markets improve the observed price performance in the presence of market power? Unfortunately, a number of procedural and structural differences exist between the experiments of Smith (1981) and its subsequent replications, and the emission permit market experiment of the last chapter. No single design difference can therefore be isolated as the cause of the non-competitive results.

Given the specific differences between the ETC experimental design and previous work, a number of possible explanations can be made to explain the market power results observed in ETC. Smith (1981) conjectured that one reason the double auction limited the successful use of market power was the ability of firms without market power to "tacitly collude" and "counterspeculate" by collectively making low price offers to the seller, withholding demand until prices fell.[6] A refinement to the ETC experiment is

4 See Smith (1981), Smith and Williams (1989) and Ledyard and Szakaly-Moore (1994).

5 Only the previously referenced authors are considered in this statement. Holt, Langan, and Villamil (1986) and Davis and Williams (1991) found repeated market power results for a common set of market supply and demand parameters, however their market design incorporated excess supply at supracompetitive prices. The markets considered in the statement above incorporated less extreme market designs where intersection of demand and supply occurred at a unique quantity and market clearing price without excess demand or supply.

6 Smith (1981) used the terms "tacit collusion" and "counterspeculation" in attempting to describe potential reasons why market power outcomes did not emerge in his double auction markets in circumstances where they were possible.

presented here to test whether a “numbers" effect" with respect to the size of the competitive fringe sector was, at least in part, responsible for the market power pricing results found in the ETC sessions. If the ability to counterspeculate in a double auction was the reason previous authors observed little influence of market power on price outcomes, the ETC experiment may have limited such a potential for unorganized collective behaviour on the part of the fringe firms by virtue of their larger numbers.[7]

To test this hypothesis, refinements in the double auction and market parameterization were introduced while leaving unaltered the theoretic predictions of the original ETC experiment with respect to the market power and competitive models.[8] Subjects were allowed to buy *or* sell auction units, provided they had the inventory to do so. This change introduced the possibility of speculation occurring. The specific double auction implementation was identical to that used by Ledyard and Szakaly-Moore (1994). Fringe size was reduced to five firms. Admittedly, any differences occurring between the new results and those of ETC would not be directly attributable to the change in fringe numbers alone, however, given the results of previous market power studies using a double auction (Smith, Smith and Williams, and Ledyard and Szakaly-Moore), we did not expect the new auction mechanism to confound the structural effect in question.

The refinements made here also extend the policy application of the experimental findings. The possibility of permit market speculation allows this investigation to provide insight into the potential impact of such activity on market based regulatory mechanisms for pollution control. This experiment also creates a market which resembles the relative sizes and numbers of sectoral participants of a proposed emission

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7 Previous experiments utilizing the "Smith" parameter set included only five fringe firms, while ETC included ten.

8 Without this change, certain permit allocations would not be possible using the endowment treatments in ETC, specifically, any allocations which had fringe firms holding more than one permit.

permit market in Ontario thus outcomes observed may reflect potential outcomes of a particular "real-world" market.

II. Structural and Procedural Differences in Experimental Design: ETC and Previous Market Power Experiments

The procedural and structural differences between the ETC sessions and previous authors' market power experiments could account for the strong market power results found in the last chapter. Seven such differences are outlined in more detail below and summarized in Table 1. Of the structural differences in market designs utilized by Smith (1981), Smith and Williams (1989) and Ledyard and Szakaly-Moore (1994) and the ETC experiment, the most obvious is that the ETC experiment was the only one to incorporate separate treatments for monopoly and monopsony power. There is no theory to suggest markets with a single seller are more or less likely to attain a strong market power outcome in a double auction than those with a single buyer. The ETC results do not suggest such a theory is required as the observed failure of the double auction to control market power pricing outcomes did not correspond to a particular market role for the dominant firm.

Previous markets using the Smith parameters contained one large seller and five smaller buyers. ETC utilized a single large market power firm and ten opposing small firms. This suggests a "numbers effect" on the fringe side of the market that could explain the divergent results. Previous authors have found when counterspeculation appears to occur, the volume of trade is often lower than the observed price would predict.[9] If all firms withholding demand, however, still acquired a unit through trade, counterspeculative

[9] Smith (1981) found the oral double auction to be the second to least effective institution in terms of controlling quantity restraint of four institutions studied.

behaviour would be collectively beneficial because trade expenditures would be reduced, even if the traded quantity did not increase over the market power prediction. By engaging in counterspeculation, firms would successfully reduce market price through unorganized collective activity. Smith described such behaviour as a form of "tacit collusion" among buyers. It may be such behaviour might more easily occur when the number of fringe firms is small. Increasing the size of the competitive fringe could increase the probability of a "coordination failure".[10] The possibility of a competitive outcome occurring may therefore be inversely related to the number of fringe firms in the market.

"Trade exclusion" might yield another explanation of the monopoly price outcomes found in the ETC experiment. The Smith parameters generate competitive and market power predictions that allow all fringe firms to acquire a unit regardless of whether competitive or market power outcomes occur. The ETC parameter set does not. For both competitive and market power predictions, some fringe firms are not able to participate profitably in trade at predicted prices. This may be viewed as an extension of the numbers effect just described, as it may become more likely as the number of firms in the fringe is expanded. Larger numbers, however, need not imply exclusion in the experiment design. Counterspeculation implies that fringe firms withhold purchases (in the monopoly case) in an effort to induce the monopolist to offer a lower price. The opposite would be true in

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[10] Coordination failure is used here to describe why possible collective actions, tacit or otherwise, which could increase the welfare (in this case payoffs or profits) of those who would participate in such a collective action (such as counterspeculation or demand withholding), do not arise. Porter (1991) has challenged "counterspeculation" among fringe firms as a theory on the grounds that a dominant firm selling at low prices and price discriminating at the end of a period is a sub-game perfect outcome in a double auction, thus such an outcome would result with prices between the monopoly and competitive predictions as often observed. We challenge this notion in the context of repeated games as fringe firms, having observed lower prices would find it in their interest to counterspeculate in subsequent periods if such a strategy were employed by the dominant firm initially, especially for large differences between optimal monopoly and competitive prices.

the monopsony case, with fringe sellers withholding supply.[11] Trade exclusion, or fear of exclusion, however, might provide an incentive for fringe firms to quickly purchase auction units instead of waiting for lower prices. The unorganized collective activity Smith considered may be more difficult to achieve if some fringe members realize they risk complete trade exclusion and profit loss by withholding demand. As in a game of musical chairs, where participants would rather sit down immediately to ensure they get a seat than wait for the music to end, firms might not want to wait to purchase a unit, but acquire one as soon as they could do so profitably.

Another structural difference which could account for the market power pricing outcomes observed in ETC markets lies in the asymmetric information about market demand the market power firms possessed as described in the previous chapter. The dominant firm in the ETC experiments was given enough information to compute market demand in the auction market, while previous authors' monopoly firms were not.[12] Such an informational asymmetry could give the dominant firm a trading advantage by (i) allowing calculation of optimal monopoly price instead of a trial and error process and (ii) allowing the dominant firm certain knowledge its price offers were not unprofitable to fringe firms. This would have provided information to the dominant firm which it otherwise could only have obtained with difficulty through market activity. The market information provided in ETC might also have increased the monopolist's resolve to keep prices high in an attempt to break fringe "resistance" in the face of counterspeculation, or stopped the dominant firm from offering prices that were too low, thereby demonstrating to the fringe that it could afford to sell at lower prices. It was noted, however, in the ETC

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[11] We are not aware of any monopsony experiments using a double auction in which counterspeculation has been observed.

[12] The dominant firm in the ETC experiment was not given explicit market demand information. Instead, it was given a description of fringe firm production and abatement costs which could be used to derive market demand.

sessions the market power subjects rarely appeared to consider or attempt to use this information.

Procedural differences may also have caused or contributed to emergence of market power pricing results in the ETC double auctions. Previous authors used experienced subjects on both sides of the market.[13] In ETC, dominant firm subjects were chosen from those subjects in each session who had previous experience in unrelated double auction experiments. This experience asymmetry effect might have been responsible for the strong market power results. The possibility of such experience allowing the dominant firm an advantage was not present in all sessions, however, as two sessions did not include subjects with this experience. Results of these sessions were not significantly different from others. Possibly the instruction methods used in ETC allowed new subjects to become familiar enough with the trading institution to negate such an effect.

Subjects in previous work were made aware they were dealing with only one seller.[14] The existence of only one seller may have been inferred indirectly in the ETC sessions but was not explicitly offered.[15] If such knowledge creates bias or resentment against

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[13] All previous authors did attempt to select subjects most likely to "be tough on the competitors" to paraphrase Smith (1981). No such selection criteria was made in the ETC sessions, only experience was considered in an attempt to ensure these subjects would not be overwhelmed by the larger set of market actions open to them. We would have preferred to use only experienced subjects however such a large pool of potential subjects did not exist at McMaster University at the time. See the work of the previous chapter for a more complete explanation of why experienced subjects were enlisted for the dominant firm subject when possible. Only Smith and Williams (1989) indicate all subjects had previous double auction experience. Smith (1981) does not declare subject's previous experience, while Ledyard and Szakaly-Moore admit at least some had previous DA experience however none as "traders". A comparison of experience across treatments on both sides of the market can therefore not be made.

[14] Communication of this fact differed in previous work. Smith (1981) used an oral double auction for trade thus the roles of each subject would be made immediately clear as the experimental sessions progressed. Smith and Williams (1990) do not state whether such information was given to subjects, however private correspondence with Arlington Williams confirmed such an announcement was made. Ledyard and Szakaly-Moore (1994) used a blackboard to identify initial trade unit allocations by subject ID, but did not identify subject's identities with these ID's.

[15] Dominant firm subjects and fringe subjects were situated in different rooms in the ETC sessions, thus no visual cues were available to other subjects to indicate one subject was "different". ETC sessions did display corresponding trader ID numbers in a trade summary on-screen and also next to the outstanding bids

other subjects, due possibly to a belief these subjects have an advantage in markets, then counterspeculation may be hypothesized to arise as a behavioural response by members of the fringe to attempt to ensure the dominant firm did not take advantage of them. Lack of such knowledge would not allow such a bias to form and this response may not arise. This argument cannot be rebutted.

Finally, uncertainty about fundamental valuation of the units traded could also have contributed to the ETC results. Previous authors distributed explicit individual unit valuations to subjects. ETC sessions incorporated a sequential market structure, where first a double auction market took place allowing trade of inputs for a production good, followed by a market for the production good in each period. The input traded in the double auction provided a cost reduction in production (just as an emission permit would allow abatement costs of pollution to be avoided), and only information describing the potential cost savings allowed per auction unit held after trade was provided to each subject. The actual value of an emission permit is the impact it has on production profits realized after the production market price is determined. In two treatments production price in ETC was market determined while in the others it was fixed and announced prior to trade. Treatments with market determined product price made unit valuations uncertain during the double auction portion of each laboratory trading period as the production for the period had not yet occurred. Fixed product price sessions allowed subjects certainty of product price and thus no uncertainty in valuation calculation or inference. Uncertainty might increase the likelihood of market power outcomes by undermining counterspeculation, especially when product markets have widely varying prices from period to period. Firm's expectations of "acceptable" prices may begin to differ as individual firm expectations of future product prices changed.

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and asks in the market. Repetition of the same ID number on one side of the market might have suggested to fringe firms that there was only one firm trading with all of them.

Counterspeculation then might not be sustainable or even arise. If counterspeculation resulted in reduced trade and reduced production, in treatments with market determined product market price, permit valuations would increase as product market prices would be higher, possibly undermining the resolve and increasing the opportunity cost for those withholding demand (or supply in monopsony sessions) to continue doing so. Valuation uncertainty effects, however, were not clearly evident in the ETC results as both fixed and market determined production price settings converged to market power predictions.

If the explanation for the market power outcomes occurring in ETC lies with any of these structural and procedural differences in Table 1, some are less likely to have been responsible than others. Additionally, there could be interaction between some of the effects, which could have increased the relevance of a particular experimental difference. A structured program of market experiments would be required to determine the effect of each difference or combination of differences on market power outcomes. Such a research agenda is daunting. If one considers the three procedural differences above and excludes only that previous authors did not include buyer-side market power from the set of structural differences outlined in Table 1, six separate experiments would be needed. If possible interaction were also considered between only two of these differences at a time, number of required experiments would increase to 21. Clearly some investigative censoring is required in the short run to examine of possible explanations and determine which characteristic(s) is(are) responsible for the observed differences in the effectiveness of the double auction to control market power pricing outcomes.

The remainder of the chapter reports an experiment (referred to as ETC2) designed to determine the effect of changing the number of fringe firms on the double auction market results and permit market system. The number of fringe subjects is changed to five, while all other structural differences remain. Of the procedural differences, a change of experiment venue forced the experience asymmetry to be lost, however as outlined above the impact of this effect has been discounted by the previous ETC results where it was not present. Because trade exclusion is present in all predicted equilibria in ETC and ETC2, any difference in the results may be ascribed only to the changes in fringe size made in this experiment or the introduction of trading. If strong market power pricing is observed again, we might assume the larger fringe alone was not responsible for the non-competitive results in ETC.[16]

III. Laboratory Implementation

III.1 Introduction

The laboratory environment used was identical to that of ETC except the ten fringe firms capable of producing a single production unit were transformed to five firms capable of producing two production units each (FA through FE in Table 2) This was accomplished by combining the production and abatement costs of each pair of the original fringe firms in ETC in ascending order. For example, in the ETC experiment, F1 had a production cost of 45 and marginal abatement cost (additional cost incurred if producing without holding a permit) of 36. F2 had a production cost of 45 and abatement cost of 75. Combined, these firms created firm FA, with production costs of 45 over both possible production units, and increasing marginal abatement costs of 36 and 75 over the first and second production units respectively. Some rearrangement of production costs was made within each new firm to ensure each had constant or increasing marginal production

[16] Because adoption of "trading" in Ledyard and Szakaly-Moore (1994) was not found to change the results observed for Smith's parameter set, we assume it will not change the results here since the underlying demand and supply parameters remain unchanged.

costs.[17] The dominant firm parameters were unchanged. No changes to market predictions used in the previous experiment were required. As noted previously, trading was allowed in the double auction to allow the possibility of fringe firms acquiring or selling more than one unit in the double auction.

All procedures used in ETC were followed with any differences reflecting design changes outlined above. Subjects were paid in Canadian dollars an amount dependent on their lab dollar earnings in the sessions in which they participated.[18] Production and abatement costs are shown in Table 2. Subjects earned an average of $25.66 CDN per session, with some variation depending on treatment.[19] The sessions reported here were conducted at the McMaster University Experimental Economics Laboratory or Laurentian University from August 23, 1995 to November 20, 1995.[20] Each session lasted approximately two hours, of which 45 minutes were used for instruction. No communication was allowed among subjects once sessions had begun. Subjects read their instructions and then participated in a trading demonstration, giving each the chance to use the double auction software. After this demonstration, subjects were shown how to do the record-keeping the experiment required. Finally, three practice periods for which subjects were not paid

[17] For example FC would have combined firms F5 and F6 from the ETC parameters. F5 had a production cost of 30 and abatement cost of 195, while F6 had production cost of 25 and abatement cost of 235. Production costs between units one and two of the new firm FC were changed such that the first production unit had production and abatement costs of 25 and 195 respectively, while the second had costs of 30 and 235. The induced production market supply curve (shown in Figure 1 for the competitive market predictions), was slightly changed relative to that in ETC, however the changes occurred in regions which did not result in any changes in predicted market price or quantity outcomes.

[18] To ensure that earnings for each subject were not too dissimilar, a different exchange rate was used for the dominant and fringe firms, and also depended on the treatment. Subjects were not made aware that individual exchange rates might differ. Exchange rates were as follows (value of 1 Lab Dollar in $CDN):

Treatment 1		Treatment 3	
dominant firm:	0.015	dominant firm:	0.01
fringe firm:	0.0075	fringe firm:	0.007
Treatment 2		Treatment 4	
dominant firm:	0.0025	dominant firm:	0.0025
fringe firm:	0.012	fringe firm:	0.015

[19] Mean payoff $25.66, high $51.25, low $20.00, standard deviation $7.14.

[20] Only one session took place at McMaster (T1-1); eleven took place at Laurentian.

were run to allow them to become familiar with the complete task.[21] Full instructions for each treatment are in Appendix C, as are all worksheets and tables subjects received. Rules of trade and costs of production and abatement were identical across all treatments. Care was taken to properly randomize treatments and session participants. All Laurentian subjects were seated far apart in a single large computer lab. The dominant-firm subject was seated in the same room. This subject was not identified to the others. None of the subjects at Laurentian had previous experience with economic experiments and assignment to fringe or dominant firm role was done by random selection. The McMaster session used subjects who had no prior experience with double-auction experiments, and dominant firm role was also assigned at random. The dominant firm was seated in a separate room at McMaster, as in ETC. All Laurentian students were undergraduates from a variety of disciplines (the majority being economics or commerce) or non-students, while McMaster subjects included two graduate students (both economics) and two non-students. Recruiting for all sessions was accomplished using on-campus advertising and announcements in undergraduate economics classes.

Four treatments, each with three replications were conducted using 72 subjects (6 per session). The dominant firm was allocated either all (Treatments 2 and 4) or none (Treatments 1 or 3) of the coupons at the start of each period. The production market price was either fixed at 125 (Treatments 1 and 2) or market determined (Treatments 3 and 4). In Treatments 3 and 4 product market price was found at the intersection of the exogenous market demand curve (given to all subjects) and total production. The experimental design is outlined in Table 3.

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[21] One extra period was used compared to ETC as subjects were "trading" in this experiment.

III.2 Laboratory Predictions

Two potential outcomes can be calculated for the parameters used in this experiment. The competitive market prediction assumes no firm manipulates market outcome through the use of market power. The market power prediction describes the outcome expected if market power were exploited by the dominant firm. Both predictions differ in terms of resultant market prices and quantities traded. These price and quantity effects result in predicted differences in distribution of profits among firms, and result in the market power model's predictions having reduced efficiency outcomes relative to a competitive market outcomes. All predicted outcomes for both models are identical to those in ETC.

One of two socially efficient distributions of permits is shown in Figure 1, given the cost parameters found in Table 2. This outcome would maximize total surplus while minimizing abatement costs incurred to meet the emission cap in the hypothetical market. The other competitive permit distribution, as well as the predicted market outcomes of the other variables, for both the competitive and market power models, are presented in Table 4. Calculation of these predictions is outlined in Appendix A. As in ETC, exclusion of fringe firms through manipulation of the permit market is possible in both Treatments 3 and 4 but predicted only for Treatment 4. Treatments 1 and 2 yield simple monopsony and monopoly predictions in the permit market and competitive solutions in the product market. If permit market outcomes were efficient and the dominant firm's market power limited to the product market, the predicted market outcome is described in the second row of Table 4. and could result in identical results across Treatments 3 and 4. This outcome might be expected if the changes made in this experiment have an effect on permit market outcomes.

The traditional method of measuring the success of market manipulation by a firm with market power in experiments, is the monopoly effectiveness index, *M*, as used by Davis and Holt (1993) and Holt (1995) to compare monopoly effectiveness across institutions and among various market power experiments. They define the monopoly effectiveness index using the earnings of the dominant firm as

$$M = \frac{(\pi - \pi_c)}{(\pi_m - \pi_c)}$$

This measure is referred to here as the "raw" monopoly effectiveness index, where π is actual dominant firm earnings, π_c is the predicted earnings if the competitive solution arises and π_m is the predicted earnings had the market power prediction relevant to the treatment actually occurred.

An "adjusted" monopoly effectiveness index is also calculated. This index is computed as above, but actual dominant firm earnings are adjusted to reflect their potential value had an optimal production decision in the product market been made by the dominant firm, given coupon holdings after the double auction, fringe production levels and assuming product market power is recognized in Treatments 3 and 4. If the optimal production decision were actually made *ex post*, the "raw" and "adjusted" indices would be identical. Previous experiments have not included a second production decision after the double auction. Since the measure of *M* uses actual dominant firm earnings, sub-optimal production decisions, which may not be related to the success or failure of the market power firm to attain the market power solution in the permit market, could influence the resultant measure. Additionally, dynamic strategies could be used where production decisions are made to influence fringe firm behaviour in subsequent periods. Sub-optimal production decisions in a static context would reduce observed earnings by the dominant firm relative to those possible. The adjusted index attempts to make the index values in this experiment and ETC comparable to other studies' results by measuring permit market manipulation only, recognizing that manipulation of the permit market may occur to influence product market outcomes.

Speculation is possible in this experiment. Two measures are calculated to determine if speculation occurred in the laboratory markets presented here. The first calculates the average number of times a single unit is exchanged, or "turned over", during a single trading period. If no speculation were to occur, traded units would change hands only once.[22] To determine a "turnover ratio" (hereafter referred to as *TO*), differentiation is made between when a unit was "traded" and when it was "flipped" during a transaction. A "trade" was defined as a trade from a net seller to a net buyer, given trading participants' unit valuations and initial endowments. In this experiment market role was identical among members of the fringe, with the dominant firm always on the opposite side of the market. A "flip" occurred whenever a unit was traded either from one net seller to another or from a net buyer to a net seller.[23] Flips are used to indicate the proportion of trade volume due to speculation. The "turnover ratio" *(TO)* was calculated as the number of transactions (total trades plus flips) in a period divided by the number of trades (total transactions minus flips). A value of 2.0 indicates for every unit traded, one is flipped. Since flips were not possible in ETC, by definition all sessions in that experiment recorded *TO* values of 1.

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[22] This is a common measure used in asset market experiments to measure speculation. For a further description, see Davis and Holt (1993), pp. 165.

[23] Therefore a flip would be defined as occurring if a fringe firm traded a unit to another fringe firm, if a unit were traded from a fringe firm to the dominant firm in Treatments 2 or 4 or if a unit were traded from the dominant firm to a fringe in Treatments 1 or 3.

The second measure used to identify speculation calculates the ratio of the intrinsic valuation of the traded unit to the subject purchasing it and the price paid. This measure is referred to as *r*.[24] Non-speculative trades would be expected to exhibit higher permit valuations than the price paid by the subject receiving it, while speculative trades would have prices exceeding the unit's intrinsic value to the buyer.[25] For Treatments 3 and 4 the intrinsic value of the traded unit is calculated using the realized market price for that period. If average *r* is observed to be less than one, it could indicate the majority of trades are speculative.

IV. Results

To determine if market power was observed in the laboratory markets, results are compared to the prices, quantities, and permit holdings predicted for the various theoretical outcomes in Table 4, using the methods presented in the last chapter. Table 5 presents the mean values of observed price and quantity outcomes. Figures 2 through 5 plot actual transaction prices over time, with market power and competitive predictions indicated by horizontal line. Figures 6, 7 and 8 describe permit holdings after trade, production levels and production market prices as observed over the course of the experiment. Actual session observations by period are denoted by their session number, with median values by period within treatment connected by solid line. Econometric

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[24] Note asset market experiments often define a measure of magnitude of price relative to intrinsic value as the *reach* (R), the ratio of the price paid minus intrinsic value over the intrinsic value. Since any unit accumulated by a fringe firm holding two permits had an intrinsic value of zero, this measure was not calculated. Reach is easily found for any non-zero observation of *r*, as $(r^{-1}-1)$. Further description of the reach statistic can be found in Davis and Holt (1993), pp. 165.

[25] The assumption is made here subjects understand the fundamental value of units purchased, or can indirectly act on it through the action of attempting to maximize trading profit. For such an assumption, payoff dominance is crucial. Subjects must be trading to earn a return. Had trading been possible in the last chapter, some "mistakes" would be considered speculative trades by the definitions used here. It should also be noted that *r* values greater than one need not indicate a lack of speculation if period prices are very low.

analysis of the effect of time on observed market variable outcomes is presented in Tables 6 through 10. All of these results are compared to outcomes observed in ETC to determine the sensitivity or robustness of the original ETC experiment findings to a change in the size of the competitive fringe sector.

Additionally, market efficiency and distribution of gains from trade are calculated and compared to the predicted outcomes and those observed in ETC. Econometric analysis of the effect of time on these variables is presented in Tables 10 through 13. Figure 9 presents calculated efficiency indices by treatment while Figure 10 presents efficiency ratios by session. Both are calculated from period six on. Earnings distribution outcomes by treatment are presented in Tables 14 through 17. Table 18 presents calculated monopoly effectiveness results. Results also consider the effect of allowing participants to "trade" in the double auction. *TO* is calculated over whole sessions, the last five periods and the last three in Table 19. Various *r* outcomes are plotted in Figures 11 through 18.

Analysis of the summary results of Table 5 yields some important impressions. The mean permit price observed throughout the experiment was 130.84, significantly higher than 105, the expected outcome had competitive results been observed throughout the experiment.[26] Mean permit prices by treatment were 100.05, 121.36, 133.95 and 163.97 respectively, reflecting the predicted deviations from the efficient outcomes of the market power model. The exception is the mean price observed in Treatment 3, which is inflated by the anomalous session results found in Session T3-1. Considering only sessions T3-2 and T3-3, the mean observed permit price is 44.84, a deviation in the predicted direction from the competitive model. Other market variables also deviate in a similar fashion

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[26] t=2.64 with 5 df., a significant difference at the 0.05 level.

from competitive predictions. These impressions are also verified by the more rigorous methods which account for the non-classical nature of experimental data.

Result 1: The results of ETC are robust with respect to the changes introduced in ETC2. All ETC double auction and permit system outcomes are reproduced by the results of this experiment.

Support:

As with ETC, the predictions of both the market power and competitive market models are rejected as exact descriptions of the data. Econometric analysis of the convergence properties of actual prices and quantities in Tables 6 through 10 indicate several predictions of both models are statistically rejected by the asymptotes of the estimated time series. The market power model predictions, however, are rejected in a fewer number of cases. Eight of eighteen asymptotes differ significantly from the market power prediction, while twelve asymptotes reject competitive model predictions using a level of significance of at least 0.05. From Figures 2 through 8, the general tendency of all data series appear best expressed by the strategic predictions.

Market power predictions are statistically supported as an accurate description of all double auction pricing outcomes across treatments. All estimated permit price time series by treatment converge to an estimated asymptote which is not significantly different from the market power prediction at the 95% confidence level. Inspection of the actual price paths of permits by treatment over time in Figures 2 through 5 indicate repeated convergence to the strategic prediction. ANOVA analysis of double auction closing prices in the final period of each session (using data found in Appendix B) indicates no statistical difference in outcomes observed in ETC and ETC2 (p=0.522). The effects of all experiment treatment variables are found significant, as is their interaction, indicating that double auction outcomes were significantly different by treatment, as predicted by the market power model.[27] ANOVA results also indicate the Efficient Coupon Market/Dominant Firm P-Mkt. prediction described in the second row of Table 4 can be rejected as that model would predict only the product market treatment effect should be significant.

Unlike pricing outcomes, dominant and fringe firm permit holdings after trade only reflect the market power predictions. Seven of twelve series in Table 7 weakly converge to the market power prediction and another three deviate from the competitive prediction in the direction suggested by the market power model. Table 5 and Figure 6 indicate convergence of permit holdings toward strategic predictions in all treatments, with the possible exception of Treatment 4. Treatments 1 and 3 indicate the dominant firm purchased fewer permits per period than even the strategic prediction. As found in ETC, the precision of the market power model is higher for prices than quantities. Under-buying or under-selling was indicated across treatments, suggesting the strategic behaviour pursued by the dominant firm was excessive. This result was also found in ETC.

Production market results all reflect those found in ETC. From Table 5, Treatment 1 and 2 mean production levels for the fringe and dominant firm support the market power prediction, albeit, with some under-production. Production levels by period for Treatments 3 and 4 are plotted by session in Figure 7, while product market prices are found in Figure 8. Observed levels for both variables appear best described by the strategic prediction. Both predicted product market price series asymptotes for

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[27] For endowment effect, $p=0.041$. For product market price effect, $p=0.003$. For the interaction of the two variables, $p=0.047$.

Treatments 3 and 4 in Table 8 do not differ significantly from the strategic predictions while rejecting the competitive model's. Estimated time series of dominant firm production in Table 9 find nine of twelve weakly convergent to the strategic prediction. Most predicted asymptotes deviate from the competitive prediction in the direction predicted by the market power model. Fringe sector production levels in Table 10 also exhibit this behaviour, with some over-production in Treatment 4. ANOVA analysis, using the data in Table 5 from both Chapters 4 and 5, indicates no statistical difference between any of the market outcomes across experiments.[28]

The dominant firm's earnings, found in Table 11, reflect the market power outcomes in permit and product markets already described. Fringe earnings, were weakly convergent in 7 of 12 instances, with another three series deviating from the competitive prediction in the direction described by the strategic prediction, though lower than that prediction would suggest. This result reflects the permit holding outcomes already described. Analysis of final distribution of total profits earned in all treatments, found in Tables 14 to 17, while indicating some losses, reflect successful manipulation by the dominant firm.

Efficiency findings also reflect those found in ETC. Only one period of 127 exhibited an efficient allocation of permits between the fringe and dominant firms over the course of the experiment. Efficiency indices, found in Figure 9, differed across treatments and in those treatments where permit market participants competed in common product markets (Treatments 3 and 4), the imposition of permit trade reduced system efficiency relative to that possible at the initial permit allocation. Figure 10 indicates little variation was observed in achieved efficiencies across sessions within each treatment after period 5. As

[28] The effect of experiment (ETC or ETC2) on the observed outcomes pooled for each variable across Table 5 of both chapters, is rejected as statistically significant ($p>0.10$ for all tests), when testing for the effect of initial allocation, product market treatment, their interaction and from which experiment the observation was made.

found in ETC, allowing permit trade in Treatments 1 and 2 increased efficiency above that at the initial allocations. In Treatment 3, the average efficiency index calculated over the last five periods was -0.42, the same value as observed in ETC. In Treatment 4, the dominant firm regularly retired permits in an apparent attempt to exclude fringe firms from the production market in at least one session. Average efficiency loss was 1.19 times the potential gain available in the economic system, somewhat lower than that found in ETC.

■

These results provide further evidence to support the relevance of market power predictions in laboratory environments which utilize double auction trading mechanisms. Permit price results indicate the experimental treatment variables (initial permit allocation, product market price and their interaction) determine market outcomes, as predicted by the market power model. Direct comparisons of the double auction pricing results of Treatments 1 and 2 indicate little difference between pricing outcomes across ETC and ETC2, except for the increased trade volume observed with the introduction of "trading" in the latter experiment. Similarly, Treatment 3 pricing results are very similar across experiments, with the exception of Session ETC2 T3-1, where trading outcomes are best described as anomalous. Only Treatment 4 indicates some contrast between experiments, as all ETC sessions observed permit prices significantly exceeding competitive predictions, while in two of three sessions of ETC2 they do not. Pricing outcomes across experiments, however, were not statistically different. All production, efficiency and equity outcomes support those found in ETC.

All strategic predictions describe the general results by treatment in these sessions. The market power results reported in ETC appear robust to the reduction in the number of competitive fringe firms and introduction of trading found in ETC2. No support is found for the "numbers effect" when the fringe size is reduced to the size found in other experiments. Results found here also appear to confirm that the introduction of trading in a double auction does not influence observed results for a given parameter set, although prices and quantities are more volatile in this experiment, as measured by their standard deviations.[29] Large variations in earnings, including losses, were also observed from session to session in most treatments, especially for fringe firms.

Result 2: Monopoly effectiveness measures for both ETC and ETC2 are very high relative to previous authors' double auction experiments.

Support:

Both raw and adjusted monopoly effectiveness indices are computed and presented in Table 18. The monopoly effectiveness indices for Treatments 1 and 2 do not suffer from production effects since product price is fixed. Differences in raw and adjusted measures reflect only poor production decisions by the dominant firm. Adjusted *M* values are clearly indicative of the success the dominant firm had in manipulating the permit market. Both experiments indicate very strong strategic manipulation across Treatment 1. Adjusted *M* for Treatment 2 also reflects a pattern of effective manipulation across experiments. The differences in measures across treatments, however, illustrates how this index is an imperfect indicator of market power. The Treatment 1 allocation leads to a predicted difference of 3 units traded and 55 Lab dollars in profits between competitive

[29] As stated previously, this change did not significantly affect the frequency of market power outcomes observed in Ledyard and Szakaly-Moore (1994) compared to the outcomes in Smith (1981) and Smith and Williams (1989). Here, the introduction of trading did not significantly alter the experimental outcomes as noted in Result 1.

and strategic prediction for the dominant firm.[30] Treatment 2 generates only a difference of 15 Lab dollars and one unit traded. This results in index values that are much more sensitive to the underselling observed by the monopoly firm in Treatment 2 than the under-buying behaviour observed in Treatment 1.

In Treatments 3 and 4, adjustments are required to differentiate between production effects and the permit market manipulation the monopoly index is used to measure. In Session ETC2 T4-2, the dominant firm ended the last double auction period having sold two permits at above 200 Lab dollars each. This subject produced five units in the product market and retired three permits, with a resultant market price (determined by her production and a total production of seven units by fringe firms) of 185. Final period profits result in M=-0.26. Had she produced seven units and retired one permit, her indicated monopoly effectiveness index would have increased by over 50%, to an adjusted index value of 0.26. This is symptomatic of the care that should be taken interpreting unadjusted index values for Treatments 3 and 4, where product price is market determined.

In another example, in the final period of ETC T4-3, the adjusted and raw index values are identical, implying, given realized P-market price, the dominant firm's production decision was optimal. The coupon market prediction for this treatment is one unit sold at a price of 185. The dominant firm sold a single unit at a price of 175. Had P-market price been at the predicted level of 185, the raw and adjusted index values would both have been 0.96, indicating the strong market manipulation being pursued by this firm relative to competitive market predictions. Over-production by the fringe of only *one unit* in this period, however, reduced product market price to 165 and the dominant firm's

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[30] The market power prediction yields predicted profit for the dominant firm of 220 versus 165 under competitive results.

profits by 160, resulting in raw and adjusted M=-0.43, clearly not indicative of the successful manipulation being pursued. Given the overproduction (and subsequent depressed product prices) in Treatment 4 and underproduction (and subsequently inflated product prices) in Treatment 3 in both ETC and ETC2, monopoly measures are significantly higher for Treatment 3. Across the last five periods, the dominant firm is able to achieve at least half of the possible strategic gains in ETC and exceed the predicted gains in ETC2, after adjustment for production. In the final period of ETC2, the success of the market power firm's manipulation in both treatments also exceeds that observed in ETC.

Comparison of the (adjusted) monopoly effectiveness values in Table 18 to M values found in other experiments underlines the success of the market power firm in these experiments. Smith and Williams (1991) found the average M value across the last period of their sessions to be 0.13 and over the last five periods to be 0.39.[31] Averaging ETC and ETC2 results over Treatment 1 and Treatment 2 generates an adjusted value over the final period of 0.35 and over the final five periods of 0.99. For Treatments 3 and 4, the average adjusted M values are 1.29 and 1.75 for the final period and last five periods, respectively. Holt (1995) reports monopoly effectiveness measures of 0.44 and 0.45 in posted-offer markets using inexperienced subjects across various author's work.[32] The double auction has been shown to produce monopoly effectiveness measures as much as 60% lower than posted offer markets for the same parameters in laboratory markets. The results here may be considered surprisingly "high" for a double auction, both relative to other double auction work and when compared to those institutions in which monopoly outcomes appear more often.[33] Clearly ETC and ETC2 generate strong

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[31] Smith (1981) and Ledyard and Szakaly-Moore (1994) do not report these measures.

[32] See Holt (1995), pp. 381. These values were generated from the work of Harrison, McKee and Rutstrom (1989) and Isaac, Ramey and Williams (1984) respectively.

[33] See Holt (1995) for such a calculation using Smith's (1981) results across various trading institutions.

market power results, even given the caution one must use when comparing this imperfect measure across experiments and accounting for downstream market production effects on earnings.

■

The ability of market participants to buy and sell, or "trade", in the double auction in ETC2 introduced the possibility of permit speculation. Transactions could occur, not to capture mutual trade gains, but to exploit differences in expectations over potential gains to be made by reselling permits. Speculation could result in a number of effects: (i) increased trading volume, (ii) greater permit price volatility, both within and across trading periods, (iii) greater losses to subjects due to increased volatility in the markets due to subjects finding themselves in "long" positions at the end of trading periods and (iv) lower allocative efficiency if speculation resulted in inefficient permit allocations. The addition of "trading" in this experiment allowed study of the effects of speculation in markets, which are presented below.

Result 3: **Speculation arises with the introduction of trading.**

Support:

Average *TO* values by session observed over all periods, from period six on, and from period eight on, are found in Table 19. Mean *TO* values observed by treatment were 2.7, 1.4, 4.1 and 1.5. Only one session (T1-3) indicated a TO=1 (no flips) occurring with regularity. On average, all treatments indicated at least 30% of trades were speculative. There appears to be no trend indicated over the course of the experiment in the observed values of *TO*.

Time paths of *r* over the course of each session are found by treatment in Figures 11 to 14. Point values of *r* by trade are identified using the ID number of the buyer while average period *r* values are connected by solid line. Only three sessions (Sessions T1-3, T3-2 and T3-3) regularly attained values of average *r* greater than one, and speculation still appeared to occur in two of them (Sessions T3-2 and T3-3) as measured by *TO*.[34] There appears to be a convergence over time in observed *r* values toward a value nearer to one. Figures 15 to 18 plot average values of *r* realized by firm type in each treatment. Average *r* by period is also included as a reference. These figures also indicate convergence nearer to one over time. In sessions indicating high turnover (T1-1, T1-2, T3-1, T3-2, and T3-3), fringe firms often had much lower observed *r* values, possibly indicating this side of the market speculated more heavily.[35] There appears to be an inverse relationship between observed *r* by period and *TO*. Of the sessions that indicated an average *r* value below 0.9 (T1-1, T1-2, T2-1, T3-1 and T4-2), the lowest TO statistic observed was 1.6, indicating at least 63% of trades were flips in these sessions.

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Speculation is apparent in most sessions and appears responsible for the higher trading volume observed in this experiment. The apparent convergence in *r* values corresponds to the observed decreases in the volatility of other market variables over time, especially permit prices. This suggests speculation, may be responsible for the greater variance in observed market variables and earnings, relative to the volume and variation observed in ETC.

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[34] Possibly this indicates the high mean *r* observed was a symptom of the low unit prices observed in the sessions.

[35] Of course this measure suffers from a truncation problem relative to the value calculated for the dominant firm as an inventory of only two permits leads to a value of *r* for a third unit accumulated of zero.

In sessions where the dominant firm was a net seller, the pursuit of high prices by the dominant firm may have deterred speculation among the buyers.[36] The following two observations describe patterns noted in the data which are moderately significant, but not quite powerful enough to meet the higher standards of significance used in the previous results. Possible relationships between these patterns and market outcomes are suggested.

Observation 1: Speculation increases when permits are initially allocated to the fringe firms.

Support:

All sessions and treatments appear to exhibit some speculation, or indications of it, using the measures *TO* and *r*. When comparing levels of speculation across various treatments, however, only *TO* is considered, as differences in *r*-values observed across treatments could be due either to speculation or the differences in price levels observed. *TO* is highest in treatments which allocate all permits to the fringe (Treatments 1 and 3). ANOVA analysis using the *TO* values of Table 19, indicates a moderately significant effect of endowment on observed *TO* across all periods (p=0.08). The effects of product market treatment and the interaction of endowment and product market treatments are not found significant (p=0.52, p=0.43 respectively). Similar findings are made for *TO* values observed over later periods, with the significance of the endowment effect increasing slightly (p=0.07) after period seven of the experiment.

■

[36] Expectations of higher permit prices appears to be limited if initial allocation makes accumulation of speculative units costly.

This observation suggests an important relationship may be present between speculation and market power, given the strong market power results observed in the double auction. The amount of speculative activity observed in treatments with allocation made to the dominant firm may have been lower because of the high prices the dominant firm was able to maintain in these treatments. For potential speculators, the price of admission into these markets may have been too high to create expectations of profitable resales. Figures 15 to 18 indicate very large differences in the *r*-values observed between the fringe and dominant firms in Treatments 1 and 3. Treatments 2 and 4 find no instances of the dominant firm speculating in four of six sessions.[37] With a larger number of firms able to participate in speculation, it appears to have spontaneously arisen. In treatments which allocated all permits to the fringe, the dominant firm had a monopsony incentive to purchase few units at low prices. If the fringe engaged in speculation, and this may have increased permit prices. This could explain the higher than predicted permit prices and low permit holdings of the dominant firm in sessions T1-2 and T3-1 compared to predicted levels.

Observation 2: Higher speculation reduces efficiency.

Support:

If markets exhibit speculation, it is possible and maybe expected that final permit allocations will not be efficient. Even if the sectoral shares of permits after trade are cost effective, speculation would increase the likelihood of an inefficient allocation among fringe firms as trades might not be based on intrinsic values. There were no efficient permit trading outcomes in Treatments 1 or 3. These were also the treatments which

[37] No speculative trades were observed in sessions T2-2, T2-3, T4-1 and T4-3.

indicated the highest amount of speculation as measured by *TO*. Regression of the efficiency index achieved over sessions after period 5 on average r value observed within period, endowment treatment and product market treatment indicates a significant positive relationship between average r and efficiency (p=0.01).[38] This suggests when observed speculation was lower and firms purchased units at prices nearer to or below their intrinsic values, efficiency increased.

■

Speculation does not appear to have depressed market power given the previous results presented. Since speculative activity was often greater among fringe firms, given the r values observed by firm type, speculation may have crowded the dominant firm out of the market in sessions in which it was a net buyer. This could have reduced allocative efficiency since the efficient allocation would see the dominant firm holding the most permits in the market. Additionally, some fringe firms could have found themselves holding more permits than they could use at the end of a period (a long position), further reducing system efficiency and possibly wasting permits. Such outcomes could have also caused the fringe losses observed.

The observed relationship between efficiency and speculation has important implications for potential permit markets. Although it can be argued speculation could sharpen a market's efficiency properties, the opposite was indicated here. This does not indicate that speculation necessarily hampers the achievement of market efficiency, however, when a larger proportion of market participants engage in such behaviour, the attainment

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$$\underset{}{effind_{ij}}=\underset{(0.17)}{0.20}+\underset{(0.16)}{0.55}r_{ij}-\underset{(0.37)}{1.81}pmkt_{ij}-\underset{(0.28)}{0.27}endow_{ij},$$

Adjusted R^2=0.63, SSE=3.45, nob=12. Estimates were corrected for heteroscedasticity using White's method, where effind= efficiency index calculated over the last five periods of the session using data in Figure 10, r=average r by session using data in Appendix B, *pmkt*=1 in Treatments 3 and 4, 0 otherwise and *endow*=1 in Treatments 1 and 3, 0 otherwise. Observations were made in treatment i and session j.

of efficient outcomes may take longer to achieve. The theoretic efficiency properties of permit markets depend on trade prices being used as signals which induce trade reallocation toward an efficient outcome. A market functions as a mechanism to induce traders to reveal their true valuations, and then exchange permits based on these valuations. Such revelation cannot be expected in command and control institutions and therefore markets theoretically result in more efficient outcomes. Market power clearly distorts prices. If speculation arises and permits are not traded based on their fundamental values but instead are exchanged due to speculative motives, the ability of the market to naturally allocate permits to the "correct" firms may be weakened further. The fact that speculation arises spontaneously, therefore, may be troubling. Although such behaviour could be expected from inexperienced traders, it was also most serious when allocation was made among only small traders, those who, in actual markets, might potentially be the least knowledgeable of actual valuations or least experienced in trade. Since these markets were conducted using inexperienced subjects, one may hypothesize this factor influenced the incidence of speculation. Previous asset market experiments have shown experience tends to reduce such activity, however experienced markets have also been known to exhibit such activity in the laboratory.[39]

When allocation of permits was made closer to the competitive allocation (Treatments 2 and 4), measured speculative activity was lower, suggesting a possible means of reducing such behaviour.[40] When speculation appeared in market-determined product price sessions, it seems to have been to the dominant firm's advantage. With the exception of

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39 See Davis and Holt (1993) or Sunder (1995) for overviews of the existing literature on experiments in this area.

40 Speculation might also be reduced through the trade of an alternative instrument such as "shares" instead of single period permits. See Godby, Mestelman, Muller and Welland (1995) for the definition of a "share" and the effect on trade volume of different traded instruments.

Session ETC2 T3-1, sessions with higher turnover ratios also indicated higher relative earnings for the dominant firm.

V. Conclusion

Results presented here indicate that neither the reduction of fringe firm numbers nor the ability to speculate in the double auction significantly changed the strong market power outcomes found in ETC. If counterspeculation is a natural form of behaviour and is influenced by a "numbers effect", as described, it could be severely undermined by the number of fringe firms found in the field. The results of the experimental markets in ETC were replicated here in an environment which had 50% fewer competitive firms making up the fringe. Efficiency and equity patterns observed in the original ETC, however, sessions were also observed here. Permit markets reduced efficiency rather than increased it, relative to traditional centralized regulation outcomes when permit market participants competed in common product markets.

The introduction of trading was not shown to influence the resulting pricing outcomes found in ETC, reinforcing the result found when comparing the Ledyard and Szakaly-Moore (1994) results to those of Smith (1981) and Smith and Williams (1991). Trading, however, did appear to generate speculation among subjects spontaneously, especially when those with the lowest valuations for traded units were initially allocated all permits. Speculation in permit markets also appeared to reduce efficiency, possibly because the post-trade allocation of permits often did not reflect the abatement costs of those left holding them, undermining the allocational benefits the market could have provided.

This experiment attempted to determine if specific differences in market structure between ETC and previous double auction market power experiments could account for differences in observed pricing results. The double auction institution could be considered as a sophisticated forum in which multi-lateral bargaining takes place among various agents over the sharing of trade gains. Viewed in this way, it becomes obvious that sorting speculation from actual bargaining in double auctions could be difficult. Both actions depend on participant's expectations. Experimental markets, however, may allow differentiation between bargaining and speculation by comparison of results, like those of ETC, with those of ETC2.

Seven procedural and structural differences were identified between previous market power work and the experiment reported in Chapter 4. The effects of procedural differences between ETC and previous work, however, are difficult to determine and suggest opportunities for future study. Possessing information regarding market demand and supply of the dominant firm or fringe could clearly influence bargaining, but such demand and supply information did not appear to be used by subjects when offered in ETC and ETC2. This experiment cannot determine whether knowing that there was only one firm on the other side of the market affected the behaviour of fringe firms. This suggests one avenue of future research; using the availability of such knowledge as a treatment variable. Experience asymmetry could also be an explanation of the strong market power results in ETC, however, ETC and ETC2 provide evidence to the contrary. No significant difference was observed between ETC results with and without this asymmetry. Further, ETC2 was conducted without experience asymmetries and results did not differ from those in ETC.

Other avenues of future research might include how the presentation of implicit versus explicit auction unit valuations affect market outcomes, or whether market power emerges more easily in monopoly or monopsony settings. Given ETC and ETC2 results, as well as previous authors', it appears different double auction implementations do not alter market results. This may have been expected since the implementation of different oral and computer mediated bargaining processes did not change the essential nature or their information content.

Counterspeculation as a bargaining strategy by the fringe against the dominant firm, might be broken by particular parameter designs. Specifically, it was suggested here that designs including two characteristics, trade exclusion or a numbers effect, might offer such potential. The results found in ETC2, however, indicate a numbers effect as defined here likely was not responsible for the original differences in pricing outcomes between ETC and previous work.

Figure 1: Competitive Product Market with Efficient Permit Allocation

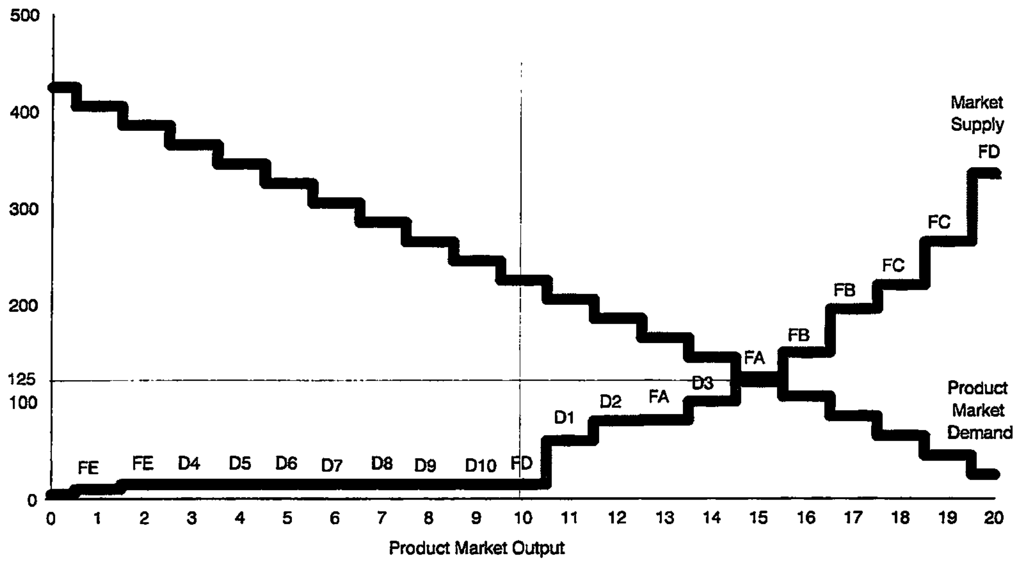
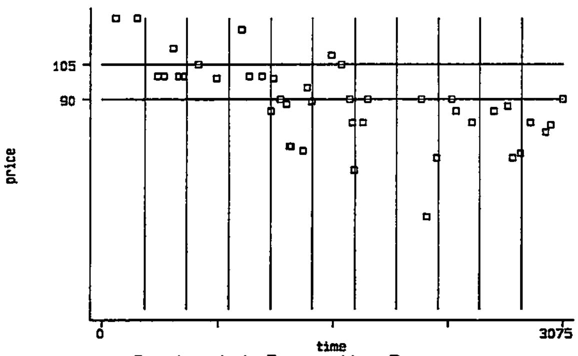
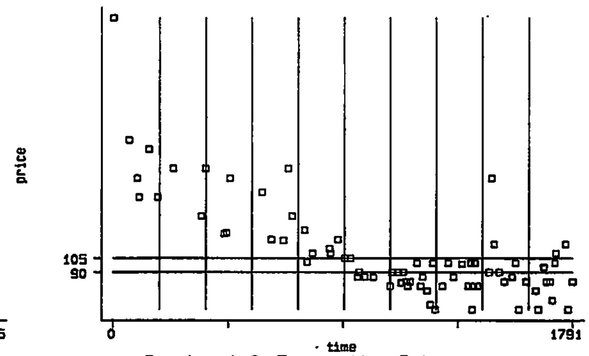


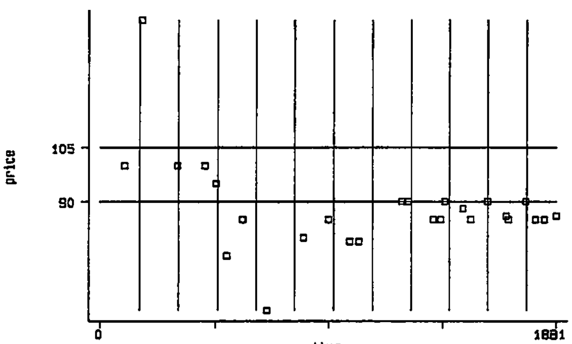
Figure 2: Permit Prices Over Time: Treatment 1



Session 1-1: Transaction Prices

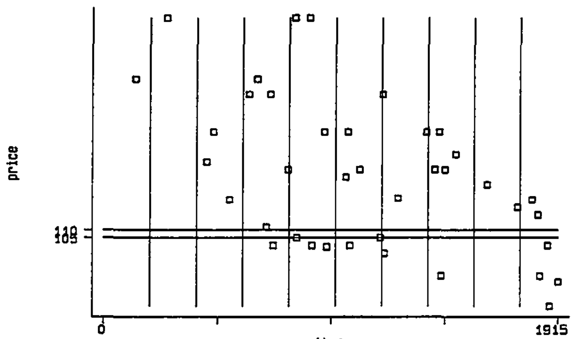


Session 1-2: Transaction Prices

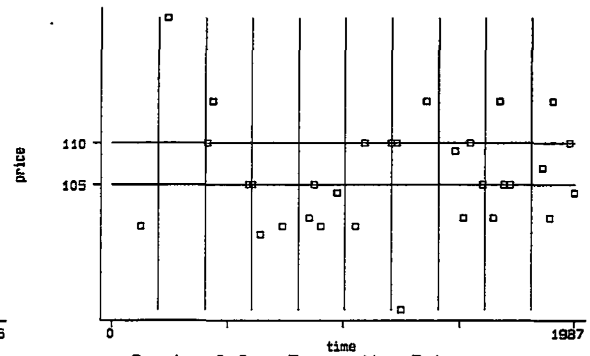


Session 1-3: Transaction Prices

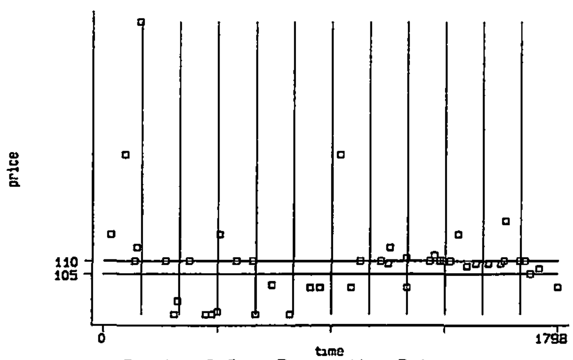
Figure 3: Permit Prices Over Time: Treatment 2



Session 2-1: Transaction Prices

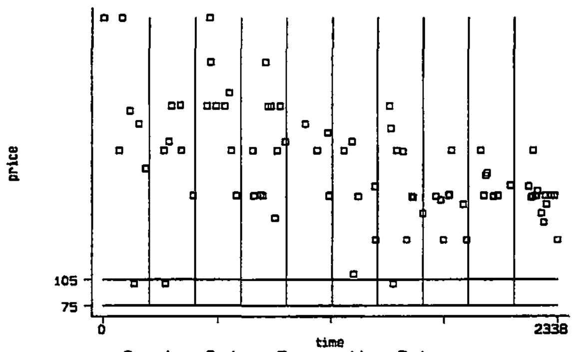


Session 2-2: Transaction Prices

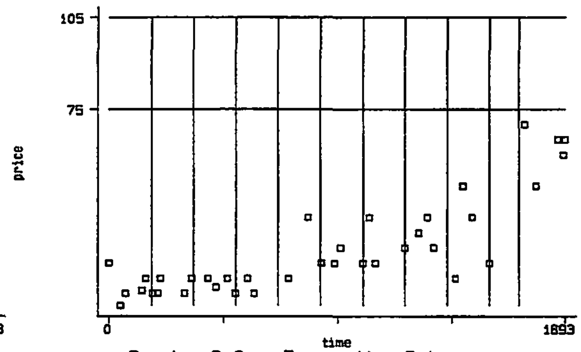


Session 2-3: Transaction Prices

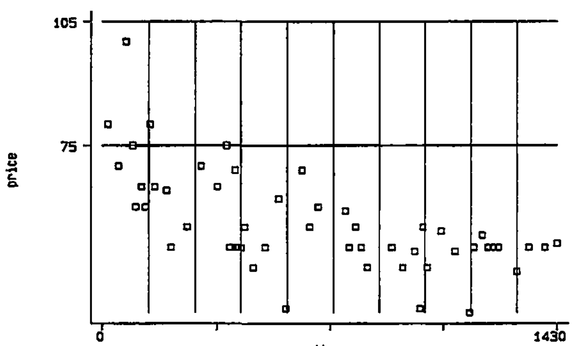
Figure 4: Permit Prices Over Time: Treatment 3



Session 3-1: Transaction Prices

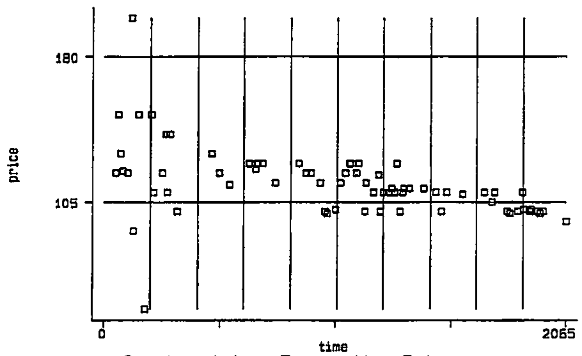


Session 3-2: Transaction Prices

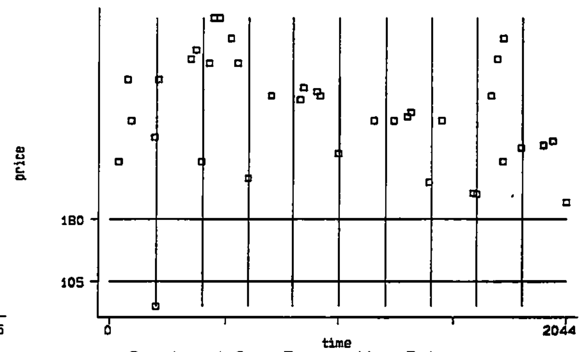


Session 3-3: Transaction Prices

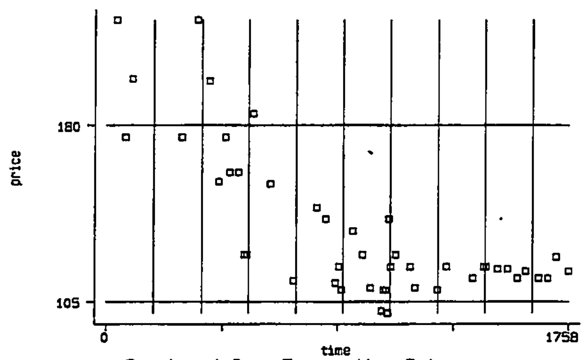
Figure 5: Permit Prices Over Time: Treatment 4



Session 4-1: Transaction Prices

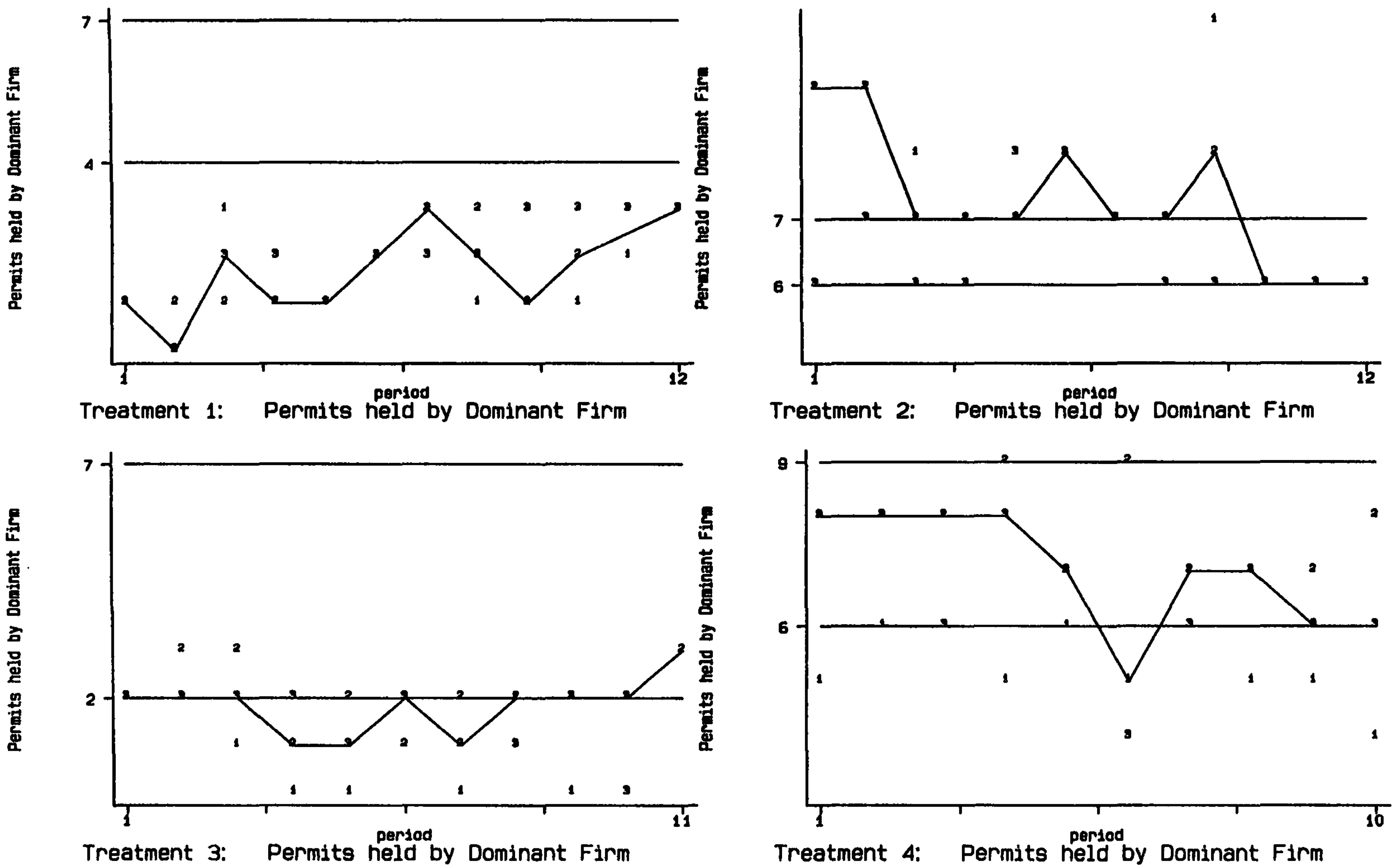


Session 4-2: Transaction Prices



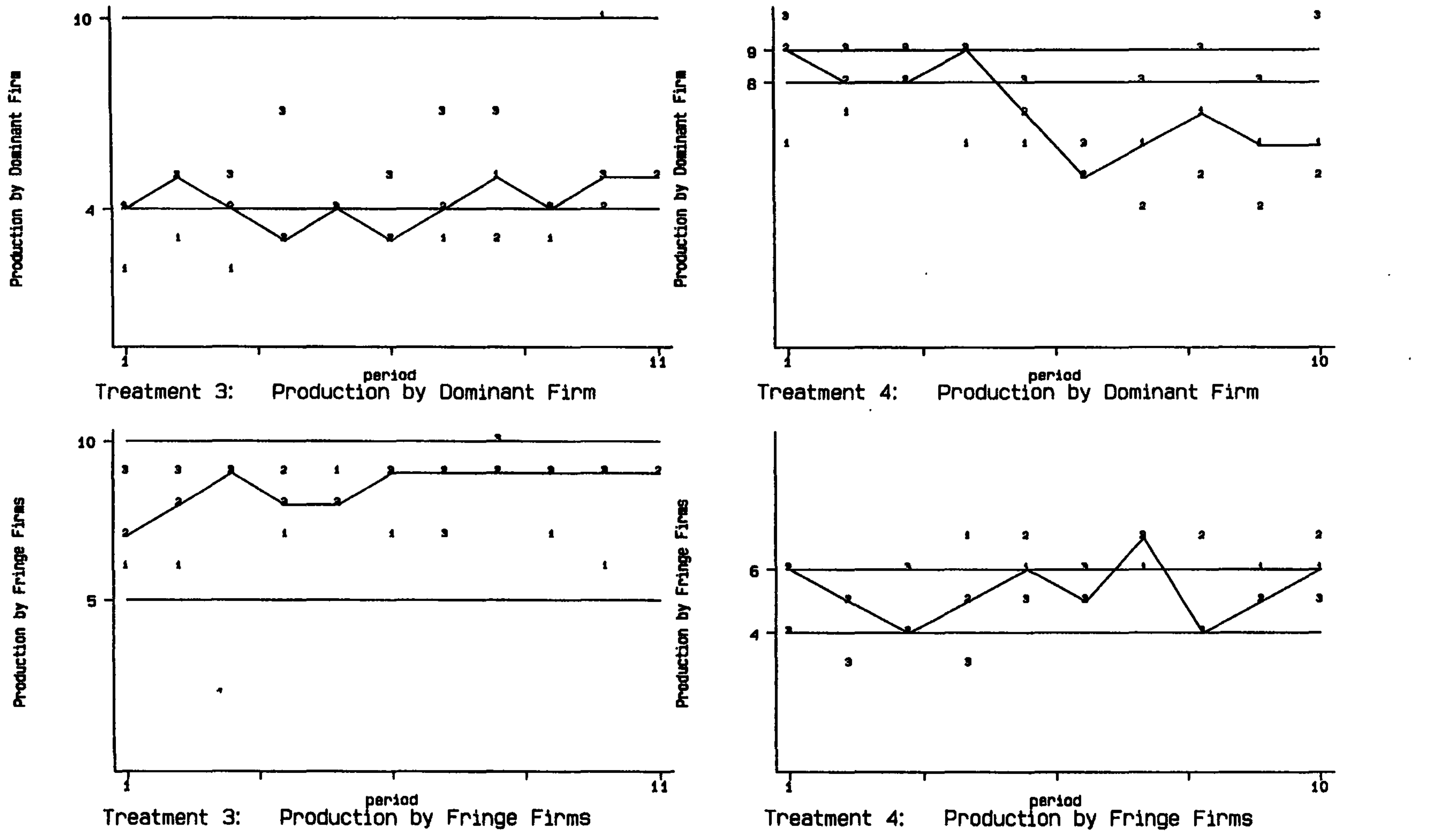
Session 4-3: Transaction Prices

Figure 6: Permits Held by Dominant Firm After Trade



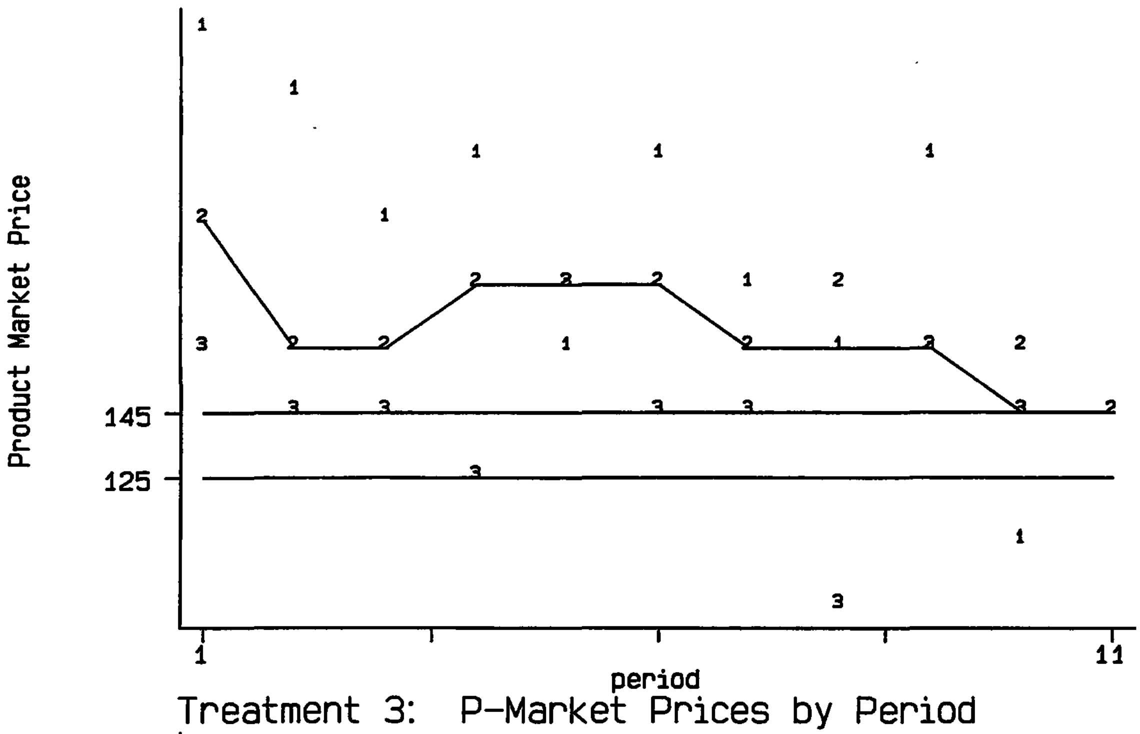
Notes: Digits 1, 2, and 3 refer to the session within treatment. The solid line connects median values.

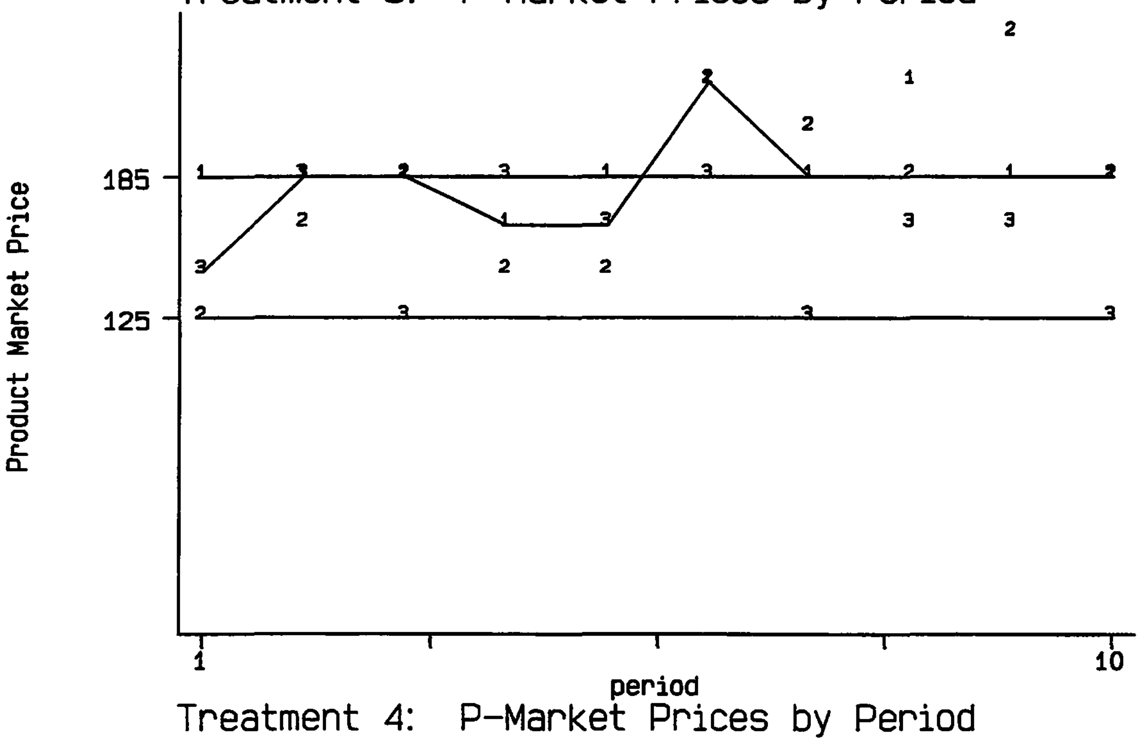
Figure 7: Production by Firms, Treatments 3 and 4



Notes: Digits 1, 2, and 3 refer to the session within treatment. The solid line connects median values.

Figure 8: Production Market Prices, Treatments 3 and 4





Notes: Digits 1, 2, and 3 refer to the session within treatment. The solid line connects median values.

Figure 9: Efficiency Index by Treatment

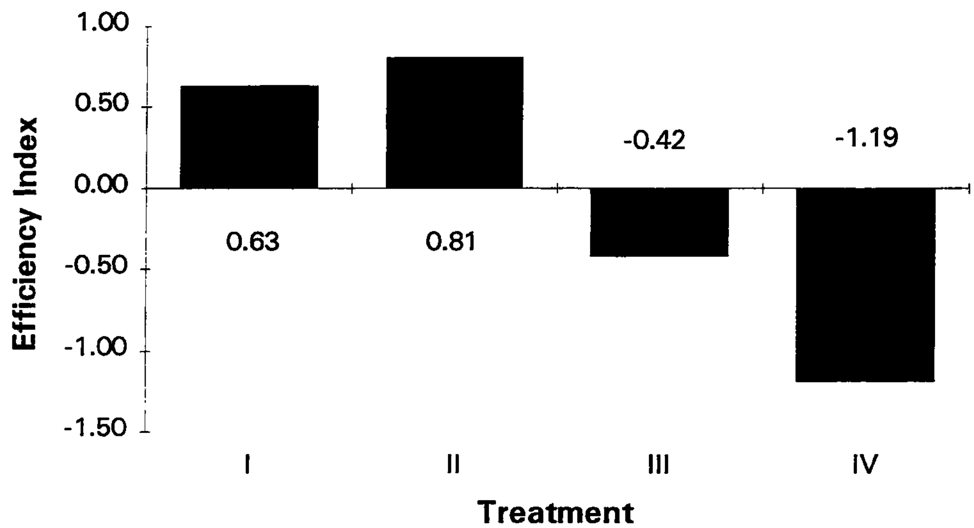


Figure 10: Efficiency Ratios by Session

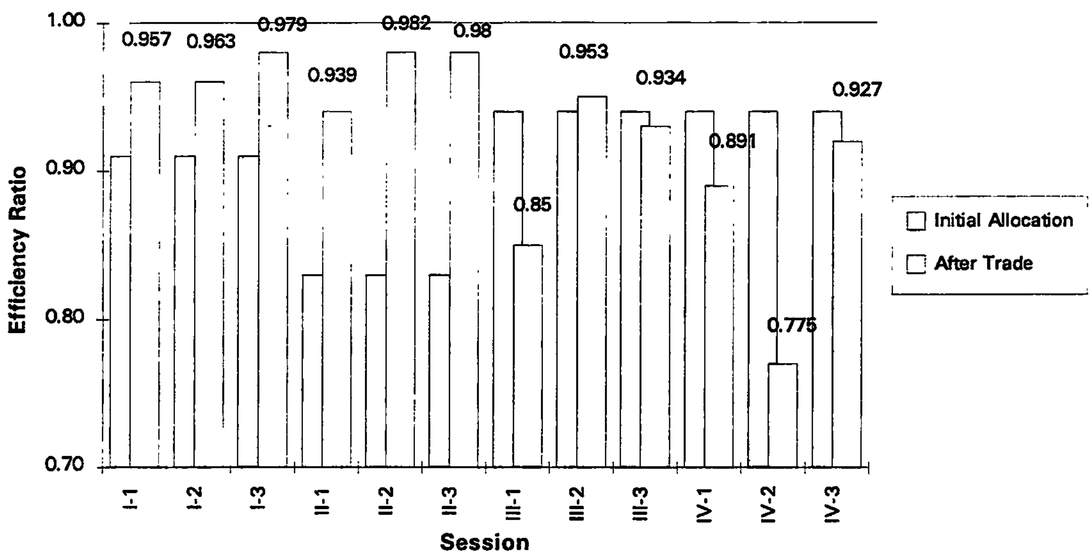
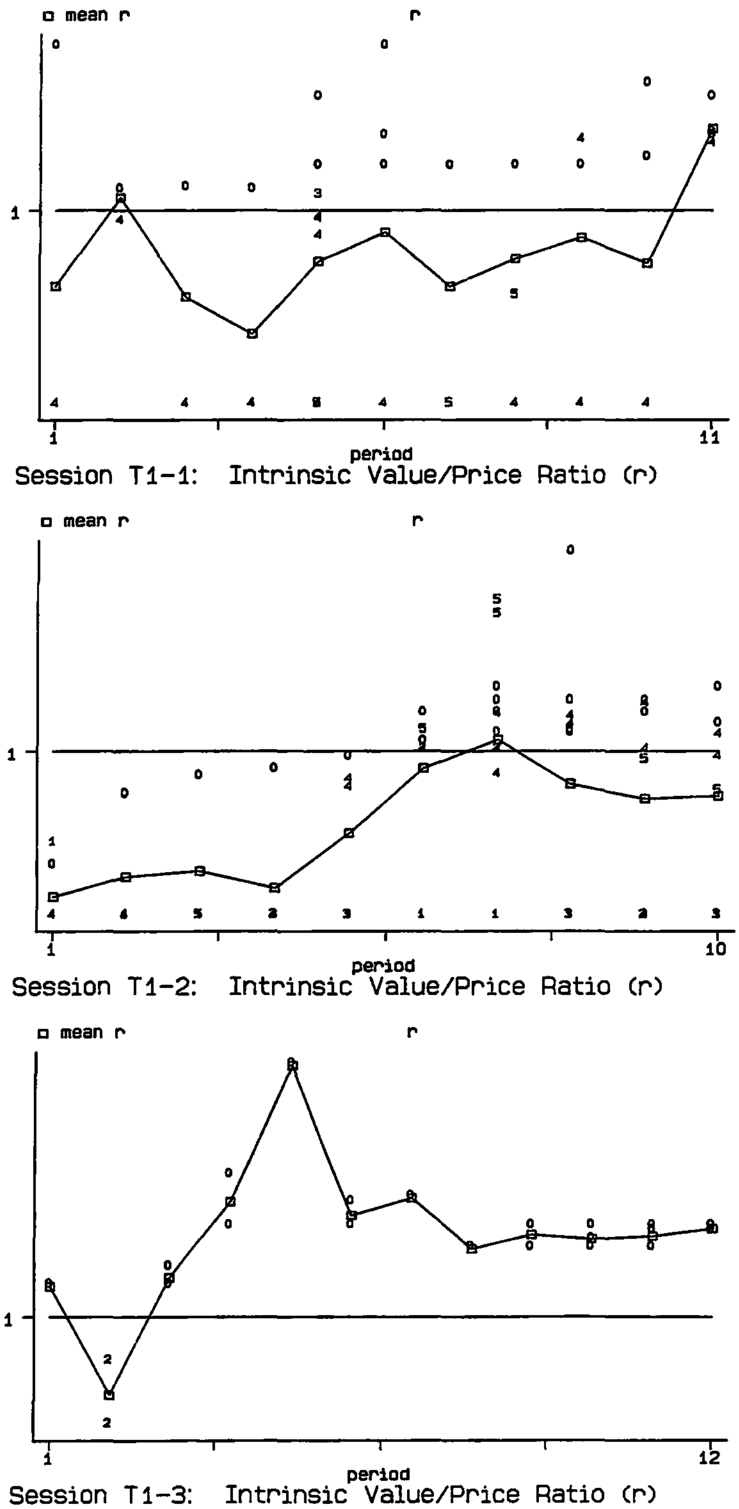
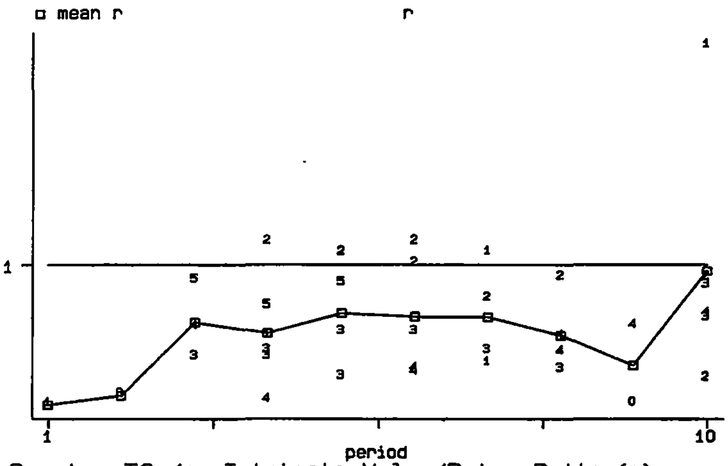


Figure 11: Intrinsic Value/Price Ratios (r), Treatment 1

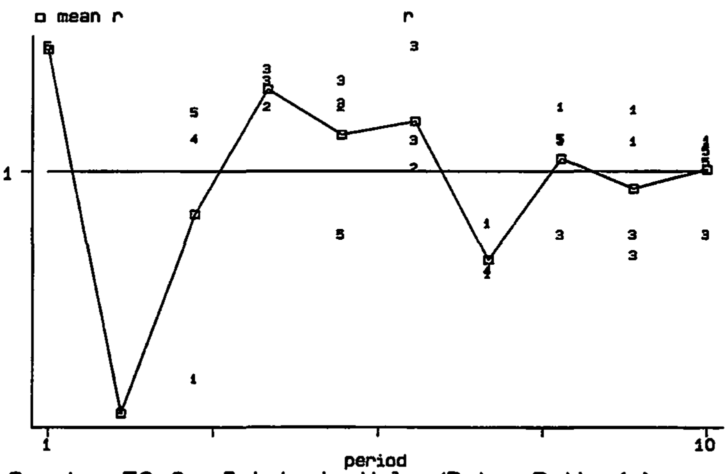


Notes: Numbers indicate buyer ID in each transaction. The solid line connects mean values.

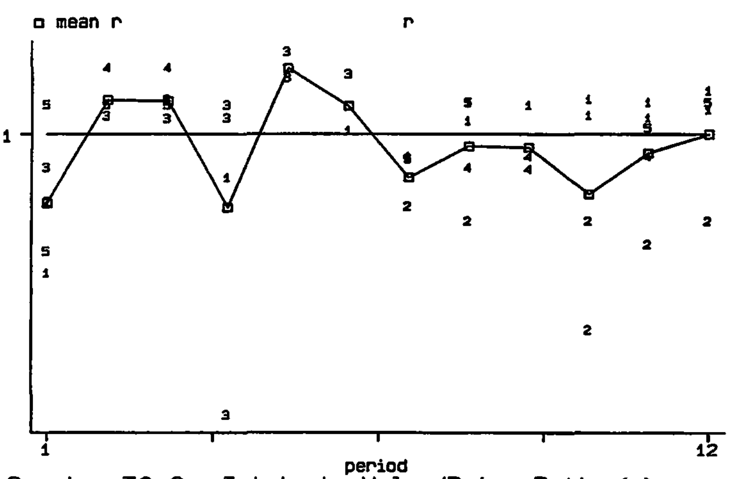
Figure 12: Intrinsic Value/Price Ratios (r), Treatment 2



Session T2-1: Intrinsic Value/Price Ratio (r)



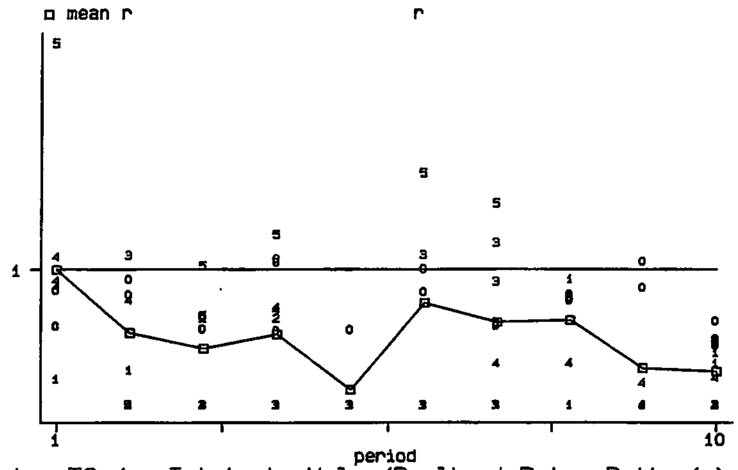
Session T2-2: Intrinsic Value/Price Ratio (r)



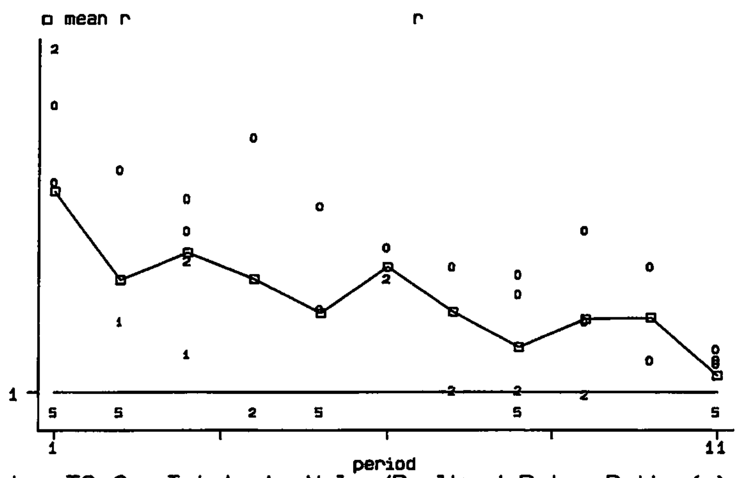
Session T2-3: Intrinsic Value/Price Ratio (r)

Notes: Numbers indicate buyer ID in each transaction. The solid line connects mean values.

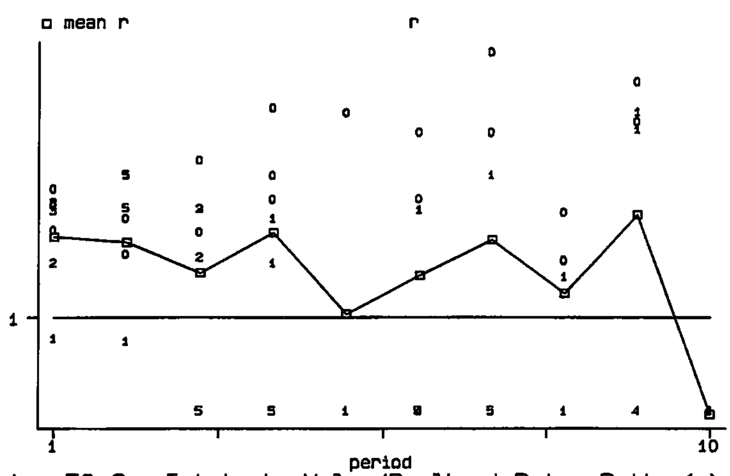
Figure 13: Intrinsic Value/Realized Price Ratios (r), Treatment 3



Session T3-1: Intrinsic Value/Realized Price Ratio (r)



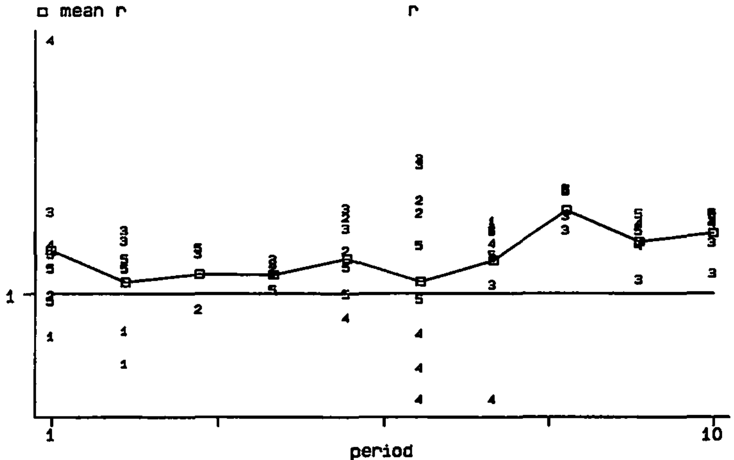
Session T3-2: Intrinsic Value/Realized Price Ratio (r)



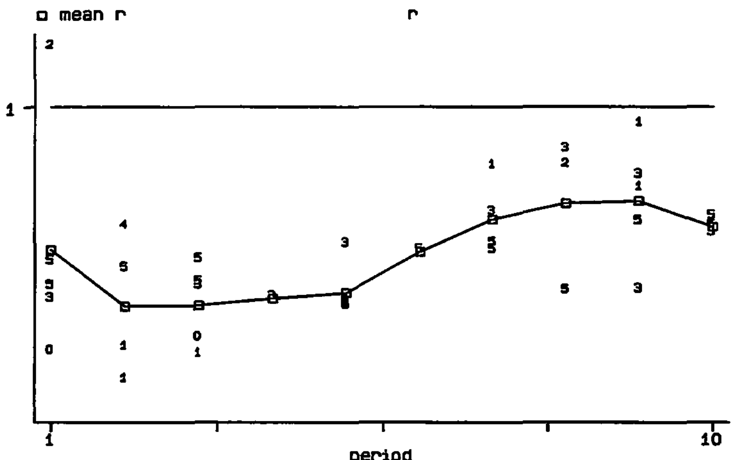
Session T3-3: Intrinsic Value/Realized Price Ratio (r)

Notes: Numbers indicate buyer ID in each transaction. The solid line connects mean values.

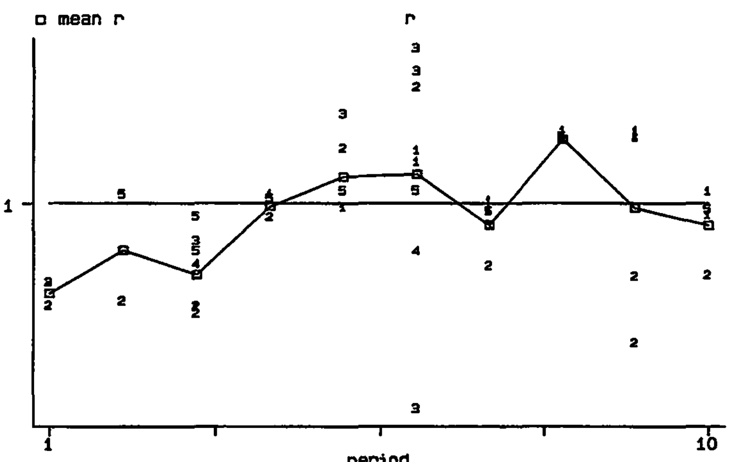
Figure 14: Intrinsic Value/Realized Price Ratios (r), Treatment 4



Session T4-1: Intrinsic Value/Realized Price Ratio (r)



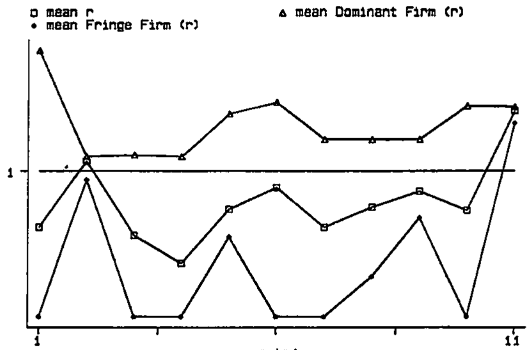
Session T4-2: Intrinsic Value/Realized Price Ratio (r)



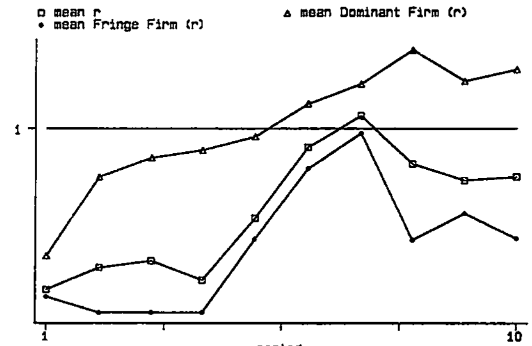
Session T4-3: Intrinsic Value/Realized Price Ratio (r)

Notes: Numbers indicate buyer ID in each transaction. The solid line connects mean values.

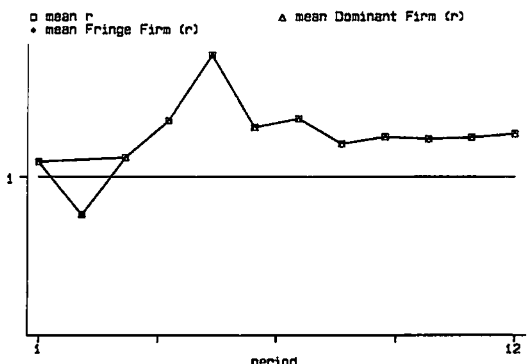
Figure 15: (r) by Firm Type, Treatment 1



Session T1-1: (r) by Firm Type

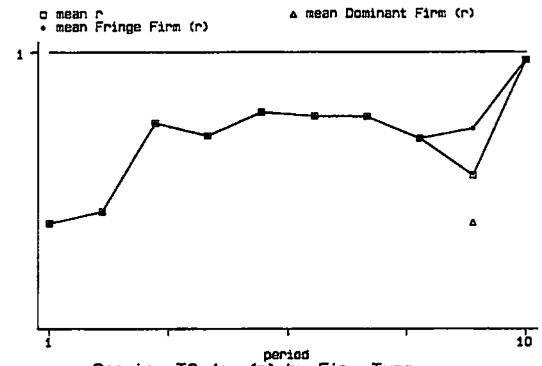


Session T1-2: (r) by Firm Type

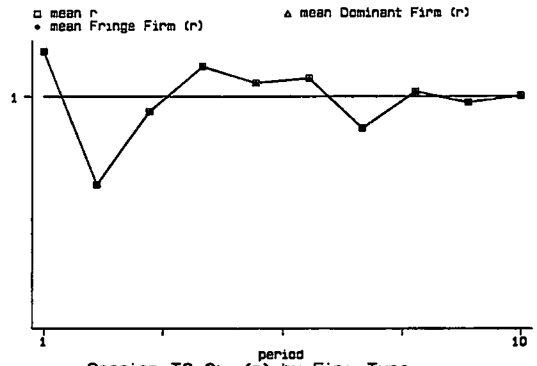


Session T1-3: (r) by Firm Type

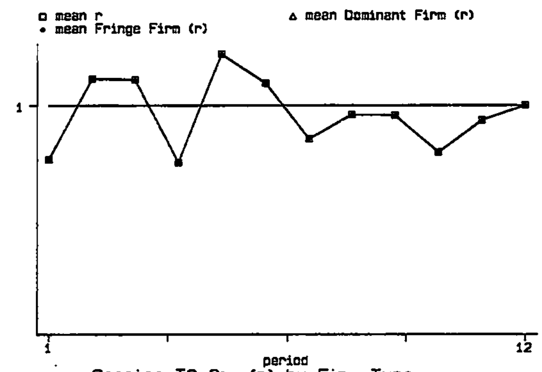
Figure 16: (r) by Firm Type, Treatment 2



Session T2-1: (r) by Firm Type

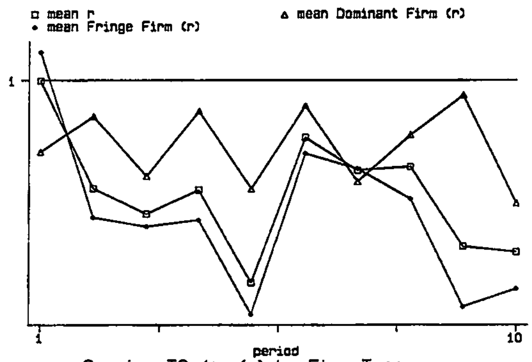


Session T2-2: (r) by Firm Type

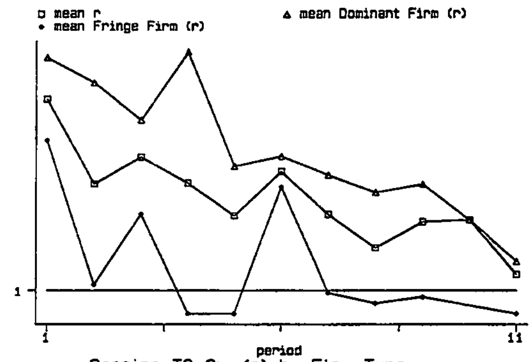


Session T2-3: (r) by Firm Type

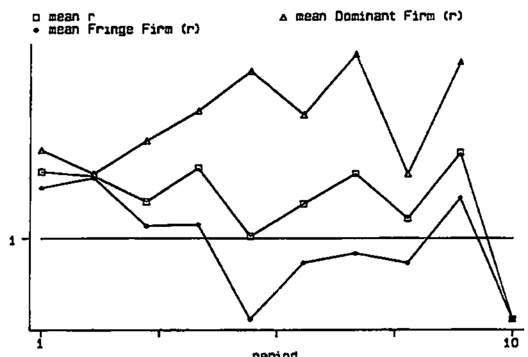
Figure 17: Realized (r) by Firm Type, Treatment 3



Session T3-1: (r) by Firm Type

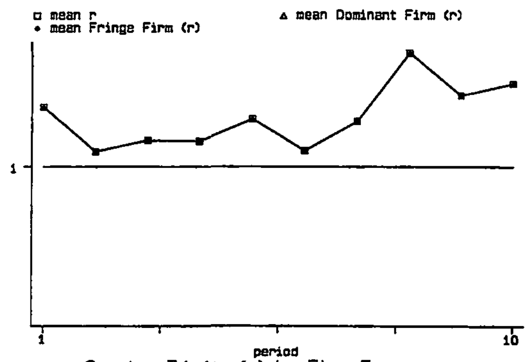


Session T3-2: (r) by Firm Type

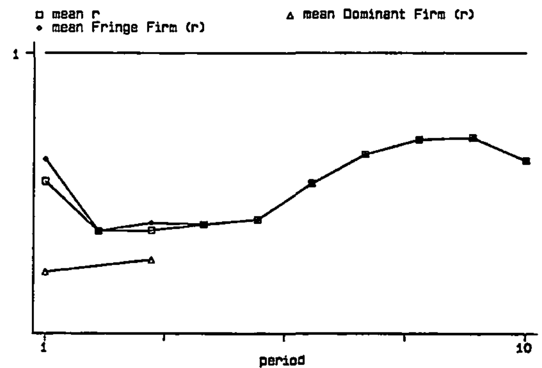


Session T3-3: (r) by Firm Type

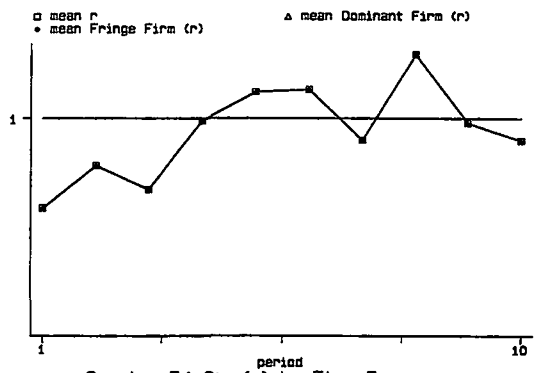
Figure 18: Realized (r) by Firm Type, Treatment 4



Session T4-1: (r) by Firm Type



Session T4-2: (r) by Firm Type



Session T4-3: (r) by Firm Type

Table 1: Market Power Experimental Designs

Authors	Monopoly or Monopsony	Fringe Size	Excluded Subjects at Predicted Equilibria	Emission Market Demand Revealed to MP Firm	Experience Asymmetry	Valuation Uncertainty	Fringe Informed of Single Seller or Buyer	Double Auction Type
Smith (1981)	monopoly	5	0	no	no	no	yes	oral (buy or sell only)
Smith and Williams (1989)	monopoly	5	0	no	no	no	yes	PLATO (buy or sell only)
Ledyard and Szakaly Moore (1994)	monopoly	5	0	no	no	no	yes	MUDA (traders)
ETC (Ch. 4)	both	10	7[1], 6[2]	yes	yes	yes	no	MUDA (buy or sell only)
ETC2 (Ch. 5)	both	5	3[3]	yes	no	yes	no	MUDA (traders)

Notes: [1] Treatment 2 and 4 competitive prediction (Mkt. power prediction differs Treatment 4).
[2] Treatments 1 and 3 competitive prediction (Mkt. power prediction differs Treatment 3).
[3] Competitive prediction (Mkt. power predictions depend on treatment).

Table 2: Laboratory Firm Costs

Firm	Unit	Marginal Production Costs	Marginal Abatement Costs
FA	1	45	36
	2	45	75
FB	1	35	115
	2	40	155
FC	1	25	195
	2	30	235
FD	1	15	275
	2	20	315
FE	1	5	355
	2	10	395
Dominant	D1	15	45
	D2	15	65
	D3	15	85
	D4	15	105
	D5	15	125
	D6	15	145
	D7	15	165
	D8	15	185
	D9	15	205
	D10	15	225

Note: D*i* indicates production unit *i* of the dominant firm.

Table 3: Experimental Design

	Allocation	
Product Market Price	**Fringe**	**Dominant**
P=125	Treatment 1 (T1)	Treatment 2 (T2)
Market Determined	Treatment 3 (T3)	Treatment 4 (T4)

Table 4. Market Predictions

	Permit Price[1] (C-Mkt.)	Final Permit Holding Fringe: Dominant	Production Fringe: Dominant: Total	Product Price[1] (P-Mkt.)
Efficient Outcome	105[2]	3:7[4] or 4:6[3]	5:10:15[4] or 6:9:15[3]	125
Efficient Coupon Mkt. Dominant Firm P-Mkt.	120-125[5] or 125-145[6]	4:6[5] or 5:5[6]	6:8:14[5] or 8:5:13[6]	145[5] or 165[6]
Treatment 1 Allocation: Fringe	90	6:4	8:8:16	125
Treatment 2 Allocation: Dominant	110	3:7	5:10:15	125
Treatment 3 Allocation: Fringe	75	8:2	10:4:14	145
Treatment 4: Allocation: Dominant	180	1:9	4:8:12	185

Notes: [1] All prices are given in Lab Dollars.
[2] Assuming marginal unit is traded (see text).
[3] Treatment 2 and 4 allocation assuming marginal unit trades.
[4] Treatment 1 and 3 allocation assuming marginal unit trades.
[5] Treatment 3 or Treatment 4 (see Appendix).
[6] Treatment 4 only(see Appendix).

Table 5: Experiment Results by Treatment

	License Price	Final License Holding: Fringe	Final License Holding: Dominant	Production Fringe	Production Dominant	Total Production	Product Price
Treatment 1							
Prediction[1]	105	3	7	5	10	15	125
Prediction[2]	90	6	4	8	8	16	125
Mean Observation	100.05	8.26	1.74	8.88	5.76	14.64	
Standard Deviation	40.69	0.93	0.93	1.07	0.92	1.35	
Treatment 2							
Prediction[1]	105	4	6	6	9	15	125
Prediction[2]	110	3	7	5	10	15	125
Mean Observation	121.36	2.78	7.22	4.34	9.22	13.59	
Standard Deviation	35.93	1.13	1.13	1.16	1.01	1.50	
Treatment 3							
Prediction[1]	105	3	7	5	10	15	125
Prediction[2]	75	8	2	10	4	14	145
Mean Observation	133.95	8.42	1.58	8.29	4.32	12.61	173.39
Standard Deviation	103.87	0.89	0.89	1.10	1.66	1.94	38.57
Treatment 4							
Prediction[1]	105	4	6	6	9	15	125
Prediction[2]	180	1	9	4	8	12	185
Mean Observation	163.97	3.32	6.67	5.37	7.10	12.47	176.33
Standard Deviation	84.79	1.57	1.57	1.19	1.75	1.50	30.93

Notes: [1] Competitive prediction.
[2] Market power model prediction.

Table 6: Convergence Patterns of Period Closing Coupon Prices Over Time

$$P_t = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_{13} \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1

$R^2 = 0.54$ Number of Obs. = 33

Adjusted $R^2 = 0.50$ SSE = 17978

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	**Prediction**	***p* value of H_0**	**Prediction**	***p* value of H_0**
β_{11}	122.30	20.81	105	**0.41**	90	**0.13**
β_{12}	215.03	20.78	105	0.00	90	0.00
β_{13}	111.80	20.85	105	**0.75**	90	**0.30**
β_2	78.67	6.33	105	0.00	90	**0.08**

Treatment 2

$R^2 = 0.55$ Number of Obs. = 31

Adjusted $R^2 = 0.51$ SSE = 20668

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	**Prediction**	***p* value of H_0**	**Prediction**	***p* value of H_0**
β_{11}	247.42	23.21	105	0.00	110	0.00
β_{12}	112.05	23.16	105	**0.76**	110	**0.93**
β_{13}	159.09	23.26	105	0.03	110	0.04
β_2	101.22	7.32	105	**0.61**	110	**0.24**

Treatment 3[1]

$R^2 = 0.86$ Number of Obs. = 31 Rho = 0.86

Adjusted $R^2 = 0.84$ SSE = 25261 Std. Err of Rho = 0.09

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	**Prediction**	***p* value of H_0**	**Prediction**	***p* value of H_0**
β_{11}	186.58	51.92	105	**0.13**	75	0.04
β_{12}	-2.63	43.07	105	0.02	75	**0.08**
β_{13}	82.07	43.57	105	**0.60**	75	**0.87**
β_2	91.89	35.14	105	**0.71**	75	**0.63**

Treatment 4[1]

$R^2 = 0.63$ Number of Obs. = 30 Rho = 0.79

Adjusted $R^2 = 0.59$ SSE = 58017 Std. Err of Rho = 0.11

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	**Prediction**	***p* value of H_0**	**Prediction**	***p* value of H_0**
β_{11}	49.73	70.18	105	**0.44**	180	**0.07**
β_{12}	87.61	55.66	105	**0.76**	180	**0.11**
β_{13}	167.61	56.22	105	**0.28**	180	**0.83**
β_2	171.87	39.04	105	**0.09**	180	**0.84**

Notes: [1] Estimates corrected for AR1 using Cochrane Orcutt technique.
Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 7: Convergence Patterns of Dominant Firm Permit Holdings Over Time

$$Q_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1
$R^2 = 0.22$ — Number of Obs. = 34
Adjusted $R^2 = 0.15$ — SSE = 22.241

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	**Prediction**	***p* value of H_0**	**Prediction**	***p* value of H_0**
β_{11}	0.39	0.72	7	0.00	4	0.00
β_{12}	0.46	0.72	7	0.00	4	0.00
β_{13}	0.66	0.72	7	0.00	4	0.00
β_2	2.19	0.21	7	0.00	4	0.00

Treatment 2
$R^2 = 0.41$ — Number of Obs. = 32
Adjusted $R^2 = 0.35$ — SSE = 23.114

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	**Prediction**	***p* value of H_0**	**Prediction**	***p* value of H_0**
β_{11}	9.57	0.76	6	0.00	7	0.00
β_{12}	9.21	0.76	6	0.00	7	0.00
β_{13}	6.07	0.76	6	**0.93**	7	**0.23**
β_2	6.82	0.24	6	0.00	7	**0.46**

Treatment 3
$R^2 = 0.14$ — Number of Obs. = 31
Adjusted $R^2 = 0.04$ — SSE = 20.272

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	**Prediction**	***p* value of H_0**	**Prediction**	***p* value of H_0**
β_{11}	1.47	0.73	7	0.00	2	**0.47**
β_{12}	2.95	0.73	7	0.00	2	**0.20**
β_{13}	2.16	0.73	7	0.00	2	**0.82**
β_2	1.33	0.23	7	0.00	2	0.01

Treatment 4
$R^2 = 0.31$ — Number of Obs. = 30
Adjusted $R^2 = 0.23$ — SSE = 39.913

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	**Prediction**	***p* value of H_0**	**Prediction**	***p* value of H_0**
β_{11}	5.02	1.03	6	**0.35**	9	0.00
β_{12}	9.37	1.03	6	0.00	9	**0.72**
β_{13}	7.95	1.03	6	**0.07**	9	**0.31**
β_2	6.34	0.33	6	**0.31**	9	0.00

Note: Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 8: Convergence Patterns of Product Market Prices Over Time

$$P_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_{13} \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 3
$R^2 = 0.51$ Number of Obs. = 31
Adjusted $R^2 = 0.46$ SSE = 21731

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	**Prediction**	***p* value of H_0**	**Prediction**	***p* value of H_0**
β_{11}	289.25	23.76	125	0.00	145	0.00
β_{12}	206.31	23.81	125	0.00	145	0.02
β_{13}	145.54	23.76	125	**0.39**	145	**0.98**
β_2	157.24	7.56	125	0.00	145	**0.12**

Treatment 4
$R^2 = 0.20$ Number of Obs. = 30
Adjusted $R^2 = 0.11$ SSE = 22136

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	**Prediction**	***p* value of H_0**	**Prediction**	***p* value of H_0**
β_{11}	187.94	24.49	125	0.02	185	**0.91**
β_{12}	137.30	24.49	125	**0.62**	185	**0.06**
β_{13}	129.89	24.49	125	**0.84**	185	0.03
β_2	186.53	7.97	125	0.00	185	**0.85**

Note: Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 9: Convergence Patterns of Dominant Firm Production Levels Over Time

$$Q_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1
$R^2 = 0.25$ Number of Obs. = 34
Adjusted $R^2 = 0.17$ SSE = 21.213

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	4.26	0.70	10	0.00	8	0.00
β_{12}	4.60	0.70	10	0.00	8	0.00
β_{13}	4.61	0.70	10	0.00	8	0.00
β_2	6.23	0.21	10	0.00	8	0.00

Treatment 2
$R^2 = 0.18$ Number of Obs. = 32
Adjusted $R^2 = 0.09$ SSE = 25.812

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	9.69	0.80	9	**0.40**	10	**0.70**
β_{12}	8.57	0.80	9	**0.59**	10	**0.08**
β_{13}	10.98	0.81	9	0.02	10	**0.23**
β_2	9.00	0.25	9	**0.98**	10	0.00

Treatment 3
$R^2 = 0.19$ Number of Obs. = 31
Adjusted $R^2 = 0.10$ SSE = 66.962

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	1.31	1.32	10	0.00	4	**0.05**
β_{12}	3.31	1.32	10	0.00	4	**0.61**
β_{13}	5.03	1.31	10	0.00	4	**0.44**
β_2	4.77	0.42	10	0.00	4	**0.08**

Treatment 4[1]
$R^2 = 0.61$ Number of Obs. = 30 Rho = 0.69
Adjusted $R^2 = 0.56$ SSE = 34.906 Std. err. of Rho = 0.13

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	5.62	1.55	9	0.04	8	**0.14**
β_{12}	9.26	1.23	9	**0.84**	8	**0.32**
β_{13}	11.29	1.24	9	**0.08**	8	0.01
β_2	6.76	0.71	9	0.00	8	**0.09**

Notes: [1] Estimates corrected for AR1 using Cochrane Orcutt technique.
Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 10: Convergence Patterns of Fringe Firm Production Levels Over Time

$$Q_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1

$R^2 = 0.21$ Number of Obs. = 34

Adjusted $R^2 = 0.13$ SSE = 29.803

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_o	Prediction	p value of H_o
β_{11}	9.39	0.83	5	0.00	8	**0.11**
β_{12}	6.94	0.83	5	0.03	8	**0.21**
β_{13}	9.86	0.83	5	0.00	8	0.03
β_2	8.93	0.25	5	0.00	8	0.00

Treatment 2

$R^2 = 0.27$ Number of Obs. = 32

Adjusted $R^2 = 0.19$ SSE = 30.337

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_o	Prediction	p value of H_o
β_{11}	3.10	0.87	6	0.00	5	0.04
β_{12}	2.49	0.87	6	0.00	5	0.01
β_{13}	5.81	0.87	6	**0.83**	5	**0.36**
β_2	4.58	0.27	6	0.00	5	**0.14**

Treatment 3

$R^2 = 0.35$ Number of Obs. = 31

Adjusted $R^2 = 0.28$ SSE = 23.488

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_o	Prediction	p value of H_o
β_{11}	5.51	0.78	5	**0.52**	10	0.00
β_{12}	7.57	0.78	5	0.00	10	0.00
β_{13}	8.89	0.78	5	0.00	10	**0.17**
β_2	8.68	0.25	5	0.00	10	0.00

Treatment 4

$R^2 = 0.16$ Number of Obs. = 30

Adjusted $R^2 = 0.07$ SSE = 34.235

			Competitive Model		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_o	Prediction	p value of H_o
β_{11}	5.49	0.96	6	**0.60**	4	**0.13**
β_{12}	5.63	0.96	6	**0.70**	4	**0.10**
β_{13}	3.28	0.96	6	0.01	4	**0.46**
β_2	5.60	0.31	6	**0.21**	4	0.00

Note: Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 11: Convergence Patterns of Dominant Firm Period Earnings Over Time

$$\pi_{it} = \beta_{11} D_1 \frac{1}{t} + ... + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1[1]
$R^2 = 0.76$ | Number of Obs. = 34 | Rho = 0.67
Adjusted $R^2 = 0.74$ | SSE = 29852 | Std. Err. of Rho = 0.13

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model p value of H_0	Market Power Model Prediction	Market Power Model p value of H_0
β_{11}	201.33	41.00	165	**0.38**	220	**0.65**
β_{12}	-124.30	32.78	165	0.00	220	0.00
β_{13}	107.83	32.83	165	**0.09**	220	0.00
β_2	201.44	17.07	165	0.04	220	**0.29**

Treatment 2
$R^2 = 0.26$ | Number of Obs. = 32
Adjusted $R^2 = 0.18$ | SSE = 263190

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model p value of H_0	Market Power Model Prediction	Market Power Model p value of H_0
β_{11}	1364.1	81.05	1220	**0.08**	1235	**0.12**
β_{12}	1044.2	81.05	1220	0.04	1235	0.03
β_{13}	1309.4	81.37	1220	**0.28**	1235	**0.37**
β_2	1222.2	25.22	1220	**0.93**	1235	**0.61**

Treatment 3
$R^2 = 0.44$ | Number of Obs. = 31
Adjusted $R^2 = 0.38$ | SSE = 786280

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model p value of H_0	Market Power Model Prediction	Market Power Model p value of H_0
β_{11}	-150.89	142.90	165	0.04	260	0.01
β_{12}	743.79	143.20	165	0.00	260	0.00
β_{13}	346.90	142.90	165	**0.21**	260	**0.55**
β_2	283.01	45.49	165	0.02	260	**0.62**

Treatment 4[1]
$R^2 = 0.48$ | Number of Obs. = 30 | Rho = -0.42
Adjusted $R^2 = 0.42$ | SSE = 742600 | Std Err. of Rho = 0.17

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model p value of H_0	Market Power Model Prediction	Market Power Model p value of H_0
β_{11}	1719.20	117.00	1220	0.00	1540	**0.14**
β_{12}	2255.20	114.10	1220	0.00	1540	0.00
β_{13}	1667.80	114.30	1220	0.00	1540	**0.27**
β_2	1533.20	36.31	1220	0.00	1540	**0.85**

Notes: [1] Estimates corrected for AR1 using Cochrane Orcutt technique.
Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 12: Convergence Patterns of Fringe Firm Period Earnings Over Time

$$\pi_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1
$R^2 = 0.05$ | Number of Obs. = 34
Adjusted $R^2 = -0.04$ | SSE = 372140

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model *p* value of H_o	Market Power Model Prediction	Market Power Model *p* value of H_o
β_{11}	886.31	93.10	1129	0.01	1054	**0.08**
β_{12}	896.30	92.80	1129	0.02	1054	**0.10**
β_{13}	999.26	93.10	1129	**0.17**	1054	**0.56**
β_2	988.73	27.71	1129	0.00	1054	0.03

Treatment 2[1]
$R^2 = 0.60$ | Number of Obs. = 32 | Rho = 0.75
Adjusted $R^2 = 0.56$ | SSE = 227510 | Std. Err. of Rho = 0.12

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model *p* value of H_o	Market Power Model Prediction	Market Power Model *p* value of H_o
β_{11}	-116.54	127.50	79	**0.14**	64	**0.17**
β_{12}	89.04	99.96	79	**0.92**	64	**0.80**
β_{13}	-168.45	100.50	79	0.02	64	0.03
β_2	-15.10	63.17	79	**0.15**	64	**0.22**

Treatment 3
$R^2 = 0.31$ | Number of Obs. = 31
Adjusted $R^2 = 0.23$ | SSE = 2293500

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model *p* value of H_o	Market Power Model Prediction	Market Power Model *p* value of H_o
β_{11}	2083.60	244.10	1129	0.00	1219	0.00
β_{12}	1288.60	244.60	1129	**0.52**	1219	**0.78**
β_{13}	1167.10	244.10	1129	**0.88**	1219	**0.83**
β_2	1175.50	77.68	1129	**0.55**	1219	**0.58**

Treatment 4
$R^2 = 0.19$ | Number of Obs. = 30
Adjusted $R^2 = 0.10$ | SSE = 1753300

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model *p* value of H_o	Market Power Model Prediction	Market Power Model *p* value of H_o
β_{11}	76.54	217.90	79	**0.99**	199	**0.58**
β_{12}	-517.41	217.90	79	0.01	199	0.00
β_{13}	-182.88	217.90	79	**0.24**	199	**0.09**
β_2	46.34	70.96	79	**0.65**	199	0.04

Notes: [1] Estimates corrected for AR1 using Cochrane Orcutt technique.
Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 13: Convergence Patterns of Period Efficiency Indices Over Time

$$EI_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1
$R^2 = 0.33$ — Number of Obs. = 34
Adjusted $R^2 = 0.26$ — SSE = 29.701

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model p value of H_0	Market Power Model Prediction	Market Power Model p value of H_0
β_{11}	-0.88	0.83	1.00	0.03	0.94	0.04
β_{12}	-3.13	0.83	1.00	0.00	0.94	0.00
β_{13}	0.01	0.83	1.00	**0.24**	0.94	**0.27**
β_2	0.31	0.25	1.00	0.01	0.94	0.02

Treatment 2
$R^2 = 0.37$ — Number of Obs. = 32
Adjusted $R^2 = 0.31$ — SSE = 9.448

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model p value of H_0	Market Power Model Prediction	Market Power Model p value of H_0
β_{11}	-0.64	0.49	1.00	0.00	1.00	0.00
β_{12}	-0.98	0.49	1.00	0.00	1.00	0.00
β_{13}	1.46	0.49	1.00	**0.35**	1.00	**0.35**
β_2	0.21	0.15	1.00	0.00	1.00	0.00

Treatment 3
$R^2 = 0.50$ — Number of Obs. = 31
Adjusted $R^2 = 0.45$ — SSE = 29.879

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model p value of H_0	Market Power Model Prediction	Market Power Model p value of H_0
β_{11}	-4.90	0.88	1.00	0.00	0.52	0.00
β_{12}	-0.57	0.88	1.00	**0.09**	0.52	**0.23**
β_{13}	0.67	0.88	1.00	**0.71**	0.52	**0.87**
β_2	-0.27	0.28	1.00	0.00	0.52	0.01

Treatment 4
$R^2 = 0.29$ — Number of Obs. = 30
Adjusted $R^2 = 0.21$ — SSE = 42.401

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model p value of H_0	Market Power Model Prediction	Market Power Model p value of H_0
β_{11}	-0.75	1.07	1.00	**0.11**	-0.68	**0.95**
β_{12}	2.10	1.07	1.00	**0.31**	-0.68	0.02
β_{13}	1.34	1.07	1.00	**0.75**	-0.68	**0.07**
β_2	-1.38	0.35	1.00	0.00	-0.68	**0.06**

Note: Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 14: Treatment 1 Total Period Profits to Producers and Total Profit Gains

		MP Firm		Fringe			
		Profit Realized	Gain	Profit Realized	Gain	Total Profit	Percent Gain
Predictions							
No Permit Trade/ Efficient P-Mkt.	**Profit**	140	0	980	0	0	0.0%
	% of Total	12.5%		87.5%			
Efficient Outcome	**Profit**	165	25	1129	149	1294	15.5%
	% of Total	12.8%		87.2%			
Strategic Prediction	**Profit**	220	80	1054	74	154	13.8%
	% of Total	17.3%		82.7%			
Outcomes (Mean outcome in last 5 periods)							
Session 1	**Profit**	170	30	976	-4	26	2.3%
	% of Total	14.8%		85.2%			
Session 2	**Profit**	198	58	976	-4	54	4.8%
	% of Total	16.9%		83.1%			
Session 3	**Profit**	204	64	1016	36	100	8.9%
	% of Total	16.7%		83.3%			
Treatment Means	**Profit**	191	51	989	9		
	% of Total	16.2%		83.8%			

Table 15: Treatment 2 Total Period Profits to Producers and Total Profit Gains

		MP Firm		Fringe			
		Profit Realized	Gain	Profit Realized	Gain	Total Profit	Percent Gain
Predictions							
No Permit Trade/ Efficient P-Mkt.	**Profit**	1100	0	49	0	0	0.0%
	% of total	95.7%		4.3%			
Efficient Outcome	**Profit**	1220	120	79	30	150	13.1%
	% of total	93.9%		6.1%			
Strategic Prediction	**Profit**	1235	135	64	15	150	13.1%
	% of total	95.1%		4.9%			
Outcomes (Mean outcome in last 5 periods)							
Session 1	**Profit**	1237	137	-91	-140	-3	-0.3%
	% of total	107.9%		-7.9%			
Session 2	**Profit**	1180	80	77	28	108	9.4%
	% of total	93.9%		6.1%			
Session 3	**Profit**	1240	140	-2	-51	89	7.7%
	% of total	100.2%		-0.2%			
Treatment Means	**Profit**	1219	119	-5	-54		
	% of Total	100.4%		-0.4%			

Table 16: Treatment 3 Total Period Profits to Producers and Total Profit Gains

		MP Firm		Fringe			
		Profit Realized	Gain[1]	Profit Realized	Gain[1]	Total	Gain
Predictions							
No Permit Trade/ Efficient P-Mkt	**Profit**	140	-115	980	-400	-515	-46.0%
	% of total	12.5%		87.5%			
Efficient Outcome	**Profit**	165	-90	1129	-251	-341	-26.4%
	% of total	12.8%		87.2%			
No Permit Trade/ Dom. Firm P-Mkt (No-trade prediction)	**Profit**	255	0	1380	0	0	0.0%
	% of total	15.6%		84.4%			
Strategic Prediction	**Profit**	260	5	1219	-161	156	-11.3%
	% of total	17.6%		82.4%			
Outcomes (Mean outcome in last 5 periods)							
Session 1	**Profit**	95	-160	1380	0	-160	-9.8%
	% of total	6.4%		93.6%			
Session 2	**Profit**	406	151	1293	-87	64	3.9%
	% of total	23.9%		76.1%			
Session 3	**Profit**	235	-20	983	-397	-417	-25.5%
	% of total	19.3%		80.7%			
Treatment Means	**Profit**	245	-10	1219	-161		
	% of Total	16.8%		83.2%			

Notes: [1] Gain is measured relative to the no-trade prediction indicated.

Table 17: Treatment 4 Total Period Profits to Producers and Total Profit Gains

		MP Firm Profit Realized	MP Firm Gain[1]	Fringe Profit Realized	Fringe Gain[1]	Total Profit	Percent Gain
Predictions							
Efficient Outcome	**Profit**	1220	-280	79	-60	-340	-20.7%
	% of total	12.8%		87.2%			
No Permit Trade/ Efficient P-Mkt	**Profit**	1500	0	139	0	0.0%	0.0%
	% of total	91.5%		8.5%			
No Permit Trade/ Dom. Firm P-Mkt [2] (No-trade Prediction)	**Profit**	1500	0	139	0	0.0%	0.0%
	% of total	91.5%		8.5%			
Strategic Prediction	**Profit**	1540	40	199	60	100	6.1%
	% of total	88.6%		11.4%			
Outcomes (Mean outcome in last 5 periods):							
Session 1	**Profit**	1605	105	250	111	355	21.7%
	% of total	86.5%		13.5%			
Session 2	**Profit**	1557	57	28	-111	-54	-3.3%
	% of total	98.2%		1.8%			
Session 3	**Profit**	1463	-37	-37	-176	-213	-13.0%
	% of total	102.6%		-2.6%			
Treatment Means	**Profit**	1542	42	80	-59		
	% of Total	95.0%		5.0%			

Notes: [1] Gain is measured relative to the no-trade prediction indicated.
[2] Dominant firm P-Mkt outcome identical to efficient P-Mkt outcome with no permit trade.

Table 18: Monopoly Indices[1] (M): Raw and Adjusted for Production[2]

ETC2 Session	Final Period Profit	Final Period Adjusted Profit	Final Period *M*	Final Period *Adjusted M*	Last Five Periods Profit	Last Five Periods Adjusted Profit	Last Five Periods *M*	Last Five Periods *Adjusted M*
T1-1	215	215	0.91	0.91	851	851	0.09	0.09
T1-2	245	245	1.45	1.45	991	1021	0.60	0.71
T1-3	214	214	0.89	0.89	1020	1020	0.71	0.71
T2-1	1196	1226	-1.60	0.40	6187	6402	1.16	4.03
T2-2	1192	1222	-1.87	0.13	5897	6058	-2.71	-0.56
T2-3	1222	1222	0.13	0.13	6198	6198	1.31	1.31
T3-1	-354	421	-8.03	3.37	475	1360	-1.43	1.18
T3-2	365	365	2.54	2.54	2030	2070	3.15	3.26
T3-3	225	315	0.49	1.81	1176	1941	0.64	2.89
T4-1	1471	1471	0.40	0.40	8025	8055	1.57	1.62
T4-2	1395	1455	-0.26	0.26	7783	8473	1.14	2.34
T4-3	1272	1617	-1.33	1.67	7315	7935	0.33	1.41
	Means:	**All:**	-0.52	1.16	**Means:**	**All:**	0.55	1.58
		T1:	1.08	1.08		**T1:**	0.47	0.51
		T2:	-1.11	0.22		**T2:**	-0.08	1.59
		T3:	-1.67	2.57		**T3:**	0.79	2.44
		T4:	-0.40	0.78		**T4:**	1.01	1.79

ETC Session	Final Period Profit	Final Period Adjusted Profit	Final Period *M*	Final Period *Adjusted M*	Last Five Periods Profit	Last Five Periods Adjusted Profit	Last Five Periods *M*	Last Five Periods *Adjusted M*
T1-1	205	210	0.73	0.82	1079	1129	0.92	1.11
T1-2	170	170	0.09	0.09	977	977	0.55	0.55
T1-3	220	220	1.00	1.00	1064	1064	0.87	0.87
T2-1	1210	1210	-0.67	-0.67	6241	6241	1.88	1.88
T2-2	1225	1225	0.33	0.33	6203	6203	1.37	1.37
T2-3	1196	1201	-1.60	-1.27	6018	6088	-1.09	-0.16
T3-1	354	379	2.38	2.75	1595	1745	1.87	2.31
T3-2	340	340	2.18	2.18	1865	1880	2.66	2.71
T3-3	245	280	0.78	1.29	1528	1563	1.67	1.77
T4-1	1349	1359	-0.66	-0.57	7083	7353	-0.07	0.40
T4-2	1300	1450	-1.09	0.22	6840	7180	-0.50	0.10
T4-3	1375	1375	-0.43	-0.43	7678	7688	0.96	0.98
	Means:	**All:**	0.25	0.48	**Means:**	**All:**	0.92	1.16
		T1:	0.61	0.64		**T1:**	0.78	0.84
		T2:	-0.64	-0.53		**T2:**	0.72	1.03
		T3:	1.78	2.07		**T3:**	2.07	2.26
		T4:	-0.73	-0.26		**T4:**	0.13	0.49

Notes: [1] Treatments 3 and 4 use an efficient C-Mkt/Dominant Firm P-Mkt in the denominator for calculation of Monopoly Index.
[2] Adjusted for production index computes monopoly index had market power firm produced optimally given product coupon inventory and market power.

Table 19: Average Turnover Ratios

Session	Periods 1-10	After Period 5	After Period 7
T1-1	2.4	1.9	2.1
T1-2	4.6	4.6	5.0
T1-3	1.1	1.0	1.0
T2-1	1.8	1.8	1.9
T2-2	1.2	1.4	1.4
T2-3	1.1	1.1	1.1
T3-1	7.4	7.3	6.9
T3-2	1.6	1.6	1.4
T3-3	3.4	3.8	4.3
T4-1	1.6	1.6	1.4
T4-2	1.6	1.3	1.4
T4-3	1.3	1.2	1.1

Chapter 6

Thin Emission Permit Double Auctions Dominated by a Single Firm

I. Introduction

This chapter presents the results of an experiment with a different endowment treatment from the previous chapters, while maintaining the treatment of vertically related product market and firm sizes of Chapter 5. The results of Chapters 4 and 5 suggest strong market power outcomes should be expected to occur whenever the conditions exist to allow them. Market power was possible in both experiments for two structural reasons: extreme initial allocations of permits and unequal firm size.[1] Hahn (1984) showed, if a firm is endowed with a large share of the permits allocated to the system, it will not necessarily be able to influence market price. Before such manipulation is possible, it must be the case the initial endowment of permits differs from the cost minimizing market allocation. The influence any firm has on price depends on how far the initial allocation is from the competitive one, as this difference increases all firm's excess demands.[2] If there is no excess demand there can be no manipulation. The initial allocation treatments of ETC and ETC2 maximized excess demand in the market and therefore the potential for price manipulation, while the relative size of the dominant firm to the fringe was not varied by treatment.

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[1] In what follows, "size" will often refer to production capacity. The larger a firm's size, the greater its production capacity.

[2] Firm excess demand functions may increase positively as allocation is moved away from efficient allocation, in which case the firm becomes a net buyer of permits, or negatively, in which case the firm becomes a net seller.

ETC and ETC2 included a vertically related product market in two of four treatments, increasing the dimension of possible permit manipulation. In addition to influencing prices to maximize permit sales revenue or to minimize permit expenditures, permit markets could also be used by a dominant firm to increase competitor's costs in downstream product markets.

There may be a regulatory means of preventing these problems. Regulators could adjust initial permit endowments in an attempt to reduce the potential for price manipulation. If competition among firms were limited to the permit market, an effort could be made to ensure an initial allocation "near" the competitive one. If competition among firms in the permit market also extended to a common product market, the initial allocation might be made to reduce or eliminate the potential for permit market exclusion. Allocating to reduce potential to exclude, however, might generate the potential for a firm to manipulate the permit market to minimize permit expenditure costs. Finding a balance between these two objectives could prove difficult.[3] Additionally, an allocation nearer to the competitive allocation could create a "thin" market, leaving only small trade gains to be captured by exchange. This would reduce the potential efficiency benefits left for the market to achieve.[4] If permit trading institutions or trading rules created transaction costs

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[3] Attempting to adjust initial allocations to inhibit market power also undermines the informational advantages a permit market is used to gain. Such activity would require an attempt to optimally allocate pollution rights. Among other reasons, markets may be introduced to reduce informational requirements on the regulator. If the initial allocation must be made with regard to reducing market power, much more information is required of the regulator, possibly approaching the level needed to efficiently implement a command and control solution. For the regulator, the required discovery of the true underlying market conditions needed to implement such initial allocations could also be made difficult given that some firms would have the incentive to misrepresent or obscure their costs and demand information to protect their market power or to avoid permit allocations which would be more costly to them.

[4] Hahn (1986) notes that requiring ambient air standards be met at each measuring site or receptor would require the number of markets to be less than or equal to the number of receptors. The number of markets could therefore be potentially large. As the number of markets increased, the potential for market power to appear within these markets could increase, as differences in firm size would become more relevant. If market power problems did not occur, the potential for trade gains to be made would certainly decrease as the number of potential traders in each market would be reduced. Thin market effects may therefore be a serious issue if regulators attempt to enforce local ceilings for emissions levels to avoid pollution "hot spots".

or trade frictions, exchange in the presence of thin markets could be reduced, and potential trade and efficiency gains might not be captured.[5]

This experiment creates a thin permit market in the ETC2 environment by making an initial permit endowment to all firms. This initial allocation more closely resembles the type of allocation that would be expected in an actual emission permit market. The endowment treatment, however, could be viewed as a logical extension to the allocation treatments used in ETC2 while maintaining the product market treatments and procedures. Chapter 5 completed the four possible treatments of product market price and initial endowment when endowments were made entirely to the fringe or the dominant firm. This chapter describes the outcomes occurring when a proportional endowment is made to firms based on production capacity. Initially endowing all firms with permits has a significant impact on the potential of the dominant firm to manipulate price. Since the allocation used here is closer to the efficient permit distribution than those in ETC2, the resulting excess demand functions among firms leave significantly less scope for manipulation when product market price is market determined, and none when it is fixed.

Firm sizes (based on emissions) in this experimental market are directly comparable to the sectoral sizes in a proposed NOx market, based on the demand information for stationary sources for Southern Ontario estimated by Nichols (1992). The uncontrolled pollution output that would be expected in this experiment given the market parameters resembles those found in the Table 1, which describes emissions in the Ontario market in 1985. The "dominant firm" (Ontario Hydro) produced 56% of the total emissions in the market, while firms in five other sectors were responsible for the remainder. Without any

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[5] Such an explanation has been offered for the apparent failure of the Fox River market (see Hahn, 1989).

restriction on emissions, the parameters of this experiment would be expected to result in the dominant firm producing 50% of total emissions (assuming an efficient product market). The five fringe firms would emit the remainder.[6] One criticism of proposed Ontario market is its predicted thinness. Only a few participants and correspondingly small volume of trade might be expected, based on the number of firms, given relative sizes and the scope of the market. The new endowment treatment here also dramatically reduces the amount of trade gains available in the market relative to ETC2.

As noted above, "near competitive" allocations could lead to problems in markets regardless of whether market power is a concern.[7] This experiment is not presented in Chapter 5 because the combination of endowment and product market treatment leads to a different set of problems from those examined previously. In particular, it addresses the ability of the double auction to capture available trade gains in thin markets. Previous authors' emission permit market experiments have usually induced potential efficiency gains of 10% to 15%, and often more.[8] The double auction mechanism has a strong history of inducing competitive outcomes, and it has been observed that experiment subjects often bargain at length over pennies in laboratory settings. This institution also, however, has the potential for speculation to occur. Speculation as defined in ETC2, could reduce efficiency in the presence of thin markets.

Uncertainty could also affect trade. An attempt to investigate small potential trade gains and uncertainty has yet to be investigated. This chapter induces uncertainty regarding product market price and thereby allows comparison of trade outcomes in markets with

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[6] Each fringe firm could represent an individual sector in the proposed Ontario market.

[7] Such an allocation could result if all emitters had similar abatement cost technologies and were all of similar size and/or competed in separate product markets.

[8] A notable exception is included in Hahn (1988) which investigated the effect on market efficiency achieved of varying potential trade gains available in the market to as low as 2%. These experiments were, however, conducted using a revenue neutral auction for permit trade.

certain and uncertain fundamental values on traded units. When product market price is uncertain, trading could leave firms more exposed to losses if future market prices prove below expected levels. Risk aversion could cause reduced trading if potential trade gains do not exceed the risk premium firms are willing to (implicitly) pay to reduce their exposure to such risk. Uncertainty could also induce speculation. The results of the previous chapter indicated that when firms were allocated permits in a way which reduced excess demand for the majority of firms, speculation increased (Treatments 1 and 3 in Chapter 5). Efficiency appears to have been reduced by speculation in ETC2. Since speculation causes re-allocation based on expectations which do not reflect true permit values, such market outcomes would be unlikely to indicate an efficiency gain.

This experiment reports the results of trading outcomes using a double auction trading environment after allocation of permits is made on the basis of historic use, or by proportional reduction to uncontrolled emissions. Do market models accurately describe observed outcomes? Do observed outcomes differ when there exists market uncertainty? Do the efficiency properties promised by a trading system in pollution rights emerge when there are thin markets? Does speculation occur and what effect does it have on the final trade allocations and system efficiency? Data are analyzed using the techniques introduced in the previous chapters to address these questions.

II. Laboratory Implementation

II.1 Introduction

All procedures and instructions (examples are provided in Appendix C) used in Chapter 5 were used, with any differences reflecting design changes outlined above. Permits were referred to as "coupons" as done previously to avoid framing effects.[9] Initial allocation of permits was proportionate to production capacity, implying the five fringe firms, FA-FE, each capable of producing two units, were endowed with one permit, while the dominant firm, capable of producing ten units, was allocated five permits initially. The induced costs are presented in Table 2. Proportional allocation reduced the number of treatments in the experiment to two, one with product price fixed at 125, and one where product price was market determined using production market institution described in Chapters 4 and 5. Permit trade was conducted using MUDA, allowing all participants to buy or sell single units, as long as their inventory made the desired trade possible.

Subjects were paid in Canadian dollars an amount proportional to their lab dollar earnings.[10] Sessions reported here were conducted at Laurentian University from November 21, 1995 to December 4, 1995. All subjects were undergraduates from a variety of disciplines (the majority being economics or commerce). Recruiting for all sessions was accomplished using on-campus advertising and announcements in undergraduate economics classes. Subjects were assigned to sessions randomly after recruitment, and sessions randomly assigned to experimental treatment. Two experimental treatments, each with three replications, were conducted using 36 subjects (6 per session). Rules of trade and costs of production and abatement were identical across treatments. All subjects were seated far apart in a single large computer lab. The dominant firm subject was seated in the same room. This subject was not identified to

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[9] As in the Chapters 4 and 5, no reference was made to pollution permits, pollution, abatement cost or the subject to be addressed by the research. Subjects were told only they were participating in an experiment which investigated the effect of trade in a "cost-reducing" input.

[10] To ensure that earnings for each subject were not too dissimilar, a different exchange rate was used for the dominant and fringe firms, and also depended on the treatment. Subjects were not made aware that individual exchange rates might differ. Exchange rates were as follows (value of 1 Lab Dollar in $CDN):

Treatment 1		Treatment 2	
dominant firm:	$0.004	dominant firm:	$0.005
fringe firm:	$0.025	fringe firm:	$0.025

Average session earnings were $35.83, with standard deviation $6.30, high $49.25, low $25.75.

the others. None of the subjects at Laurentian had previous experience with economic experiments. Subject assignment to fringe or dominant firm role was done by random selection. No communication was allowed among subjects once each session had begun. Each session took approximately two hours to run, of which 45 minutes were used for instruction. Experiment instructions were conducted in exactly the same manner as ETC2.

II.2 Laboratory Predictions

If one were to imagine a unregulated market system using the same production costs and product market demand as that presented in Chapter 5, with no abatement required, a total of 19 production units would be produced and 19 units of pollution emitted.[11] Imposition of an efficient permit market using this experiment's initial allocation, would cause a reduction of four output units and 9 pollution units at efficient levels of production.[12] There are two socially efficient distributions of permits. One is found in Figure 1. A product market price of 125 would maximize total surplus after establishment of the permit market. Efficient trade would result in the dominant firm, firm FE and possibly firm FD purchasing permits at prices between 100 and 105.[13] Fringe firms would

[11] Firm FA has highest production costs of 45 for each of two potential production units, which results in an intersection of induced permit market demand and abatement cost at a price of 45, and quantity of 19, all produced without abatement.

[12] Imposition of the permit market envisioned here represents a serious reduction in pollution allowed, as 47% of previously allowable emissions must now be abated (9 of 19 units). An efficient permit market/dominant firm product market outcome would lead to total profits of 1299, due to the higher market price caused by the lower production level, and consumer surplus of 2250. This represents a loss or cost to society of 526 to attain lower emissions. Cost of reducing emissions in this case is 531 if the previous product market were efficient. If price in the product market were fixed at 125 (or the dominant firm does not recognize its market power in the product market or competed in a market where it did not have market power), emissions would be reduced by 10 units, and output by five units. Total firm profits per period would be 465, while consumer surplus would equal 3610.

[13] The dominant firm and fringe firm FD both have identical valuations for the marginal unit traded, however only one is able to acquire a permit at the efficient outcome.

produce five or six production units, while the dominant firm would produce ten. This is the only possible prediction in Treatment 1; as the initial allocation results in no potential market power for the dominant firm in the permit market. Since the dominant firm is a net buyer, any attempt to depress price by under-buying would result in fringe firm FD being ensured a purchase, with no effect on predicted market price, since both firms have identical valuations over their last unit purchased. This is clearly evident in Figure 1 by the flat region of the induced market demand curve in the neighbourhood of market equilibrium.

Treatment 2 allows two other predictions due to the market determined product market price. The dominant firm could exclude firm FD from purchasing a permit. This would result in permit prices of 125 to 127 Lab dollars. The dominant firm would then produce an extra unit, with FD producing one less, leaving product market price unchanged. If manipulation were restricted to the product market alone, with an efficient trade result in the permit market, the dominant firm would restrict its output by two units in the product market relative to the competitive solution. Permit price would range between 120 and 125, and result in the fringe holding four permits while the dominant firm acquired one additional permit through trade. Predicted efficiencies for either market power prediction are virtually identical, resulting in approximately a 1% loss relative to an efficient outcome. The exclusion outcome is actually slightly more efficient than the efficient permit market/dominant firm product market prediction by virtue of the dominant firm's slightly lower production costs compared to firm FD's last unit. It also results in a higher profit for the dominant firm. All predictions are shown in Table 3 and mathematically derived in Appendix. A.

III. Results

To determine if the theoretic predictions are supported in actual experimental markets, prices, quantity produced, and permit holdings observed in the markets are compared to the various theoretical outcomes in Table 2. An estimation of the apparent time paths of observed market variables is conducted using the methods outlined in Chapter 4. Table 4 summarizes mean results by treatment. Appendix B contains additional market results observed in the experiment.

The summary results of Table 4 yield impressions which are later verified by more rigorous methods which account for the non-classical nature of experimental data. By session, using the data presented in Table 4 and that in Appendix B, the mean permit price observed throughout the experiment was 121.52, significantly higher than the efficient prediction of 100-105 expected had competitive results been observed throughout the experiment.[14] From Table 4, mean permit price in Treatment 1 was 107.75, while in Treatment 2 it was 134.91. This is a highly significant difference, when comparing prices directly using a Student t or Wilcoxon test.[15] Product market treatment appears to have affected observed permit prices.

Casual observation of apparent time paths of the observed market variables also yields impressions later verified by statistical methods. Figure 2 plots actual transaction prices over time for Treatment 1 (fixed product market price) and Treatment 2 (market-determined product price). Predictions are indicated by horizontal line and labeled on the

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[14] t=2.64 with 5 df., which is significant at a confidence level of 0.05.

[15] Using a t-test and accounting for the fact variances may be unequal across treatments, t=-4.28 with 2.08 df. The Wilcoxon Rank-Sum test finds z=1.96. Both tests are significant at the 0.05 level.

vertical axis. Few observed transactions fall in the predicted price bands. A number of sessions appear to indicate a cyclical pattern occurring in observed prices over time. Figure 3 plots permits held by the dominant firm by treatment. Data points are labeled by reference to the session in which they were observed, with median values by period connected by solid line. Both treatments indicate consistently lower than predicted permit inventories held by the dominant firm over time. Figure 4 plots production by firm type and Figure 5 plots realized product market price for Treatment 2. Again, predictions are indicated on the vertical axis with data points labeled by session and median observations joined by solid line. There appears to have been systematic underproduction by the dominant firm and over-production by fringe firms relative to predictions, while product market price was usually higher than predicted. These impressions are all verified by the following results.

Result 1: Treatment 1 results do not support the competitive prediction in the permit or product market.

Support:

From Figure 2, no trades at predicted prices occurred in Session T1-1, and only 36 of 114 transaction prices were in the predicted region over the course of Treatment 1. Convergence to predicted prices was not indicated by closing prices. The hypothesis that observed prices arise from identical populations is rejected at the 1% level, over all periods, the last five and the last three, suggesting prices do not converge to a common value across sessions as would be expected for efficient outcomes.[16] From Table 5, we can also reject the competitive prediction using the estimated effect of time on market

[16] Chi-square statistics of 48.765, 15.490 and 9.892 for all periods, periods 8 to 12 and periods 10 to 12 respectively, all with 2 df.

variables. Assuming all markets within the treatment converge to a common value, the estimated asymptote of closing permit prices is 109.80, and significantly different from the predicted band of the competitive model (p=0.00)

The volume of trade (reported in Appendix B) approached the predicted value, with a mean number of transactions per period of 3.1. When accounting for actual "trades", though, the number falls to 2.1, almost one full trade below the predicted level.[17] On average, the dominant firm held too few permits, with an inventory of 5.08 found across the treatment. Only three of 36 periods (periods 8, 10 and 12 in Session T1-3) achieved an efficient allocation of permits (either the dominant firm holding seven, with firm FE holding two, and firm FD holding one permit, or the dominant firm holding six permits with fringe firms FE and FD holding two permits each). The dominant firm's permit asymptote, found in Table 6, is 5.24, and significantly different from either competitive prediction ($p \leq 0.02$). Table 8 indicates production levels converged to a level significantly below the expected level of 10 units, while corresponding overproduction by the fringe was also observed as indicated in Table 9.

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In general, the price and quantity results in the permit market do not support the competitive model, nor do they indicate general convergence to predictions when product market price is fixed. The following result finds the competitive and strategic predictions are also unsuccessful in describing the observed market outcomes when product market price is uncertain.

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[17] The number "trades" indicates the number of transactions which moved units from those with negative to those with positive excess demands.

Result 2: Treatment 2 market results do not support any of the theoretic predictions.

Support:

Observed permit prices in Treatment 2 exceeded competitive and strategic predictions on average. Average permit price was 134.91, with session means of 132.56, 135.05, and 135.08 for Sessions T2-1 through T2-3 respectively. Thirteen of 123 transactions in Treatment 2 were observed in the competitive prediction price band of 100-105, the majority observed in the first two periods of Sessions T2-2 and T2-3, while only nineteen were observed in the price band defined by combining both strategic predictions (120-127). Only the price path of Session T2-2 hinted convergence to a strategic prediction, while Session T2-1 varied cyclically over time and Session T2-3 appeared to converge to a price level near 170. From Table 5, assuming convergence to a common value across sessions in the treatment, the predicted asymptote of permit closing prices is 145.75, significantly higher than any strategic or competitive prediction (p=0.05).

None of the post-trade permit allocations predicted in Table 3 were observed in even a single period of Treatment 2. Trading volume also did not reflect the level predicted. Session T2-1 observed 2.3 transactions per period, with only 1.2 actual trades observed on average.[18] Sessions T2-2 and T2-3 indicated higher volume (3.6 and 3.7 transactions/period respectively) than predicted, but actual trades were also below prediction (1.8 and 1.9 transactions/period respectively). On average, data from Table 4 indicates fringe firms actually increased their permit holdings during trade, suggesting a trade pattern in the "wrong" direction. This resulted in a lower than predicted permit inventory for the dominant firm. Table 6 indicates across sessions in the treatment, the

[18] This uses the word "trade" to mean a transaction between a predicted net buyer and a predicted net seller, as introduced in the last chapter.

dominant firm's holdings converged to 4.54 permits, significantly lower than any market prediction (p=0.00), implying the fringe sector's holdings converged to a value significantly above the predicted levels of any of the models summarized in Table 4.

Production levels also did not reflect predictions. On average the dominant firm underproduced throughout the treatment, while fringe firms overproduced in Sessions T2-2 and T2-3 relative to any of the predictions. Given permit holdings, however, the fringe also underproduced given realized product market prices. Product market prices were approximately 40 lab dollars higher than strategic predictions in Sessions T2-1 and Session T2-2, and 50 lab dollars higher in Session T2-3. As indicated in Figure 5, product prices did not fall over time. Table 7 suggests convergence of product market prices to 180.50, significantly higher than the predicted value of 145 (p=0.00). Table 8 suggests convergence to a production level of just over 5 units per period for the dominant firm, significantly lower than strategic or efficient predictions (p=0.00), while Table 9 suggests significant overproduction by the fringe relative to predicted levels ($p \leq 0.03$).

■

Previous chapters indicated permit market asymptotes were accurately described using strategic predictions. Although it is common for some market predictions to fail to exactly describe observed market outcomes or estimated asymptotes, none of the market predictions of Table 3, are described by any of the estimated asymptotes in the experiment. The complete failure of the theoretic models also extends to the direction of convergence.

Result 3: In both treatments, the direction of data convergence is generally not described by the efficient or strategic models.

Support:

From Tables 5 to 10, only 5 of 27 estimated time paths exhibit weak convergence, to any of the possible market predictions.[19] Three of the convergent series are found in session T1-3.[20] In Treatment 2, the dominant firm production levels in Sessions T2-2 and T2-3 appear to exhibit weak convergence to the exclusion prediction, however, none of the other observed market variables in these sessions suggest convergence to any prediction. ■

To those who favour the implementation of decentralized mechanisms such as permit markets to allocate pollution rights, the findings of this experiment will prove troublesome, especially if the proposed markets are expected to be "thin". These results indicate a double auction market with relatively small trade gains available should not be expected to attain an efficient or even a strategic outcome as a matter of course. Both treatments resulted in significantly different closing and mean transaction prices from those that would have been observed for an efficient solution or strategic solution. This has obvious implications for those who argue permit market prices would signal the value of abatement technology improvements.

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[19] Weak convergence is defined to occur when the following conditions are true: (i) estimated β_2 is closer the model's prediction than β_{i1} when both estimated values are significantly different from the model predictions (ii) if the p-value of β_2>p-value on β_{i1} (iii) or if both estimated p-values are greater than 0.05, indicating neither is significantly different from the model prediction at the 0.05 level, therefore the series is said to have already converged at its starting point and the series did not deviate away. See chapters 4 and 5 for more detail.

[20] The series are closing coupon price, dominant firm permit holdings and fringe production levels.

Market models predict a trade pattern toward the dominant firm. Given the low volume of actual trades, this pattern was not supported by observed results. Had trade occurred in the predicted manner, both dominant and fringe firm sectors could have increased their earnings. Such a pattern was not observed in the data.

Result 4: In Treatment 1, only fringe firms gained from trade.

Support:

Table 10 outlines the predicted earnings for the dominant and fringe firms in Treatment 1, and mean outcomes observed by treatment and session over the last five periods. As predicted, only fringe firms generally improved profits from those possible at the initial allocation. From Table 11, the estimated asymptote of the time path of dominant firm earnings by period is 701.77, indicating convergence to a small market gain. Only one series, however, was weakly convergent. Estimated time paths of fringe earnings from Table 12 indicate an estimated asymptotic gain of 18.4 Lab Dollars per period. Again weak convergence is noted in one series of three. On average, the dominant firm did not realize any profit gain over the level of earnings expected without permit trade. Mean earnings for fringe firms by session exceeded that at initial allocation, indicating some gains were captured from trade in the permit market, however, only 35% of the available profit gains to fringe firms were achieved.

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Result 5: In Treatment 2 total profit gains to all firms exceeded any prediction.

Support:

From Table 13, average profit increases observed (relative to those possible if no permit trade occurred and product market outcome reflected the dominant firm's market power) exceeded any prediction. Average profit gain realized by the dominant firm over the treatment was 61 lab dollars, 106 lab dollars higher than the level at the strategic prediction. Fringe gain was even higher, on average, 154 lab dollars higher than that under of the strategic prediction. Tables 11 and 12 reinforce these impressions, as the estimated asymptotes of the dominant and fringe firms are significantly higher than the market power predictions ($p \leq 0.01$), which in turn exceed efficient levels. None of the sessions indicate weak convergence toward the strategic prediction. Observed profit results appear best described by the earnings possible with no permit trade and a dominant firm outcome in the product market had taken place. This prediction, however, was expected to be unstable as fringe firms have trade opportunities which remain unexploited. Further trade would have led to higher output levels (assuming fringe firms acted as price-takers), resulting in the lower prices and profits described under the "fringe trade only/dominant firm product market" outcome. Although no permit trade would be collectively optimal, private incentives would be expected to prohibit this result, with individual firms exploiting remaining trade gains.

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The low volume of actual trades (as opposed to transactions) hints at a possible explanation of the pricing results. Mean earnings and permit holdings indicate the dominant firm did not participate in trade. Fringe firms, however, did. When product market price was uncertain, firms faced a risk of loss that was not present in Treatment 1. Losses, however, were not generally observed.

In Treatment 1, fringe production levels were higher and average total abatement costs lower than predicted had the efficient outcome arisen, reflecting the unexpectedly high permit inventories of fringe firms after trade. The combination of these two factors created higher observed profits for the fringe. These results contrast with those of the dominant firm, which generally experienced little or no gain in profits. Permit holdings increased little from the initial endowment and the dominant firm then had little opportunity to increase its production at lower cost. The earnings pattern observed in Treatment 1 might therefore be attributed to the fact little trade took place between the fringe and the dominant firm.

In Treatment 2, the high observed profits appear to be the result of the higher than predicted prices in the product market, which in turn were the direct result of low production by the dominant firm. This appears to have been caused by the dominant firm holding fewer permits than predicted. From Table 4, it would seem that on average the dominant firm actually sold permits instead of buying them. This explanation is reflected in Tables 6 to 9, where the dominant firm's permit holdings converge to a level lower than its initial endowment and production asymptotes converge to lower levels than predicted. Fringe production levels converge to higher than predicted levels of output, a result of holding more permits than predicted. Total output is below prediction, as system costs are higher than would have occurred for predicted patterns of trade, causing product market prices to converge to higher than predicted levels.

If no downstream market manipulation were possible, "selling" the benefits of a market based program of pollution rights re-allocation on the basis of increased profits would be difficult given the results found here. As noted in Result 4, in Treatment 1, only fringe firms attained a profit increase, and captured only one third of the trade gains possible.

The dominant firm did not experience any profit improvement. When downstream manipulation was possible, all firms enjoyed very large profit gains, at the expense of the hypothetical consumers in the experimental markets. Both results could make the political viability of such markets questionable.

Permit trade patterns also appear to have resulted in contrasting efficiency effects by treatment across the permit market system.

Result 6: Observed efficiencies differ across treatments. When market power is present in the product market, permit trade yields negative efficiency gains.

Support:

The competitive permit allocation would apply six or seven permits to the dominant firm and three or four in total to fringe firms FE and FD. These allocations would minimize abatement control costs, given production levels. Only twenty periods of 66 exhibited efficient sectoral allocation of permits between fringe and dominant firm over the course of the experiment. Eleven of these observations occurred in Treatment 1 but only one of these occasions resulted in fringe firms FD and FE holding permits reflecting the competitive allocation. In Treatment 2, none of the nine periods with efficient sectoral shares exhibited the efficient allocation of permits among fringe firms.

To determine quantitatively the impact of allowing permit trade on market efficiency, the efficiency index used previously is employed. This measure is calculated for the last five periods of each treatment and reported in Figure 6.[21] Obvious differences appear in the

[21] Again, as in previous chapters, later observations were used to allow the market time to converge.

amount of potential efficiency gain captured across treatments. Figure 7 illustrates the calculated efficiency ratios by session over the final five periods of each session. For reference the efficiency ratio that would occur if no trade had taken place (command-and-control allocation) is also indicated. Markets do not capture all trade gains possible. On average, Treatment 2 exhibited an efficiency loss equal to 33% of the possible gain (had the efficient outcome arisen in both markets after trade was permitted). By comparison, Treatment 1 indicated an efficiency increase over the command and control (no-trade) of 32% as the efficient product market price of Treatment 1 forced high efficiency in the production market. Any actual trades in the permit market increased efficiency in Treatment 1 by increasing firm profits while leaving consumer surplus unaffected.[22] Negative efficiency gains in Treatment 2 indicate most of the loss came from the dead weight loss caused by the exercise of market power in the product market.[23] Underproduction given permit holdings by fringe firms, as reported in Result 2, also contributed to the efficiency loss observed. Table 14 reports the results of the estimated time paths of efficiency index measures by treatment. Treatment 1 trading achieved outcomes converging to an efficiency improvement of 44% over the initial endowment. Treatment 2, however, converged to a decrease in efficiency of 23% relative to the initial allocation.

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Treatment 1 allowed a possible 2% improvement in system efficiency, and on average less than one third of this improvement was achieved. Chapter 5 found the maximum efficiency achieved in any market in which product price was fixed was 0.98, the efficiency at the initial allocation of Treatment 1 in this experiment. Comparison of

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22 Again, "trade" refers to transactions only between net buyers and net sellers.

23 Some of the efficiency loss recorded also occurred due to inefficient trading outcomes, however these accounted for a very small proportion of the total.

actual efficiencies achieved in Treatment 1 of this experiment to those in the fixed product market price treatments of Chapter 5 indicates the proportional endowment used here appears to have resulted in only a small efficiency gain after trading.[24] Treatment 2 allowed a 6% potential increase in efficiency. Actual results indicated efficiency levels 2% below that possible had no trade occurred. The efficiency results found here are not significantly different from those found in Chapter 5 when product price was market determined.[25] Trade reallocation to a cost-effective outcome rarely occurred in any treatment or session. Based on the results of the previous chapters, permit trade with a common product market reduces system efficiency achieved.

Hahn (1988) found that competitive markets using a revenue neutral auction did not achieve significant gains from trade if potential trade gains were 2% or less. For potential gains above this threshold, experimental markets observed have been very successful in achieving most of the gains available from trade. Ledyard and Szakaly-Moore (1994) note the revenue neutral auction appears to exhibit slower convergence properties than the double auction under competitive circumstances. The results of Hahn (1988) are reproduced here in a double auction environment when firms do not compete in a vertically related product market.

Consider how the efficiency results translate into actual pollution and cost reductions occurring in the laboratory markets. If one were to imagine these markets were implemented at the same time as a reduction in allowable pollution, Treatment 1 would have been expected to result in either a nine unit pollution reduction and a 5 or 6 unit pollution abatement effort. The social cost of the pollution decrease would have been a 3

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24 This result is significant (p=0.012) using an exact randomization test. See Moir (1996) for a description of the test.

25 Using an exact randomization test, the difference between efficiencies found here and those in Chapter 5 for variable market prices are not significantly different (p=0.50).

or 4 unit production decrease, depending on which of the possible trading outcomes outlined in Table 3 occurred. Actual results indicate a 3.5 unit average production decrease occurred, however, 5.5 pollution units were abated on average per period over the last five periods in Treatment 1. As indicated by the efficiency findings, little loss took place in this treatment.

In Treatment 2, had the product market outcome been determined by market power considerations, there would have been a five unit production decrease (from 19 units that would be produced assuming the dominant firm used its market power in the product market prior to the pollution reduction) for the required nine unit pollution reduction. Therefore, the predicted theoretic outcome would result in an abatement effort of four units. The actual nine unit pollution reduction was accomplished with an average abatement effort of 2.1 units across all sessions and production decrease of almost seven units on average. Too little abatement was done and the pollution reduction was instead accomplished with inefficient production decreases. Again this reflects the efficiency findings already reported. From Result 5, when product market price could be affected by firm decisions, profits increased substantially due to reduced output relative to that predicted had trade not been allowed. The hypothetical consumers in this product market were faced with an excessive product price. Surplus was actually lost after trading, while redistribution of remaining surplus occurred from the consumption to the production sector. Although any reduction in pollution would be costly to society, the lack of trade in permit markets here increased this cost, through reduced consumer surplus and the deadweight loss generated by manipulation of the permit market and mis-allocation of abatement. Few of the social cost benefits or efficiency gains were achieved in these laboratory markets.

Trading and efficiency results might be directly attributable to the following results.

Result 7: Permit speculation arises with the introduction of permit trade.

Support:

As in Chapter 5, two measures, *TO* and *r*, are calculated to measure speculation in laboratory markets. Average *TO* values by session, for all periods, for the final five periods and for the final three periods are found in Table 15. On average, for both treatments, at least 30% of all transactions were "flips". Turnover appears to have fallen over time. Only one session (T1-3) indicated almost no turnover, with an observed *TO*=1.1 occurring in the last three periods. Calculating average *TO* values in Treatments 1 and 2, finds values of 1.9 and 2.5 respectively. This indicates a moderate statistical difference (p=0.08 for the last three periods observations), possibly indicating that product market uncertainty increases observed speculation.

The other measure used to identify speculation computes the ratio, *r*, of the intrinsic valuation for the traded unit to the subject purchasing it and the price paid.[26] Time paths of *r* over the course of each session are found in Figures 8 and 9.[27] Point values of *r* by trade are identified using the ID number of the buyer while average period *r* values are connected by solid line. For Treatment 2 (Figure 9), the intrinsic value of the traded unit was calculated using the realized market price for that period. If the majority of trades were speculative or speculative trade prices were very high, average *r* would be less than

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[26] Note asset market experiments often define a measure of magnitude of price relative to intrinsic value as the *reach* (R), the ratio of the price paid minus intrinsic value over the intrinsic value. Since any unit accumulated by a fringe firm holding two permits had an intrinsic value of zero, this measure was not calculated. Reach is easily found for any non-zero observation of *r*, as (r^{-1}-1). Further description of the reach statistic can be found in Davis and Holt (1993), p. 165.

[27] The assumption is made here subjects understand the fundamental value of units purchased, or can indirectly act on it through the action of attempting to maximize trading profit. For such an assumption, payoff dominance is crucial. Note had trading been possible in the last chapter, "mistakes" would be considered speculative trades by the definitions used here. It should also be noted *r* values greater than one need not indicate a lack of speculation if period prices are very low.

one. Three sessions (Sessions T1-3, T2-1 and T2-2) regularly attained values of average *r* greater than one, however, some speculation was still indicated in early periods. Notably, these were also the sessions in which turnover was lower within treatment.[28]

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The following observation is made with regard to speculation. It is termed an observation as statistically there are too few data points to assume it is an actual relationship.

Observation 1: Sessions with higher speculation also recorded lower efficiencies.

Support:

If sessions are ranked within treatment on the basis of observed period *TO* and *r* values in the last five periods of the experiment, in Treatment 1, Session T1-1 had the highest speculation scores (*TO*=1.8 and mean *r*=0.83), followed by T1-2 (*TO*=1.7 and mean *r*=0.92) while lowest speculation scores were found in T1-3 (*TO*=1.5 and mean *r*=1.08). The highest efficiency in the last five periods was observed in Session T1-3 (0.991), which attained an improvement in efficiency 20% greater than Session T1-2 and 35% greater than Session T1-1, using the data in Figure 7. For Treatment 2, Session T2-3 had the highest speculation scores (*TO*=2.8 and mean *r*=0.87), followed by T2-2 (*TO*=2.5 and mean *r*=1.19) while lowest speculation scores were found in T2-1 (*TO*=1.4 and mean *r*=1.24). Observed efficiency ratio was highest for T2-1, with an efficiency improvement after trade of 8.3% of the available gain, and lowest for T2-3, where an efficiency loss of equivalent to 70% of the available gain was observed. A regression of mean efficiency index values by session on a constant, product market treatment (0=Treatment 1,

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[28] Note, speculation could still occur, even if period mean *r* was observed to be positive. "Middlemen" could buy units while having an intrinsic value below the price paid, and then sell it to a buyer with an intrinsic valuation greater than the price paid in that transaction. A value of *r* greater than one could result if the observed *r* in the second transaction was high enough.

1=Treatment 2) and average period *TO* value over the last five periods from Table 15, indicates a significant negative influence on observed efficiency due to increased speculative activity (p=0.04).[29]

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In Treatments 1 and 2, observed profit levels were very similar to those expected had no permit trade taken place. Transaction volume, however, indicates exchange did occur and was higher than predicted. Given the volume of "transacting", summary statistics indicate the majority of trades occurred between fringe firms only, as final sectoral holdings of permits did not differ greatly from initial sectoral allocations. These results suggest the cause of the inferior results observed here relative to potential outcomes may have been speculation. Trade volume in all sessions, defined as reallocation from net-buyers to net-sellers given induced excess demands by initial allocation, was low relative to that possible for an efficient outcome. Inspection of price paths in Figure 2 suggest permit prices were susceptible to cycles. These are evident for Sessions T1-1, T1-2 and T2-1. Casual observation indicates time paths of average r values may also be cyclical.[30] Such patterns would be more likely observed for speculative behaviour.

In Treatment 2, observed profit results are closest to an unstable market prediction, that which would occur if no permit trade occurred and a dominant firm product market outcome was observed in the product market. This may indicate markets may be very slow to converge to equilibria described by the individual profit maximizing incentives to trade, especially when there are only small trading gains to be achieved from trade and/or

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$$effindex_{ij} = \underset{(0.327)}{1.853} - \underset{(0.139)}{0.215}\,treatment_{ij} - \underset{(0.211)}{0.743}\,TO_{ij}$$

adjusted R^2=0.86, SSE=0.089, NOB=6, standard errors in parentheses.

30 Admittedly the time path has not been tested to determine whether observed prices and r values are actually cyclical or the product of a random walk.

when markets are characterized by high levels of speculation. If trades did not occur based on intrinsic permit values, such unstable outcomes could have persisted as long as speculative behaviour was present.

Predictions indicated even in the presence of market manipulation, an efficiency improvement should have been expected in the market. As found in Chapter 5 and as suggested by the nature of speculation, which implies trade at prices not reflecting fundamental permit values, efficiency increases appear to have decreased as speculation increased. Comparing turnover statistics found here with those in Chapter 5, the magnitude of speculation observed in the markets in this experiment was not as extreme as found when allocation was made to fringe firms only in Chapter 5 and more extreme than when allocation was made to the dominant firm in Chapter 5 (given product market treatment). This experiment lends support to the finding that allocations away from the net buyer in a market to net sellers increases speculation. As in Chapter 5, product market treatment was not indicated as the determinant of speculation. This may indicate speculation occurs when valuations of trade units are low, as opposed to when they are uncertain.

Because speculation may have driven the efficiency results, the choice of trading institution used could be important. Clearly a double-auction allows speculation as it allows easy resale. The use of a mechanism like the revenue neutral auction, considered by Ledyard and Szakaly-Moore (1994), could lead to an improvement in efficiency results when market power is present and allocation is not extreme. By forcing bids and offers to reflect intrinsic valuations based on abatement costs and product market considerations, the potential for speculation could be reduced using such an institution. Hahn's (1988) results. However, suggest this institution may be incapable of capturing trade gains when markets are thin.

V. Conclusion

Four research questions were to be addressed by the results of this experiment. They are answered in turn. The first asked whether theoretic market models accurately describe the market outcomes observed here. Previous experimental economic work, including that of Chapters 4 and 5, has indicated the double auction is generally very successful in attaining theoretic equilibria, whether they describe efficient or market power outcomes. The ability of the double auction to capture remaining efficiency gains in thin markets, however, had not been tested. Given the results presented here, the double auction would appear unable to realize these gains when participants can buy or sell. None of the theoretic outcomes described by either competitive or market power models, were achieved in any of the markets.

The second question was whether market uncertainty about the product market affected market outcomes. We answered in the affirmative. Market outcomes were significantly different when there existed market uncertainty. Treatment 1 permit market outcomes differed significantly from those in Treatment 2. Patterns of trade also differed, with little actual trade occurring in markets without uncertainty, while those with uncertainty witnessed trade in an unpredicted direction. Permit system efficiency also was affected by product market treatment, with the unpredicted efficiency losses observed in Treatment 2. Market predictions for both treatments predicted an efficiency gain that went unrealized. Production outcomes were lower than would be predicted and it would appear differences in the pattern of permit trading across treatments may have been at least partially responsible. Permit trade occurred in the "wrong" direction in Treatment 2.

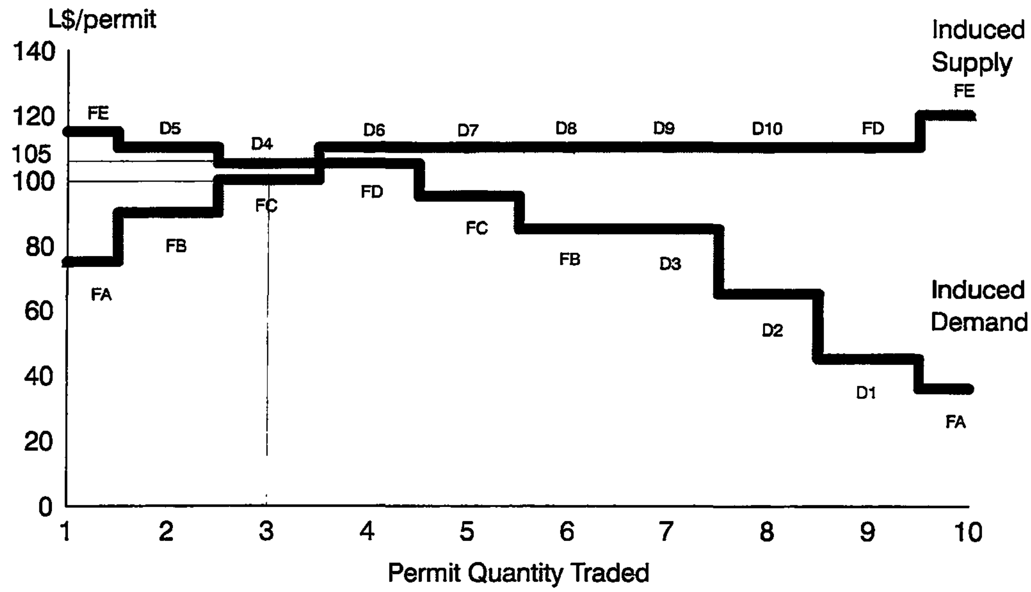
This may have exacerbated the systematic underproduction by the dominant firm, and resulted in the efficiency losses experienced.

The third question concerned speculation. Speculation was observed in these markets. As in Chapter 5, there may also have been an apparent relationship between market efficiency and the amount of speculative activity in the market. As speculation increased, realized efficiency decreased. Speculation appears to have accounted for at least 50% of the volume of trade in Treatment 1 and over 60% in Treatment 2. A comparison of levels of identifiable speculative activity to those found in the results of Chapter 5 supports the contention that initial allocations can influence the amount of speculation observed.

The final question was whether the efficiency gains expected from emissions trading would emerge when markets are thin. The experimental results suggest they do not. Subjects realized losses in efficiency when the product market was variable and less than one third of the available gains when product market prices were constant. In this experiment, markets were thin because the initial allocation of permits was made "nearly competitive" so as to reduce market power. Consequently, the available gains from trade were small and speculation appears to have prevented them from being realized. Because the parameters of this experiment were broadly similar to a proposed market for NO_X in Ontario, policy-makers should be concerned by the results.

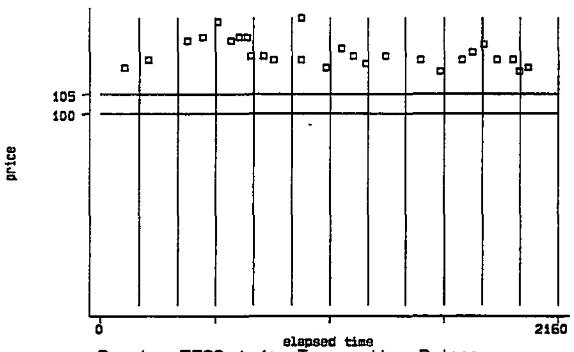
Experiments ETC and ETC2 showed that a double auction will not prevent price manipulation. Consequently regulators may wish to allocate permits to reduce the potential for market manipulation. Because this allocation may create thin markets susceptible to speculation, regulators may wish to choose trading institutions which curb speculation and encourage realizing the limited gains from trade. Which institutions could accomplish this would be a useful topic of future research.

<u>Figure 1: Efficient Coupon Market Solution</u>[1]

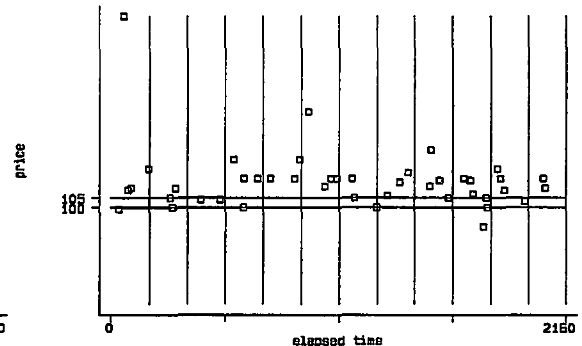


Note: [1] Assuming dominant firm buys the marginal unit and product price=125

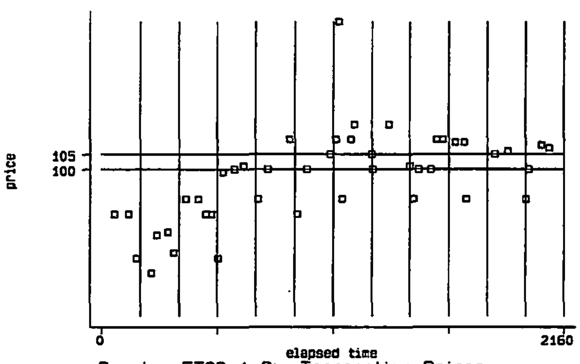
Figure 2: Transactions Prices by Period



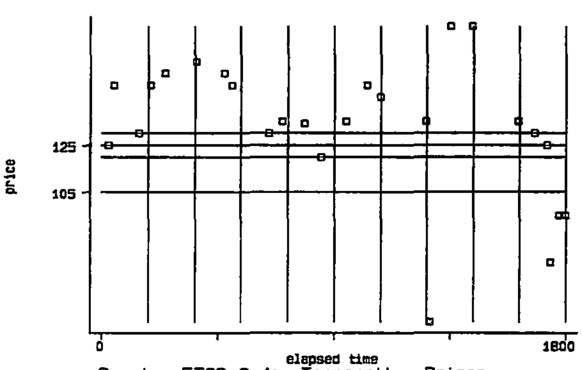
Session ETC3 1-1: Transaction Prices



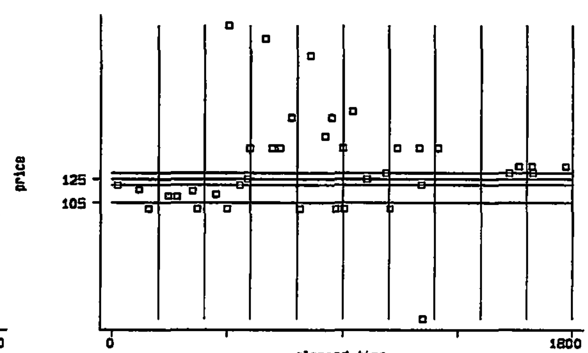
Session ETC3 1-2: Transaction Prices



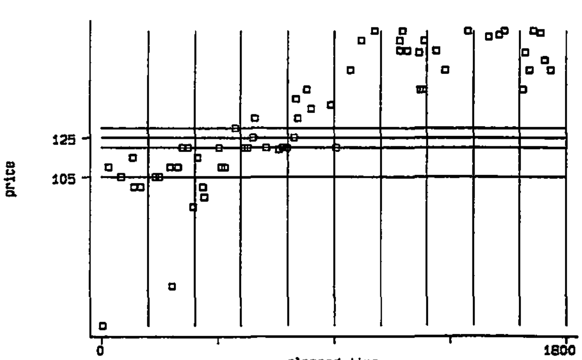
Session ETC3 1-3: Transaction Prices



Session ETC3 2-1: Transaction Prices

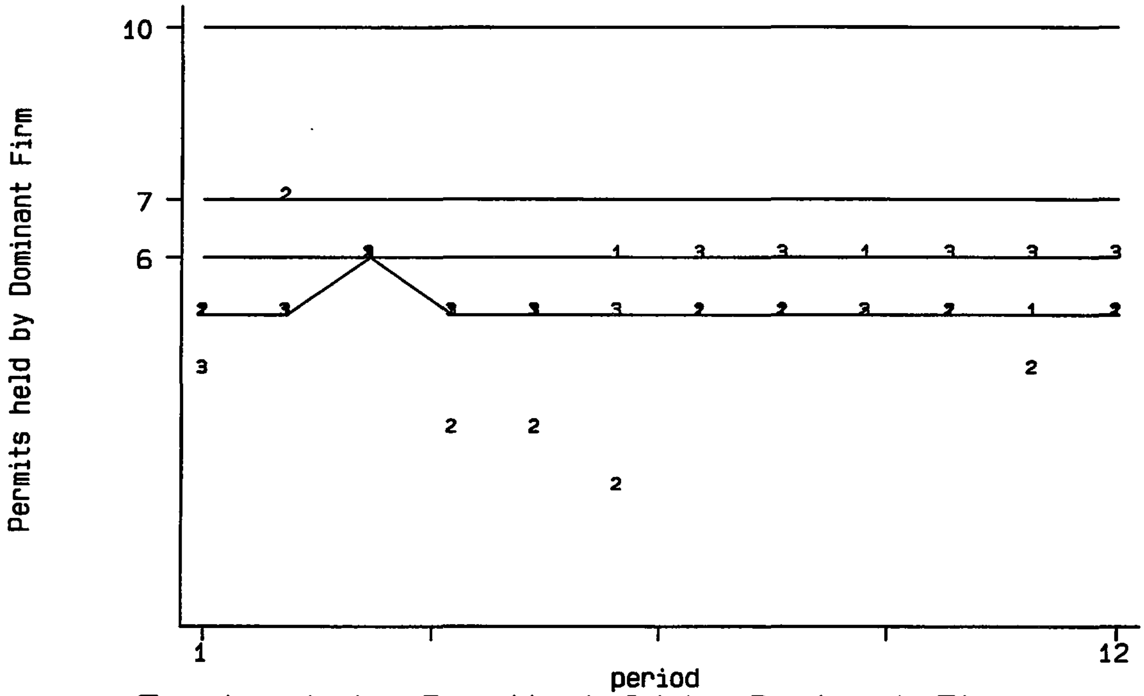


Session ETC3 2-2: Transaction Prices

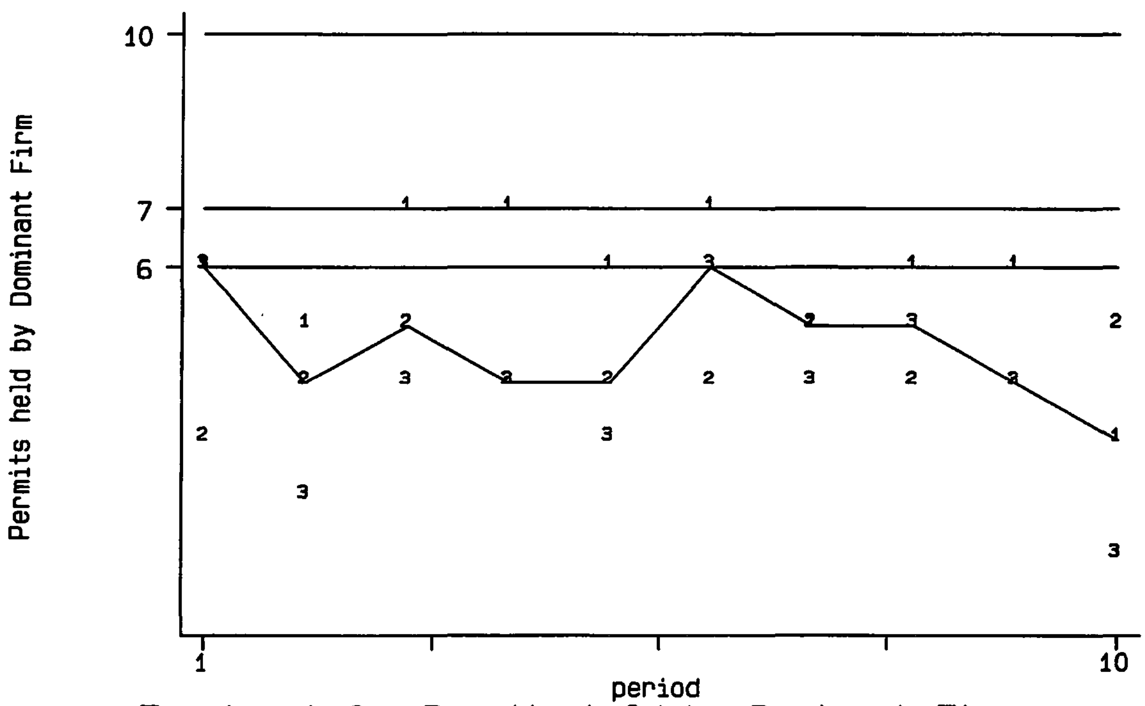


Session ETC3 2-3: Transaction Prices

Figure 3: Permits held by Dominant Firm After Trade



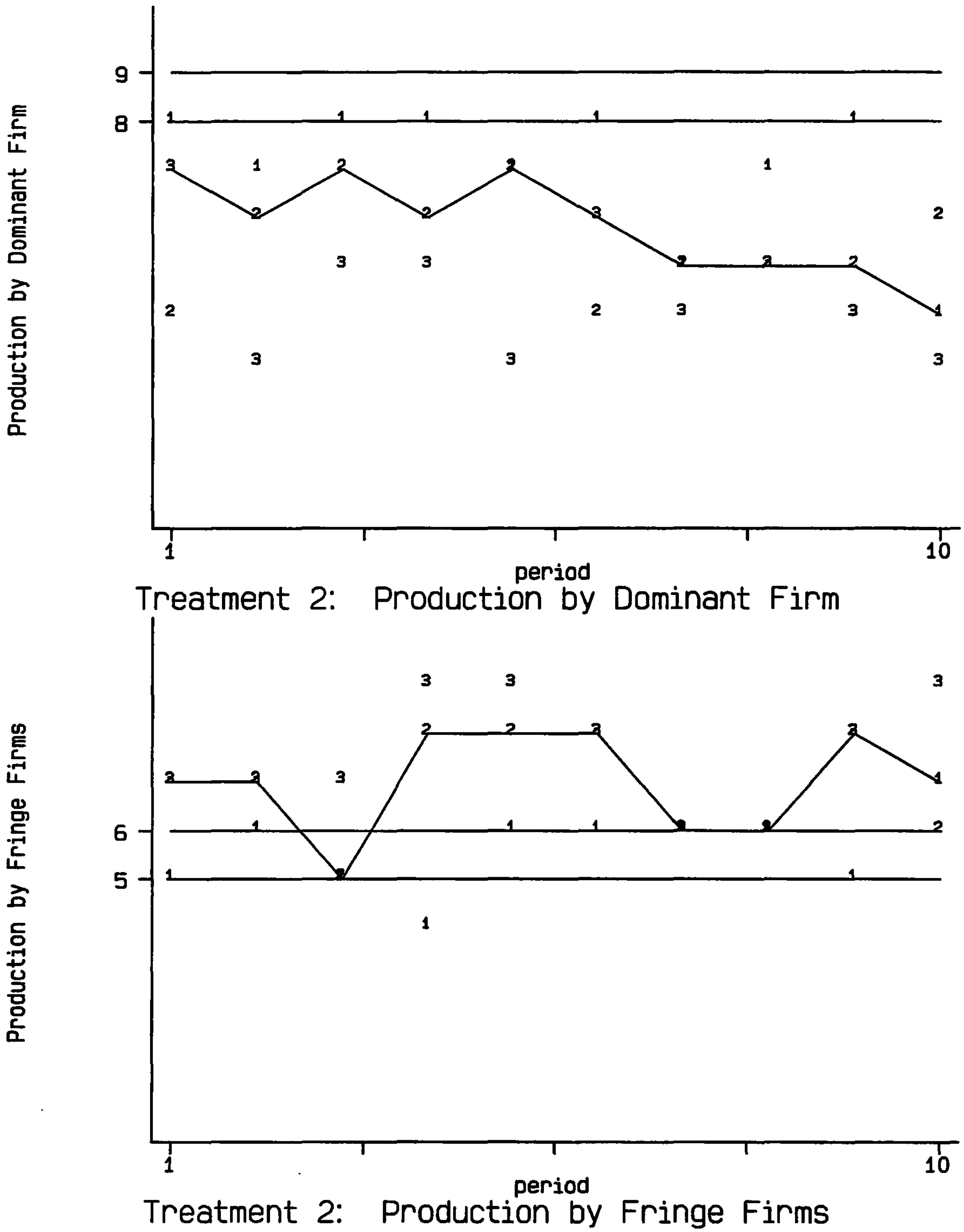
Treatment 1: Permits held by Dominant Firm



Treatment 2: Permits held by Dominant Firm

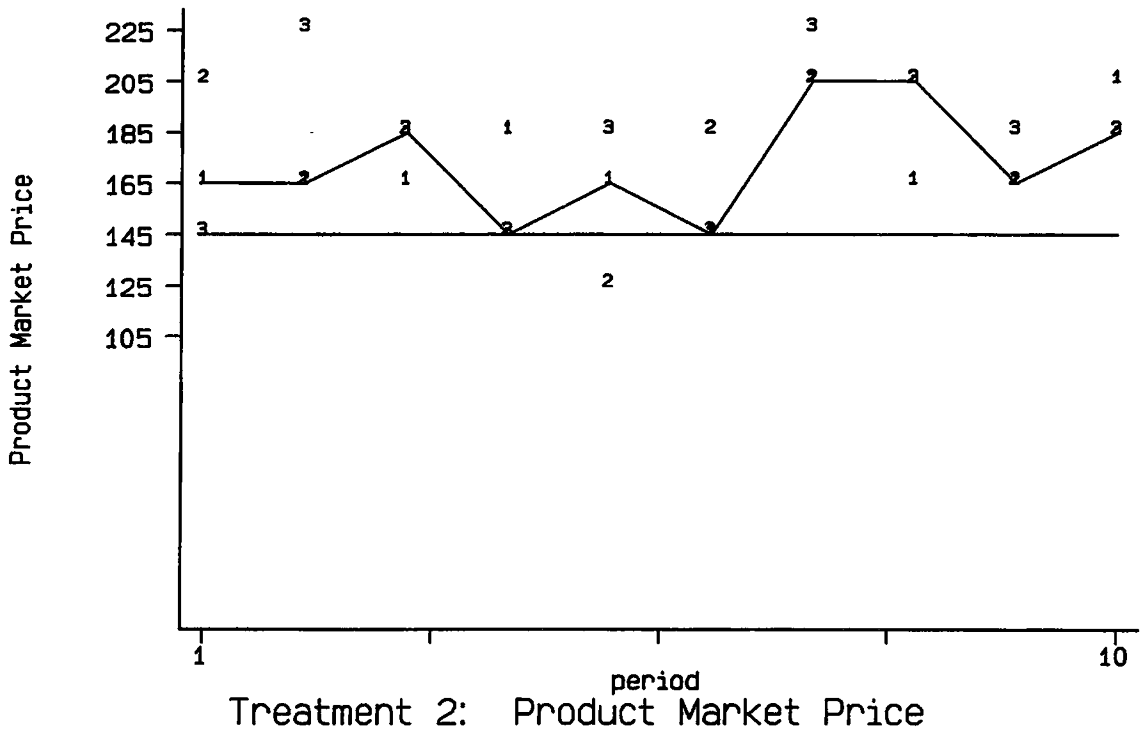
Notes: Digits 1, 2, and 3 refer to the session within treatment. The solid line connects median values.

Figure 4: Production by Firms, Treatment 2



Notes: Digits 1, 2, and 3 refer to the session within treatment. The solid line connects median values.

Figure 5: Product Market Price by Period, Treatment 2



Notes: Digits 1, 2, and 3 refer to the session within treatment. The solid line connects median values.

Figure 6: Efficiency Indices by Treatment

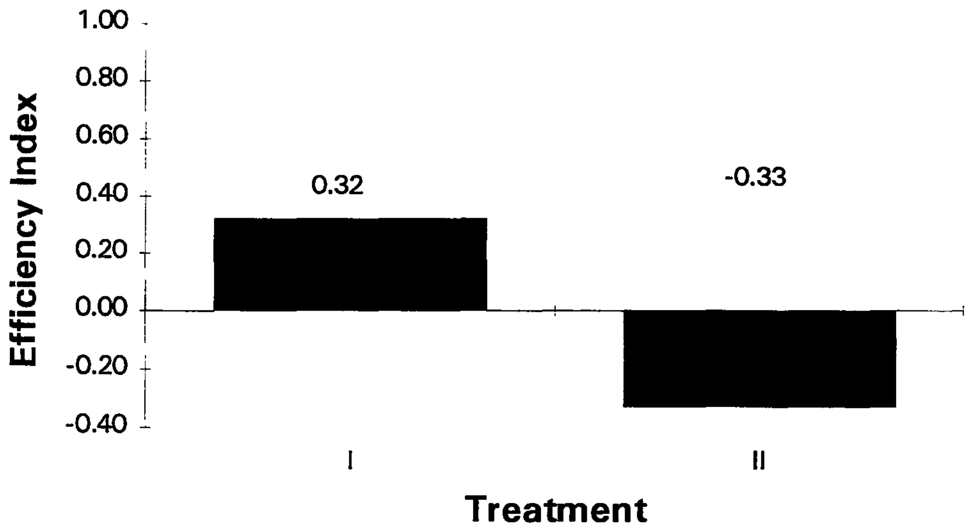
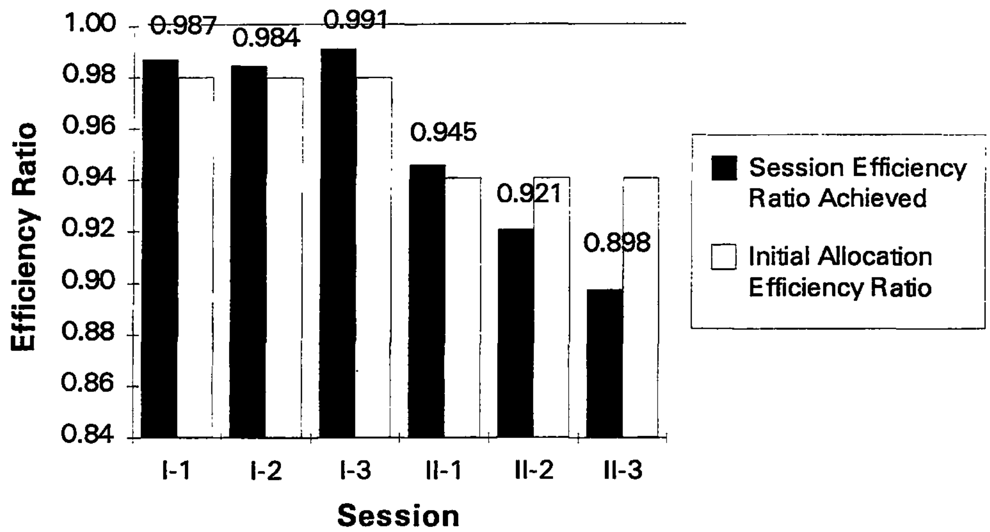
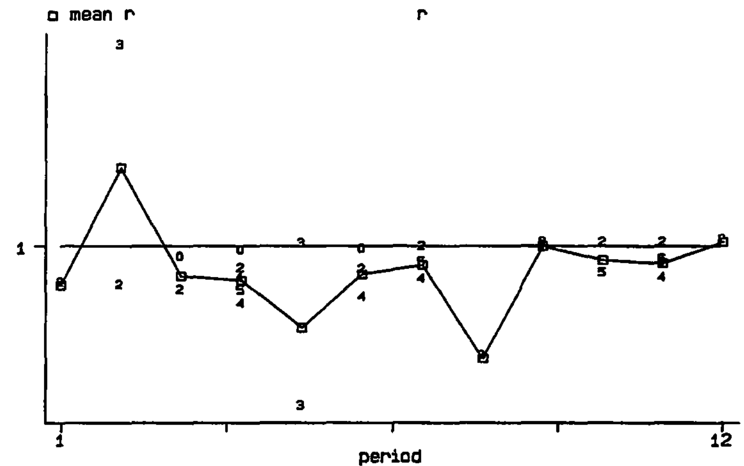


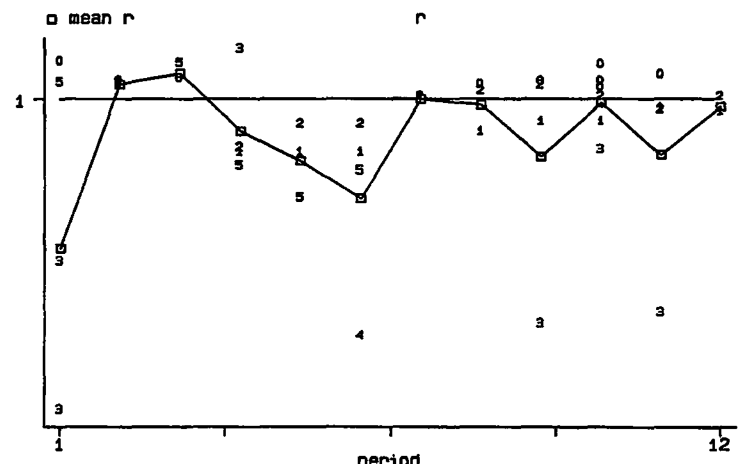
Figure 7: Efficiency Ratios by Session



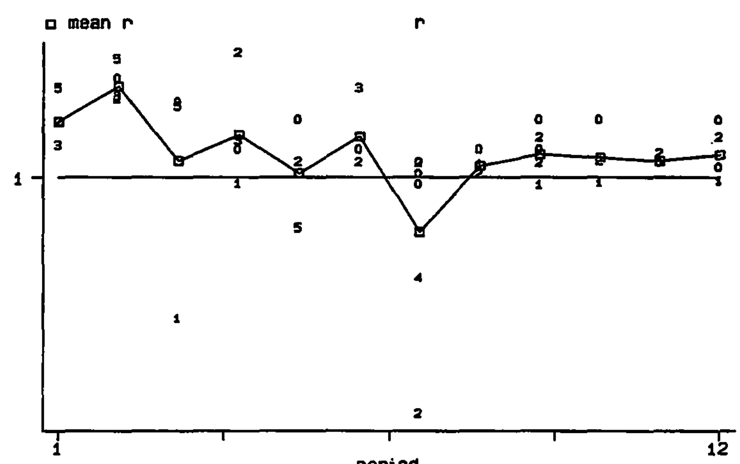
<u>Figure 8: Intrinsic Value/Price Ratios (r) by Period, Treatment 1</u>



Session T1-1: Intrinsic Value/Price Ratio (r)



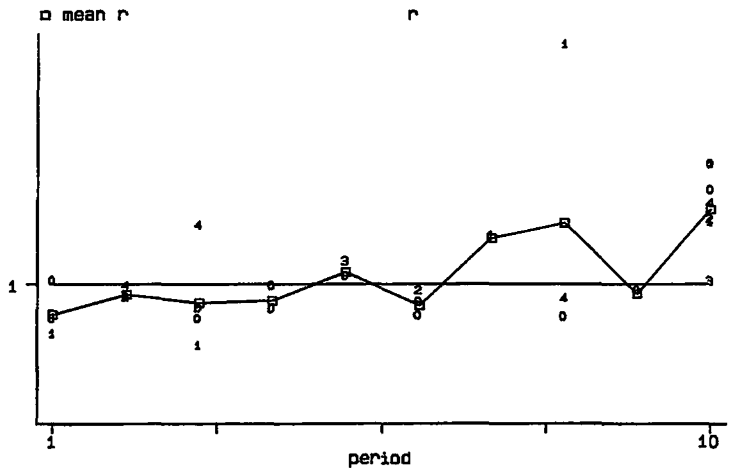
Session T1-2: Intrinsic Value/Price Ratio (r)



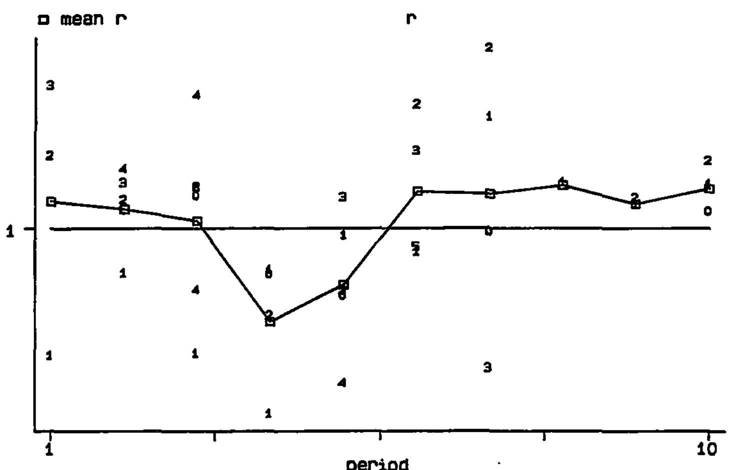
Session T1-3: Intrinsic Value/Price Ratio (r)

Notes: Numbers refer to buyer ID. The solid line connects mean values (r) values.

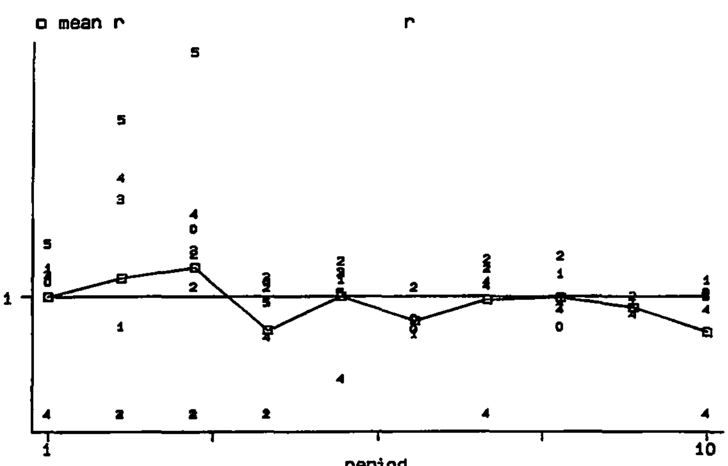
Figure 9: Intrinsic Value/Realized Price Ratios (r) by Period, Treatment 2



Session T2-1: Intrinsic Value/Realized Price Ratio (r)



Session T2-2: Intrinsic Value/Realized Price Ratio (r)



Session T2-3: Intrinsic Value/Realized Price Ratio (r)

Notes: Numbers refer to buyer ID. The solid line connects mean values (r) values.

Table 1: NOx Emissions from Stationary Sources by Sector in Southern Ontario[1]

Industry/Sector	Emissions (1985) Tonnes	Emissions (1985) Percent
Electrical Generation	88000	56.9%
Refining	12900	8.3%
Iron and Steel	15300	9.9%
Industrial Boilers and Heaters	17500	11.3%
Cement/Glass Manufacture	8000	5.2%
Chemical Processes	12900	8.3%
Total	154600	99.9%[2]

Notes: [1] Source: Nichols (1992)
[2] Does not total 100% due to rounding.

Table 2: Laboratory Firm Costs

Firm	Unit	Marginal Production Costs	Marginal Abatement Costs
FA	1	45	36
	2	45	75
FB	1	35	115
	2	40	155
FC	1	25	195
	2	30	235
FD	1	15	275
	2	20	315
FE	1	5	355
	2	10	395
Dominant	D1	15	45
	D2	15	65
	D3	15	85
	D4	15	105
	D5	15	125
	D6	15	145
	D7	15	165
	D8	15	185
	D9	15	205
	D10	15	225

Note: D*i* indicates production unit *i* of the dominant firm.

Table 3: Theoretic Predictions

	Permit Price[1] (C-Mkt.)	Final Permit Holding Fringe:Dominant	Production Fringe:Dominant:Total	Product Price[1] (P-Mkt.)	Predicted Efficiency
Treatment 1 (Efficient Outcome)	100-105	3:7[2] or 4:6[3]	5:10:15[2] or 6:10:16[3]	125	1.00 1.00
Efficient Coupon Mkt. Dominant Firm Product-Mkt.	120-125	4:6	6:8:14	145	0.988[4]
Treatment 2 (Exclusion Outcome)	125-127	3:7	5:9:14	145	0.990[5]

Notes: 1 All prices are given in Lab Dollars.
2 Dominant Firm purchases marginal unit.
3 Firm FD purchases marginal unit.
4 Evaluated for permit price of 125.
5 Evaluated for permit price of 125.

Table 4: Experiment Results by Treatment

	License Price	Final License Holding: Fringe	Final License Holding: Dominant	Production Fringe	Production Dominant	Total Production	Produc Price
Treatment 1							
Prediction[1]	105	3	7	5	10	15	125
Prediction[2]	105	4	6	6	10	16	125
Mean Observation	107.75	4.92	5.08	6.47	9.03	15.50	
Standard Deviation	16.37	0.97	0.97	1.23	0.97	0.81	
Treatment 2							
Prediction[1]	105	4	6	6	9	15	125
Prediction[2]	105	4	6	6	10	16	125
Prediction[3]	120-125	4	6	6	8	14	145
Prediction[4]	125-127	3	7	5	9	14	145
Mean Observation	134.91	5.37	4.63	6.70	5.67	12.37	177.67
Standard Deviation	31.42	1.45	1.45	1.32	1.63	1.27	25.45

Notes: [1] Efficient Permit and Product Markets (one of two possible predictions).
[2] Efficient Permit and Product Markets (one of two possible predictions).
[3] Efficient Permit Market/Dominant Firm P-Mkt.
[4] Exclusion in Permit Market.

Table 5: Convergence Patterns of Period Closing Coupon Prices Over Time

$$P_t = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_{13} \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1
$R^2 = 0.69$ — Number of Obs. = 36
Adjusted $R^2 = 0.66$ — SSE = 1555.5

			Competitive Model	
	Coeff.	Std. err.	**Prediction**	***p* value of *H₀***
β_{11}	117.70	5.81	103	0.02
β_{12}	116.89	5.81	103	0.02
β_{13}	62.36	5.81	103	0.00
β_2	109.80	1.67	103	0.00

Treatment 2
$R^2 = 0.12$ — Number of Obs. = 30
Adjusted $R^2 = 0.02$ — SSE = 30749

			Market Power Model		Eff. C-Mkt/Dom. Firm P-Mkt		Comp. Model	
	Coeff.	Std. err.	**Prediction**	***p* value of H_0**	**Prediction**	***p* value of H_0**	**Prediction**	***p* value of H_0**
β_{11}	131.67	28.86	126	**0.85**	123	**0.77**	103	**0.33**
β_{12}	92.32	28.86	126	**0.25**	123	**0.30**	103	**0.71**
β_{13}	100.43	28.86	126	**0.38**	123	**0.44**	103	**0.93**
β_2	145.75	9.40	126	0.05	123	0.02	103	0.00

Note: Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 6: Convergence Patterns of Dominant Firm Permit Holdings Over Time

$$Q_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1[1]

$R^2 = 0.19$	Number of Obs. = 36	Rho. = 0.44
Adjusted $R^2 = 0.11$	SSE = 26.671	Std. Err. of Rho = 0.15

	Coeff.	Std. err.	Competitive Model (2 possible outcomes) Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	5.05	0.99	7	0.06	6	0.35
β_{12}	4.71	0.89	7	0.01	6	0.16
β_{13}	4.31	0.89	7	0.00	6	0.07
β_2	5.24	0.32	7	0.00	6	0.02

Treatment 2

$R^2 = 0.22$	Number of Obs. = 30
Adjusted $R^2 = 0.13$	SSE = 47.623

			Eff. C-Mkt/Dom. Firm P-Mkt		Market Power Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	7.17	1.14	6	**0.31**	7	**0.88**
β_{12}	3.24	1.14	6	0.02	7	0.00
β_{13}	4.13	1.14	6	**0.11**	7	0.02
β_2	4.54	0.37	6	0.00	7	0.00

Notes: [1] Adjusted for AR1 using Cochrane Orcutt technique.
Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 7: Convergence Patterns of Product Market Prices Over Time

$$P_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_{13} \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 2

R^2 = -0.08 Number of Obs. = 30

Adjusted R^2 = 0.04 SSE = 18118

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model p value of H_0	Market Power Models Prediction	Market Power Models p value of H_0
β_{11}	158.55	22.16	125	**0.14**	145	**0.55**
β_{12}	183.28	22.16	125	**0.01**	145	**0.10**
β_{13}	170.65	22.16	125	**0.05**	145	**0.26**
β_2	180.50	7.21	125	0.00	145	0.00

Note: Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 8: Convergence Patterns of Dominant Firm Production Levels Over Time

$$Q_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1
$R^2 = 0.16$ | Number of Obs. = 36 | Rho = 0.39
Adjusted $R^2 = 0.08$ | SSE = 27.71 | Std. Err. of Rho = 0.16

	Coeff.	Std. err.	**Competitive Model** Prediction	*p* value of H_0
β_{11}	9.29	1.93	10	0.71
β_{12}	8.65	0.91	10	0.15
β_{13}	8.40	0.91	10	0.08
β_2	9.15	0.34	10	0.02

Treatment 2
$R^2 = 0.28$ | Number of Obs. = 30
Adjusted $R^2 = 0.20$ | SSE = 55.222

			Market Power Model		**Eff. C-Mkt/Dom. Firm P-Mkt**		**Comp. Model**	
	Coeff.	Std. err.	Prediction	*p* value of H_0	Prediction	*p* value of H_0	Prediction	*p* value of H_0
β_{11}	9.30	1.22	9	**0.81**	8	**0.30**	10	**0.57**
β_{12}	5.18	1.22	9	0.00	8	0.03	10	0.00
β_{13}	4.90	1.22	9	0.00	8	0.02	10	0.00
β_2	5.34	0.40	9	0.00	8	0.00	10	0.00

Note: Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 9: Convergence Patterns of Fringe Firm Production Levels Over Time

$$Q_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1[1]

$R^2 = 0.24$	Number of Obs. = 36	Rho = 0.49
Adjusted $R^2 = 0.17$	SSE = 40.01	Std. Err. of Rho = 0.15

	Coeff.	Std. err.	Competitive Model (2 possible outcomes) Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	5.91	2.55	5	**0.72**	6	**0.97**
β_{12}	6.12	1.12	5	**0.32**	6	**0.91**
β_{13}	7.46	1.12	5	0.04	6	**0.20**
β_2	6.44	0.46	5	0.00	6	**0.35**

Treatment 2

$R^2 = 0.27$	Number of Obs. = 30
Adjusted $R^2 = 0.19$	SSE = 42.125

	Coeff.	Std. err.	Eff. C-Mkt/Dom. Firm P-Mkt Prediction	p value of H_0	Market Power Model Prediction	p value of H_0
β_{11}	4.16	1.03	6	**0.08**	5	**0.42**
β_{12}	7.04	1.03	6	**0.32**	5	**0.06**
β_{13}	7.95	1.03	6	**0.07**	5	0.01
β_2	6.73	0.32	6	0.03	5	0.00

Notes: [1] Adjusted for AR1 using Cochrane Orcutt technique.
Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 10: Treatment 1 Total Period Profits to Producers and Total Profit Gains

		MP Firm		Fringe			
		Profit Realized	Gain	Profit Realized	Gain	Total Gain	Percent Gain
Predictions							
No Permit Trade/ Efficient P-Mkt. (No-trade Prediction)	**Profit**	690	0	544	0	0	0%
	% of Total	55.9%		44.1%			
Efficient Outcome	**Profit**	695	5	604	60	65	5.3%
	% of Total	53.5%		46.5%			
Outcomes (Mean outcome in last 5 periods)							
Session 1	**Profit**	689	-1	565	21	20	1.8%
	% of Total	54.9%		45.1%			
Session 2	**Profit**	676	-14	556	23	-2	-0.2%
	% of Total	54.9%		45.1%			
Session 3	**Profit**	704	14	569	25	39	3.5%
	% of Total	55.3%		44.7%			
Treatment Means	**Profit**	690	0	563	23		
	% of Total	55.0%		45.0%			

Table 11: Convergence Patterns of Dominant Firm Period Earnings Over Time

$$\pi_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1
$R^2 = 0.26$ Number of Obs. = 36
Adjusted $R^2 = 0.19$ SSE = 5380.2

			Competitive Model	
	Coeff.	Std. err.	Prediction	p value of H_o
β_{11}	676.44	10.80	695	**0.10**
β_{12}	700.57	10.80	695	**0.60**
β_{13}	666.80	10.80	695	0.01
β_2	701.77	3.10	695	0.04

Treatment 2
$R^2 = 0.14$ Number of Obs. = 30
Adjusted $R^2 = 0.04$ SSE = 398930

			Mkt. Power Model		Eff. C-Mkt/Dom. Firm P-Mkt		Comp. Model	
	Coeff.	Std. err.	Prediction	p value of H_o	Prediction	p value of H_o	Prediction	p value of H_o
β_{11}	928.15	104.00	810	**0.27**	805	**0.25**	695	0.03
β_{12}	1020.20	104.00	810	0.05	805	0.05	695	0.00
β_{13}	736.65	104.00	810	**0.49**	805	**0.52**	695	**0.69**
β_2	911.92	33.85	810	0.01	805	0.00	695	0.00

Note: Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 12: Convergence Patterns of Fringe Firm Period Earnings Over Time

$$\pi_{it} = \beta_{11} D_1 \frac{1}{t} + ... + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1
$R^2 = 0.23$ Number of Obs. = 36
Adjusted $R^2 = 0.16$ SSE = 127490

			Competitive Model	
	Coeff.	Std. err.	**Prediction**	**p value of H_o**
β_{11}	496.96	52.58	604	0.05
β_{12}	395.60	52.58	604	0.00
β_{13}	577.30	52.58	604	**0.62**
β_2	562.40	15.07	604	0.01

Treatment 2
$R^2 = 0.10$ Number of Obs. = 30
Adjusted $R^2 = 0.01$ SSE = 855060

			Competitive Model		Market Power Models	
	Coeff.	Std. err.	**Prediction**	**p value of H_o**	**Prediction**	**p value of H_o**
β_{11}	760.86	152.20	604	**0.31**	744	**0.91**
β_{12}	902.53	152.20	604	**0.06**	744	**0.31**
β_{13}	598.66	152.20	604	**0.97**	744	**0.35**
β_2	870.57	49.55	604	0.00	744	0.02

Note: Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 13: Treatment 2 Total Period Profits to Producers and Total Profit Gains

		MP Firm		Fringe			
		Profit Realized	Gain[1]	Profit Realized	Gain[1]	Total Gain	Percent Gain
Predictions							
No Permit Trade/ Efficient P-Mkt	**Profit**	690	-165	544	-250	-415	-25.2%
	% of total	55.9%		44.1%			
Efficient Outcome	**Profit**	695	-160	604	-190	-350	-21.2%
	% of total	53.5%		87.2%			
No Permit Trade/ Dom. Firm P-Mkt (No-trade prediction)	**Profit**	855	0	794	0	0	0.0%
	% of total	51.8%		48.2%			
Fringe Trade Only/Dom. Firm P-mkt.	**Profit**	800	-55	739	-55	-110	-6.7%
	% of total	52.0%		48.0%			
Efficient C-Mkt/Dom. Firm P-Mkt	**Profit**	805	-50	744	-50	-100	-6.1%
	% of total	52.0%		48.0%			
Exclusion Prediction	**Profit**	810	-45	744	-50	-95	-5.8%%
	% of total	52.1%		47.9%			
Outcomes (Mean outcome in last 5 periods)							
Session 1	**Profit**	881	26	924	130	156	9.5%
	% of total	48.8%		51.2%			
Session 2	**Profit**	970	115	900	106	221	13.4%
	% of total	51.9%		48.1%			
Session 3	**Profit**	898	43	869	75	118	7.2%
	% of total	50.8%		49.2%			
Treatment Means	**Profit**	916	226	898	356		
	% of Total	50.5%		49.5%			

Notes: [1] Gain is measured relative to the no-trade prediction indicated.

Table 14: Convergence Patterns of Period Efficiency Indices Over Time

$$EI_{it} = \beta_{11} D_1 \frac{1}{t} + \ldots + \beta_{13} D_3 \frac{1}{t} + \beta_2 \frac{t-1}{t} + u_t$$

Treatment 1
$R^2 = 0.22$ Number of Obs. = 36
Adjusted $R^2 = 0.15$ SSE = 29.409

	Coeff.	Std. err.	Competitive Model Prediction	Competitive Model p value of H_0
β_{11}	-0.92	0.80	1.00	0.02
β_{12}	-2.11	0.80	1.00	0.00
β_{13}	0.16	0.80	1.00	**0.30**
β_2	0.44	0.23	1.00	0.02

Treatment 2
$R^2 = 0.21$ Number of Obs. = 30
Adjusted $R^2 = 0.12$ SSE = 17.003

			Market Power Model		Eff. C-Mkt/Dom. Firm P-Mkt		Comp. Model	
	Coeff.	Std. err.	Prediction	p value of H_0	Prediction	p value of H_0	Prediction	p value of H_0
β_{11}	0.54	0.68	0.83	**0.68**	0.80	**0.71**	1.00	**0.51**
β_{12}	0.29	0.68	0.83	**0.43**	0.80	**0.46**	1.00	**0.31**
β_{13}	-1.67	0.68	0.83	0.00	0.80	0.00	1.00	0.00
β_2	-0.23	0.22	0.83	0.00	0.80	0.00	1.00	0.00

Note: Bolded values indicate retention of the maintained hypothesis of competition or market power as appropriate at the 95% confidence level or greater.

Table 15: Average Turnover Ratios

Session	All Periods	Last 5 Periods	Last 3 Periods
T1-1	1.9	1.8	1.8
T1-2	2.0	1.7	1.7
T1-3	1.9	1.5	1.1
Mean	1.9	1.7	1.5
T2-1	1.4	1.4	1.8
T2-2	3.2	2.5	2.0
T2-3	2.9	2.8	2.5
Mean	2.5	2.2	2.1

Chapter 7

Conclusion

The theoretical case for emission trading in competitive markets is well understood. Canadian policy-makers have recently been considering the implementation of emission permit markets to allocate pollution allowances and minimize the cost of pollution control. Of concern to these regulators, however, has been the possibility that market power may emerge in the proposed permit markets. Market power distortions may arise solely from structural conditions within an emission permit market, or it may be the result of strategic manipulation by one (or more) participant(s) attempting to secure market power in an output market where they and other emission market participants also compete. The possibility of market power distortions is particularly relevant in Canada as the proposed markets are expected to be thin, to include few potential participants, and to be dominated by single firms.

Under these conditions two types of market manipulation could be pursued

- cost minimizing, or "simple" manipulation: the dominant firm in an emission permit market acts as a monopolist or monopsonist, either restricting its sales of permits to other firms, increasing market price above efficient levels, or restricting purchases from other firms to depress market price. This was formally described in Hahn (1984).

- exclusionary manipulation: the dominant firm in an emission permit market attempts to "hoard" permits in the market, either by reducing sales of permits to other firms or by "over-buying", thereby increasing the other firms' production costs in a downstream product market and improving their own competitive position. The formal description of this type of manipulation was first described by Misiolek and Elder (1989).

The effects of both types of manipulation may vary. Each results in price changes relative to competitive predictions, implying marginal abatement costs across firms will not be equal and the resultant market outcome inefficient. Cost minimizing manipulation still increases a permit market's cost-effectiveness over the initial permit allocation, however, the cost-effectiveness is reduced from that which would occur under competitive conditions. Exclusionary manipulation can result in either an increase or decrease in the cost effectiveness of the permit market relative to that possible before trade. Both types of manipulation result in permit price distortions, which could result in the perceived value to technological innovations in the market to be too high or low, and inducing an inefficient level of pollution control innovation.

Existing American market experience sheds little light on the relevance of these problems as most programs have included many more participants than proposed Canadian markets would, and it is unclear that any firms have had serious market power in the US. markets. Given the lack of empirical data, experimental economic methods have been used here in an attempt to determine whether the problems outlined above should be expected to seriously undermine the efficiency benefits emission permit markets offer.

Market experiments are valuable complements to theoretic analysis. Functioning markets exhibit convergence processes which lack confident theoretic explanations, thus general economic theory only attempts to describe the resultant equilibria occurring after all trading takes place. Laboratory experiments allow the researcher the ability to simplify markets to capture the essential features to be explored and to observe market trading patterns and convergence to market equilibrium. Insights provided by experiments also allow test-bedding of theory and the opportunity for emission market designs to be changed to identify possible problems before they are implemented.

Although theoretic predictions of the impact of market power on emission permit markets can be made, they are only predictions. Their accuracy must still be tested. This thesis has reported three economic experiments, each specifically designed to capture the essential elements of an emission permit market dominated by a single firm, to address two questions: (i) will market power be successfully exploited as predicted by theory when a dominant firm in an emission market is given the opportunity to do so and (ii) if so, is the resulting outcome serious enough to merit special consideration by regulators. These experiments explicitly recognized the relationship between permit holdings and the production decision and were designed to compare the implications of two types of market manipulation possible.

The experiments proceeded using the following assumptions: a permit market had been chosen as a means of pollution regulation with overall cost-effectiveness as the regulator's goal. The airshed or watershed had been suitably defined, and the allowable emissions cap determined. Firms in the area produced a product for sale in a product market, each unit of which created a unit of emission discharge. Each emission permit was a one period allowance to emit an emission discharge unit. Complete abatement for any emissions over and above the amount covered by permit holdings after trade was required of all firms; therefore, to produce a production unit without incurring abatement costs each firm required an emission permit. Initial permit allowances were distributed at no charge to the participating firms with allocations decided upon by the regulator. For reference, initial allocations were defined as the command and control allocation. Permit trade was then allowed using a double auction because it is a natural type of market to expect in such circumstances. Firms made production decisions after permit trade, and sold all of their output in the product market. These assumptions captured the essence of the organization of a number of existing or proposed permit markets.[1]

The results of the experiments of Chapters 4 and 5 indicate that even in markets with very unsophisticated subjects, market power outcomes emerge. Since in naturally occurring markets, agents making trading decisions are often experienced traders, it would not be unexpected for outcomes there to similarly exploit any market power opportunities. Consideration of the efficiency implications indicated that, as predicted theoretically, when simple manipulation of permit markets was pursued, realized efficiency gains were dampened relative to those possible. When exclusionary manipulation was possible, resulting system efficiency was reduced to below that which would have occurred had no trade been allowed after initial allocation had been made in the permit market. Both of these general results imply market power should be of concern to regulators, and further, the efficiency costs of such distortions may be significant enough to actually increase the costs incurred to society for using markets to allocate pollution allowances.

Chapter 5 allowed speculation to occur in the laboratory markets. It was found that speculation occurred naturally and that its effect on market outcome depended on the initial allocation of permits. Specifically, allocating permits to firms with lower use values increased the amount of speculation observed. There was also a inverse correspondence observed between speculation and efficiency. As speculation increased, the observed efficiency of laboratory markets decreased.

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[1] One trading scheme proposed in southern Ontario relies on privately negotiated trading, however, most do rely on public trading.

The experiment of Chapter 6 attempted to determine whether allowing trade in thin markets (characterized by only small potential trade gains available to participants) would still increase the cost effectiveness of pollution control. In naturally occurring economies, such market conditions could be caused by an attempt to distribute permits in a manner which avoided the potential for market power to be exploited. The experiment utilized initial permit allocations which did not allow the simple manipulation to be pursued, thereby allowing the thin market effect alone to be studied. Final trade results were not encouraging. Permit markets which included participants who did not compete in a common product market achieved only marginal increases in market efficiency by trading. When participants did compete in a common product market, as found in the previous experiments, efficiency was actually reduced relative to that at the initial allocation. The speculation results described in Chapter 5 were also reproduced.

In all of these experiments, the dominant firm's competitors were other existing yet smaller firms. They could just as easily have represented new entrants to an existing permit market. When permits were grandfathered to the large firm, or if the existing firm holds all permits when new firms enter the market, the ability to exclude rivals (or new entrants) appears to be a significant potential problem. Further, even when the dominant firm was allocated none of the available permits, there was no instance of an efficiency gain due to the imposition of permit markets in vertically related environments. Grandfathering as an allocation mechanism has been employed in existing programs and suggested for a number of proposed markets. The evidence here suggests that, before emission markets using such an allocation method are adopted, the competitive conditions in related product markets should be scrutinized to determine whether permit market participants also compete with one another. The effect of market power could be very serious, as the magnitude of efficiency loss depended on initial allocation. In these circumstances, policy-makers may have justifiable concerns about market power. When competition among firms is limited to permit markets, market power may be more detrimental to dynamic efficiency, due to its impact on innovation decisions made with respect to distorted price outcomes. Actual efficiency gains achieved by trade in these circumstances were significant as long as markets were not too thin. Permit markets do not appear to be effective when there are few trade gains available regardless of the competitive conditions in product markets. Initial allocations "closer" to efficient outcome may not always be "better".

No subject firm in our studies would necessarily have been made worse off for participating in the experiments. Firms were free to buy or sell endowed rights in the permit-market and then produce in the product-market afterward. Simply not participating in trade would not incur loss. Losses in efficiency, relative to the competitive prediction, in sessions which only allowed cost minimizing manipulation, occurred as a result of reduced profits across the market due to pollution abatement effort by the "wrong" firms. Losses in efficiency in the exclusionary manipulation treatments occurred because total system efficiency must also consider the effect of final permit distribution on downstream markets. The losses in these treatments in efficiency were completely borne by the consumers who were forced to pay higher prices for firm output.

Extensions to the work presented in this thesis could proceed in a number of directions. With respect to emission permit market design, one could consider the effect of the design of the traded instrument on market outcomes when market manipulation is possible. If the instrument was a time-stream of future pollution permits, if banking of permits were allowed, as considered in Godby, Mestelman, Muller and Welland (1995), the use of market power may be found to have even more deleterious effects on market efficiency as such outcomes may be more persistent once achieved. Such markets would be similar in many respects to those considered in Anderson (1991).

Another direction might be to investigate further the effect of alternative market trading institutions on observed market power and thin market results. Specifically, an institution which did not allow speculation to occur might allow market efficiencies to improve. Ledyard and Szakaly-Moore (1994) describe preliminary results regarding the revenue neutral auction, however as noted previously, the experimental parameters used may have been responsible for the types of outcomes they observed.

The results of the experiments reported here also indicate further research could focus on the double auction and market power. It has been claimed in the literature that certain market trading institutions may limit the ability of a single seller to manipulate price. Smith's (1981) monopoly experiments comparing several market institutions indicated the actual impact of a market structure imperfection on market outcome is dependent on the trading institution utilized. The oral double auction was shown to be very effective in controlling monopoly pricing. The double auction findings of Smith were replicated by Smith and Williams (1990) and to a lesser degree by Ledyard and Szakaly-Moore (1994), all using the same parameter set. The results of the market power experiments reported here indicate the generality of the competitive convergence properties of double auctions may be weaker than previous experimental evidence suggests.

The first of the emission permit market experiments here observed prices converging to levels equal to or exceeding market power predictions in ten of twelve sessions. These double auction experiments are the first to consistently show repeated market power outcomes in a majority of sessions using monopoly (or monopsony) markets with standard demand and supply parameters. This presented an important question: can structural differences in markets improve the observed price performance of a double auction in the presence of market power? Seven procedural and structural differences between this and previous work on market power in double auctions were identified, thus no single design difference could be isolated as the reason for the failure of this institution. Further work might attempt to determine whether any of these differences can be identified as reason for the strong market power outcomes observed.

The theoretical benefits of transferable emission permit markets have been argued by many critics of current regulatory methods. The reductions in the social cost of pollution control and their inherent effects on market efficiency, as well as the policy compatibility of pollution control with growth promised by such programs are very appealing. The method of allocation and initial distribution of permits has not often been discussed since under the assumption of perfect competition it doesn't matter. The results reported here would suggest otherwise. Admitting the possibility of simple (cost minimizing) or exclusionary manipulation of permit markets 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. Proposed emission programs must recognize this problem and incorporate regulatory designs which minimize the impact of market power if they are adopted.

Appendix A

Calculation of Chapter 4 and Chapter 5 Experiment Predictions[1]

Calculation of treatment predictions for simple or exclusionary manipulation is done using the general theoretical apparatus described above. Special consideration must be made for discreteness in the experimental parameters. The experimental product market demand curve is a step-function and subjects may only choose quantity decisions which are of an integer value. Continuous, smooth approximations of the required functions can be defined and used however, so long as solutions are verified to ensure the positive integer constraint is met. For brevity, this constraint is assumed in the following calculations though not explicitly defined. Experiment subject parameters are found in Table 2 of both chapters. There are 10 coupons (permits) available in the market, and firms may only produce units for which they have costs.

Quantity demanded in the market demand is defined as

$$Q^D = 425 - 20\sum_{i=1}^{11} q_i \qquad (1)$$

where q_i is the quantity supplied by firm i and the dominant firm is defined using the subscript one in what follows, while the fringe firms are defined using subscripts two through eleven in the order presented in Table 2 in both chapters.

[1] Note these predictions also apply to both chapters as no change is made in allocation or parameters except as outlined in the text.

(i) Efficient Markets Prediction

Calculation of the competitive outcome (in both markets) in Table 4 of both chapters is arrived at by arraying firms production cost in ascending order, assuming the production of units with the ten highest abatement costs occurs with a permit[2]. This array constructs the industry supply curve when efficient permit allocation takes place. Intersection of the supply and market demand curve imply a competitive product market price prediction ranging from 120-125, with 15 units produced. Units F8, F9, F10 and D4-D10 are produced with a permit while all others are not (units D1-D3, F1 and F2). Given P_p = 125, the predicted efficient permit price is found by calculating the marginal profit of a permit on each possible production unit, that is P_p minus production cost, or the abatement cost, whichever is lower. Assuming for simplicity that either all permits are endowed to the dominant firm or the fringe firms and constructing demand and supply curves for permits based on their redemption value and endowment, the efficient permit market price is 105. After trade fringe firms hold 3 or 4 permits while the dominant firm holds 6 or 7[3].

(ii) Calculation of Simple Manipulation Predictions (Treatments 1 and 2):

Using the firm costs, the continuous approximation of the dominant firm's total production cost function is

$$TC_1 = 15q_1 + 35(q_1 - c_1) + 10(q_1 - c_1)^2 \qquad (2) .$$

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[2] Recall efficient trade would imply firms with the highest abatement costs hold permits.

[3] Predicted price is unique, however allocation may effect the number of units traded. If product price is 125, a fringe firm and dominant firm both have a redemption value of 105, thus this unit may or may not be traded without effect on efficiency.

The fringe output market supply function, given product market price and fringe coupon holdings[4] is

$$Q_f^S(P_p,\sum_{i=2}^{11} c_i) = \frac{P_p}{40} - \frac{10}{7} + \sum_{i=2}^{11} c_i \qquad (3)^5.$$

In Treatments 1 and 2, P_p is fixed at 125. For Treatment 1, the ten fringe firms are each endowed one coupon. The resulting valuations for coupons given product market price for the dominant firm are

$$\begin{aligned} P_c &= 110 && \text{for } c_1 \le 6 \\ P_c &= 245 - 20c_1 && \text{for } c_1 \ge 7 \end{aligned} \qquad \text{(4a and 4b).}$$

The coupon supply function of the fringe is described as

$$P_c = 70 + 5c_1 \qquad \text{for } c_1 \ge 2 \qquad (5)$$

which generates a marginal factor cost function for the dominant firm of

$$P_c = 70 + 10c_1 \qquad \text{for } c_1 \ge 2 \qquad (6).$$

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[4] It is assumed that the permit market clears, that is, after the permit market closes, all fringe firms hold permits if only if their permit valuation is above the final permit market price (that price which the last transaction occurs at).

[5] Note that the supply function is actually described as $Q_f^S(P_p,\sum_{i=2}^{11} c_i) = \frac{P_2}{35} - \frac{10}{7} + \sum_{i=2}^{11} c_i$, however equation 12 was used as the numbers of errors due to discreteness constraints was minimized at relevant (given efficient allocation) levels of price and coupon holdings.

Note alternative cases are not considered given the efficient allocation of coupons. Setting (6) equal to (4a) or (4b), the cost minimizing level of coupons for the dominant firm is four (the fringe hold six). By equation (5), $P_C = 90$. Maximizing profit using total costs defined by (2), $q_1 = 8$ while fringe output using (3) is 8[6].

For Treatment 2 the dominant firm is initially endowed with all coupons. Coupon valuations for the dominant firm are given as

$$P_c = 225 - 20c_1 \qquad \text{for } 6 \le c_1 \le 9 \tag{7}$$

where again alternative cases are not considered given efficient allocation results and the dominant firm's incentives. The fringe coupon demand schedule is

$$P_c = P_p - 50 + 5c_1 \qquad \text{for } c_1 \ge 2 \tag{8}$$

which implies a marginal revenue function for the dominant firm of

$$P_c = P_p - 100 + 10c_1 \qquad \text{for } c_1 \ge 2 \qquad (9).$$

Setting (7) equal to (9), the profit maximizing level of coupons for the dominant firm is 7, while selling three. The coupons are sold at a price of 110, using equation (8). Given equations (2) and (3), the dominant firm produces 10 units for the output market while the fringe produce 5 units.

<u>(iii) Calculation of Exclusionary Manipulation Predictions (Treatments 3 and 4):</u>

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[6] Note from Figure 3 in Chapter 4, efficient total product output may be 15 or 16 units.

For Treatments 3 and 4, where product market price is determined by the market demand and total production by all firms in the experiment, the dominant firm chooses output market price (implying an output level to support this price) since the fringe are assumed to be price takers. None of the fringe have market power which they can realize. Although their output decisions influence market price by a factor of 20 lab dollars per unit produced, because each fringe firm may only produce one unit, the effect of an output decision on price cannot be exploited by any individual firm.

The dominant firm maximizes product market profit given residual product demand. Given equations (1) and (3), the residual demand function is

$$q_1 = \frac{355}{28} - \frac{3P_p}{40} + c_1 \qquad (10).$$

As before, assuming the fringe are price-takers, the coupon market price is defined as

$$\begin{aligned} P_c &= P_p - 55 + 5c_1 \qquad \text{for } c_1 \geq 3 \\ P_c &= 40c_1 - 5 \qquad \text{for } 1 \leq c_1 \leq 2 \end{aligned} \qquad \text{(11a and 11b)}^7.$$

For Treatment 3, the dominant firm's maximization problem is

$$\max_{\{P_p,\, c_1\}} \quad \pi_1 = P_p q_1 - 15q_1 - 35(q_1 - c_1) - 10(q_1 - c_1)^2 - P_c c_1 \qquad (12).$$

st. equations (10) and (11a or 11b).

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7 Note these equations are also defined given a product market price of at least 125. Since the dominant firm will at worst accept the efficient price, this is the lowest product market price considered. This assumption dismisses consideration of dynamic strategies such as predatory pricing. Given the conditions in the experiment, since no exit opportunity exists for fringe firms, theoretically predatory pricing cannot be pursued profitably.

For $c_1 < 3$, first order conditions are

P_p: $$\frac{1985}{56} - P_p \frac{21}{80} + c_1 = 0 \tag{13a}$$

c_1: $$P_p - 10 - 80c_1 = 0 \tag{14a}.$$

For $c_1 \geq 3$, first order conditions are

P_p: $$P_p = \frac{80}{21} \cdot \frac{1985}{56} = 135 \tag{13b}$$

c_1: $$c_1 = 4 \quad \forall P_p \tag{14b}.$$

Substitution of (14a) into (13a) and solving for P_p and c_1, substituting into residual demand, checking integer constraints and comparison of profits earned when compared to solutions implied by (13b) and (14b) yields $q_1 = 4,\ c_1 = 2,\ P_p = 145,\ P_c = 75$. In this case, efforts to exclude are too costly given the firm's constraints, thus monopsony cost minimization is pursued.

For Treatment 4, the dominant firm is endowed with all ten coupons, thus the maximization problem becomes

$$\max_{\{P_p,\ c_1\}} \quad \pi_1 = P_p q_1 - 15q_1 - 35(q_1 - c_1) - 10(q_1 - c_1)^2 + P_c(10 - c_1) \tag{15}.$$

st. equations (8) and (10).

First order conditions yield

P_p: $$P_p = 173 \tag{16}$$

c_1: $c_1 = 8.5$ (17).

Discreteness implies a product market price of 165 or 185, and coupon holdings by the dominant firm of 8 or 9. Substitution of these values into the constraints and to derive fringe output and coupon market price, and evaluating profits, indicates it is optimal for the dominant firm to produce 8 units of output, at a market price of 185, while the fringe produces 4 units. The fringe hold one coupon while the dominant firm holds 9. Coupon market price is 180. Clearly this treatment yields a case of predicted exclusion since the dominant firm idles one coupon in production, foregoing the revenue that coupon could generate if sold.

(iv) Efficient Coupon Market and Dominant Firm in the Product Market

If coupon market trade were to allocate coupons in an efficient manner, and the dominant firm were to limit its use of market power strictly to the product market, the coupon market allocation would reflect the market power in the product market. Since product market product price will be at least as high as that found in the efficient product market case, only product prices above 125 are considered. Further, since the dominant firm does not use permits to exclude, fringe production will be higher than in Treatment 4, thus the product market price will fall in the range between these extreme values. Valuations of fringe firms reflect product price as argued above.

Since efficient coupon market allocation implies initial endowment does not determine final endowment, we can define market supply and demand using any convenient allocation. Using the allocation in Treatments 2 and 4, for the relevant quantities traded in an efficient market, the coupon demand and supply equations are (expressed for convenience in terms of units purchased by the fringe[8])

$$P_p - 5c_f = P_c \quad \text{(Demand of fringe)}$$
$$c_f \geq 3 \qquad (18)$$

$$25 + 20c_f = P_c \quad \text{(Supply by dominant firm)} \qquad (19).$$
$$P_p \geq 125,\ c_f \leq 4 + 0.05(P_p - 125)$$

Equating quantities supplied and demanded, the efficient market price condition is

$$P_c = \frac{4P_p + 25}{5} \qquad (20)^9.$$

The dominant firm's marginal cost of production and marginal revenue function are

$$MC = 40 + 20(q_1 - c_1) \qquad (21)$$

$$MR = \frac{40}{3} \cdot \frac{355}{28} - \frac{80}{3}q_1 + \frac{40}{3}c_1 \qquad (22)^{10}.$$

Setting (21) and (22) equal and expressing in terms of fringe coupon holdings

$$q_1 = \frac{971}{98} - \frac{5}{7}c_f \qquad (23).$$

[8] This is done for clarity. Clearly the fact that there are only ten coupons available implies this can also be written in terms of coupons held by the fringe firm.

[9] When solving, quantity is equated because in equilibrium it may be the case that redemption values are not exactly equal, however quantity must be.

[10] Rearranging residual demand, as previously defined, for price, defining total revenue and taking its derivative with respect to output by the dominant firm.

Equating this with the residual demand (equation (10)) expressed in terms of fringe coupon holdings, we find

$$P_p = \frac{40}{3} \cdot \frac{2503}{196} - \frac{80}{21} c_f \quad (24).$$

Substitution of (20) into (19), rearranging the result for product price, and equating to (24) yields a fringe holding of 5 coupons in equilibrium. This implies product price is 151 and a coupon market price of 125. Because P_p must either be 145 or 165, coupon market price is either 121 or 137, using the functions above.

Although an efficient permit market should not allow endowment to effect market outcome if demand and supply functions are continuous. Because they are not there is an endowment effect. It is always the case, *if one considers the product market only,* that the dominant firm earns more profits in the product market if it maintains a lower product price of 145[11]. Since the product market price has an effect on coupon valuations, only 4 permits are held by the fringe thus the combination of lower product price and lower coupon holding leaves a larger market share to the dominant firm. If one considers the endowment effect though, the predictions are unclear. In Treatment 3 the dominant firm is not endowed with coupons thus an efficient coupon market allocation entails expenditure. Calculating profits including this expenditure, the dominant firm is always better off to set product price at 145, sell 8 units in the product market (the fringe sell 6), and buy six coupons at a price ranging from 120-125. Total profits in this case are between 180-210 lab dollars. The higher profits in the product market offset the

[11] If product price is set at 165, and the fringe hold five coupons, the dominant firm earns 750 lab dollars/period for this solution in the product market alone. If product market price is set at 145 and the fringe are sold four coupons, product market profit net of coupon revenue is 930. This is true for either Treatment 3 or 4.

increased expenditure required at the lower product market price. The lower product market price also shifts the coupon supply function inward.

In Treatment 4 the result is not as clear. Selling permits to the fringe provides contrary incentives as selling generates revenue (an "income" effect). However selling extra coupons to the fringe increases their output due to the effect on the fringe supply curve (a "substitution" effect), reducing residual demand. The prediction for Treatment 3, or a product price of 165, with the dominant firm producing 5 units (the fringe produce 8), and selling 5 coupons at a price range of 125-145 are both possible. The new prediction always dominates that described for Treatment 3 if a coupon price of 136 or higher is maintained with a product price of 165. Also, the new prediction always dominates if product market price is set at 145 but coupon prices fall below 112. In both cases the "income" effect is greater than the "substitution" effect. For other cases, either prediction is possible. Even with an efficient coupon market, because the product market is imperfect, endowment can determine the system outcome, in spite of the fact the coupon market is not used strategically by the market power firm.

Calculation of Chapter 6 Experiment Predictions

All parameters in this experiment remain as defined in ETC2 except initial permit allocation distributes five permits to the fringe (one to each firm) and five to the dominant firm. Treatment 1, which sets product market price at the efficient level of 125, causes the only prediction given valuations as that outlined in the text, of an efficient permit market. Treatment 2 however, with a market determined product market price, allows the dominant firm some ability to use its market power (due to its larger allocation of permits). If competitive outcomes occur in both permit and product markets the prediction for Treatment 1 applies. Additionally, if market power is confined to the product market while an efficient trade allocation occurs in the permit market, the efficient market-dominant firm product market solution outlined for Treatment 3 in ETC applies[12]. Profit for the dominant firm in this case would range between 805 and 810 lab dollars per period, depending on permit market prices, which may range between 120 and 125. A third solution exists in which the dominant firm might purchase extra coupons in the permit market to exclude, forcing a reduction in fringe output and allowing the dominant firm a greater share of the product market.

The problem for the dominant firm is defined as

$$\max_{\{P_p,\, c_1\}} \quad \pi_1 = P_p q_1 - 15q_1 - 35(q_1 - c_1) - 10(q_1 - c_1)^2 - P_c(c_1 - 5) \qquad (25)$$

st. equations (10) and (11a).

First order conditions yield

P_p: $\quad P_p = 154 \qquad (26)$

c_1: $\quad c_1 = 6.5 \qquad (27).$

Discreteness implies a product market price of 145 or 165, and coupon holdings by the dominant firm of 6 or 7. If the dominant firm holds 6 coupons and price is 145 in the product market, the efficient coupon market-dominant firm product market solution outlined in the previous section occurs, generating profits between 805 and 810 lab dollars per period. If the dominant firm holds 7 coupons and produces 9 units, with product market price of 145, it can attain profits of between 806 and 810 lab dollars per

12 As outlined in the section above, this solution results in a product market price of 145 with permits selling at 120 to 125 lab dollars. The solution outlined for ETC Treatment 4 does not apply as the dominant firm is still a net-buyer of permits at these prices.

period. In this case the dominant firm excludes firm FD from a permit purchase by offering a permit price of between 125 and 127. Alternative solutions generate inferior profit levels to those just outlined. Market power can be exercised in the product market and may be preferred to an efficient coupon market solution if prices rise above 121 for permits. In this case the dominant firm can maximize profit by ensuring an offer of 126 is outstanding in the market always, thus excluding firm FD from the market. The increase in profit is due to the dominant firm's constant marginal costs across all units, giving it a 5 lab dollar advantage over firm FD on on the fringe firm's second production unit. As long as the increased permit expenditure is less than the five lab dollar cost advantage (i.e. when permit price is below 128 and above or equal to the 125 required to purchase the added coupon), higher profits can be captured by the dominant firm.

Appendix B

The following pages contain summary data from the experiments of Chapters 4, 5 and 6 which was not included in the text.

Table 1: ETC (Chapter 4) Experiment Results by Session

	License Price	Final License Holding Fringe	Final License Holding Dominant	Production Fringe	Production Dominant	Total Production	Product Price
Session 1 (I-1)							
Prediction*	90	6.0	4.0	8.0	8.0	16.0	125.0
Mean Observation	91	8.42	1.58	9.25	5.50	14.75	
Standard Deviation	17	1.00	1.00	0.75	0.90	0.97	
Session 2 (III-1)							
Prediction*	75	8.0	2.0	10.0	4.0	14.0	145.0
Mean Observation	233	8.90	1.10	7.50	3.80	11.30	201.00
Standard Deviation	38	0.99	0.99	1.36	2.35	2.45	46.95
Session 3 (II-1)							
Prediction*	110	3.0	7.0	5.0	10.0	15.0	125.0
Mean Observation	162	2.20	7.80	4.20	8.90	13.10	
Standard Deviation	45	1.23	1.23	1.48	1.10	1.45	
Session 4 (IV-1)							
Prediction*	180	1.0	9.0	4.0	8.0	12.0	185.0
Mean Observation	119	4.40	5.60	5.50	6.30	11.80	191.00
Standard Deviation	17	1.17	1.17	0.97	0.82	0.79	18.97
Session 5 (I-2)							
Prediction*	90	6.0	4.0	8.0	8.0	16.0	125.0
Mean Observation	126.00	8.40	1.60	7.90	5.80	13.70	
Standard Deviation	50.00	0.84	0.84	1.10	0.92	1.34	
Session 6 (IV-2)							
Prediction*	180	1.0	9.0	4.0	8.0	12.0	185.0
Mean Observation	313	2.20	7.80	5.80	6.40	12.20	181.00
Standard Deviation	46	0.79	0.79	1.14	2.01	1.87	37.48
Session 7 (II-2)							
Prediction*	110	3.0	7.0	5.0	10.0	15.0	125.0
Mean Observation	107	2.50	7.50	4.10	8.60	12.70	
Standard Deviation	7	0.97	0.97	1.10	0.97	1.34	
Session 8 (III-2)							
Prediction*	75	8.0	2.0	10.0	4.0	14.0	145.0
Mean Observation	30	7.91	2.09	8.64	3.91	12.55	174.09
Standard Deviation	14	0.70	0.70	0.67	0.70	0.82	16.40
Session 9 (II-3)							
Prediction*	110	3.0	7.0	5.0	10.0	15.0	125.0
Mean Observation	109	3.50	6.50	4.75	10.00	14.75	
Standard Deviation	12	0.80	0.80	0.87	0.00	0.87	
Session 10 (I-3)							
Prediction*	90	6.0	4.0	8.0	8.0	16.0	125.0
Mean Observation	88	8.00	2.00	9.33	6.00	15.33	
Standard Deviation	14	0.95	0.95	0.78	0.95	1.30	
Session 11 (III-3)							
Prediction*	75	8.0	2.0	10.0	4.0	14.0	145.0
Mean Observation	55	8.50	8.70	5.30	14.00	11.64	145.00
Standard Deviation	9	0.71	0.82	1.25	1.33	1.86	26.67
Session 12 (IV-3)							
Prediction*	180	1.0	9.0	4.0	8.0	12.0	185.0
Mean Observation	142	3.40	6.60	4.80	8.60	13.40	157.00
Standard Deviation	34	1.26	1.26	1.32	1.17	1.26	25.30

* Prediction under strategic manipulation.

Table 2: ETC (Chapter 4) C-mkt Prices: Treatment 1

C-Mkt. Price Outcomes by Treatment and Session

Treatment 1

Session 1	# of Trans.	Mean	Std. Dev.	Min.	Max.	Opening	Closing	α2*	α2**
Period 1	1	41.00	0.00	41	41	41	41	2401.00	4096.00
Period 2	1	42.00	0.00	42	42	42	42	2304.00	3969.00
Period 3	1	40.00	0.00	40	40	40	40	2500.00	4225.00
Period 4	0								
Period 5	1	43.00	0.00	43	43	43	43	2209.00	3844.00
Period 6	1	40.00	0.00	40	40	40	40	2500.00	4225.00
Period 7	2	37.50	3.54	35	40	35	40	2768.75	4568.75
Period 8	1	38.00	0.00	38	38	38	38	2704.00	4489.00
Period 9	1	38.00	0.00	38	38	38	38	2704.00	4489.00
Period 10	1	40.00	0.00	40	40	40	40	2500.00	4225.00
Mean (period 1-10)	**1**	**39.94**	**0.39**	**40**	**40**	**40**	**40**	**2510.08**	**4236.75**
Mean (period 6-10)	**1**	**38.70**	**0.71**	**38**	**39**	**38**	**39**	**2635.35**	**4399.35**
Mean (period 8-10)	**1**	**38.67**	**0.00**	**39**	**39**	**39**	**39**	**2636.00**	**4401.00**
Strategic Prediction:	**4**	**90**							
Efficient Prediction:	**6**	**105**							
Session 2									
Period 1	7	95.00	17.56	65	120	65	100	333.32	408.32
Period 2	7	107.14	9.06	100	120	100	120	376.02	86.73
Period 3	6	105.83	6.65	95	110	100	110	294.85	44.86
Period 4	3	96.67	5.77	90	100	90	100	77.79	102.78
Period 5	3	95.00	0.00	95	95	95	95	25.00	100.00
Period 6	3	91.67	5.77	85	95	85	95	36.12	211.11
Period 7	3	89.33	5.13	85	95	85	95	26.78	271.79
Period 8	3	89.67	0.58	89	90	89	90	0.44	235.43
Period 9	4	92.75	2.22	90	95	90	95	12.48	154.98
Period 10	2	95.00	0.00	95	95	95	95	25.00	100.00
Mean (period 1-10)	**4**	**95.81**	**5.27**	**89**	**102**	**89**	**100**	**120.78**	**171.60**
Mean (period 6-10)	**3**	**91.68**	**2.74**	**89**	**94**	**89**	**94**	**20.16**	**194.66**
Mean (period 8-10)	**3**	**92.47**	**0.93**	**91**	**93**	**91**	**93**	**12.64**	**163.47**
Strategic Prediction:	**4**	**90**							
Efficient Prediction:	**6**	**105**							
Session 3									
Period 1	4	91.25	10.31	80	105	80	90	107.82	295.32
Period 2	4	87.50	2.89	85	90	90	85	14.58	314.58
Period 3	4	83.75	2.50	80	85	80	85	45.31	457.81
Period 4	3	83.33	2.89	80	85	80	85	52.78	477.79
Period 5	3	83.33	2.89	80	85	85	85	52.78	477.79
Period 6	3	86.67	12.58	75	100	75	85	169.44	494.43
Period 7	3	85.67	0.58	85	86	85	86	19.11	374.10
Period 8	3	89.67	0.58	89	90	90	89	0.44	235.43
Period 9	4	90.00	0.00	90	90	90	90	0.00	225.00
Period 10	4	90.00	0.00	90	90	90	90	0.00	225.00
Mean (period 1-10)	**4**	**87.12**	**3.52**	**83**	**91**	**85**	**87**	**46.23**	**357.73**
Mean (period 6-10)	**3**	**88.40**	**2.75**	**86**	**91**	**86**	**88**	**37.80**	**310.79**
Mean (period 8-10)	**4**	**89.89**	**0.19**	**90**	**90**	**90**	**90**	**0.15**	**228.48**
Strategic Prediction:	**4**	**90**							
Efficient Prediction:	**6**	**105**							

* Coefficient of Convergence to strategic prediction.
** Coefficient of Convergence to competitive prediction.

Table 3: ETC (Chapter 4) C-mkt Prices: Treatment 2

C-Mkt. Price Outcomes by Treatment and Session

Treatment 2

Session 1	**# of Tran**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Opening**	**Closing**	**α2***	**α2****
Period 1	1	265.00	0.00	265	265	265	265	24025.00	25600.00
Period 2	3	306.67	11.55	300	320	300	300	38811.24	40802.91
Period 3	0								
Period 4	1	127.00	0.00	127	127	127	127	289.00	484.00
Period 5	2	197.50	109.60	120	275	275	120	19668.85	20568.85
Period 6	4	285.00	10.00	280	300	300	280	30725.00	32500.00
Period 7	1	135.00	0.00	1235	135	135	135	625.00	900.00
Period 8	3	119.00	1.73	117	120	120	117	84.00	199.00
Period 9	2	117.00	2.83	115	119	119	115	57.00	152.00
Period 10	3	110.67	1.16	110	112	110	112	1.78	33.45
Mean (period 1-10)	2	184.76	15.21	297	197	195	175	12698.54	13471.13
Mean (period 6-10)	3	153.33	3.14	371	157	157	152	6298.56	6756.89
Mean (period 8-10)	3	115.56	1.91	114	117	116	115	47.59	128.15
Strategic Prediction:	3	110							
Efficient Prediction:	3	105							

Session 2	**# of Tran**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Opening**	**Closing**	**α2***	**α2****
Period 1	0								
Period 2	2	118.00	2.83	116	120	120	116	72.00	177.00
Period 3	2	117.50	3.54	115	120	120	115	68.75	168.75
Period 4	3	115.67	4.04	112	120	120	112	48.44	130.11
Period 5	3	107.33	10.79	95	115	115	95	123.45	121.78
Period 6	3	114.67	3.06	112	118	118	114	31.11	102.78
Period 7	5	113.00	1.87	110	115	114	113	12.50	67.50
Period 8	4	110.00	0.82	109	111	111	109	0.67	25.67
Period 9	4	111.00	0.82	110	112	111	110	1.67	36.67
Period 10	3	106.67	2.89	105	110	110	105	19.44	11.11
Mean (period 1-10)	3	112.65	3.40	109	116	115	110	42.00	93.49
Mean (period 6-10)	4	111.07	1.89	109	113	113	110	13.08	48.75
Mean (period 8-10)	4	109.22	1.51	108	111	111	108	7.26	24.48
Strategic Prediction:	3	110							
Efficient Prediction:	3	105							

Session 3	**# of Tran**	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**Opening**	**Closing**	**α2***	**α2****
Period 1	4	85.50	24.24	50	102	102	90	1187.92	967.92
Period 2	4	100.50	1.00	100	102	102	100	91.25	21.25
Period 3	3	98.67	3.22	95	101	100	95	138.77	50.44
Period 4	5	96.40	1.34	95	98	97	95	186.76	75.76
Period 5	5	95.40	1.52	94	97	97	94	215.46	94.46
Period 6	4	105.75	2.75	103	109	104	103	25.64	8.14
Period 7	3	106.00	1.00	105	107	105	106	17.00	2.00
Period 8	5	105.20	2.95	102	110	105	102	31.74	8.74
Period 9	4	104.25	1.71	102	106	104	102	35.98	3.48
Period 10	5	102.20	2.59	99	105	105	99	67.54	14.54
Mean (period 1-10)	4	99.99	4.23	95	104	102	99	199.81	124.67
Mean (period 6-10)	4	104.68	2.20	102.20	107.40	104.60	102.40	35.58	7.38
Mean (period 8-10)	5	103.88	2.42	101	107	105	101	45.09	8.92
Strategic Prediction:	3	110							
Efficient Prediction:	3	105							

* Coefficient of Convergence to strategic prediction.
** Coefficient of Convergence to competitive prediction.

Table 4: ETC (Chapter 4) C-mkt Prices: Treatment 3

C-Mkt. Price Outcomes by Treatment and Session

Treatment 3

Session 1	# of Trans	Mean	Std. Dev.	Min.	Max.	Opening	Closing	α2*	α2**
Period 1	4	39.75	0.50	39	40	40	40	1242.81	4257.81
Period 2	3	44.33	1.16	43	45	45	45	941.80	3681.82
Period 3	3	45.67	1.15	45	47	45	47	861.76	3521.74
Period 4	3	47.67	2.08	46	50	46	50	751.42	3291.40
Period 5	4	51.25	3.78	48	55	48	55	578.31	2903.31
Period 6	2	57.00	2.82	55	59	59	55	331.95	2311.95
Period 7	2	53.50	2.12	52	55	52	55	466.75	2656.75
Period 8	2	51.50	0.71	51	52	51	52	552.75	2862.75
Period 9	2	55.00	0.00	55	55	55	55	400.00	2500.00
Period 10	2	55.50	0.71	55	56	55	56	380.75	2450.75
Mean (period 1-10)	**3**	**50.12**	**1.50**	**49**	**51**	**50**	**51**	**650.83**	**3043.83**
Mean (period 6-10)	**2**	**54.50**	**1.27**	**54**	**55**	**54**	**55**	**426.44**	**2556.44**
Mean (period 8-10)	**2**	**54.00**	**0.47**	**54**	**54**	**54**	**54**	**444.50**	**2604.50**
Strategic Prediction:	**2**	**75**							
Efficient Prediction:	**6**	**105**							
Session 2									
Period 1	3	64.67	0.58	64	65	64	65	107.10	1627.08
Period 2	5	83.60	10.81	69	99	69	85	190.75	574.75
Period 3	1	62.00	0.00	62	62	62	62	169.00	1849.00
Period 4	1	65.00	0.00	65	65	65	65	100.00	1600.00
Period 5	1	70.00	0.00	70	70	70	70	25.00	1225.00
Period 6	2	70.00	0.00	70	70	70	70	25.00	1225.00
Period 7	2	68.00	4.24	65	71	65	71	67.00	1387.00
Period 8	1	70.00	0.00	70	70	70	70	25.00	1225.00
Period 9	2	74.50	14.85	64	85	64	85	220.74	1150.74
Period 10	1	65.00	0.00	65	65	65	65	100.00	1600.00
Mean (period 1-10)	**2**	**69.28**	**3.05**	**66**	**72**	**66**	**71**	**102.96**	**1346.36**
Mean (period 6-10)	**2**	**69.50**	**3.82**	**67**	**72**	**67**	**72**	**87.55**	**1317.55**
Mean (period 8-10)	**1**	**69.83**	**4.95**	**66**	**73**	**66**	**73**	**115.25**	**1325.25**
Strategic Prediction:	**2**	**75**							
Efficient Prediction:	**6**	**105**							
Session 3									
Period 1	2	52.50	17.67	40	65	65	40	818.37	3068.37
Period 2	2	50.00	0.00	50	50	50	50	625.00	3025.00
Period 3	0								
Period 4	0								
Period 5	1	70.00	0.00	70	70	70	70	25.00	1225.00
Period 6	1	110.00	0.00	110	110	110	110	1225.00	25.00
Period 7	1	100.00	0.00	100	100	100	100	625.00	25.00
Period 8	1	104.00	0.00	104	104	104	104	841.00	1.00
Period 9	2	94.00	14.14	84	104	104	84	561.00	321.00
Period 10	2	105.00	7.07	100	110	110	100	950.00	50.00
Mean (period 1-10)	**1**	**85.69**	**4.86**	**82**	**89**	**89**	**82**	**708.80**	**967.55**
Mean (period 6-10)	**1**	**102.60**	**4.24**	**100**	**106**	**106**	**100**	**840.40**	**84.40**
Mean (period 8-10)	**2**	**101.00**	**7.07**	**96**	**106**	**106**	**96**	**784.00**	**124.00**
Strategic Prediction:	**2**	**75**							
Efficient Prediction:	**6**	**105**							

* Coefficient of Convergence to strategic prediction.

** Coefficient of Convergence to competitive prediction.

Table 5: ETC (Chapter 4) C-mkt Prices: Treatment 4

C-Mkt. Price Outcomes by Treatment and Session

Treatment 4

Session 1	# of Trans.	Mean	Std. Dev.	Min.	Max.	Opening	Closing	α2*	α2**
Period 1	0								
Period 2	2	187.50	3.54	185	190	190	185	68.75	6818.75
Period 3	5	180.00	11.31	161	190	190	161	127.92	5752.92
Period 4	5	172.00	10.37	155	180	180	155	171.50	4596.50
Period 5	4	164.50	1.73	162	166	162	165	243.25	3543.25
Period 6	4	161.25	9.67	151	170	169	155	445.13	3257.63
Period 7	4	164.00	10.83	156	180	180	160	373.33	3598.33
Period 8	4	156.75	2.22	155	160	155	156	545.48	2682.98
Period 9	3	153.67	1.53	152	155	154	155	695.76	2370.81
Period 10	3	149.67	4.51	145	154	150	145	940.42	2015.47
Mean (period 1-10)	**3**	**165.48**	**6.19**	**158**	**172**	**170**	**160**	**401.28**	**3848.51**
Mean (period 6-10)	**4**	**157.07**	**5.75**	**152**	**164**	**162**	**154**	**600.02**	**2785.04**
Mean (period 8-10)	**3**	**153.36**	**2.75**	**151**	**156**	**153**	**152**	**727.22**	**2356.42**
Strategic Prediction:	**1**	**180**							
Efficient Prediction:	**3**	**105**							
Session 2									
Period 1	1	285.00	0.00	285	285	285	285	11025.00	32400.00
Period 2	1	245.00	0.00	245	245	245	245	4225.00	19600.00
Period 3	1	228.00	0.00	228	228	228	228	2304.00	15129.00
Period 4	3	230.00	13.23	220	245	245	220	2675.01	15800.01
Period 5	0								
Period 6	3	230.00	26.46	200	250	250	200	3199.97	16324.97
Period 7	2	245.00	7.07	240	250	250	240	4275.00	19650.00
Period 8	1	250.00	0.00	250	250	250	250	4900.00	21025.00
Period 9	1	240.00	0.00	240	240	240	240	3600.00	18225.00
Period 10	1	250.00	0.00	250	250	250	250	4900.00	21025.00
Mean (period 1-10)	**1**	**244.78**	**5.20**	**240**	**249**	**249**	**240**	**4567.11**	**19908.78**
Mean (period 6-10)	**2**	**243.00**	**6.71**	**236**	**248**	**248**	**236**	**4174.99**	**19249.99**
Mean (period 8-10)	**1**	**246.67**	**0.00**	**247**	**247**	**247**	**247**	**4466.67**	**20091.67**
Strategic Prediction:	**1**	**180**							
Efficient Prediction:	**3**	**105**							
Session 3									
Period 1	2	387.50	123.74	300	475	300	475	58367.84	95117.84
Period 2	1	295.00	0.00	295	295	295	295	13225.00	36100.00
Period 3	1	252.00	0.00	252	252	252	252	5184.00	21609.00
Period 4	1	290.00	0.00	290	290	290	290	12100.00	34225.00
Period 5	1	225.00	0.00	225	225	225	225	2025.00	14400.00
Period 6	4	300.00	69.64	230	395	275	300	19249.73	42874.73
Period 7	1	211.00	0.00	211	211	211	211	961.00	11236.00
Period 8	1	200.00	0.00	200	200	200	200	400.00	9025.00
Period 9	1	192.00	0.00	192	192	192	192	144.00	7569.00
Period 10	1	175.00	0.00	175	175	175	175	25.00	4900.00
Mean (period 1-10)	**1**	**252.75**	**19.34**	**237**	**271**	**242**	**262**	**11168.16**	**27705.66**
Mean (period 6-10)	**2**	**215.60**	**13.93**	**202**	**235**	**211**	**216**	**4155.95**	**15120.95**
Mean (period 8-10)	**1**	**189.00**	**0.00**	**189**	**189**	**189**	**189**	**189.67**	**7164.67**
Strategic Prediction:	**1**	**180**							
Efficient Prediction:	**3**	**105**							

* Coefficient of Convergence to strategic prediction.
** Coefficient of Convergence to competitive prediction.

Table 6: ETC2 (Chapter 5) Experiment Results by Session

	License Price	Final License Holding Fringe	Final License Holding Dominant	Production Fringe	Production Dominant	Total Production	Product Price
Session 1 (I-1)							
Prediction*	90	6.0	4.0	8.0	8.0	16.0	125.0
Mean Observation	88.88	8.42	1.58	9.25	5.50	14.75	
Standard Deviation	17.56	1.00	1.00	0.75	0.90	0.97	
Session 2 (III-1)							
Prediction*	75	8.0	2.0	10.0	4.0	14.0	145.0
Mean Observation	230.77	8.90	1.10	7.50	3.80	11.30	201.00
Standard Deviation	63.51	0.99	0.99	1.35	2.35	2.45	46.95
Session 3 (II-1)							
Prediction*	110	3.0	7.0	5.0	10.0	15.0	125.0
Mean Observation	145.97	2.20	7.80	4.20	8.90	13.10	
Standard Deviation	49.90	1.23	1.23	1.48	1.10	1.45	
Session 4 (IV-1)							
Prediction*	180	1.0	9.0	4.0	8.0	12.0	185.0
Mean Observation	114.17	4.40	5.60	5.50	6.30	11.80	191.00
Standard Deviation	18.43	1.17	1.17	0.97	0.82	0.79	18.97
Session 5 (I-2)							
Prediction*	90	6.0	4.0	8.0	8.0	16.0	125.0
Mean Observation	110.49	8.40	1.60	7.90	5.80	13.70	
Standard Deviation	52.27	0.84	0.84	1.10	0.92	1.34	
Session 6 (IV-2)							
Prediction*	180	1.0	9.0	4.0	8.0	12.0	185.0
Mean Observation	298.17	2.20	7.80	5.80	6.40	12.20	181.00
Standard Deviation	68.28	0.79	0.79	1.14	2.01	1.87	37.48
Session 7 (II-2)							
Prediction*	110	3.0	7.0	5.0	10.0	15.0	125.0
Mean Observation	106.19	2.50	7.50	4.10	8.60	12.70	
Standard Deviation	6.72	0.97	0.97	1.10	0.97	1.34	
Session 8 (III-2)							
Prediction*	75	8.0	2.0	10.0	4.0	14.0	145.0
Mean Observation	29.43	7.91	2.09	8.64	3.91	12.55	174.09
Standard Deviation	15.98	0.70	0.70	0.67	0.70	0.82	16.40
Session 9 (II-3)							
Prediction*	110	3.0	7.0	5.0	10.0	15.0	125.0
Mean Observation	110.47	3.50	6.50	4.75	10.00	14.75	
Standard Deviation	18.51	0.80	0.80	0.87	0.00	0.87	
Session 10 (I-3)							
Prediction*	90	6.0	4.0	8.0	8.0	16.0	125.0
Mean Observation	88.38	8.00	2.00	9.33	6.00	15.33	
Standard Deviation	13.36	0.95	0.95	0.78	0.95	1.30	
Session 11 (III-3)							
Prediction*	75	8.0	2.0	10.0	4.0	14.0	145.0
Mean Observation	56.01	8.50	1.50	8.70	5.30	14.00	145.00
Standard Deviation	12.34	0.71	0.82	0.82	1.25	1.33	26.67
Session 12 (IV-3)							
Prediction*	180	1.0	9.0	4.0	8.0	12.0	185.0
Mean Observation	135.96	3.40	6.60	4.80	8.60	13.40	157.00
Standard Deviation	32.17	1.26	1.26	1.32	1.17	1.26	25.30

* Prediction under Strategic Manipulation

Table 7: ETC2 (Chapter 5) C-mkt Prices: Treatment 1

C-Mkt. Price Outcomes by Treatment and Session

Treatment 1

Session 1	# of Trans.	# of "Flips"	Mean	Std. Dev.	Min.	Max.	Opening	Closing	α2*	α2**
Period 1	2	2	125.00	0.00	125	125	125	125	1225.00	400.00
Period 2	5	2	102.40	5.37	100	112	100	100	182.60	35.60
Period 3	2	1	102.00	4.24	99	105	105	99	161.98	26.98
Period 4	3	2	106.67	11.55	100	120	120	100	411.29	136.19
Period 5	9	7	83.78	11.57	68	99	85	89	172.55	584.15
Period 6	5	2	88.80	19.87	60	109	109	60	396.26	657.26
Period 7	2	1	85.00	7.07	80	90	80	90	74.98	449.98
Period 8	3	2	65.00	25.00	40	90	90	65	1250.00	2225.00
Period 9	3	2	85.00	5.00	80	90	90	80	50.00	425.00
Period 10	4	2	76.00	11.60	65	87	85	67	330.56	975.56
Period 11	4	1	81.25	6.08	76	90	80	90	113.53	601.03
Mean (period 1-10)	**3.8**	**2.2**	**90.99**	**9.76**	**81**	**102**	**97**	**88**	**397**	**592**
Mean (period 6-10)	**3.5**	**1.7**	**80.18**	**12.44**	**66.83**	**92.67**	**89.00**	**75.33**	**369.22**	**888.97**
Mean (period 8-11)	**3.5**	**1.8**	**76.81**	**11.92**	**65.25**	**89.25**	**86.25**	**75.50**	**436.02**	**1056.65**
Strategic Prediction:	**4**		**90**							
Efficient Prediction:	**6**		**105**							
Session 2										
Period 1	6	5	223.33	71.46	170	360	360	170	22883.42	19108.52
Period 2	3	2	183.33	28.87	150	200	200	200	9543.97	6969.07
Period 3	3	2	151.00	33.78	131	190	131	190	4862.09	3257.09
Period 4	5	4	154.80	32.82	124	200	175	150	5276.19	3557.19
Period 5	6	5	116.00	12.17	101	135	135	125	824.11	269.11
Period 6	7	5	90.00	11.18	75	105	105	75	124.99	349.99
Period 7	14	11	79.93	14.67	50	100	90	50	316.61	843.71
Period 8	10	7	83.40	16.57	50	100	75	75	318.12	741.12
Period 9	9	8	98.33	39.05	50	190	90	80	1594.29	1569.39
Period 10	11	9	81.36	23.24	50	120	70	80	614.75	1098.95
Mean (period 1-10)	**7.4**	**5.8**	**126.15**	**28.38**	**95**	**170**	**143**	**120**	**4635.85**	**3776.41**
Mean (period 6-10)	**10.2**	**8.0**	**86.60**	**20.94**	**55**	**123**	**86**	**72**	**593.75**	**920.63**
Mean (period 8-10)	**10.0**	**8.0**	**87.70**	**26.29**	**50**	**137**	**78**	**78**	**842.39**	**1136.49**
Strategic Prediction:	**4**		**90**							
Efficient Prediction:	**6**		**105**							
Session 3										
Period 1	1	0	100.00	0.00	100	100	100	100	100.00	25.00
Period 2	2	2	120.00	28.28	100	140	140	120	1699.76	1024.76
Period 3	2	0	97.50	3.54	95	100	100	95	68.78	68.78
Period 4	2	0	80.00	7.07	75	85	75	85	149.98	674.98
Period 5	1	0	60.00	0.00	60	60	60	60	900.00	2025.00
Period 6	2	0	82.50	3.54	80	85	80	85	68.78	518.78
Period 7	2	0	79.00	0.00	79	79	79	79	121.00	676.00
Period 8	2	0	90.00	0.00	90	90	90	90	0.00	225.00
Period 9	3	0	86.67	2.89	85	90	85	90	19.44	344.34
Period 10	3	0	87.67	2.52	85	90	88	90	11.78	306.68
Period 11	3	0	87.00	2.65	85	90	86	90	16.02	331.02
Period 12	3	0	85.33	0.58	85	86	85	86	22.14	387.24
Mean (period 1-12)	**2.2**	**0.2**	**87.97**	**4.26**	**84.92**	**91.25**	**89.00**	**89.17**	**264.81**	**550.63**
Mean (period 6-12)	**2.6**	**0.0**	**85.45**	**1.74**	**84.14**	**87.14**	**84.71**	**87.14**	**37.02**	**398.44**
Mean (period 8-12)	**2.8**	**0.0**	**87.33**	**1.73**	**86.00**	**89.20**	**86.80**	**89.20**	**13.88**	**318.86**
Strategic Prediction:	**4**		**90**							
Efficient Prediction:	**6**		**105**							

* Coefficient of Convergence to strategic prediction.
** Coefficient of Convergence to competitive prediction.

Table 8: ETC2 (Chapter 5) C-mkt Prices: Treatment 2

C-Mkt. Price Outcomes by Treatment and Session

Treatment 2

Session 1	# of Trans.	# of "Flips"	Mean	Std. Dev.	Min.	Max.	Opening	Closing	α2*	α2**
Period 1	1	0	210.00	0.00	210	210	210	210	10000.00	11025.00
Period 2	1	0	250.00	0.00	250	250	250	250	19600.00	21025.00
Period 3	3	1	153.33	22.55	130	175	155	130	2385.99	2844.29
Period 4	6	3	162.00	48.33	100	210	200	150	5039.79	5584.79
Period 5	6	3	163.17	73.09	99	250	250	99	8169.20	8725.90
Period 6	5	3	135.00	31.82	100	175	145	105	1637.51	1912.51
Period 7	4	1	150.25	46.59	95	200	200	175	3790.69	4218.19
Period 8	5	2	143.00	36.67	80	175	150	160	2433.69	2788.69
Period 9	2	2	132.50	10.61	125	140	140	125	618.82	868.82
Period 10	6	2	94.33	27.14	60	130	130	76	982.13	850.43
Mean (period 1-10)	3.9	1.7	159.36	29.68	125	192	183	148	5465.78	5984.36
Mean (period 6-10)	4.4	2.0	131.02	30.57	92	164	153	128	1892.57	2127.73
Mean (period 8-10)	4.3	2.0	123.28	24.81	88	148	140	120	1344.88	1502.65
Strategic Prediction:	3		110							
Efficient Prediction:	3		105							
Session 2										
Period 1	1	0	100.00	0.00	100	100	100	100	100.00	25.00
Period 2	1	0	125.00	0.00	125	125	125	125	225.00	400.00
Period 3	3	0	110.00	5.00	105	115	110	105	25.00	50.00
Period 4	3	0	101.33	3.21	99	105	105	100	85.47	23.77
Period 5	4	1	102.50	2.38	100	105	101	104	61.91	11.91
Period 6	3	1	106.67	5.77	100	110	100	110	44.38	36.08
Period 7	3	0	105.00	13.23	90	115	110	115	200.03	175.03
Period 8	4	1	106.25	4.11	101	110	109	105	30.95	18.45
Period 9	4	2	106.50	5.97	101	115	101	105	47.89	37.89
Period 10	5	1	107.40	5.41	101	115	107	104	36.03	35.03
Mean (period 1-10)	3.1	0.6	107.07	4.51	102	112	107	107	85.67	81.32
Mean (period 6-10)	3.8	1.0	106.36	6.90	99	113	105	108	71.86	60.50
Mean (period 8-10)	4.3	1.3	106.72	5.16	101	113	106	105	38.29	30.46
Strategic Prediction:	3		110							
Efficient Prediction:	3		105							
Session 3										
Period 1	5	1	139.00	37.48	110	200	120	200	2245.75	2560.75
Period 2	3	0	98.33	10.41	90	110	110	95	244.56	152.86
Period 3	4	0	95.25	9.84	90	110	110	91	314.39	191.89
Period 4	4	0	107.50	12.58	90	120	120	90	164.51	164.51
Period 5	2	0	95.50	7.78	90	101	101	90	270.78	150.78
Period 6	2	0	100.00	0.00	100	100	100	100	100.00	25.00
Period 7	3	0	120.00	26.46	100	150	150	110	800.13	925.13
Period 8	5	1	109.00	5.52	100	115	110	100	31.47	46.47
Period 9	4	0	110.50	1.00	110	112	110	110	1.25	31.25
Period 10	4	0	111.75	5.56	108	120	110	109	33.98	76.48
Period 11	5	1	112.60	6.95	109	125	109	110	55.06	106.06
Period 12	4	0	105.50	4.20	100	110	110	100	37.89	17.89
Mean (period 1-12)	3.8	0.3	108.74	10.65	99.75	122.75	113.33	108.75	358.31	370.76
Mean (period 6-12)	3.7	0.4	109.91	7.10	103.86	118.86	114.14	105.57	151.40	175.47
Mean (period 8-12)	4.4	0.4	109.87	4.65	105.40	116.40	109.80	105.80	31.93	55.63
Strategic Prediction:	3		110							
Efficient Prediction:	3		105							

* Coefficient of Convergence to strategic prediction.

** Coefficient of Convergence to competitive prediction.

Table 9: ETC2 (Chapter 5) C-mkt Prices: Treatment 3

C-Mkt. Price Outcomes by Treatment and Session

Treatment 3

Session 1	# of Trans.	# of "Flips"	Mean	Std. Dev.	Min.	Max.	Opening	Closing	α2*	α2**
Period 1	7	5	279.29	103.94	100	400	400	230	52537.93	41180.53
Period 2	7	5	237.29	69.61	100	301	250	200	31183.60	22346.20
Period 3	8	7	301.88	60.00	200	400	300	200	55074.53	42361.73
Period 4	11	11	253.27	55.23	175	350	250	260	34830.55	25034.35
Period 5	4	4	250.00	35.59	200	280	280	200	31891.65	22291.65
Period 6	6	4	196.67	57.54	111	260	250	150	18114.44	11714.24
Period 7	9	9	211.22	63.54	100	300	300	180	22593.22	15320.02
Period 8	8	6	191.88	31.85	150	250	199	150	14674.19	8561.69
Period 9	7	7	215.29	18.69	199	250	250	211	20030.60	12513.20
Period 10	14	12	196.57	22.13	150	250	210	150	15269.00	8874.80
Mean (period 1-10)	**8.1**	**7.0**	**233.34**	**51.81**	**149**	**304**	**269**	**193**	**29619.97**	**21019.84**
Mean (period 6-10)	**8.8**	**7.6**	**202.33**	**38.75**	**142**	**262**	**242**	**168**	**18136.29**	**11396.79**
Mean (period 8-10)	**9.7**	**8.3**	**201.25**	**24.22**	**166**	**250**	**220**	**170**	**16657.93**	**9983.23**
Strategic Prediction:	**2**		**75**							
Efficient Prediction:	**6**		**105**							
Session 2										
Period 1	5	3	17.40	5.32	11	25	25	20	3346.06	7702.06
Period 2	5	2	17.00	2.74	15	20	15	20	3371.51	7751.51
Period 3	4	1	18.00	2.45	15	20	20	15	3255.00	7575.00
Period 4	2	1	17.50	3.54	15	20	20	15	3318.78	7668.78
Period 5	2	0	30.00	14.14	20	40	20	40	2224.94	5824.94
Period 6	3	2	26.67	2.89	25	30	25	30	2344.14	6143.94
Period 7	3	1	30.00	8.66	25	40	25	25	2100.00	5700.00
Period 8	4	2	33.75	4.79	30	40	30	30	1724.51	5099.51
Period 9	3	1	36.67	15.28	20	50	20	40	1702.67	4902.47
Period 10	2	0	47.50	31.82	25	70	25	70	1768.76	4318.76
Period 11	4	1	60.00	7.07	50	65	50	65	274.98	2074.98
Mean (period 1-11)	**3.4**	**1.3**	**30.41**	**8.97**	**22.82**	**38.18**	**25.00**	**33.64**	**2311.94**	**5887.45**
Mean (period 6-11)	**3.2**	**1.2**	**39.10**	**11.75**	**29.17**	**49.17**	**29.17**	**43.33**	**1652.51**	**4706.61**
Mean (period 8-11)	**3.3**	**1.0**	**44.48**	**14.74**	**31.25**	**56.25**	**31.25**	**51.25**	**1367.73**	**4098.93**
Strategic Prediction:	**2**		**75**							
Efficient Prediction:	**6**		**105**							
Session 3										
Period 1	7	5	72.86	14.10	60	100	80	60	203.39	1231.79
Period 2	5	3	62.80	11.48	50	80	80	55	280.63	1912.63
Period 3	7	5	61.29	10.95	50	75	70	50	307.87	2030.47
Period 4	6	4	49.50	9.14	35	62	50	35	733.79	3163.79
Period 5	3	2	61.33	7.09	55	69	69	60	237.14	1957.34
Period 6	5	3	51.80	5.36	45	59	59	45	566.97	2858.97
Period 7	5	4	46.80	7.50	35	55	50	55	851.49	3443.49
Period 8	4	3	45.50	8.50	34	54	45	34	942.50	3612.50
Period 9	6	4	49.50	2.95	44	53	50	44	658.95	3088.95
Period 10	3	3	50.33	0.58	50	51	50	51	608.94	2989.14
Mean (period 1-10)	**5.1**	**3.6**	**55.17**	**7.76**	**46**	**66**	**60**	**49**	**539.17**	**2628.91**
Mean (period 6-10)	**4.6**	**3.4**	**48.79**	**4.98**	**42**	**54**	**51**	**46**	**725.77**	**3198.61**
Mean (period 8-10)	**4.3**	**3.3**	**48.44**	**4.01**	**43**	**53**	**48**	**43**	**736.80**	**3230.20**
Strategic Prediction:	**2**		**75**							
Efficient Prediction:	**6**		**105**							

* Coefficient of Convergence to strategic prediction.
** Coefficient of Convergence to competitive prediction.

Table 10: ETC2 (Chapter 5) C-mkt Prices: Treatment 4

C-Mkt. Price Outcomes by Treatment and Session

Treatment 4

Session 1	# of Trans.	# of "Flips"	Mean	Std. Dev.	Min.	Max.	Opening	Closing	α2*	α2**
Period 1	9	4	125.67	41.56	50	200	120	50	4678.98	2154.48
Period 2	7	3	124.29	19.02	100	150	150	100	3465.36	733.86
Period 3	3	1	121.33	8.08	114	130	130	114	3507.46	331.96
Period 4	5	0	122.40	4.34	115	125	125	115	3336.60	321.60
Period 5	7	3	111.43	11.09	99	125	125	101	4824.83	164.33
Period 6	10	4	114.90	9.07	100	125	115	100	4320.27	180.27
Period 7	10	5	111.30	6.00	100	125	110	112	4755.69	75.69
Period 8	4	1	107.25	4.86	100	110	110	109	5316.18	28.68
Period 9	7	2	104.86	5.18	99	110	110	110	5672.85	26.85
Period 10	7	2	99.43	2.07	95	101	101	95	6495.81	35.31
Mean (period 1-10)	6.9	2.5	114.29	11.13	97	130	120	101	4637.40	405.30
Mean (period 6-10)	7.6	2.8	107.55	5.44	99	114	109	105	5312.16	69.36
Mean (period 8-10)	6.0	1.7	103.85	4.04	98	107	107	105	5828.28	30.28
Strategic Prediction:	1		180							
Efficient Prediction:	3		105							

Session 2	# of Trans.	# of "Flips"	Mean	Std. Dev.	Min.	Max.	Opening	Closing	α2*	α2**
Period 1	5	3	251.00	104.90	75	350	250	75	16045.01	32320.01
Period 2	4	2	340.25	62.02	250	386	350	250	29526.54	59189.04
Period 3	4	2	342.50	76.32	230	400	370	230	32230.99	62230.99
Period 4	1	0	330.00	0.00	330	330	330	330	22500.00	50625.00
Period 5	5	2	318.00	32.90	260	340	325	260	20126.41	46451.41
Period 6	1	0	300.00	0.00	300	300	300	300	14400.00	38025.00
Period 7	4	1	285.00	40.21	225	310	300	225	12641.84	34016.84
Period 8	3	0	241.00	51.10	211	300	300	211	6332.21	21107.21
Period 9	5	2	324.40	65.45	250	400	330	267	25135.06	52420.06
Period 10	3	1	248.33	41.93	200	275	270	200	6427.11	22301.61
Mean (period 1-10)	3.5	1.3	298.05	47.48	233	339	313	235	18536.52	41868.72
Mean (period 6-10)	3.2	0.8	279.75	39.74	237	317	300	241	12987.25	33574.15
Mean (period 8-10)	3.7	1.0	271.24	52.83	220	325	300	226	12631.46	31942.96
Strategic Prediction:	1		180							
Efficient Prediction:	3		105							

Session 3	# of Trans.	# of "Flips"	Mean	Std. Dev.	Min.	Max.	Opening	Closing	α2*	α2**
Period 1	3	1	200.00	25.00	175	225	225	200	1025.00	9650.00
Period 2	2	0	200.00	35.36	175	225	175	225	1650.33	10275.33
Period 3	7	3	157.14	26.31	125	199	199	125	1214.80	3410.80
Period 4	3	1	151.33	35.64	114	185	185	114	2092.18	3416.68
Period 5	5	2	125.60	15.95	110	145	145	110	3213.76	678.76
Period 6	8	2	116.50	15.09	100	140	135	140	4259.96	359.96
Period 7	5	1	117.20	6.46	110	125	120	110	3985.57	190.57
Period 8	3	0	118.33	2.89	115	120	120	120	3811.54	186.04
Period 9	5	1	118.20	1.93	115	120	120	118	3822.96	177.96
Period 10	4	0	118.00	4.24	115	124	115	118	3861.98	186.98
Mean (period 1-10)	4.5	1.1	142.23	16.89	125	161	154	138	2893.81	2853.31
Mean (period 6-10)	5.0	0.8	117.65	6.12	111	126	122	121	3948.40	220.30
Mean (period 8-10)	4.0	0.3	118.18	3.02	115	121	118	119	3832.16	183.66
Strategic Prediction:	1		180							
Efficient Prediction:	3		105							

* Coefficient of Convergence to strategic prediction.
** Coefficient of Convergence to competitive prediction.

Table 11: ETC3 (Chapter 6) Experiment Results by Session

	License Price	Final License Holding Fringe	Final License Holding Dominant	Production Fringe	Production Dominant	Total Production	Product Price
Session 1 (I-1)							
Prediction*	105	3	7	5	10	15	125
Prediction*	105	4	6	6	10	16	125
Mean Observation	115.81	4.75	5.25	6.33	9.25	15.58	
Standard Deviation	3.69	0.45	0.45	1.07	0.45	1.00	
Session 2 (I-2)							
Prediction*	105	3	7	5	10	15	125
Prediction*	105	4	6	6	10	16	125
Mean Observation	113.53	5.42	4.58	7.08	8.42	15.50	201.00
Standard Deviation	16.72	1.38	1.38	1.24	1.31	0.67	46.95
Session 3 (I-3)							
Prediction*	105	3	7	5	10	15	125
Prediction*	105	4	6	6	10	16	125
Mean Observation	97.14	4.58	5.42	6.00	9.42	15.42	
Standard Deviation	15.27	0.67	0.67	1.21	0.67	0.79	
Session 4 (II-1)							
Prediction*	105	4	6	6	9	15	125
Prediction*	105	4	6	6	10	16	125
Prediction**	120-125	4	6	6	8	14	145
Prediction***	125-127	3	7	5	9	14	145
Mean Observation	132.56	4.20	5.80	5.60	7.00	12.60	173.00
Standard Deviation	28.87	1.23	1.23	0.84	1.41	0.96	19.32
Session 5 (II-2)							
Prediction*	105	4	6	6	9	15	125
Prediction*	105	4	6	6	10	16	125
Prediction**	120-125	4	6	6	8	14	145
Prediction***	125-127	3	7	5	9	14	145
Mean Observation	135.05	5.80	4.20	6.90	5.50	12.40	177.00
Standard Deviation	42.63	0.63	0.63	1.10	1.08	1.35	27.00
Session 6 (II-3)							
Prediction*	105	4	6	6	9	15	125
Prediction*	105	4	6	6	10	16	125
Prediction**	120-125	4	6	6	8	14	145
Prediction***	125-127	3	7	5	9	14	145
Mean Observation	135.08	6.10	3.90	7.60	4.50	12.10	183.00
Standard Deviation	33.34	1.60	1.60	1.17	1.35	1.52	30.48

* Efficient Permit and Product Markets (2 possible predictions)
** Efficient Permit Market only
*** Exclusion in Permit Market

Table 12: ETC3 (Chapter 6) C-mkt Prices: Treatment 1

C-Mkt. Price Outcomes by Treatment and Session

Treatment 1

Session 1	# of Trans.	# of "Flips"	Mean	Std. Dev.	Min.	Max.	Opening	Closing	α2
Period 1	1	1	112.00	0.00	112	112	112	112	49.00
Period 2	1	1	114.00	0.00	114	114	114	114	81.00
Period 3	2	1	119.50	0.71	119	120	119	120	210.75
Period 4	5	3	119.60	3.21	115	124	124	115	223.46
Period 5	2	0	114.50	0.71	114	115	115	114	90.75
Period 6	3	1	117.00	7.00	112	125	114	112	193.00
Period 7	3	2	115.00	2.00	113	117	117	113	104.00
Period 8	1	1	115.00	0.00	115	115	115	115	100.00
Period 9	2	0	112.50	2.12	111	114	114	111	60.74
Period 10	2	1	115.00	1.41	114	116	114	116	101.99
Period 11	4	2	114.25	2.87	111	118	118	111	93.80
Period 12	1	0	112.00	0.00	112	112	112	112	49.00
Mean (period 1-12)	**2.3**	**1.1**	**115.0**	**1.7**	**113.5**	**116.8**	**115.7**	**113.8**	**113.1**
Mean (period 7-12)	**2.2**	**1.0**	**114.0**	**1.4**	**112.7**	**115.3**	**115.0**	**113.0**	**84.9**
Mean (period 10-12)	**2.3**	**1.0**	**113.8**	**1.4**	**112.3**	**115.3**	**114.7**	**113.0**	**81.6**
Efficient Prediction:	**3**		**105**						

Session 2	# of Trans.	# of "Flips"	Mean	Std. Dev.	Min.	Max.	Opening	Closing	α2
Period 1	5	3	127.60	41.14	99	200	99	120	2203.26
Period 2	3	1	105.00	5.00	100	110	105	110	25.00
Period 3	2	0	104.00	0.00	104	104	104	104	1.00
Period 4	4	3	113.75	10.31	100	125	125	115	182.86
Period 5	3	3	118.33	5.77	115	125	115	125	210.98
Period 6	4	3	122.75	18.26	111	150	150	115	648.49
Period 7	3	1	106.67	7.64	100	115	115	100	61.16
Period 8	3	1	112.33	6.02	106	118	106	118	89.97
Period 9	4	2	115.00	10.68	105	130	111	105	214.06
Period 10	6	3	105.17	9.33	90	115	115	100	87.08
Period 11	4	2	111.75	7.37	103	120	120	103	99.88
Period 12	2	0	112.50	3.54	110	115	115	110	68.78
Mean (period 1-12)	**3.6**	**1.8**	**112.9**	**10.4**	**103.6**	**127.3**	**115.0**	**110.4**	**324.4**
Mean (period 7-12)	**3.7**	**1.5**	**110.6**	**7.4**	**102.3**	**118.8**	**113.7**	**106.0**	**103.5**
Mean (period 10-12)	**4.0**	**1.7**	**109.8**	**6.7**	**101.0**	**116.7**	**116.7**	**104.3**	**85.2**
Efficient Prediction:	**3**		**105**						

	# of Trans.	# of "Flips"	Mean	Std. Dev.	Min.	Max.	Opening	Closing	α2
Period 1	3	3	80.00	8.66	70	85	85	70	700.00
Period 2	4	2	73.50	6.45	65	79	65	72	1033.85
Period 3	4	2	87.50	2.89	85	90	90	85	314.60
Period 4	4	2	92.50	15.02	70	101	70	101	381.85
Period 5	3	2	100.00	10.00	90	110	90	110	125.00
Period 6	3	2	96.67	10.41	85	105	85	105	177.76
Period 7	6	4	113.33	19.92	90	150	110	105	466.20
Period 8	3	0	105.33	8.39	100	115	100	101	70.50
Period 9	5	3	102.00	8.37	90	110	90	110	79.06
Period 10	3	0	102.67	10.97	90	109	109	90	125.77
Period 11	2	0	105.50	0.71	105	106	105	106	0.75
Period 12	4	1	101.25	8.30	90	108	90	107	82.95
Mean (period 1-12)	**3.7**	**1.8**	**96.7**	**9.2**	**85.8**	**105.7**	**90.8**	**96.8**	**296.5**
Mean (period 7-12)	**3.8**	**1.3**	**105.0**	**9.4**	**94.2**	**116.3**	**100.7**	**103.2**	**137.5**
Mean (period 10-12)	**3.0**	**0.3**	**103.1**	**6.7**	**95.0**	**107.7**	**101.3**	**101.0**	**69.8**
Efficient Prediction:	**3**		**105**						

* Coefficient of Convergence to market prediction.

Table 13: ETC3 (Chapter 6) C-mkt Prices: Treatment 2

C-Mkt. Price Outcomes by Treatment and Session

Treatment 2

Session 1	# of Trans.	# of "Flips"	Mean	Std. Dev.	Min.	Max.	Opening	Closing	α2*	α2**
Period 1	3	1	135.00	13.23	125	150	125	130	275.03	1075.03
Period 2	2	1	152.50	3.54	150	155	150	155	768.78	2268.78
Period 3	3	1	155.00	5.00	150	160	160	150	925.00	2525.00
Period 4	2	0	132.50	3.54	130	135	130	135	68.78	768.78
Period 5	2	0	127.00	9.89	120	134	134	120	101.81	581.81
Period 6	3	0	143.33	7.64	135	150	135	145	394.36	1527.56
Period 7	1	0	135.00	0.00	135	135	135	135	100.00	900.00
Period 8	3	1	133.33	72.17	50	175	50	175	5277.90	6011.10
Period 9	1	0	135.00	0.00	135	135	135	135	100.00	900.00
Period 10	5	3	104.00	23.02	75	130	130	95	970.92	530.92
Mean (period 1-10)	**2.5**	**0.7**	**135.27**	**13.80**	**121**	**146**	**128**	**138**	**898.26**	**1708.90**
Mean (period 6-10)	**2.6**	**0.8**	**130.13**	**20.57**	**106**	**145**	**117**	**137**	**1368.64**	**1973.92**
Mean (period 8-10)	**3.0**	**1.3**	**124.11**	**31.73**	**87**	**147**	**105**	**135**	**2116.27**	**2480.67**
Strategic Prediction:	3		125-127							
Efficient Prediction:	3		105							
Session 2										
Period 1	3	3	112.00	10.58	100	120	120	100	280.94	160.94
Period 2	4	4	108.75	6.29	100	115	110	100	303.63	53.63
Period 3	6	5	142.83	55.06	100	250	112	150	3349.51	4462.71
Period 4	4	2	178.50	42.01	150	239	239	175	4627.09	7167.09
Period 5	6	3	151.67	47.61	100	225	100	150	2978.00	4444.80
Period 6	4	3	133.75	33.51	100	180	100	130	1199.48	1949.48
Period 7	5	3	106.00	57.71	10	150	100	10	3691.44	3331.44
Period 8	1	1	150.00	0.00	150	150	150	150	625.00	2025.00
Period 9	2	1	132.50	3.54	130	135	130	135	68.78	768.78
Period 10	3	1	133.00	2.89	130	135	135	135	72.35	792.35
Mean (period 1-10)	**3.8**	**2.6**	**134.90**	**25.92**	**107**	**170**	**130**	**124**	**1719.62**	**2515.62**
Mean (period 6-10)	**3.0**	**1.8**	**131.05**	**19.53**	**104**	**150**	**123**	**112**	**1131.41**	**1773.41**
Mean (period 8-10)	**2.0**	**1.0**	**138.50**	**2.14**	**137**	**140**	**138**	**140**	**255.38**	**1195.38**
Strategic Prediction:	3		125-127							
Efficient Prediction:	3		105							
Session 3										
Period 1	6	3	93.33	31.57	30	115	30	100	1999.65	1132.85
Period 2	8	6	101.25	22.80	50	120	105	90	1083.90	533.90
Period 3	7	5	111.43	11.80	95	130	115	130	323.38	180.58
Period 4	8	5	122.38	5.42	119	135	120	120	36.24	331.44
Period 5	6	4	139.50	8.69	125	150	125	142	285.77	1265.77
Period 6	4	2	158.75	27.20	120	180	120	180	1878.90	3628.90
Period 7	6	5	169.00	10.20	150	180	175	150	2040.04	4200.04
Period 8	5	2	167.00	12.04	150	180	150	180	1908.96	3988.96
Period 9	3	1	178.33	1.53	177	180	177	180	2846.43	5379.63
Period 10	7	6	166.14	10.82	150	180	150	160	1809.57	3855.17
Mean (period 1-10)	**6.0**	**3.9**	**140.71**	**14.21**	**117**	**155**	**127**	**143**	**1421.29**	**2449.73**
Mean (period 6-10)	**5.0**	**3.2**	**167.84**	**12.36**	**149**	**180**	**154**	**170**	**2096.78**	**4210.54**
Mean (period 8-10)	**5.0**	**3.0**	**170.49**	**8.13**	**159**	**180**	**159**	**173**	**2188.32**	**4407.92**
Strategic Prediction:	3		125-127							
Efficient Prediction:	3		105							

* Coefficient of Convergence to strategic prediction of 125.

** Coefficient of Convergence to competitive prediction.

Appendix C

The following pages contain complete instructions distributed to subjects in each experiment.

Chapter 4: (Contains only Treatment 1 and 4 instructions. Treatment 2 and 3 differ only in details specific to the treatment.

Dominant firm instructions-Treatment 1 (4 pages).
Dominant firm instructions-Treatment 4 (4 pages).
Fringe firm instructions-Treatment 1 (4 pages).
Fringe firm instructions-Treatment 4 (4 pages).
Dominant firm recordsheet-Treatment 1.
Dominant firm recordsheet-Treatment 4.
Fringe firm recordsheet-all Treatments.
Demand Schedule given to all firms: Treatments 3 and 4.
Fringe costs list given to Dominant firm

Chapters 5 and 6: (Contains only those documents which differed from materials used in Chapter 4)

Dominant firm instructions-Treatments 1 and 2 (7 pages).
Dominant firm instructions-Treatments 3 and 4 (7 pages).
Fringe firm instructions-Treatments 1 and 2 (7 pages).
Fringe firm instructions-Treatments 3 and 4 (7 pages).
All firm's recordsheet
Fringe costs list given to Dominant firm

Miscellaneous:

Screen subjects use for double auction trading.
History screen in MUDA showing previous transactions.

ETC Dominant Firm Instructions: Treatment 1

Instructions

You are about to participate in an experiment in the economics of decision making. Read the following instructions carefully. If you have any questions please raise your hand and wait for a monitor to come and help you. The money you will earn in this session will depend on the decisions you and the other participants make and will be paid to you in CASH at the end of the session.

In this experiment you will be a producer in a market with several trading periods. Attached to the instructions, you will find a record sheet for each period to enter transactions. The record sheet also gives information about the decisions you make. **The information on the record sheet is your private information and is not to be revealed to anyone. Do not speak or otherwise communicate to others at any time during trading periods.** Your ID number is found on the outside of your instruction folder. Please write your name, date and ID number at the top of the recordsheet. Do this now.

In the following instructions all dollar amounts are in Lab Dollars. The conversion rate of Lab Dollars to real money will be told to you before you begin.

General Information:

You are a producer of a ficticious commodity. In each trading period you will participate in two markets. The first is an input market where you are given an opportunity to buy an input which will lower your production costs. The second is the production market where you have the chance to sell your product, if you want to. You may or may not want to participate in one or both of these markets. That decision is left to you.

Instructions: selling your output and calculating your profit

In each trading period you may choose to produce and sell up to ten (10) units of a fictitious commodity, which you can sell in the primary market (P-market). The price in the P-market is L$125. For example, if you decide to produce 5 units you will have revenue of L$625. If you produced 10 units you would have revenue of L$1250.

For each unit you decide to produce you will have a production cost of L$____________. In addition to this production cost you will have an additional cost that increases with each unit produced, and is added to the production cost. The rightmost column of each worksheet shows your additional costs. When you sell your unit in the P-market your profit is the total revenue from the sale of the units (sales price x the number of units sold) minus the total production cost AND minus the total additional cost.

Profit = [total revenue] - [total production cost] - [total additional cost]

Instructions: Lowering Production Costs with Coupons

Before you decide how many units you want to produce and sell in the P-market, 10 coupons will be allocated amongst all the producers (you and the other subjects). These coupons cover the additional cost on each unit produced. In other words, if you have one coupon, you **don't** have to pay the additional cost on the last unit you produce. If you have two coupons you **don't** have to pay the additional costs on the last two units you produce, and so on.

Once the coupons have been allocated, you will have an opportunity to sell your coupons (if you were given any), or buy them (if you weren't given any and want some). This coupon market (C-market) is conducted using the computers, and occurs before you need to decide whether you wish to produce and sell anything in the P-market. Instructions for participating in the C-market follow.

You will not receive any coupons to begin each trading period, therefore you are a buyer in the C-market. You may purchase up to 10 coupons. If you buy a coupon you will mark the sale price you received on your record sheet in the leftmost column.

How to Buy Coupons

Numbers used here are illustrative only and will have no relationship to those used in the actual session.

During each trading period you will be free to purchase from the market as many units as you would like. **These units will be sold one at a time.** There are two ways of buying a unit: you can accept a seller's asking price, or a seller can accept your bid.

During the trading period, the computer will display the lowest asking price by any seller. Later you will be told how to accept this ASK (asking price). The computer will also display the highest price bid by any buyer. Later, you will be told how to make your own BID.

Refer to your record sheet. For each unit you buy, you MUST record the price in the column labeled **PRICE**. The record sheet MUST be filled in for each price after each transaction. For example, if you bought your first unit for L$60, you would record L$60 in the **PRICE** column. If you bought another unit for L$55 you would record this price in the **PRICE** column. At the end of the period total up your expenditures and write this number on the **Total Coupon Purchases** line. Were these the only purchases you made in the period you would enter L$115 on this line.

Market Organization

The market is opened for a trading period lasting for __________ minutes. Any buyer or seller is free to submit bids (or asks) to the market for single units of a good. Below is a list of commands used to do so. The actual operation of the market will be demonstrated in a few minutes. For now it is important that you understand intuitively how the market works. Once a bid (or ask) is submitted to the market it is displayed in the bid (or ask) window. Other buyers (or sellers) may then submit their own bids (or asks) which must be improvements over those currently displayed. A buyer may only submit a bid greater than that already displayed on the market to have it accepted. Similarly, a seller may only submit an ask which is below that currently displayed in the market to be accepted. Bids and offers may also be withdrawn using the command list below. Any seller (or buyer) is free to accept a current bid (or ask). If a bid is accepted, a unit is sold by the seller who has decided to accept the bid to the buyer who submitted the current bid on the market. The bid display is then cleared and awaits new bids to be submitted. If an ask is accepted by a buyer, a unit is sold to that buyer by the seller who submitted the current ask price. The ask display is then cleared and awaits new asks to be submitted.

To enter a bid:

Type the quantity (1 in this experiment always) in the market box (the split red box to the right of your screen) then hit the space bar to move to the price box and enter your bid. then hit the F1 key. If you make an error in either box use the backspace key or delete key to remove your entry. Hitting the F1 key sends your bid to the market where it is displayed in the centre of the screen in the BIDS box. The market will not accept bids below the standing market bid already displayed in the bids box.

To buy a unit at the standing market ask price (to accept an ask):

The standing ask is displayed in the ASK box. To accept this ask, type the quantity (always 1 in this experiment) in the quantity side of the red market box, or leave it blank, and press the CTRL and F2 keys at the same time.

To cancel a bid you have sent to the market:

If you have already submitted a bid to the market by hitting the F1 key after entering it in the red market box, and it is the standing bid, you may cancel it, provided someone does not accept your bid before you have canceled it. To do so press the ALT and F3 keys at the same time. This will remove your bid from the BIDS box, restoring the previous standing bid.

Command Summary:

Move the cursor in the red market box: SPACEBAR
Clear entry in the red market box: BACKSPACE or DELETE

To submit a bid: enter 1 unit and bid price in market box and press F1
To cancel a submitted bid: press ALT-F3

To accept the current market ask (buy a unit from a seller): CTRL-F2

Often encountered problems:

Market will not take your bid:

1) press F1 only, not CTRL-F1
2) bid must be above standing bid

Fail to buy

1) make sure CTRL key is held down when hitting F2
2) red market box must be empty or exactly same as standing market ask
3) red market box must be empty or quantity must equal 1.

How to Sell your firms's Output:

After the close of the C-market you must indicate how many units you are producing for the P-market. You do this by writing the number of units you want to produce in the **Units Produced** box. Total Revenue is found by multiplying this number by L$125. You may then calculate your profit or loss for the period.

Once these calculations have been made, a new round will begin. Because the coupons are only good for one period , a new allocation of coupons is made. The number of rounds is predetermined, but unknown to you.

There will be 3 practice rounds before the experiment starts to familiarize you with the record sheet and the working C-market. After these rounds your balance will be put back to L$500 and you will be given new "production" and "additional" cost schedules. You will be paid in cash for your earnings for all periods after the first three.

If you have any questions please raise your hand and it will be answered as soon as possible. Please do not ask any questions aloud which give away any information on your record sheet.

ETC Dominant Firm Instructions: Treatment 4

Instructions

You are about to participate in an experiment in the economics of decision making. Read the following instructions carefully. If you have any questions please raise your hand and wait for a monitor to come and help you. The money you will earn in this session will depend on the decisions you and the other participants make and will be paid to you in CASH at the end of the session.

In this experiment you will be a producer in a market with several trading periods. Attached to the instructions, you will find a record sheet for each period to enter transactions. The record sheet also gives information about the decisions you make. **The information on the record sheet is your private information and is not to be revealed to anyone. Do not speak or otherwise communicate to others at any time during trading periods.** Your ID number is found on the outside of your instruction folder. Please write your name, date and ID number at the top of the recordsheet. Do this now.

In the following instructions all dollar amounts are in Lab Dollars. The conversion rate of Lab Dollars to real money will be told to you before you begin.

General Information:

You are a producer of a ficticious commodity. In each trading period you will participate in two markets. The first is an input market where you are given an opportunity to buy an input which will lower your production costs. The second is the production market where you have the chance to sell your product, if you want to. You may or may not want to participate in one or both of these markets. That decision is left to you.

Instructions: selling your output and calculating your profit

In each trading period you may choose to produce and sell up to ten (10) units of a fictitious commodity, which you can sell in the primary market (P-market). The price in the P-market is determined by adding up the total amount of production from everyone and reading from the list of numbers (attached to the instructions). For example, if you decide to produce **and the total production level for all firms** is 10 units, you will sell your units for L$225.

For each unit you decide to produce you will have a production cost of L$____________.
In addition to this production cost you will have an additional cost that increases with each unit produced, and is added to the production cost. The rightmost column of each worksheet shows your additional costs. When you sell your unit in the P-market your profit is the total revenue from the sale of the units (sales price x the number of units sold) minus the total production cost AND minus the total additional cost.

Profit = [total revenue] - [total production cost] - [total additional cost]

<u>Instructions:</u> lowering production costs with coupons

Before you decide how many units you want to produce and sell in the P-market, 10 coupons will be allocated amongst all the producers (you and the other subjects). These coupons cover the additional cost on each unit produced. In other words, if you have one coupon, you **<u>don't</u>** have to pay the additional cost on the last unit you produce. If you have two coupons you **<u>don't</u>** have to pay the additional costs on the last two units you produce, and so on.

Once the coupons have been allocated, you will have an opportunity to sell your coupons (if you were given any), or buy them (if you weren't given any and want some). This coupon market (C-market) is conducted using the computers, and occurs before you need to decide whether you wish to produce and sell anything in the P-market. Instructions for participating in the C-market follow.

You will receive 10 coupons at the beginning of each trading period, therefore you are a seller in the C-market. You may decide either to sell none, some, or all of your coupons. If you sell a coupon you will mark the sale price you received on your record sheet in the leftmost column. You may not sell more coupons than you are given.

How to Sell Coupons

Numbers used here are illustrative only and will have no relationship to those used in the actual session.

During each trading period you will be free to sell to the market as many units as you would like. **These units will be sold one at a time.** There are two ways of selling a unit: you can accept a buyer's bid, or a buyer can accept your asking price.

During the trading period, the computer will display the highest bid by any buyer. Later you will be told how to accept this BID. The computer will also display the lowest asking price made by any seller. Later, you will be told how to make your own ASK.

Refer to your record sheet. For each unit you sell, you MUST record the price in the column labeled **PRICE**. <u>The record sheet MUST be filled in for each price after each transaction.</u> For example, if you sold your first unit for L$60, you would record L$60 in the **PRICE** column. If you sold another unit for L$55 you would record this price in the **PRICE** column. At the end of the period total up your sales revenues and write this number on the **Total Coupon Sales** line. Were these the only sales you made in the period you would enter L$15 on this line.

Market Organization

The market is opened for a trading period lasting for __________ minutes. Any buyer or seller is free to submit bids (or asks) to the market for single units of a good. Below is a list of commands used to do so. The actual operation of the market will be demonstrated in a few minutes. For now it is important that you understand intuitively how the market works. Once a bid (or ask) is submitted to the market it is displayed in the bid (or ask) window. Other buyers (or sellers) may then submit their own bids (or asks) which must be improvements over those currently displayed. A buyer may only submit a bid greater than that already displayed on the market to have it accepted. Similarly, a seller may only submit an ask which is below that currently displayed in the market to be accepted. Bids and offers may also be withdrawn using the command list below. Any seller (or buyer) is free to accept a current bid (or ask). If a bid is accepted, a unit is sold by the seller who has decided to accept the bid to the buyer who submitted the current bid on the market. The bid display is then cleared and awaits new bids to be submitted. If an ask is accepted by a buyer, a unit is sold to that buyer by the seller who submitted the current ask price. The ask display is then cleared and awaits new asks to be submitted.

To enter an ask:

Type the quantity (1 in this experiment always) in the market box (the split red box to the right of your screen) then hit the space bar to move to the price box and enter your ask, then hit the F2 key. If you make an error in either box use the backspace key or delete key to remove your entry. Hitting the F2 key sends your ask to the market where it is displayed in the centre of the screen in the ASKS box. The market will not accept asks above the standing market ask already displayed in the asks box.

To sell a unit at the standing market bid price (to accept a bid):

The standing ask is displayed in the BIDS box. To accept this bid, type the quantity (always 1 in this experiment) in the quantity side of the red market box, or leave it blank, and press the CTRL and F1 keys at the same time.

To cancel an ask you have sent to the market:

If you have already submitted an ask to the market by hitting the F2 key after entering it in the red market box, and it is the standing ask, you may cancel it, provided someone does not accept your ask before you have canceled it. To do so press the ALT and F4 keys at the same time. This will remove your ask from the ASKS box, restoring the previous standing ask.

Command Summary:

Move the cursor in the red market box: SPACEBAR
Clear entry in the red market box: BACKSPACE or DELETE

To submit an ask: enter 1 unit and bid price in market box and press F2
To cancel a submitted ask: press ALT-F4

To accept the current market bid (sell a unit to a buyer): CTRL-F1

Often encountered problems:

Market will not take your ask:

check:
1) press F2 only, not CTRL-F2
2) bid must be below standing ask

Fail to sell (accept a bid)
check:
1) make sure CTRL key is held down when hitting F1
2) red market box must be empty or exactly same as standing market bid
3) red market box must be empty or quantity must equal 1.

How to Sell your firms's Output:

After the close of the C-market you must indicate how many units you are producing for the P-market. You do this by writing the amount you wish to produce on a card and placing it on the right hand corner of your desk. Also record this in the **Units Produced** box on your record sheet. When the price is announced, record it on your record sheet and will take the amount you decided to produce and multiply it by the announced price, and write this number in the column marked Total Revenue on your record sheet. You may then calculate your profit or loss for the period.

Once these calculations have been made, a new round will begin. Because the coupons are only good for one period , a new allocation of coupons is made. The number of rounds is predetermined, but unknown to you. There will be 3 practice rounds before the experiment starts to familiarize you with the record sheet and the working C-market. After these rounds your balance will be put back to L$500 and you will be given new "production" and "additional" cost schedules. You will be paid in cash for your earnings for all periods after the first three. If you have any questions please raise your hand and it will be answered as soon as possible. Please do not ask any questions aloud which give away any information on your record sheet.

ETC Fringe Firm Instructions: Treatment 1

Instructions

You are about to participate in an experiment in the economics of decision making. Read the following instructions carefully. If you have any questions please raise your hand and wait for a monitor to come and help you. The money you will earn in this session will depend on the decisions you make and will be paid to you in CASH at the end of the session.

In this experiment you will be a producer in a market with several trading periods. Attached to the instructions, you will find a record sheet to enter transactions. The record sheet also gives information about the decisions you make. **The information on the record sheet is your private information and is not to be revealed to anyone. Do not speak or otherwise communicate to others at any time during trading periods.** Please write your name, date and ID number at the top of the recordsheet. Your ID number is found on the outside of your instruction folder.

In the following instructions all dollar amounts are in Lab Dollars. The conversion rate of Lab Dollars to real money will be told to you before you begin.

General Information:

You are a producer of a ficticious commodity. In each trading period you will participate in two markets. The first is an input market where you are given an opportunity to buy an input which will lower you production costs. The second is the production market where you have the chance to sell your product, if you want to. You may or may not want to participate in one or both of these markets. That decision is left to you.

Instructions: Selling Your Output and Calculating Your Profit

In this experiment you will be a seller in a market with several trading periods. You will start the experiment with a balance of L$500.

In each trading period you may choose to produce nothing or produce and sell ONE unit of a commodity. If you produce the unit, you will be guaranteed to sell it in the primary market (P-market). The price in the P-market is L$125. That is, if you decide to produce a unit you will sell it in the P-market and receive L$125.

If you decide to produce a unit you will incur a production cost. In addition to this production cost you will have an additional cost which is added to the production cost. These costs will be distributed to you by a monitor before the session starts. When you sell your unit in the P-market your profit is the selling price of your unit (L$125) minus the production cost AND minus the additional cost.

Profit = [L$125] - [production cost] - [additional cost]

Lowering Production Costs with Coupons

Before you decide if you want to produce and sell in the P-market, 10 coupons will be allocated amongst all the producers (you and the other subjects). These coupons cover the additional cost on each unit produced. In other words, if you have one coupon, you **don't** have to pay the additional cost on the last unit you produce.

Once the coupons have been allocated, you will have an opportunity to sell your coupon (if you were given one), or buy one (if you weren't given any and want one). This coupon market (C-market) is conducted using the computers and occurs before you need to decide whether you wish to produce and sell anything in the P-market. Instructions for participating in the C-market follow.

You will receive one coupon at the beginning of each trading period, therefore you are a seller in the C-market. This will be shown in the INVENTORY box on your computer screen. You may decide either to sell it or not. If you sell your coupon you will mark the sale price you received on your record sheet. You may not sell more coupons than you are given.

How to Sell Coupons

Numbers used here are illustrative only and will have no relationship to those used in the actual session.

During each trading period you will be free to sell one coupon. **Coupons will be sold in this market one at a time.** There are two ways of selling a unit: you can accept a buyer's bid, or a buyer can accept your asking price.

During the trading period, the computer will display the lowest asking price by any seller. Later you will be told how to submit an ASK (asking price). The computer will also display the highest price bid by any buyer. Later, you will be told how to accept this BID.

Refer to your record sheet. For each unit you sell, you MUST record the price in the column labeled **Price and CIRCLE the PLUS SIGN**. You should also write the ADDITIONAL COST you will have to pay if you decide to produce in the appropriate column. The record sheet MUST be filled in for each price after each transaction. For example, if you sold your coupon for L$60, you would record L$60 in the **Price** column and circle the plus sign.

Market Organization

The market is opened for a trading period lasting for ___________ minutes. Any buyer (or seller) is free to submit bids (or asks) to the market for a coupon. Below is a list of commands used to do so. The actual operation of the market will be demonstrated in a few minutes. For now it is important that you understand intuitively how the market works. Once a bid (or ask) is submitted to the market it is displayed in the bid (or ask) window. Other buyers (or sellers) may then submit their own bids (or asks) which must be improvements over those currently displayed. A buyer may only submit a bid greater than that already displayed on the market to have it accepted. Similarly, a seller may only submit an ask which is below that currently displayed in the market to be accepted. Bids and asks may also be withdrawn using the command list below. Any seller (or buyer) is free to accept a current bid (or ask). If a bid is accepted, a unit is sold by the seller who has decided to accept the bid to the buyer who submitted the current bid on the market. The bid display is then cleared and awaits new bids to be submitted. If an ask is accepted by a buyer, a unit is sold to that buyer by the seller who submitted the current ask price. The ask display is then cleared and awaits new asks to be submitted.

To enter an ask:

Type the quantity (1 in this experiment always) in the market box (the split red box to the right of your screen) then hit the space bar to move to the price box and enter your ask, then hit the F2 key. If you make an error in either box use the backspace key or delete key to remove your entry. Hitting the F2 key sends your ask to the market where it is displayed in the centre of the screen in the ASKS box. The market will not accept asks above the standing market ask already displayed in the asks box.

To sell a unit at the standing market bid price (to accept a bid):

The standing bid is displayed in the BID box. To accept this bid, type the quantity (always 1 in this experiment) in the quantity side of the red market box, or leave it blank, and press the CTRL and F1 keys at the same time.

To cancel an ask you have sent to the market:

If you have already submitted an ask to the market by hitting the F2 key after entering it in the red market box, and it is the standing ask, you may cancel it, provided someone does not accept your ask before you have canceled it. To do so press the ALT and F4 keys at the same time. This will remove your ask from the ASK box, restoring the previous standing ask.

Command Summary:

Move the cursor in the red market box: SPACEBAR
Clear entry in the red market box: BACKSPACE or DELETE

To submit an ask: enter 1 unit and bid price in market box and press F2
To cancel a submitted ask: press ALT-F4

To accept the current market bid (sell a unit to a buyer): CTRL-F1

Often encountered problems:

Market will not take your ask:

check:

1) press F2 only, not CTRL-F2
2) bid must be below standing ask

Fail to sell (accept a bid)

check:

1) make sure CTRL key is held down when hitting F1
2) red market box must be empty or exactly same as standing market bid
3) red market box must be empty or quantity must equal 1.

How to Sell your firms's Output:

After the close of the C-market you must indicate if you are producing a unit for the P-market. You do this by writing L$125 in the column marked **Total Revenue** on your record sheet. If you did not produce, write a zero in this column. You should then calculate your profit or loss for the period. Each period your firm will also earn a fixed revenue of L$0.50. This is shown on your record sheet each period. Once these calculations have been made, a new round will begin. Because the coupons are only good for one period , a new allocation of coupons is made, and the C-market opens again before you make another production choice. The number of rounds is predetermined, but unknown to you.

There will be three practice rounds before your decisions result affect the cash you earn. To familiarize you with the record sheet and the working C-market. After these rounds your balance will be put back to L$500 and you will be given new "production" and "additional" cost numbers. You will be paid in cash for your earnings for all periods after the first three. If you have any questions please raise your hand and it will be answered as soon as possible.

ETC Fringe Firm Instructions: Treatment 4

Instructions

You are about to participate in an experiment in the economics of decision making. Read the following instructions carefully. If you have any questions please raise your hand and wait for a monitor to come and help you. The money you will earn in this session will depend on the decisions you make and will be paid to you in CASH at the end of the session.

In this experiment you will be a producer in a market with several trading periods. Attached to the instructions, you will find a record sheet to enter transactions and a list of numbers. The record sheet also gives information about the decisions you make. **The information on the record sheet is your private information and is not to be revealed to anyone. Do not speak or otherwise communicate to others at any time during trading periods.** Please write your name, date and ID number at the top of the recordsheet. Your ID number is found on the outside of your instruction folder.

In the following instructions all dollar amounts are in Lab Dollars. The conversion rate of Lab Dollars to real money will be told to you before you begin.

General Information:

You are a producer of a ficticious commodity. In each trading period you will participate in two markets. The first is an input market where you are given an opportunity to buy an input which will lower you production costs. The second is the production market where you have the chance to sell your product, if you want to. You may or may not want to participate in one or both of these markets. That decision is left to you.

Instructions: Selling your Output and Calculating Your Profit

In this experiment you will be a seller in a market with several trading periods. You will start the experiment with a balance of L$500. In each trading period you may choose to produce nothing or produce and sell ONE unit of a commodity. If you produce the unit, you will be guaranteed to sell it in the primary market (P-market). The price in the P-market is determined by adding up the total amount of production from everyone and reading the price from thelist of numbers (attached to the instructions). For example, if you decide to produce and **the total production level for all firms** is 10 units, you will sell your unit for L$225.

If you decide to produce a unit you will incur a production cost. In addition to this production cost you will have an additional cost which is added to the production cost. These costs will be distributed to you by a monitor before the session starts. When you sell your unit in the P-market your profit is the selling price of your unit (L$125) minus the production cost AND minus the additional cost.

Profit = [P-market Price] - [production cost] - [additional cost]

Lowering Production Costs with Coupons

Before you decide if you want to produce and sell in the P-market, 10 coupons will be allocated amongst all the producers (you and the other subjects). These coupons cover the additional cost on each unit produced. In other words, if you have one coupon, you **don't** have to pay the additional cost on the last unit you produce.

Once the coupons have been allocated, you will have an opportunity to sell your coupon (if you were given one), or buy one (if you weren't given any and want one). This coupon market (C-market) is conducted using the computers and occurs before you need to decide whether you wish to produce and sell anything in the P-market. Instructions for participating in the C-market follow.

You will not receive any coupons to begin each trading period, therefore you are a buyer in the C-market. You may purchase up to 10 coupons. If you buy a coupon you will mark the sale price you received on your record sheet in the leftmost column.

How to Buy Coupons

Numbers used here are illustrative only and will have no relationship to those used in the actual session.

During each trading period you will be free to purchase one unit. If you purchase more than one in any period you will be fined L$5. **Units will be sold in this market one at a time.** There are two ways of buying a unit: you can accept a seller's asking price, or a seller can accept your bid.

During the trading period, the computer will display the lowest asking price by any seller. Later you will be told how to accept this ASK (asking price). The computer will also display the highest price bid by any buyer. Later, you will be told how to make your own BID.

Refer to your record sheet. For each unit you buy, you MUST record the price in the column labeled **Price and CIRCLE the MINUS SIGN.** The record sheet MUST be filled in for each price after each transaction.

Market Organization

The market is opened for a trading period lasting for __________ minutes. Any buyer or seller is free to submit bids (or asks) to the market for a coupon. Below is a list of commands used to do so. The actual operation of the market will be demonstrated in a few minutes. For now it is important that you understand intuitively how the market works. Once a bid (or ask) is submitted to the market it is displayed in the bid (or ask) window. Other buyers (or sellers) may then submit their own bids (or asks) which must be improvements over those currently displayed. A buyer may only submit a bid greater than that already displayed on the market to have it accepted. Similarly, a seller may only submit an ask which is below that currently displayed in the market to be accepted. Bids and offers may also be withdrawn using the command list below. Any seller (or buyer) is free to accept a current bid (or ask). If a bid is accepted, a unit is sold by the seller who has decided to accept the bid to the buyer who submitted the current bid on the market. The bid display is then cleared and awaits new bids to be submitted. If an ask is accepted by a buyer, a unit is sold to that buyer by the seller who submitted the current ask price. The ask display is then cleared and awaits new asks to be submitted.

To enter a bid:

Type the quantity (1 in this experiment always) in the market box (the split red box to the right of your screen) then hit the space bar to move to the price box and enter your bid. then hit the F1 key. If you make an error in either box use the backspace key or delete key to remove your entry. Hitting the F1 key sends your bid to the market where it is displayed in the centre of the screen in the BIDS box. The market will not accept bids below the standing market bid already displayed in the bids box.

To buy a unit at the standing market ask price (to accept an ask):

The standing ask is displayed in the ASK box. To accept this ask, type the quantity (always 1 in this experiment) in the quantity side of the red market box, or leave it blank, and press the CTRL and F2 keys at the same time.

To cancel a bid you have sent to the market:

If you have already submitted a bid to the market by hitting the F1 key after entering it in the red market box, and it is the standing bid, you may cancel it, provided someone does not accept your bid before you have canceled it. To do so press the ALT and F3 keys at the same time. This will remove your bid from the BIDS box, restoring the previous standing bid.

Command Summary:

Move the cursor in the red market box: SPACEBAR
Clear entry in the red market box: BACKSPACE or DELETE

To submit a bid: enter 1 unit and bid price in market box and press F1
To cancel a submitted bid: press ALT-F3

To accept the current market ask (buy a unit from a seller): CTRL-F2

Often encountered problems:

Market will not take your bid:

1) press F1 only, not CTRL-F1
2) bid must be above standing bid

Fail to buy

1) make sure CTRL key is held down when hitting F2
2) red market box must be empty or exactly same as standing market ask
3) red market box must be empty or quantity must equal 1.

How to Sell your firms's Output:

After the close of the C-market you must indicate if you are producing a unit for the P-market. You do this by using the card on your desk. If you wish to produce, turn your card so that one (1) is facing up. If you don't wish to produce put the zero (0) side up. Once the total number being produced is determined the market price will be announced. If you produced a unit put the announced price in the column marked **Total Revenue** on your record sheet. If you didn't produce put a zero in this column. You should then calculate your profit or loss for the period. Each period your firm will also earn a fixed revenue of L$50. This is shown on your record sheet each period.

Once these calculations have been made, a new round will begin. Because the coupons are only good for one period , a new allocation of coupons is made, and the C-market opens before you make your production choice. The number of rounds is predetermined, but unknown to you. There will be 3 practice rounds before the experiment starts to familiarize you with the record sheet and the working C-market. After these rounds your balance will be put back to L$500 and you will be given new "production" and "additional" cost numbers. You will be paid in cash for your earnings for all periods after the first three. If you have any questions please raise your hand and it will be answered as soon as possible.

Dominant firm Recordsheet: Treatment 1

Record Sheet

Period
Date

Name:
ID#.

This sheet will help you keep track of your income and costs.

Include total coupon expenditures in your profit calculations.

Trading Period Coupons Purchased Price	UNIT	Cost Schedules: Production Costs(L$) Cost/unit	Production Costs(L$) Total	Additional Costs($) Cost/unit	Additional Costs($) Total
1 ______	1	15	15	45	45
2 ______	2	15	30	65	110
3 ______	3	15	45	85	195
4 ______	4	15	60	105	300
5 ______	5	15	75	125	425
6 ______	6	15	90	145	570
7 ______	7	15	105	165	735
8 ______	8	15	120	185	920
9 ______	9	15	135	205	1125
10 ______	10	15	150	225	1350

______ **Total Coupon Purchases**

Calculation of Profit

Total Revenue	-	Total Production Cost	-	Total Additional Cost	-	Coupon Purchases	=	Profit

Units Produced

Price Announced in P-market (L$): 125

note: total revenue is found by multiplying units produced by price announced.

Dominant firm Recordsheet: Treatment 4

Record Sheet **Period**

Name:
ID#.

This sheet will help you keep track of your income and costs.

If you hold coupons as ending inventory simply cross out the additional cost of one more unit for each coupon you hold at the end of the L-market.

Include total coupon sales revenue in your profit calculations.

Trading Period Coupons Sales

Price		UNIT	Cost Schedules: Production Costs(L$) Cost/unit	Production Costs(L$) Total	Additional Costs(L$) Cost/unit	Additional Costs(L$) Total
1	______	1	15	15	45	45
2	______	2	15	30	65	110
3	______	3	15	45	85	195
4	______	4	15	60	105	300
5	______	5	15	75	125	425
6	______	6	15	90	145	570
7	______	7	15	105	165	735
8	______	8	15	120	185	920
9	______	9	15	135	205	1125
10	______	10	15	150	225	1350

______ **Total Coupon Sales**

Calculation of Profit

Total Revenue	-	Total Production Cost	-	Total Additional Cost	+	Coupon Sales	=	Profit

Units Produced

Price Announced in P-market: [ ]

note: total revenue is found by multiplying units produced by price announced.

Fringe Firm Recordsheet: All Treatments

Record Sheet

Name:
I.D. #:
Date:

Period	Total Revenue	-	Total Production Cost	-	Total Additional Cost	+or -	Price	Profit	Fixed Revenue (L$)	Total Payment
1		-		-		+or -			50	
2		-		-		+or -			50	
3		-		-		+or -			50	
4		-		-		+or -			50	
5		-		-		+or -			50	
6		-		-		+or -			50	
7		-		-		+or -			50	
8		-		-		+or -			50	
9		-		-		+or -			50	
10		-		-		+or -			50	
11		-		-		+or -			50	
12		-		-		+or -			50	
13		-		-		+or -			50	
14		-		-		+or -			50	
15		-		-		+or -			50	
16		-		-		+or -			50	
17		-		-		+or -			50	
18		-		-		+or -			50	
19		-		-		+or -			50	
20		-		-		+or -			50	
21		-		-		+or -			50	
22		-		-		+or -			50	
23		-		-		+or -			50	
						Total Profit				

Demand Schedule Given to all Firms: Treatments 3 and 4

P-Market
Price
Schedule

Total Quantity	Price
1	405
2	385
3	365
4	345
5	325
6	305
7	285
8	265
9	245
10	225
11	205
12	185
13	165
14	145
15	125
16	105
17	85
18	65
19	45
20	25

Fringe Costs List given to Dominant Firm

	Other Firms Costs	
	Production Costs	Additional Cost
Firm A	$0.45	$0.36
Firm B	$0.45	$0.75
FirmC	$0.40	$1.15
Firm D	$0.35	$1.55
Firm E	$0.30	$1.95
Firm F	$0.25	$2.35
Firm G	$0.20	$2.75
Firm H	$0.15	$3.15
Firm I	$0.10	$3.55
Firm J	$0.05	$3.95

Notes:

- there are 10 firms in the other room.
- each firm produces a single unit with costs above (1 set of costs per firm (letters A-J))

Dominant firm instructions-Treatments 1 and 2

Instructions

You are about to participate in an experiment in the economics of decision making. Read the following instructions carefully. If you have any questions please raise your hand and wait for a monitor to come and help you. The money you will earn in this session will depend on the decisions you and the other participants make and will be paid to you in CASH at the end of the session.

Attached to the instructions, you will find a recordsheet for each period to enter transactions. You will find a production and additional cost schedule. You will also find a list of costs for the other firms. **The information on the production and additional costs schedule is your private information and is not to be revealed to anyone. Do not speak or otherwise communicate to others at any time during trading periods.** Your ID number is found on the outside of your instruction folder. Please write your name, date and ID number at the top of each recordsheet you use. Do this now.

In the following instructions all dollar amounts are in Lab Dollars. The conversion rate of Lab Dollars to real money will be told to you before you begin.

General Information:

You are a producer of a fictitious commodity. In each trading period you will participate in two markets. The first is an input (called the coupon market) market where you are given an opportunity to buy and sell an input which will lower your production costs. The second is the production market where you have the chance to sell your product, if you want to. You may or may not want to participate in one or both of these markets. That decision is left to you. The first market is conducted on computers. The operation of these computers is explained below.

Instructions:

How to Buy and Sell Coupons in the coupon market:

Numbers used here are illustrative only and will have no relationship to those used in the actual session.

During each trading period you will be free to sell or purchase from the market as many coupons as you would like (however you may only sell coupons you already own). **These coupons will be bought and sold one at a time. There are two ways of buying a coupon: you can accept a seller's asking price, or a seller can accept your bid. Similarly there are two ways to sell a coupon, a buyer can accept your asking price or you can accept a buyer's bid.**

During the trading period, the computer will display the lowest asking price by any seller. Later you will be told how to accept this ASK (asking price) to purchase a coupon. You will also be told how to make your own ASK of you wish to sell a coupon. The computer will also display the highest price bid by any buyer. Later, you will be told how to accept this BID to sell a coupon if you wish to. You will also be shown how to make your own BID to buy a coupon. The computer also displays your current coupon holdings (inventory). Please note unused coupon inventories **do not carry into the next period.**

Selling:

Refer to your record sheet. For each unit you sell, you MUST record the price in the column labeled **Selling Price**. The record sheet MUST be filled in for each price after each transaction. For example, if in your first transaction you sold your first coupon for L$60, you would record L$60 in the **Selling Price** column in the first row. If you sold another coupon for L$55 you would record this price in the **Selling Price** column in the second row. At the end of the period total up your sales revenues and write this number on the **Totals** line under the **Selling Price** column. Were these the only sales you made in the period you would enter L$115 on this line.

Buying:

For each coupon you buy, you MUST also record the price in the column labeled **Purchase Price**. The record sheet MUST be filled in for each price after each transaction. For example, if in your third transaction you bought your first coupon for L$60, you would record L$60 in the **Purchase Price** column next in the third transaction row. If in your next transaction you bought another coupon for L$40 you would record this price in the **Purchase Price** column in the fourth row. Note that although these were your first and second purchases, they were your third and fourth transactions, and so are recorded in the third and fourth transactions rows. At the end of the period total up your expenditures and write this number on the **Totals** line under the **Purchase Price** column. Were these the only purchases you made in the period you would enter L$110 on this line. Note there are many transactions rows to accommodate re-selling and re-buying if it occurs. If you were to run out of rows use the back of the sheet.

If you forget to record a purchase or selling price the HISTORY button (F3) is available to review past transactions.

Market Organization

The market is opened for a trading period lasting for some minutes (announced before each period). The actual operation of the market will be demonstrated in a few minutes. For now it is important that you understand intuitively how the market works. Once a bid (or ask) is submitted to the market it is displayed in the bid (or ask) window. Other buyers (or sellers) may then submit their own bids (or asks) which must be improvements over those currently displayed. A buyer may only submit a bid greater than that already

displayed on the market to have it accepted and displayed as the standing market bid. Similarly, a seller may only submit an ask which is below that currently displayed in the market to be accepted. Bids and offers may also be withdrawn using the command list below. Anyone holding a coupon is free to accept a current bid to buy a coupon (you must be holding a coupon in order to sell it to the bidder). If a bid is accepted, a coupon is sold by the seller who has decided to accept the bid to the buyer who submitted the current bid on the market. The bid display is then cleared and awaits new bids to be submitted. If an ask is accepted by a buyer, a unit is sold to that buyer by the seller who submitted the current ask price. The ask display is then cleared and awaits new asks to be submitted.

To enter a bid:

Type the quantity (1 always) in the market box (the split red box to the right of your screen) then hit the space bar to move to the price box and enter your bid. Then hit the F1 key. If you make an error in either box use the backspace key or delete key to remove your entry. Hitting the F1 key sends your bid to the market where it is displayed in the centre of the screen in the BIDS box. The market will not accept bids below the standing market bid already displayed in the bids box.

To buy a unit at the standing market ask price (to accept an ask):

The standing ask is displayed in the ASK box. To accept this ask, type the quantity (always 1 in this experiment) in the quantity side of the red market box, or leave it blank, and press the CTRL and F2 keys at the same time.

To cancel a bid you have sent to the market:

If you have already submitted a bid to the market by hitting the F1 key after entering it in the red market box, and it is the standing bid, you may cancel it, provided someone does not accept your bid before you have canceled it. To do so press the ALT and F3 keys at the same time. This will remove your bid from the BIDS box, restoring the previous standing bid.

To enter an ask:

Type the quantity (1 in this experiment always) in the market box (the split red box to the right of your screen) then hit the space bar to move to the price box and enter your ask, then hit the F2 key. If you make an error in either box use the backspace key or delete key to remove your entry. Hitting the F2 key sends your ask to the market where it is displayed in the centre of the screen in the ASK box. The market will not accept asks above the standing market ask already displayed in the asks box.

To sell a unit at the standing market bid price (to accept a bid):

The standing ask is displayed in the BIDS box. To accept this bid, type the quantity (always 1 in this experiment) in the quantity side of the red market box, or leave it blank, and press the CTRL and F1 keys at the same time.

To cancel an ask you have sent to the market:

If you have already submitted an ask to the market by hitting the F2 key after entering it in the red market box, and it is the standing ask, you may cancel it, provided someone does not accept your ask before you have canceled it. To do so press the ALT and F4 keys at the same time. This will remove your ask from the ASK box, restoring the previous standing ask.

Command Summary:

Move the cursor in the red market box: SPACEBAR
Clear entry in the red market box: BACKSPACE or DELETE

To submit a bid: enter 1 unit and bid price in market box and press F1
To cancel a submitted bid: press ALT-F3
To submit an ask: enter 1 unit and bid price in market box and press F2
To cancel a submitted ask: press ALT-F4

To accept the current market ask (buy a unit from a seller): CTRL-F2
To accept the current market bid (sell a unit to a buyer): CTRL-F1

History key to view previous transactions: F3

Often encountered problems:

Market will not take your bid:

1) press F1 only, not CTRL-F1
2) bid must be above standing bid

Fail to buy

1) make sure CTRL key is held down when hitting F2
2) red market box must be empty or exactly same as standing market ask
3) red market box must be empty or quantity must equal 1.

Market will not take your ask:

1) press F2 only, not CTRL-F2
2) bid must be below standing ask

Fail to sell (accept a bid)

1) make sure CTRL key is held down when hitting F1
2) red market box must be empty or exactly same as standing market bid
3) red market box must be empty or quantity must equal 1.

PLEASE PUT DOWN YOUR INSTRUCTIONS NOW AND WHEN EVERYONE IS READY WE WILL DEMONSTRATE HOW THE COMPUTERS WORK.

Selling your output and calculating your profit

In each trading period you may choose to produce and sell up to ten (10) units of a fictitious commodity, which you can sell in the primary market (P-market). The price in the P-market is L$125. For example, if you decide to produce 5 units you will have revenue of L$625. If you produced 10 units you would have revenue of L$1250.

For each unit you decide to produce you will have a production cost of L$15 (lab dollars). In addition to this production cost you will have an additional cost that increases with each unit produced, and is added to the production cost. The "Production and Additional Costs Schedule" shows your additional costs. When you sell your unit(s) in the P-market your profit is the total revenue from the sale of the unit(s) (sales price multiplied by the number of units sold) minus the total production cost(s) AND minus the total additional cost(s).

Profit = [total revenue] - [total production cost] - [total additional cost]

Lowering Production Costs with Coupons

Before you decide how many units you want to produce and sell in the P-market, 10 coupons will be allocated amongst all the producers (you and the other subjects). These coupons cover the additional cost on each unit produced. In other words, if you have one coupon, you **don't** have to pay the additional cost on the last unit you produce. If you have two coupons you **don't** have to pay the additional costs on the last two units you produce, and so on.

Once the coupons have been allocated, you will have an opportunity to sell your coupons (if you were given any), buy them (if you weren't given any and want some) or re-sell or re-buy coupons. This coupon market (C-market) is conducted using the computers, and occurs before you need to decide whether you wish to produce and sell anything in the P-market. Instructions for participating in the C-market follow.

You may or may not be initially endowed with coupons to begin each trading period. If you are endowed with coupons or purchase some in a trading period you may sell or re-sell them. There is no limit to the number of coupons you may buy or sell, except that you may not sell coupons you do not have. If you buy or sell a coupon you will mark the purchase or selling price you received on your record sheet in the appropriate column. **Note each transaction you make is recorded in order.**

<u>How to Sell your firm's Output:</u>

After the close of the C-market you must indicate how many units you are producing for the P-market. You do this by writing the number of units you want to produce in the **Units Produced** box. Total Revenue is found by multiplying this number by L$125. You may then calculate your profit or loss for the period.

Once these calculations have been made, a new round will begin. Because the coupons are only good for one period , a new allocation of coupons is made. The number of rounds is predetermined, but unknown to you.

There will be 2 or 3 practice rounds before the experiment starts to familiarize you with the record sheet and the working C-market. After these rounds your balance will be put back to L$0. You will be paid in cash for your earnings for all periods after the first three.

When the session is over your earnings will be based on your profits earned in the session. You will be told beforehand what the conversion rate for Lab dollars to Canadian dollars before we begin. **NEGATIVE PROFITS WILL COUNT AGAINST YOUR EARNINGS.**

If you have any questions please raise your hand and it will be answered as soon as possible. Please do not ask any questions aloud which give away any information on your record sheet.

Dominant firm instructions-Treatments 3 and 4

Instructions

You are about to participate in an experiment in the economics of decision making. Read the following instructions carefully. If you have any questions please raise your hand and wait for a monitor to come and help you. The money you will earn in this session will depend on the decisions you and the other participants make and will be paid to you in CASH at the end of the session.

Attached to the instructions, you will find a recordsheet for each period to enter transactions. You will find a production and additional cost schedule, as well as a P-market price schedule. You will also find a list of costs for the other firms. **The information on the production and additional costs schedule is your private information and is not to be revealed to anyone. Do not speak or otherwise communicate to others at any time during trading periods.** Your ID number is found on the outside of your instruction folder. Please write your name, date and ID number at the top of each recordsheet you use. Do this now.

In the following instructions all dollar amounts are in Lab Dollars. The conversion rate of Lab Dollars to real money will be told to you before you begin.

General Information:

You are a producer of a fictitious commodity. In each trading period you will participate in two markets. The first is an input (called the coupon market) market where you are given an opportunity to buy and sell an input which will lower your production costs. The second is the production market where you have the chance to sell your product, if you want to. You may or may not want to participate in one or both of these markets. That decision is left to you. The first market is conducted on computers. The operation of these computers is explained below.

Instructions:

How to Buy and Sell Coupons in the coupon market:

Numbers used here are illustrative only and will have no relationship to those used in the actual session.

During each trading period you will be free to sell or purchase from the market as many coupons as you would like (however you may only sell coupons you already own). **These coupons will be bought and sold one at a time. There are two ways of buying a coupon: you can accept a seller's asking price, or a seller can accept your bid. Similarly there are two ways to sell a coupon, a buyer can accept your asking price or you can accept a buyer's bid.**

During the trading period, the computer will display the lowest asking price by any seller. Later you will be told how to accept this ASK (asking price) to purchase a coupon. You will also be told how to make your own ASK of you wish to sell a coupon. The computer will also display the highest price bid by any buyer. Later, you will be told how to accept this BID to sell a coupon if you wish to. You will also be shown how to make your own BID to buy a coupon. The computer also displays your current coupon holdings (inventory). Please note unused coupon inventories **do not carry into the next period.**

Selling:

Refer to your record sheet. For each unit you sell, you MUST record the price in the column labeled **Selling Price**. The record sheet MUST be filled in for each price after each transaction. For example, if in your first transaction you sold your first coupon for L$60, you would record L$60 in the **Selling Price** column in the first row. If you sold another coupon for L$55 you would record this price in the **Selling Price** column in the second row. At the end of the period total up your sales revenues and write this number on the **Totals** line under the **Selling Price** column. Were these the only sales you made in the period you would enter L$115 on this line.

Buying:

For each coupon you buy, you MUST also record the price in the column labeled **Purchase Price**. The record sheet MUST be filled in for each price after each transaction. For example, if in your third transaction you bought your first coupon for L$70, you would record L$60 in the **Purchase Price** column next in the third transaction row. If in your next transaction you bought another coupon for L$40 you would record this price in the **Purchase Price** column in the fourth row. Note that although these were your first and second purchases, they were your third and fourth transactions, and so are recorded in the third and fourth transactions rows. At the end of the period total up your expenditures and write this number on the **Totals** line under the **Purchase Price** column. Were these the only purchases you made in the period you would enter L$110 on this line. Note there are many transactions rows to accommodate re-selling and re-buying if it occurs. If you were to run out of rows use the back of the sheet.

If you forget to record a purchase or selling price the HISTORY button (F3) is available to review past transactions.

Market Organization

The market is opened for a trading period lasting for some minutes (announced before each period). The actual operation of the market will be demonstrated in a few minutes. For now it is important that you understand intuitively how the market works. Once a bid (or ask) is submitted to the market it is displayed in the bid (or ask) window. Other buyers (or sellers) may then submit their own bids (or asks) which must be improvements over those currently displayed. A buyer may only submit a bid greater than that already displayed on the market to have it accepted and displayed as the standing market bid. Similarly, a seller may only submit an ask which is below that currently displayed in the market to be accepted. Bids and offers may also be withdrawn using the command list below. Anyone holding a coupon is free to accept a current bid to buy a coupon (you must be holding a coupon in order to sell it to the bidder). If a bid is accepted, a coupon is sold by the seller who has decided to accept the bid to the buyer who submitted the current bid on the market. The bid display is then cleared and awaits new bids to be submitted. If an ask is accepted by a buyer, a unit is sold to that buyer by the seller who submitted the current ask price. The ask display is then cleared and awaits new asks to be submitted.

To enter a bid:

Type the quantity (1 always) in the market box (the split red box to the right of your screen) then hit the space bar to move to the price box and enter your bid. Then hit the F1 key. If you make an error in either box use the backspace key or delete key to remove your entry. Hitting the F1 key sends your bid to the market where it is displayed in the centre of the screen in the BIDS box. The market will not accept bids below the standing market bid already displayed in the bids box.

To buy a unit at the standing market ask price (to accept an ask):

The standing ask is displayed in the ASK box. To accept this ask, type the quantity (always 1 in this experiment) in the quantity side of the red market box, or leave it blank, and press the CTRL and F2 keys at the same time.

To cancel a bid you have sent to the market:

If you have already submitted a bid to the market by hitting the F1 key after entering it in the red market box, and it is the standing bid, you may cancel it, provided someone does not accept your bid before you have canceled it. To do so press the ALT and F3 keys at the same time. This will remove your bid from the BIDS box, restoring the previous standing bid.

To enter an ask:

Type the quantity (1 in this experiment always) in the market box (the split red box to the right of your screen) then hit the space bar to move to the price box and enter your ask, then hit the F2 key. If you make an error in either box use the backspace key or delete key to remove your entry. Hitting the F2 key sends your ask to the market where it is displayed in the centre of the screen in the ASK box. The market will not accept asks above the standing market ask already displayed in the asks box.

To sell a unit at the standing market bid price (to accept a bid):

The standing ask is displayed in the BIDS box. To accept this bid, type the quantity (always 1 in this experiment) in the quantity side of the red market box, or leave it blank, and press the CTRL and F1 keys at the same time.

To cancel an ask you have sent to the market:

If you have already submitted an ask to the market by hitting the F2 key after entering it in the red market box, and it is the standing ask, you may cancel it, provided someone does not accept your ask before you have canceled it. To do so press the ALT and F4 keys at the same time. This will remove your ask from the ASK box, restoring the previous standing ask.

Command Summary:

Move the cursor in the red market box: SPACEBAR
Clear entry in the red market box: BACKSPACE or DELETE

To submit a bid:	enter 1 unit and bid price in market box and press F1
To cancel a submitted bid:	press ALT-F3
To submit an ask:	enter 1 unit and bid price in market box and press F2
To cancel a submitted ask:	press ALT-F4

To accept the current market ask (buy a unit from a seller): CTRL-F2
To accept the current market bid (sell a unit to a buyer): CTRL-F1

History key to view previous transactions: F3

Often encountered problems:

Market will not take your bid:

1) press F1 only, not CTRL-F1
2) bid must be above standing bid

Fail to buy

1) make sure CTRL key is held down when hitting F2
2) red market box must be empty or exactly same as standing market ask
3) red market box must be empty or quantity must equal 1.

Market will not take your ask:

1) press F2 only, not CTRL-F2
2) bid must be below standing ask

Fail to sell (accept a bid)

1) make sure CTRL key is held down when hitting F1
2) red market box must be empty or exactly same as standing market bid
3) red market box must be empty or quantity must equal 1.

PLEASE PUT DOWN YOUR INSTRUCTIONS NOW AND WHEN EVERYONE IS READY WE WILL DEMONSTRATE HOW THE COMPUTERS WORK.

Selling your output and calculating your profit

In each trading period you may choose to produce and sell up to ten (10) units of a fictitious commodity, which you can sell in the product market (P-market). The price in the P-market is determined by adding up the total amount of production from everyone and reading from the list of numbers (attached to the instructions). For example, if you decide to produce 5 units, **and the total production level for all firms** is 10 units, you will sell your units for L$225. This gives you total revenues of L$1125 (5 x L$225 = L$1125).

For each unit you decide to produce you will have a production cost of L$15 (lab dollars). In addition to this production cost you will have an additional cost that increases with each unit produced, and is added to the production cost. The "Production and Additional Costs Schedule" shows your additional costs. When you sell your unit(s) in the P-market your profit is the total revenue from the sale of the unit(s) (sales price multiplied by the number of units sold) minus the total production cost(s) AND minus the total additional cost(s).

Profit = [total revenue] - [total production cost] - [total additional cost]

Lowering Production Costs with Coupons

Before you decide how many units you want to produce and sell in the P-market, 10 coupons will be allocated amongst all the producers (you and the other subjects). These coupons cover the additional cost on each unit produced. In other words, if you have one coupon, you **don't** have to pay the additional cost on the last unit you produce. If you have two coupons you **don't** have to pay the additional costs on the last two units you produce, and so on.

Once the coupons have been allocated, you will have an opportunity to sell your coupons (if you were given any), buy them (if you weren't given any and want some) or re-sell or re-buy coupons. This coupon market (C-market) is conducted using the computers, and occurs before you need to decide whether you wish to produce and sell anything in the P-market. Instructions for participating in the C-market follow.

You may or may not be initially endowed with coupons to begin each trading period. If you are endowed with coupons or purchase some in a trading period you may sell or re-sell them. There is no limit to the number of coupons you may buy or sell, except that you may not sell coupons you do not have. If you buy or sell a coupon you will mark the purchase or selling price you received on your record sheet in the appropriate column. **Note each transaction you make is recorded in order.**

How to Sell your firm's Output:

After the close of the C-market you must indicate how many units you are producing for the P-market. You do this by writing this amount in the **Units Produced** box on your record sheet. An experimenter will come around and record your decision which cannot be changed once recorded. When the price is announced, record it on your record sheet and take the amount you decided to produce and multiply it by the announced price (found after total production by everyone is known). Write this number in the column marked Total Revenue on your record sheet. You may then calculate your profit or loss for the period.

Once these calculations have been made, a new round will begin. Because the coupons are only good for one period , a new allocation of coupons is made. The number of rounds is predetermined, but unknown to you.

There will be 2 or 3 practice rounds before the experiment starts to familiarize you with the record sheet and the working C-market. After these rounds your balance will be put back to L$0. You will be paid in cash for your earnings for all periods after the first three.

When the session is over your earnings will be based on your profits earned in the session. You will be told beforehand what the conversion rate for Lab dollars to Canadian dollars before we begin. **NEGATIVE PROFITS WILL COUNT AGAINST YOUR EARNINGS.**

If you have any questions please raise your hand and it will be answered as soon as possible. Please do not ask any questions aloud which give away any information on your record sheet.

Fringe firm instructions-Treatments 1 and 2

Instructions

You are about to participate in an experiment in the economics of decision making. Read the following instructions carefully. If you have any questions please raise your hand and wait for a monitor to come and help you. The money you will earn in this session will depend on the decisions you and the other participants make and will be paid to you in CASH at the end of the session.

Attached to the instructions, you will find a recordsheet for each period to enter transactions. You will also find a production and additional cost schedule. **The information on the production and additional costs schedule is your private information and is not to be revealed to anyone. Do not speak or otherwise communicate to others at any time during trading periods.** Your ID number is found on the outside of your instruction folder. Please write your name, date and ID number at the top of each recordsheet you use. Do this now.

In the following instructions all dollar amounts are in Lab Dollars. The conversion rate of Lab Dollars to real money will be told to you before you begin.

General Information:

You are a producer of a fictitious commodity. In each trading period you will participate in two markets. The first is an input (called the coupon market) market where you are given an opportunity to buy and sell an input which will lower your production costs. The second is the production market where you have the chance to sell your product, if you want to. You may or may not want to participate in one or both of these markets. That decision is left to you. The first market is conducted on computers. The operation of these computers is explained below.

Instructions:

How to Buy and Sell Coupons in the coupon market:

Numbers used here are illustrative only and will have no relationship to those used in the actual session.

During each trading period you will be free to sell or purchase from the market as many coupons as you would like (however you may only sell coupons you already own). **These coupons will be bought and sold one at a time. There are two ways of buying a coupon: you can accept a seller's asking price, or a seller can accept your bid. Similarly there are two ways to sell a coupon, a buyer can accept your asking price or you can accept a buyer's bid.**

During the trading period, the computer will display the lowest asking price by any seller. Later you will be told how to accept this ASK (asking price) to purchase a coupon. You will also be told how to make your own ASK of you wish to sell a coupon. The computer will also display the highest price bid by any buyer. Later, you will be told how to accept this BID to sell a coupon if you wish to. You will also be shown how to make your own BID to buy a coupon. The computer also displays your current coupon holdings (inventory). Please note unused coupon inventories **do not carry into the next period.**

Selling:

Refer to your record sheet. For each unit you sell, you MUST record the price in the column labeled **Selling Price**. The record sheet MUST be filled in for each price after each transaction. For example, if in your first transaction you sold your first coupon for L$60, you would record L$60 in the **Selling Price** column in the first row. If you sold another coupon for L$55 you would record this price in the **Selling Price** column in the second row. At the end of the period total up your sales revenues and write this number on the **Totals** line under the **Selling Price** column. Were these the only sales you made in the period you would enter L$115 on this line.

Buying:

For each coupon you buy, you MUST also record the price in the column labeled **Purchase Price**. The record sheet MUST be filled in for each price after each transaction. For example, if in your third transaction you bought your first coupon for L$70, you would record L$60 in the **Purchase Price** column next in the third transaction row. If in your next transaction you bought another coupon for L$40 you would record this price in the **Purchase Price** column in the fourth row. Note that although these were your first and second purchases, they were your third and fourth transactions, and so are recorded in the third and fourth transactions rows. At the end of the period total up your expenditures and write this number on the **Totals** line under the **Purchase Price** column. Were these the only purchases you made in the period you would enter L$110 on this line. Note there are many transactions rows to accommodate re-selling and re-buying if it occurs. If you were to run out of rows use the back of the sheet.

If you forget to record a purchase or selling price the HISTORY button (F3) is available to review past transactions.

Market Organization

The market is opened for a trading period lasting for some minutes (announced before each period). The actual operation of the market will be demonstrated in a few minutes. For now it is important that you understand intuitively how the market works. Once a bid (or ask) is submitted to the market it is displayed in the bid (or ask) window. Other buyers (or sellers) may then submit their own bids (or asks) which must be improvements over those currently displayed. A buyer may only submit a bid greater than that already

displayed on the market to have it accepted and displayed as the standing market bid. Similarly, a seller may only submit an ask which is below that currently displayed in the market to be accepted. Bids and offers may also be withdrawn using the command list below. Anyone holding a coupon is free to accept a current bid to buy a coupon (you must be holding a coupon in order to sell it to the bidder). If a bid is accepted, a coupon is sold by the seller who has decided to accept the bid to the buyer who submitted the current bid on the market. The bid display is then cleared and awaits new bids to be submitted. If an ask is accepted by a buyer, a unit is sold to that buyer by the seller who submitted the current ask price. The ask display is then cleared and awaits new asks to be submitted.

To enter a bid:

Type the quantity (1 always) in the market box (the split red box to the right of your screen) then hit the space bar to move to the price box and enter your bid. Then hit the F1 key. If you make an error in either box use the backspace key or delete key to remove your entry. Hitting the F1 key sends your bid to the market where it is displayed in the centre of the screen in the BIDS box. The market will not accept bids below the standing market bid already displayed in the bids box.

To buy a unit at the standing market ask price (to accept an ask):

The standing ask is displayed in the ASK box. To accept this ask, type the quantity (always 1 in this experiment) in the quantity side of the red market box, or leave it blank, and press the CTRL and F2 keys at the same time.

To cancel a bid you have sent to the market:

If you have already submitted a bid to the market by hitting the F1 key after entering it in the red market box, and it is the standing bid, you may cancel it, provided someone does not accept your bid before you have canceled it. To do so press the ALT and F3 keys at the same time. This will remove your bid from the BIDS box, restoring the previous standing bid.

To enter an ask:

Type the quantity (1 in this experiment always) in the market box (the split red box to the right of your screen) then hit the space bar to move to the price box and enter your ask, then hit the F2 key. If you make an error in either box use the backspace key or delete key to remove your entry. Hitting the F2 key sends your ask to the market where it is displayed in the centre of the screen in the ASK box. The market will not accept asks above the standing market ask already displayed in the asks box.

To sell a unit at the standing market bid price (to accept a bid):

The standing ask is displayed in the BIDS box. To accept this bid, type the quantity (always 1 in this experiment) in the quantity side of the red market box, or leave it blank, and press the CTRL and F1 keys at the same time.

To cancel an ask you have sent to the market:

If you have already submitted an ask to the market by hitting the F2 key after entering it in the red market box, and it is the standing ask, you may cancel it, provided someone does not accept your ask before you have canceled it. To do so press the ALT and F4 keys at the same time. This will remove your ask from the ASK box, restoring the previous standing ask.

Command Summary:

Move the cursor in the red market box: SPACEBAR
Clear entry in the red market box: BACKSPACE or DELETE

To submit a bid: enter 1 unit and bid price in market box and press F1
To cancel a submitted bid: press ALT-F3
To submit an ask: enter 1 unit and bid price in market box and press F2
To cancel a submitted ask: press ALT-F4

To accept the current market ask (buy a unit from a seller): CTRL-F2
To accept the current market bid (sell a unit to a buyer): CTRL-F1

History key to view previous transactions: F3

Often encountered problems:

Market will not take your bid:

1) press F1 only, not CTRL-F1
2) bid must be above standing bid

Fail to buy

1) make sure CTRL key is held down when hitting F2
2) red market box must be empty or exactly same as standing market ask
3) red market box must be empty or quantity must equal 1.

Market will not take your ask:

1) press F2 only, not CTRL-F2
2) bid must be below standing ask

Fail to sell (accept a bid)

1) make sure CTRL key is held down when hitting F1
2) red market box must be empty or exactly same as standing market bid
3) red market box must be empty or quantity must equal 1.

PLEASE PUT DOWN YOUR INSTRUCTIONS NOW AND WHEN EVERYONE IS READY WE WILL DEMONSTRATE HOW THE COMPUTERS WORK.

Selling your output and calculating your profit

In each trading period you may choose to produce and sell up to two (2) units of a fictitious commodity, which you can sell in the product market (P-market). The price in the P-market is L$125. For example, if you decide to produce 1 unit you will have revenue of L$125. If you produced 2 units you would have revenue of L$250.

For each unit you decide to produce you will have a production cost. In addition to this production cost you will have an additional cost that increases with each unit produced, and is added to the production cost. The "Production and Additional Costs Schedule" describes your production and additional costs. When you sell your unit(s) in the P-market your profit is the total revenue from the sale of the unit(s) (sales price multiplied by the number of units sold) minus the total production cost(s) AND minus the total additional cost(s).

Profit = [total revenue] - [total production cost] - [total additional cost]

Lowering Production Costs with Coupons

Before you decide how many units you want to produce and sell in the P-market, 10 coupons will be allocated amongst all the producers (you and the other subjects). These coupons cover the additional cost on each unit produced. In other words, if you have one coupon, you **don't** have to pay the additional cost on the last unit you produce. If you have two coupons you **don't** have to pay the additional costs on the last two units you produce, and so on.

Once the coupons have been allocated, you will have an opportunity to sell your coupons (if you were given any), buy them (if you weren't given any and want some) or re-sell or re-buy coupons. This coupon market (C-market) is conducted using the computers, and occurs before you need to decide whether you wish to produce and sell anything in the P-market.

You may or may not be initially endowed with coupons to begin each trading period. If you are endowed with coupons or purchase some in a trading period you may sell or re-sell them. There is no limit to the number of coupons you may buy or sell, except that you may not sell coupons you do not have. If you buy or sell a coupon you will mark the purchase or selling price you received on your record sheet in the appropriate column. **Note each transaction you make is recorded in order.**

How to Sell your firm's Output:

After the close of the C-market you must indicate how many units you are producing for the P-market. You do this by writing the number of units you want to produce in the **Units Produced** box (either a zero, one or two). Total Revenue is found by multiplying this number by L$125. You may then calculate your profit or loss for the period using information on your costs schedule and coupon market totals on your recordsheet .

Once these calculations have been made, a new round will begin. Because the coupons are only good for one period , a new allocation of coupons is made. The number of rounds is predetermined, but unknown to you.

There will be 2 or 3 practice rounds before the experiment starts to familiarize you with the record sheet and the working C-market. After these rounds your balance will be put back to L$0.

When the session is over your earnings will be based on your profits earned in the session. You will be told beforehand what the conversion rate for Lab dollars to Canadian dollars before we begin. **NEGATIVE PROFITS WILL COUNT AGAINST YOUR EARNINGS.**

If you have any questions please raise your hand and it will be answered as soon as possible. Please do not ask any questions aloud which give away any information on your record sheet.

Fringe firm instructions-Treatments 3 and 4

Instructions

You are about to participate in an experiment in the economics of decision making. Read the following instructions carefully. If you have any questions please raise your hand and wait for a monitor to come and help you. The money you will earn in this session will depend on the decisions you and the other participants make and will be paid to you in CASH at the end of the session.

Attached to the instructions, you will find a recordsheet for each period to enter transactions. You will also find a production and additional cost schedule, as well as a P-market price schedule. **The information on the production and additional costs schedule is your private information and is not to be revealed to anyone. Do not speak or otherwise communicate to others at any time during trading periods.** Your ID number is found on the outside of your instruction folder. Please write your name, date and ID number at the top of each recordsheet you use. Do this now.

In the following instructions all dollar amounts are in Lab Dollars. The conversion rate of Lab Dollars to real money will be told to you before you begin.

General Information:

You are a producer of a fictitious commodity. In each trading period you will participate in two markets. The first is an input (called the coupon market) market where you are given an opportunity to buy and sell an input which will lower your production costs. The second is the production market where you have the chance to sell your product, if you want to. You may or may not want to participate in one or both of these markets. That decision is left to you. The first market is conducted on computers. The operation of these computers is explained below.

Instructions:

How to Buy and Sell Coupons in the coupon market:

Numbers used here are illustrative only and will have no relationship to those used in the actual session.

During each trading period you will be free to sell or purchase from the market as many coupons as you would like (however you may only sell coupons you already own). **These coupons will be bought and sold one at a time. There are two ways of buying a coupon: you can accept a seller's asking price, or a seller can accept your bid. Similarly there are two ways to sell a coupon, a buyer can accept your asking price or you can accept a buyer's bid.**

During the trading period, the computer will display the lowest asking price by any seller. Later you will be told how to accept this ASK (asking price) to purchase a coupon. You will also be told how to make your own ASK of you wish to sell a coupon. The computer will also display the highest price bid by any buyer. Later, you will be told how to accept this BID to sell a coupon if you wish to. You will also be shown how to make your own BID to buy a coupon. The computer also displays your current coupon holdings (inventory). Please note unused coupon inventories **do not carry into the next period.**

Selling:

Refer to your record sheet. For each unit you sell, you MUST record the price in the column labeled **Selling Price.** The record sheet MUST be filled in for each price after each transaction. For example, if in your first transaction you sold your first coupon for L$60, you would record L$60 in the **Selling Price** column in the first row. If you sold another coupon for L$55 you would record this price in the **Selling Price** column in the second row. At the end of the period total up your sales revenues and write this number on the **Totals** line under the **Selling Price** column. Were these the only sales you made in the period you would enter L$115 on this line.

Buying:

For each coupon you buy, you MUST also record the price in the column labeled **Purchase Price.** The record sheet MUST be filled in for each price after each transaction. For example, if in your third transaction you bought your first coupon for L$70, you would record L$60 in the **Purchase Price** column next in the third transaction row. If in your next transaction you bought another coupon for L$40 you would record this price in the **Purchase Price** column in the fourth row. Note that although these were your first and second purchases, they were your third and fourth transactions, and so are recorded in the third and fourth transactions rows. At the end of the period total up your expenditures and write this number on the **Totals** line under the **Purchase Price** column. Were these the only purchases you made in the period you would enter L$110 on this line. Note there are many transactions rows to accommodate re-selling and re-buying if it occurs. If you were to run out of rows use the back of the sheet.

If you forget to record a purchase or selling price the HISTORY button (F3) is available to review past transactions.

Market Organization

The market is opened for a trading period lasting for some minutes (announced before each period). The actual operation of the market will be demonstrated in a few minutes. For now it is important that you understand intuitively how the market works. Once a bid (or ask) is submitted to the market it is displayed in the bid (or ask) window. Other buyers (or sellers) may then submit their own bids (or asks) which must be improvements over those currently displayed. A buyer may only submit a bid greater than that already

displayed on the market to have it accepted and displayed as the standing market bid. Similarly, a seller may only submit an ask which is below that currently displayed in the market to be accepted. Bids and offers may also be withdrawn using the command list below. Anyone holding a coupon is free to accept a current bid to buy a coupon (you must be holding a coupon in order to sell it to the bidder). If a bid is accepted, a coupon is sold by the seller who has decided to accept the bid to the buyer who submitted the current bid on the market. The bid display is then cleared and awaits new bids to be submitted. If an ask is accepted by a buyer, a unit is sold to that buyer by the seller who submitted the current ask price. The ask display is then cleared and awaits new asks to be submitted.

To enter a bid:

Type the quantity (1 always) in the market box (the split red box to the right of your screen) then hit the space bar to move to the price box and enter your bid. Then hit the F1 key. If you make an error in either box use the backspace key or delete key to remove your entry. Hitting the F1 key sends your bid to the market where it is displayed in the centre of the screen in the BIDS box. The market will not accept bids below the standing market bid already displayed in the bids box.

To buy a unit at the standing market ask price (to accept an ask):

The standing ask is displayed in the ASK box. To accept this ask, type the quantity (always 1 in this experiment) in the quantity side of the red market box, or leave it blank, and press the CTRL and F2 keys at the same time.

To cancel a bid you have sent to the market:

If you have already submitted a bid to the market by hitting the F1 key after entering it in the red market box, and it is the standing bid, you may cancel it, provided someone does not accept your bid before you have canceled it. To do so press the ALT and F3 keys at the same time. This will remove your bid from the BIDS box, restoring the previous standing bid.

To enter an ask:

Type the quantity (1 in this experiment always) in the market box (the split red box to the right of your screen) then hit the space bar to move to the price box and enter your ask, then hit the F2 key. If you make an error in either box use the backspace key or delete key to remove your entry. Hitting the F2 key sends your ask to the market where it is displayed in the centre of the screen in the ASK box. The market will not accept asks above the standing market ask already displayed in the asks box.

To sell a unit at the standing market bid price (to accept a bid):

The standing ask is displayed in the BIDS box. To accept this bid, type the quantity (always 1 in this experiment) in the quantity side of the red market box, or leave it blank, and press the CTRL and F1 keys at the same time.

To cancel an ask you have sent to the market:

If you have already submitted an ask to the market by hitting the F2 key after entering it in the red market box, and it is the standing ask, you may cancel it, provided someone does not accept your ask before you have canceled it. To do so press the ALT and F4 keys at the same time. This will remove your ask from the ASK box, restoring the previous standing ask.

Command Summary:

Move the cursor in the red market box: SPACEBAR
Clear entry in the red market box: BACKSPACE or DELETE

To submit a bid:	enter 1 unit and bid price in market box and press F1
To cancel a submitted bid:	press ALT-F3
To submit an ask:	enter 1 unit and bid price in market box and press F2
To cancel a submitted ask:	press ALT-F4

To accept the current market ask (buy a unit from a seller): CTRL-F2
To accept the current market bid (sell a unit to a buyer): CTRL-F1

History key to view previous transactions: F3

Often encountered problems:

Market will not take your bid:

1) press F1 only, not CTRL-F1
2) bid must be above standing bid

Fail to buy

1) make sure CTRL key is held down when hitting F2
2) red market box must be empty or exactly same as standing market ask
3) red market box must be empty or quantity must equal 1.

Market will not take your ask:

1) press F2 only, not CTRL-F2
2) bid must be below standing ask

Fail to sell (accept a bid)

1) make sure CTRL key is held down when hitting F1
2) red market box must be empty or exactly same as standing market bid
3) red market box must be empty or quantity must equal 1.

PLEASE PUT DOWN YOUR INSTRUCTIONS NOW AND WHEN EVERYONE IS READY WE WILL DEMONSTRATE HOW THE COMPUTERS WORK.

Selling your output and calculating your profit

In each trading period you may choose to produce and sell up to two (2) units of a fictitious commodity for the P-market. The price in the P-market is determined by adding up the total amount of production from everyone and reading from the list of numbers (attached to the instructions). For example, if you decide to produce 2 units, **and the total production level for all firms** is 10 units, you will sell your units for L$225. This gives you total revenues of L$450 (2 x L$225) .

For each unit you decide to produce you will have a production cost. In addition to this production cost you will have an additional cost that increases with each unit produced, and is added to the production cost. The "Production and Additional Costs Schedule" describes your production and additional costs. When you sell your unit(s) in the P-market your profit is the total revenue from the sale of the unit(s) (sales price multiplied by the number of units sold) minus the total production cost(s) AND minus the total additional cost(s).

Profit = [total revenue] - [total production cost] - [total additional cost]

Lowering Production Costs with Coupons

Before you decide how many units you want to produce and sell in the P-market, 10 coupons will be allocated amongst all the producers (you and the other subjects). These coupons cover the additional cost on each unit produced. In other words, if you have one coupon, you **don't** have to pay the additional cost on the last unit you produce. If you have two coupons you **don't** have to pay the additional costs on the last two units you produce, and so on.

Once the coupons have been allocated, you will have an opportunity to sell your coupons (if you were given any), buy them (if you weren't given any and want some) or re-sell or re-buy coupons. This coupon market (C-market) is conducted using the computers, and occurs before you need to decide whether you wish to produce and sell anything in the P-market.

You may or may not be initially endowed with coupons to begin each trading period. If you are endowed with coupons or purchase some in a trading period you may sell or re-sell them. There is no limit to the number of coupons you may buy or sell, except that you may not sell coupons you do not have. If you buy or sell a coupon you will mark the purchase or selling price you received on your record sheet in the appropriate column. **Note each transaction you make is recorded in order.**

How to Sell your firm's Output:

After the close of the C-market you must indicate how many units you are producing for the P-market. You do this by using the card on your desk. Write your ID number, period number and units number you wish to produce on the card and someone come around to record this decision. Also write this number down on your recordsheet in the appropriate box. Once this decision is made it cannot be changed. Once the total number of units being produced for everyone is determined the market price will be announced. Write the announced price in the box labeled **Price Announced in P-Market is (L$)** on your record sheet. You should then calculate your profit or loss for the period.

For example, if you decide to produce 1 unit you would write this along with the period number and your ID number on a card provided. Record this on your recordsheet in the appropriate box. If after this is recorded it is announced total production by everyone is 10 units, price will be found on the P-Market Price Schedule to be L$225. Write this down in the P-Market price box on your recordsheet and calculate your profits.

Once these calculations have been made, a new round will begin. Because the coupons are only good for one period , a new allocation of coupons is made. The number of rounds is predetermined, but unknown to you.

There will be 2 or 3 practice rounds before the experiment starts to familiarize you with the record sheet and the working C-market. After these rounds your balance will be put back to L$0.

When the session is over your earnings will be based on your profits earned in the session. You will be told beforehand what the conversion rate for Lab dollars to Canadian dollars before we begin. **NEGATIVE PROFITS WILL COUNT AGAINST YOUR EARNINGS.**

If you have any questions please raise your hand and it will be answered as soon as possible. Please do not ask any questions aloud which give away any information on your record sheet.

All firm's recordsheet

Record Sheet

Name:
ID#.

Period
Date

Trading Period Coupon Transactions

Transaction	Purchase Price	Selling Price
1	________	________
2	________	________
3	________	________
4	________	________
5	________	________
6	________	________
7	________	________
8	________	________
9	________	________
10	________	________
11	________	________
12	________	________

Note: If you need more space for entries use back of sheet

Totals	________	________

Number of Units you wish to produce:	

Calculation of Profit

Total Revenue	-	Total Production Cost	-	Total Additiona Cost	-	Coupon Purchases	+	Coupon Sales	=	**Profit**

Price Announced in P-market (L$): 125

note: total revenue is found by multiplying units produced by price announced.

Fringe costs list given to Dominant firm

	Unit	Production Costs		Other Firms Costs Additional Costs	
		per unit	Total	per unit	Total
Firm A	1	45	45	36	36
	2	45	90	75	111
Firm B	1	35	35	115	115
	2	40	75	155	270
Firm C	1	25	25	195	195
	2	30	55	235	430
Firm D	1	15	15	275	275
	2	20	35	315	590
Firm E	1	5	5	355	355
	2	10	15	395	750

Notes:

- there are 5 firms in the other room.
- each firm may produce two units with costs above (1 set of costs per firm (letters A-E))

Screen subjects use for double auction trading.

ID: 1 CASH ON HAND 500

Market	Period	Time	ID	BID PRICE	QNTY	ID	ASK PRICE	QNTY	INVNTRY	PRICE	QNTY
01 Market 1	1	0:00:00							10		

F1 BID F2 ASK F3 HIST Ctrl ACCEPT Alt CANCEL

History screen in MUDA showing previous transactions.

CONTRACTS HISTORY

MARKET # MARKET 1

PERIOD	TIME	BUYER/SELLER	PRICE	QNTY	TOTAL VALUE
1	0:00:12	1/ 2	100	1	100
1	0:00:49	1/ 4	120	1	120

(+) NEXT MARKET (-) PREVIOUS MARKET ESC- PREVIOUS SCREEN

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