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Designing organizations for trading pollution rights

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Abstract

Regulators and academicians have recently become interested in using a marketable permits program as a new way to control aggregate pollution emissions. Our research focuses on choosing a permit trading mechanism that is both economically efficient and politically viable. We consider an organized trading process and a revenue neutral auction, both of which involve an initial allocation of permits based on past history. Each is tested in a competitive and in a non-competitive environment to determine which mechanism performs best. The results of our research suggest that, overall, the organized trading process outperforms the revenue neutral auction.

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1. Introduction

Regulators and academicians have recently become interested in using some form of a marketable permits program as a new way to control aggregate pollution

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emissions. They argue that a tradeable permits system increases the flexibility with which individual firms can respond to pollution control requirements and, therefore, it becomes easier, cheaper, and politically more palatable to achieve significant reductions at the aggregate level. The efficiency and viability of regulation are improved. Several versions of such systems have been put into practice, with varying results (Hahn, 1989, pp. 95–114, Hahn and Hester, 1989, pp. 361–406, Hahn and Hester, 1989, pp. 109–153). Much has been written evaluating the performance of existing permit systems, but less work has appeared regarding the optimal design of a such systems. We add to the latter literature.

In designing a marketable permits system, two major factors must be addressed: market organization and political viability. [3] How well a system of tradeable permits performs its task will depend significantly on how the market is organized. Reductions will be easier to implement if, and only if, the market significantly increases the efficiency with which pollution abatement takes place. The extent to which these improvements in efficiency occur depends critically on the market architecture selected. Two major design choices are usually proposed: a sealed-bid auction and multi-lateral trading. [4]

Some have argued that sealed-bid auctions are the preferred form. It is claimed that (1) they can be organized to prevent firms that control a large proportion of the permits from exercising monopoly power and (2) they enhance price stability which aids rational planning of abatement by firms (see, e.g., Hahn and Noll, 1982). Others have argued for some form of continuous multi-lateral trading, often called an aftermarket, that would operate after an initial distribution of permits. It is claimed that efficiencies will be higher (see, e.g., Grether, Isaac, Plott, 1989). In this paper we reexamine these claims from both a theoretical and experimental point of view. We do that in two entirely different environments: one in which efficiency is relatively easy to accomplish because market power is evenly spread among users and one in which efficiency is very hard to accomplish because one firm holds an absolute monopoly position.

But, efficiency is not the only relevant performance criterion. It is equally important to consider the political realities that must be faced by any designer of a

[3] Another major design choice is the trading instrument; that is, what is being bought or sold. This is one point at which the market comes into contact with the regulatory process. In this paper, we assume the instrument choice has already been made. In practice, the characteristics of the instrument will affect the performance of the market and the choice must be a critical part of the design process. See Carlson and Sholtz (1993) and Carlson, et al. (1993a) for a discussion of potential problems associated with certain instrument designs and methods for avoiding such shortcomings.

[4] Choosing one of these designs still leaves open many options which can affect the performance. For example, if we choose a sealed-bid auction, how often should it be held? If we choose a multi-lateral trading market, should the regulatory agency play a passive role or should it provide a bulletin board environment to facilitate trades?

new process. The choice of market organization does not occur in a vacuum. In almost all cases, a marketable permits system replaces an existing system of standards and individual limits that have been in place for some time. The transition to markets from a well-established "command and control" process will almost always cause significant redistributions of wealth. For example, one major factor influencing the political viability of a mechanism is whether or not it extracts revenues (Riker, 1989, pp. 24–25). Under pre-existing committee systems, fees are not usually charged and participants are reluctant to embrace any new market system that forces them to pay for what was once free. The potential losers can be expected to try to prevent the transition from taking place. If the group of losers is powerful enough, they will prevail and politics will overrule the selection of even the most economically efficient mechanism (Grether, Isaac, and Plott, 1981).

A simple example illustrates the potential gains from improved economic efficiency and the potential political forces that can prevent the achievement of those gains. Suppose there are two polluters, firm A and firm B, and that each is currently regulated to produce x and y units of pollution, respectively. Suppose a total reallocation of permits from B to A would cause A's profits to increase by $1 million while B's profits would decline by $.5 million. Then, allowing A to pollute x + y and requiring B not to pollute at all is more efficient than the current allocation. The gains from efficiency are measured as $.5 million [5]. There are potential efficiency gains from a voluntary reallocation of rights. What about political viability? If each right to pollute one unit were to be sold by the regulatory agency for a price of, say, [.75/(x + y)] millions of $, then A would buy them all, increasing his net profits by $.25 in the process. B would not be willing to buy any since they cost more than B would save by buying them. B's profits decrease by $.5 million because of this. The regulatory agency makes $.75 million, which it could take in reduced permits instead of cash. The gains from trade have been fully realized, since. 25 − .5 + .75 = .5, but the distribution of the gains will prevent the sale from taking place if B can anticipate the outcome and has any ability to veto through the political system. Without compensation, B is $.5 million worse off under the new system. The price at which the permits are sold and the extent of the efficiency gains may depend on the method by which the government conducts the sale, but B loses no matter what pricing mechanism is employed. If efficiency gains are to be achieved, then A must buy more permits than x and B must buy less permits than y. This can only occur at a price between $1/(x + y) million and $.5/(x + y) million. At these prices B loses either in payments to the regulatory agency or in costs of pollution abatement.

[5] The idea is that A should be willing to compensate B for not polluting and B should be willing to accept the compensation. Both are potentially better off.

If the regulatory agency sells the permits and keeps the revenue then, although efficiency is improved and some polluters will gain, many may indeed be worse off. This prospect can easily prevent a permit trading organization from being implemented. There are several ways to prevent this redistribution from becoming a political liability. One is to redistribute the revenue back to the firms, after the sale is held. In the example above if the agency were to distribute at least $0.5 million to firm B then everyone would be as well off after the transition as before. The real impediment to the agency's ability to carry out such a rebate program is the clear incentive firms have to overstate the impact of the program on them. A second way that seems more credible and places less reliance on honest revelation of information is to use the principle of ''grandfathering''. Each firm is ''endowed'' with the right to pollute in amounts equal to what they had been doing before the transition to markets. [6] Thus, B should receive back $px million and A would receive $py million. With this grandfathering, both A and B will be better off after the sale. Successful transition requires every reasonably powerful actor to believe they will be at least as well off after the change as before. Economists call this a Pareto-superior move; we call it political viability, and will evaluate the designs we examine in this dimension also.

To summarize, we are looking for a trading permits system that is both politically viable and economically efficient. The former requires predictable protection from significant redistributions of the surplus; the latter requires a stable trading process and a measure of control over monopoly. In our research, we initially examined four different systems that had been proposed for consideration: (1) a uniform price, sealed bid auction (FIPR, 1991, pp. 7–25), (2) a laissez-faire trading process (Hahn and Noll, 1983, pp. 71–73), (3) the Hahn-Noll revenue neutral auction (Hahn and Noll, 1983, pp. 75–76) and (4) an organized trading process with grandfathered initial allocations (GIP, 1989, pp. 56–60).

A uniform price, sealed bid auction is a natural, naive suggestion by those who understand efficiency but are ignorant about political viability. Participants are asked to submit sealed bids for numbers of permits, similar to a treasury bill auction. The permits are all awarded to the highest bidders at a per unit price determined by the last accepted (or, sometimes, the first rejected) bid. The reason this approach is rarely a contender is that it is not politically viable no matter what its efficiency. Look back at the example above. If the pollution control authorities hold an auction for the permits and do not find a way to return money to those being currently regulated, all who should reduce pollution on efficiency grounds will actually be worse off. [7] The only situation in which this organizational

[6] This assumes that all can agree on each firm's exact prior level of pollution. In practice these baseline data are hotly disputed since so much is at stake.

[7] This claim does not depend on how the price is determined. It will be true even if all are charged exactly what they bid. It also does not depend on the sealed-bid characteristic and would be true for an ascending bid (English) auction.

solution is politically viable is if there is no trade that can improve efficiency, but then, in this case we don't need a new system. [8]

A laissez-faire trading process is a natural, naive suggestion by those who understand political viability but are ignorant about the possibilities for increased efficiencies. The pollution control authorities distribute permits to potential polluters, usually on the basis of past use and political clout, and then take a passive role in any process of redistribution. The reason this system is rarely a contender is that it is unlikely to increase efficiency even if it is political viable. See Hahn and Noll, 1983, p. 74. Because there is no provision for a central clearing house, the transaction costs involved in finding trading partners are significant, market liquidity is low, and many efficiency improving trades may go unrealized.

So a sealed-bid auction of rights with the authorities retaining the revenues is rejected on the grounds of political viability. A laissez-faire trading system with authorities grandfathering rights is rejected on the grounds of low economic efficiency. What about the other two mechanisms? Both the revenue neutral auction and the organized trading market address the political viability issue by initially distributing all the rights to be allocated on the basis of past performance and, possibly, political impact. This grandfathering scheme is intended to give the participants the option to continue performing as they do presently and to avoid any negative impact of the transition. Voluntary exchange should then leave everyone at least as well off as they are under the current system. As long as no one is forced to trade, grandfathering should make the new system politically viable.

While both mechanisms satisfy the political viability constraint, quite diverse opinions arise with respect to their economic performance. Hahn and Noll (1983) believe allocating rights and using an aftermarket for trading may not be a good allocation mechanism because it leads to monopolistic behavior if one participant owns a significant portion of the rights. Moreover, if too few trades occur because of an insufficient number of buyers and sellers, highly variable price signals result that will undermine a buyer's/seller's ability to make efficient choices when planning abatement procedures. Indeed, a major theme throughout their paper is the need to have many buyers and sellers actively participating in the market from the beginning to help achieve stable prices and to avoid problems associated with thin markets.

Hahn and Noll briefly suggest four ways to organize the market to avoid the problems mentioned above, but three are either politically not viable or require

[8] Economists are often surprised at the strong, vocal reaction individuals have towards policies that simply recommend "let there be markets". Political scientists are often surprised economists make such recommendations. Proposals to auction permits are this kind of policy. Economists make them because of the obvious and potentially large increases in efficiencies. Political scientists are surprised because of the obvious and potentially large redistributional implications.

information that the regulators and market organizers simply cannot have. [9] The most interesting mechanism they propose allocates permits to firms, through grandfathering, and then uses a uniform price auction to determine trades. [10]. In the uniform price auction, all participants submit a demand schedule for permits. The permits are allocated to those who submit the N highest bids. These individuals pay the same price for each unit – the highest rejected bid. Next, the unique feature of the revenue neutral auction is applied. Immediately after the revenue, $\Sigma_i p^* n_i$ (where n_i = number of permits purchased by person i), is collected, it is **redistributed back** to those individuals who were initially allocated the permits before the auction took place. Each person who was initially allocated a permit receives the market price for that unit. [11] Thus, each individual pays only for his net purchase of permits or is reimbursed for his net sale of permits. For example, if m_i permits were initially allocated to person i and he did not purchase any units at the auction (which would happen if he were to bid 0 on each unit), then he receives a rebate equal to $p^*(m_i - 0)$ – the price times the difference in the number of permits allocated and purchased. In effect, he has sold his permits at the price p. Thus, the organization redistributes the revenue back to the users and the auctioneer receives zero revenue.

An organized trading process with grandfathered initial allocations such as the double auction works similarly to the Hahn-Noll zero-revenue auction but uses a different price discovery process. An amount of permits is distributed to each of the I participants who then can sell their endowment or buy more from others. The buying and selling is carried out through a centralized, organized market. That is, bids, offers, and trades are registered through this market. Many market architectures are possible, but the natural forms are like either the pit of the Chicago Commodities Exchange or a bulletin board system. We chose to use the Multiple-Unit Double Auction (MUDA) developed at Caltech for our experimental study (Plott, 1991). MUDA is a PC-based electronic trading system that allows participants to continuously access and supply bids and offers for multiple units and to complete trades in an orderly fashion; it is a highly organized trading system. Though the conclusions are discussed in terms of the MUDA results, the findings can be applied to double auctions in general because only one unit was traded at a time in all of the experiments run.

[9] For example, one system would allocate permits so the monopolist would have the appropriate competitive equilibrium allocation. This requires the allocator to have perfect information about just what the competitive allocation will be; a fact no one knows for sure a priori. It also violates the political viability constraint we have imposed.

[10] Each participant must outbid the others in order to retain the permits just allocated. Thus, this initial distribution is merely an accounting device to identify how much of the revenue is to be distributed back to each participant. The distribution entails no guarantee of property right, although, as we will see in footnote 16, the participants, can always retain their initial allocation at a zero cost to themselves.

[11] The terms unit and permit will be used interchangeably.

The main differences between the double auction (DA) and the revenue-neutral auction (RNA) are (1) DA processes trade continuously; RNA does so only once, (2) DA trades can occur at very different prices; RNA prices trades identically in each time period, (3) DA allows bids and offers to be revised; RNA does not (4) DA makes all current best bids and offers public information; RNA never reveals that information, and (5) DA reveals trading information during its operation; RNA does not. In our research, we want to know whether each mechanism performs differently and which system achieves better results. Our criteria for judging each process are (a) efficiency gains beyond the initial endowment, (b) efficiency gains in start-up periods, [12] (c) price stability, and (d) the distribution of the gains from trade claimed by all participants. We will analyze the two trading systems in two different environments: one that includes a monopoly firm which receives all of the initial allocation of rights and another in which rights are initially distributed evenly. The monopoly environment is used to test how well these organizations perform under the most severe anti-competitive trading situation. The other environment tests how well the mechanisms perform in a more realistic atmosphere.

The rest of this paper is organized as follows: in Section 2, we provide some comparative theoretical analyses of the two mechanisms; in Section 3, we describe prior experimental work; in Section 4, we describe the experiments that we conducted and the results; and in Section 5, we summarize our findings and describe some directions for future research.

2. Theory

2.1. Competitive environments

It is well known, and often replicated, that in competitive environments (with relatively evenly distributed units), the DA generally produces prices and allocations near those predicted by the law of supply and demand. That is, one should expect to see competitive equilibrium prices and allocations. [13] The allocation of

[12] In most marketable permit systems, the allocation and trading of permits will occur once and may not be repeated for several years; therefore, the present participants may not be the same ones with the same objective function k years from now when permits are reissued. Thus, high efficiencies in early periods are very desirable.

[13] This is also predicted by the theory proposed by Easley and Ledyard (1993) especially for the Double Oral Auction. No one has yet, to our knowledge, generalized that theory to the case of MUDA.

initial endowments to the participants should not change that prediction if one simply replaces demand and supply functions with excess demand functions. No further analysis seems necessary.

The state of theoretical knowledge is somewhat different for the RNA. The natural theory would seem to be the theory of auctions. If all subjects want to buy or sell at most one unit per person then that standard theory predicts that everyone will bid exactly the value of that unit to them, [14] the allocation will be that predicted by demand-supply theory and the price will be a competitive equilibrium price. However, as Noussair (1992) has shown, if there are a known number of units to be sold and buyers want to buy more than one unit then the intuition of the single-unit theory no longer applies even if the auctioneer sets the price by using the first-rejected bid. In a symmetric Bayes equilibrium, buyers will still bid their true value for the first unit they want to acquire but will generally underrepresent on their other bids since those may set the price. That is, the incentives for bidding for units other than the first are essentially the same as those in a first-price sealed bid auction. Myerson and Satterthwaite (1983) have provided a single-unit theory for auctions with both buyers and sellers and have established that, in general, the equilibria are less than 100% efficient because of the incentives for buyers to bid less than their true value and for sellers to bid more than their true value. [15] Gresik and Satterthwaite (1989) have shown, however, that this loss in efficiency may decline quadratically as the number of traders increases [16]. If we take a rather large leap of faith, we can describe our expectations for the RNA even though the full theoretical analysis has not yet been done. We would expect misrepresentations of values in the bidding because of the multiple-unit effect. Whether these are over- or under-misrepresentations depends on the bidder's endowment and beliefs about the probable equilibrium price. If the individual is initially allocated w units in endowment through the grandfathering process, define *the marginal endowment value* to be the value to her of the wth unit. If she expects the market price (the n + 1st highest bid if a total of n units are initially allocated) to be higher than her marginal endowment value then she expects to be a seller and we would expect her to overstate her values in her bids. If she expects the equilibrium price to be lower than her marginal endowment value then she expects to be a buyer and we would expect her to understate her values in her bids. It follows that we would expect to see bids higher than her values on very infra-marginal units (relative to the endowment) and bids lower than her values on very extra-marginal units. It is not obvious what will be bid on units near the marginal endowment,

[14] In fact there is a stronger prediction. Bidding their true value is a dominant strategy for each agent.

[15] It is common knowledge how many buyers and how many sellers there are. This will not be true in the RNA since individuals can be either, a priori.

[16] We use the phrase "may decline" here since they prove this only for optimally designed mechanisms. It is not known whether the RNA does or does not belong to that class.

unless she has very precise equilibrium price expectations. [17] So the we expect the equilibrium bids, which are just reported demand functions, to be twisted versions of the true demand functions with higher reports on units up to that equal to the endowment and lower reports on the units after the initial endowment. If this is a symmetric equilibrium then one might expect risk-neutral subjects to produce equilibrium allocations near those predicted by the competitive equilibrium, with perhaps a little loss in efficiency because marginal units do not trade. So we would predict

Prediction: In a competitive environment (with a relatively equal distribution of endowments),

(a) DA will produce prices and quantities near those predicted by the law of supply and demand,

(b) RNA will produce prices near those predicted by the law of supply and demand, but will produce less reallocation than predicted by the competitive equilibrium, and bids will be higher than values on infra-marginal units and less than values on extra-marginal units,

(c) the efficiencies produced by DA will be higher than those produced by RNA.

2.2. Monopolistic environments

What about predictions for a monopolistic environment? These are simply extensions of the theory we have already developed since these environments arise if the distribution of the initial allocation is significantly skewed towards one individual. To see the extremes, let us suppose that a single individual is allocated the entire initial endowment. [18] The natural extension of the theory for DA is to assume that the monopolist, inferring the demand function of the others, simply acts as if he computes a marginal revenue curve and then sets a monopoly price and quantity to which he holds in the bargaining. [19] In effect he acts as if the values of his units are higher than they are: he overstates his values. This would yield higher prices and lower efficiencies than predicted for the competitive environment. A slightly more sophisticated theory would predict the monopolist would take advantage of the features of DA, that allow transactions to take place at different prices, to price discriminate. This would yield higher efficiencies but

[17] For example, if she knew with probability 1 that the equilibrium price will be less than the value of her third unit of endowment then she can bid an infinitely high amount on her first three units without affecting her equilibrium outcome since she will not be selling those units. Although she will be buying them back, her net transaction on these units will be a wash since she will be reimbursed for whatever she pays. The downside of such a strategy only arises if the equilibrium price is higher than the value of her third unit and she would have wanted to then sell it. But if she believes this occurs with zero probability there is no problem.

[18] This is highly unlikely politically if grandfathering is used, although it is possible that say 50% is allocated to one firm especially in the areas which involve public utilities.

[19] Such theories are explained in every introductory text.

lower surplus to the buyers. (Of course, buyers should try to resist this practice so we would not expect to see it very often.)

There is also a natural extension of the auction theory. Here the seller is setting reservation prices so as to maximize her net revenue from the sale. [20] Because of the concentration of the units in the hands of one seller, the Gresik-Satterthwaite limit results do not apply and we would expect that efficiencies would be lower and prices higher than in the competitive environment. Further, because of the one price feature of the RNA we will not see any price discrimination. Thus we would expect that efficiencies will be no higher than for DA and prices no lower.

Prediction: In a monopolistic environment (with a single seller holding all endowments),

(a) DA will produce prices and quantities near those predicted by a Robinsonian theory of monopoly except in the rare case in which full price discrimination occurs,

(b) RNA will produce higher prices than those predicted by the law of supply and demand, and will produce lower sales than predicted by the competitive equilibrium,

(c) the efficiencies produced by DA will be at least as high as those produced by RNA.

In effect we are predicting that DA will produce higher efficiencies in both monopolistic and competitive environments; that is, no matter what the initial allocation is. Let us turn to the experimental evidence.

3. Prior experiment methodology and results

Very few experiments have been conducted comparing institutions for trading permit rights. [21] Three studies, however, are relevant to our present research. Franciosi, Isaac, Pingry, and Reynolds [1991] compared the revenue neutral auction to a uniform price auction under conditions simulating a pollution permits market. Grether, Isaac, and Plott [1989] tested the efficiency and price variability of several mechanisms for an airline slot allocation project. Although not a permit model, it did include a sealed-bid auction and an organized trading process. Smith [1981] compared several mechanisms as monopoly constraining institutions.

Several of the experiments conducted by Franciosi, Isaac, Pingry, and Reynolds [1991], hereafter known as FIPR, compared the RNA (as described above) to a

[20] The RNA monopolist is essentially a seller of permits, setting a reservation price for all units. He has the power to retain ownership without penalty by bidding an infinite price for the permits (the price he pays equals his rebate if he bids an infinite price for all of the units); thus, he can restrict the quantity purchased by other bidders.

[21] Three papers not directly related to our research are Plott (1983), Brown-Kruse and Elliott (1990), and Mestelman and Mueller (1992).

uniform price auction (UPA). The economy they designed consisted of 10 bidders of different economic (number of units with positive values) and historic (number of units initially allocated) size. Thus, the economy consisted of 2–3 bidders from each of the following combinations: large economically and historically, large economically but small historically, small economically but large historically, and small economically and historically. [22] In FIPR's experiment, four measures of performance were used: market price, market efficiency, demand revelation, and earnings distribution. Summarizing their results briefly, according to the measures listed above, both the RNA and UPA tracked the competitive price well and had high per period efficiencies. The RNA mechanism experienced high bidding patterns over the extreme infra-marginal units; that is, bids for the infra-marginal units were in many cases more than double the redemption value for the same units. Over most of the bidding range, however, both the RNA and UPA reflected a modest amount of underbidding. Finally, as expected, the winners from the RNA were those bidders who were large historically but not economically (that is, those who had a lot to sell with little value for the units). These participants made a significant profit because of the rebate feature. [23]

Grether, Isaac, and Plott [1989], hereafter known as GIP, analyzed a problem similar to that of FIPR. GIP, in coordination with the Civil Aeronautics Board, tested and proposed a new method for allocating airport takeoff and landing slots. After the Airline Deregulation Act in 1978, entry into the airline industry increased dramatically. Many large airports were already at full capacity for takeoff and landing slots; thus, these slots became even more scarce as more airlines entered the industry. Many of the scarcity problems were blamed on the means of allocating slots – a committee process that heavily favored large, well established airlines. GIP were asked to devise a more efficient mechanism for allocating airport slots.

[22] Their experiment was designed to reflect both a private and public permits market, but a fully operational private market was never constructed. FIPR incorporated a pseudo-private market into their analysis by allowing only a percentage of the total permits to be sold at any time. The remaining unsold permits remained with their original owners, representative of a "failed" private market.

[23] FIPR do mention briefly in their conclusion that the extreme overbidding of the infra-marginal units could signify a "hoarding effect." Those bidders who are initially endowed with units can retain those units, by bidding almost infinite sums for the units while recovering the amount paid through the rebate feature of the mechanism. They state that because of this feature, "an RNA may not be the ideal institution to counteract [the hoarding effect]." (FIPR, 1991, p. 24). The amount of hoarding is not an independent performance criterion. FIPR define hoarding as participants bidding above their revealed demand to retain ownership of units they value. We view this simply as the natural strategic action of a seller. In the same way that buyers try to get a lower price, sellers try to get a higher price than their value. At its worst this form of hoarding, through misrepresentation of values, might lead to participants selling and buying less than they would at a fully efficient allocation. The existence of a single seller may lead to monopoly inefficiencies. But the negative aspect of hoarding is still simply a lessening of efficiency. Our measure of efficiency will pick all that up. There is no need for an independent measure.

GIP conducted a series of laboratory experiments, testing and comparing the standard committee process with a one-price sealed bid auction (e.g., UPA) and with grandfathering plus an oral trading market (e.g., DOA). [24] They judged these mechanisms on the basis of efficiency, responsiveness to changing circumstances, susceptibility to monopoly or collusion, implementation costs, service to small communities, and long-term industry growth. The committee process was ruled inferior to the other two mechanisms on all criteria. It was not governed by economics, but almost entirely by the initial distribution because that was the outcome whenever the committee could not reach a unanimous decision.

To solve the airport slot problem, GIP proposed the sealed-bid auction with aftermarket that redirected the money collected towards airport expansion. This mechanism was highly efficient and satisfied the other judging criteria well. Grandfathering plus trading was not chosen because they believed that grandfathering would reinforce the power of the status quo, making it harder for new entrants to break into the market. We do not agree with the model chosen. In particular, the use of funds for airport expansion actually led to the downfall of the proposal because the airlines would not agree to use a mechanism that extracted rents from the system and then used it towards airport expansion; that is, they would not pay for services that they currently received free. The auction was abandoned and considered politically non-viable.

In addition to the work done by FIPR and GIP, another important study worth discussing is Smith's [1981] paper that compared the efficacy of several institutions in containing monopoly power. In our work, we examine different institutions in both competitive and anti-competitive environments; therefore, Smith's results are of interest to us. [25] The mechanisms that he tested included the double oral auction, a posted bid auction, an offer auction, and a posted offer auction experiment. He wanted to use experimental evidence to answer several commonly posed questions: Can monopoly advantage be neutralized by an institution that underreveals demand to the monopolist? Can the Pareto inefficiency generated by the monopolist's actions be improved by any of the institutions? Do some institutions enable buyers to counteract monopoly power better than others?

Smith conducted ten experiments, varying the mechanisms under monopoly and duopoly conditions. His results showed that the double oral auction allowed monopolists to restrict their output more effectively than all of the other mechanisms except for the posted offer. In addition, the average allocational efficiency of the double oral auction was the lowest of all the institutions, lower than even

[24] The Double Oral Auction (DOA) is a predecessor of MUDA that allowed one unit to be traded at a time.

[25] The term "competitive" in our experimental work does not imply perfect competition. It denotes an environment in which the initial allocation of permits is distributed among all participants. None of the subjects hold a majority of permits, though some hold significantly more than others.

Table 1
Summary of prior experiments

Environment	Comparison (Efficiency)
FIPR (non-monopoly)	RNA > UPA
GIP (non-monopoly)	UPA > DOA
Smith (monopoly)	PO, PB/UPA, OA > DOA

Table 2
Number of experiments conducted

	RNA	MUDA
Non-monopoly	3	3
Monopoly	4	3

the monopoly equilibrium. Of the four types of mechanisms, the offer auction was the most efficient and the most effective at diminishing a monopolist's power.

We summarize the findings of FIPR, GIP, and Smith in Table 1.

Assuming transitivity between different experiments, the ordering from most efficient to least efficient mechanism is RNA > UPA (and others mentioned) > DOA or DA, which appears to be at odds with our first prediction in section 2. [26] In addition, FIPR (and Hahn-Noll) conjecture that the RNA reduces the likelihood of a subject exercising market power better than an aftermarket, but do not test this conjecture. We felt it was time to confront these issues directly. We do not test the UPA because even if it is highly efficient, it is not politically viable. We do compare the RNA and the DA under both non-monopoly and monopoly conditions. We measure and compare the stability of prices, efficiency, and the final distribution of the gains from trade.

4. Our experiment methodology and results

Both the RNA and the DA (henceforth, termed MUDA) mechanisms were tested under non-monopoly and monopoly conditions. The number of experiments conducted is shown in Table 2.

An extra experiment using the RNA under the monopoly environment was run because we could not find any experiments testing the Hahn-Noll mechanism under this condition. [27] Moreover, under the monopoly environment, the results

[26] Of course the environments differed across these experiments. A comparison should be made in the same environment before jumping to conclusions.

[27] The other three boxes had been tested: monopoly-DOA by Smith [1981], competitive-DOA by Smith and GIP, competitive-RNA by FIPR [1991].

were evaluated according to the relative strength of the monopolist. Whether the monopolist was powerful or weak played a crucial role in our experiments.

Three measurements were used to evaluate the mechanisms: (1) efficiency, (2) price stability and (3) equity. *Efficiency* is measured as the efficiency gains from trading (gains from trade). The gains from trade efficiency was used instead of standard efficiency measures so that a mechanism is not judged highly efficient simply because the initial distribution of permits is close to the optimal distribution. The mechanism must improve on the initial allocation. If no trades occur, then the gains from trade efficiency is zero. The following formula is used:

$$\text{gft} = \frac{\Sigma_i \text{ experimental payoffs} - \Sigma_i \text{ status quo value}}{\Sigma_i \text{ maximum efficiency payoffs} - \Sigma_i \text{ status quo values}},$$

where $i = 1$ to the number of players participating in the experiment

Price stability is measured by looking at two factors: (1) do prices fluctuate greatly from period to period and (2) how well do they track the competitive price? *Equity* (considered in monopoly experiments only) is measured by the final distribution of the gains from trade claimed by the participants (monopolist and consumers).

4.1. Non-monopoly environment

4.1.1. Design

The non-monopoly experiments used FIPR's [1991] parameters for the 20 unit case. [28] These parameters are given in the Appendix. [29] To give the reader a feel for the difficulty of achieving 100% of the gains from trade in the environment we have included Figures 10 and 12 which show the frequency and cumulative probability distribution of efficiencies achieved by randomly allocating the units. The average efficiency is about 75%, and there is a 30% probability of attaining this level or higher.

Ten subjects (all Caltech undergraduates) participated in each experiment. Subjects were allowed to participate in one MUDA and one RNA, but not in the same environment (in most cases, subjects participated in only one experiment). Due to the complicated nature of the MUDA software, all subjects were required to have participated in a previous MUDA experiment or have trained on the demonstration package. We do not believed this training significantly alters the results in favor of the MUDA; though, asymmetric training cannot completely be ruled out without further experimental investigation. Subjects were still "new" to MUDA when they participated in our experiment, however, because we allowed

[28] FIPR's experiments started with 40 units for sale and over the course of the experiment, this number was periodically reduced until 20 units was reached.

[29] The parameters indicate that participant #5 may be inclined to behave as a monopsonist. From our experimental results, we saw little evidence of this type of behavior.

them to be "traders" – to both buy and sell units. In most MUDA experiments conducted at Caltech, subjects are either buyers or sellers, but not both.

In both the MUDA and the RNA, one to two practice periods were conducted to acquaint subjects with the mechanisms (these practice periods were not recorded in the data). Subjects were encouraged to practice trading units and then record their transactions. In both types of experiments, participants did not use their redemption value sheets during practice; thus, the only information gained in the practice periods was additional familiarization with the mechanisms.

All subjects were given complete information regarding the initial allocation of endowments; that is, each subject's ID# and endowment (the number of units) were posted on the board. [30] In the RNA, the final allocation of units each period was not known (at the end of each period, subjects were handed a slip of paper with the number of units they purchased written on it). In the MUDA experiment, because the software comes equipped with a history screen of all transactions, it is possible for subjects to know who purchased how many units; however, due to the brief period of time between periods, it is unlikely that anyone took advantage of this capability. Subjects were not allowed to communicate with each other during the experiment, so they could not obtain the information directly.

Subjects were given a resale value sheet in their packets that remained the same over the course of the experiment. Units purchased did not roll over from one period to the next; that is, each period started with the subjects receiving only their initial endowment. This endowment remained the same over the course of the experiment. Each experiment lasted 10 periods (only the experimenter knew this information). For the MUDA experiment, each period was 3 minutes and 30 seconds long. A soft close rule applied if no trades occurred within 20 seconds; however, it was never invoked. A copy of the instructions for one of the non-monopoly experiments can be found in the Appendix. [31]

4.1.2. Results

Results from the non-monopoly experiments can be found in Figures 1, 2 and Table 3. Figure 1 shows that, when comparing per period efficiencies, the MUDA outperforms the RNA. The MUDA, on average, had higher efficiency levels throughout the experiment, and these efficiency levels were more stable than the RNA. In one experiment (MUDA 2), for example, subjects reached full efficiency by period 4 and remained there for the rest of the experiment. Moreover, randomly distributing the initial allocation yields an average efficiency higher than the RNA. There is approximately a 62% probability of achieving an efficiency greater than or equal to the RNA by random allocation.

[30] We posted this information because it is generally common knowledge to all participants in pollution rights markets because of the public regulatory authority. Neither FIPR nor GIP provided this information in their experiments.

[31] These instructions, as well as those for the monopoly experiments, were read out loud to the subjects.

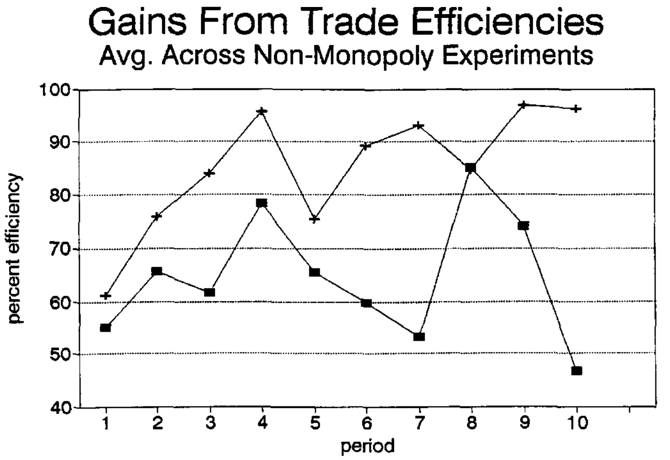

Fig. 1.

Considering only periods 1–4 yields a similar conclusion. The MUDA is, on average, 10 percentage points higher than the RNA over the first few periods. While this may, in part, be the result of prior training on the MUDA mechanism, it strongly reflects the difference in the amount of information each mechanism provides. The RNA was conducted once per period, while the MUDA allows trading to occur over a 3 minute 30 second time frame. The multiple price signals appear to allow subjects to learn and adapt to the environment faster than the

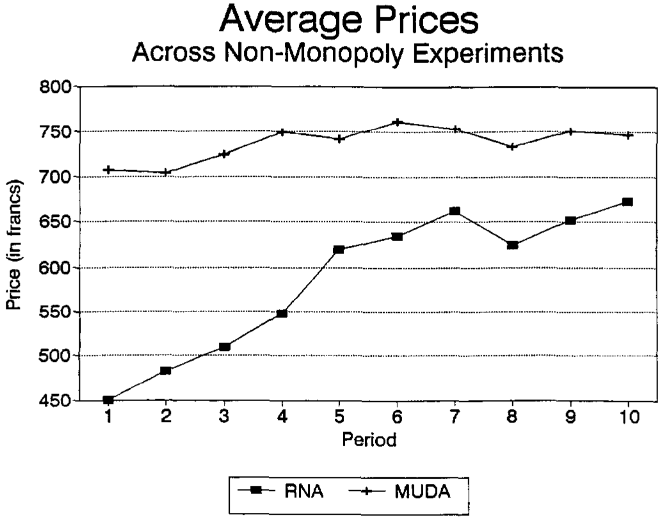

Fig. 2.

Table 3
Efficiencies in competitive environment

	Avg. Over All Periods and Experiments	Avg. Over Periods 1–4 and all Experiments	Prob (Random > Avg. Over All Periods)
MUDA	85.2	79.2	5%
RNA	64.6	65.2	62%
Random Allocation	75.0	N/A	N/A

Table 4
Efficiencies in monopoly environment

	Avg. Over All Periods and Exper.	Avg. Over Periods 1–4 and all Exper.	Strong Monopolist	Weak Monopolist
MUDA*	61.5	49.6	71.5	51.5
	71.3	66.5	71.5	71.1
RNA	62.5	57.7	52.3	72.8
DOA (Smith)	62.9	57.4	N/A	N/A
Random Allocation	80.0	N/A	N/A	N/A

* The first line includes period 1 of the experiment in which a serious error was made by one of the subjects. Line 2 shows the increased efficiencies if we do not include this one period.

RNA, which is a sealed-bid auction and allows subjects to see only one price (the highest rejected bid) each period. The data are summarized in Table 3.

We also see the rapid rate of learning associated with the MUDA mechanism reflected in the transaction prices. Figure 2 displays the average period prices for the MUDA and the period equilibrium prices for the RNA. The theoretical competitive equilibrium price, where demand equals supply, is 760 francs for both experiments. From the figure, we notice the MUDA does not fluctuate more than 100 francs (the equivalent of one dollar) over the course of the experiment. [32] The RNA does not stabilize near the competitive price until the seventh period, and overall, remains below it. Between periods 1–7, the RNA equilibrium price monotonically increases by 200 francs before it finally levels out below the competitive equilibrium price.

By both measurements, gains from trade and price stability, we find that the MUDA performs better than the RNA in the competitive environment of FIPR. The MUDA is highly efficient and achieves stable prices that track the competitive price closely.

[32] Even if we look at the low price from each period in the MUDA experiment rather than the average, our conclusions do not change substantially. The low price is within 60 francs of the predicted competitive price from period 3 to period 10, stabilizing much faster than the RNA prices.

4.2. Monopoly environment

4.2.1. Design

The parameters for the monopoly experiments came from an experiment conducted by Smith [1981], though we altered the experiment by allowing all participants to be traders (buyers and sellers). [33] These parameters are given in the Appendix. To give the reader a feel for the difficulty of achieving 100% of the gains from trade in the environment we have included Figures 11 and 13 that show the frequency and cumulative distribution of efficiencies achieved by randomly allocating the units. The average efficiency achieved this way is about 85% with a 50% probability of attaining a higher efficiency through random allocation.

As in the non-monopoly experiments, all subjects were Caltech undergraduates. For each experiment, one subject was allocated all ten units (the total number of units for sale) and the other five subjects were not allocated any units. The allocation of the endowments according to ID number was common knowledge because it was posted on the blackboard. As in the non-monopoly experiments, all subjects were traders, each experiment lasted ten periods, no talking during the experiment was allowed, and no units were carried over from period to period. A copy of the instructions for one of the monopoly experiments can be found in the appendix.

4.2.2. Results

Figure 3 displays the efficiencies from the monopoly experiments (including the average efficiency levels from Smith's experiments). The two mechanisms tested at Caltech exhibit no significant differences in efficiency levels from period 2–10 (in period 1, there was a serious error made in one of the MUDA experiments, driving down the average efficiency calculation). This result means that RNA has no special claim to controlling monopoly power. Average price levels also did not differ greatly between the two mechanisms across periods, though prices for the MUDA were higher in the earlier periods. These findings contradict statements made by Hahn and Noll and FIPR that initial allocations followed by an RNA do not allow monopolies to prosper. They do not acknowledge the similarities in the strategic situation facing the monopolist under each mechanism. In the RNA, the monopolist can control prices and quantity sold by

[33] While we would have preferred to use the FIPR parameters for both the non-monopoly and monopoly experiments, the differences in price and quantity between equilibria were too small. If we allowed the most appropriate subject in the FIPR design to be the monopolist (participant #5), according to the given parameters, only one unit separates the two equilibrium quantities supplied and only 31 francs separates the equilibrium prices. Under the Smith parameters, three units separate competitive and monopoly equilibrium quantities. While the difference in equilibrium prices is only 20 francs, the range of prices is much tighter and variance more significant under the Smith parameters than under the FIPR parameters (e.g., non-zero resale values ranged from 60 to 150 francs under the Smith design and 39 to 1165 francs in the FIPR design).

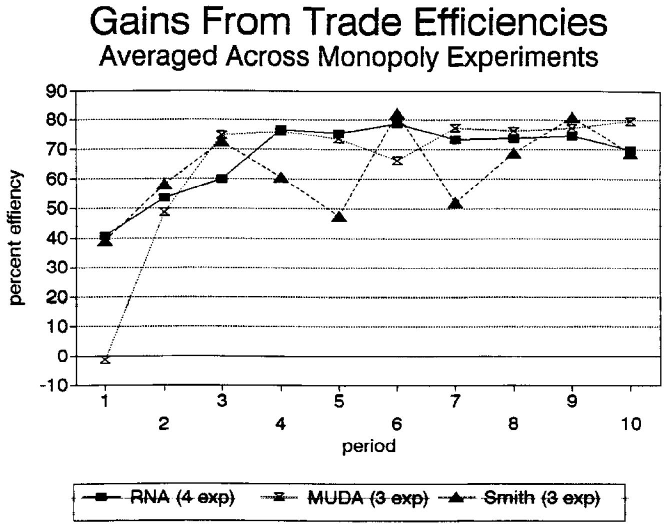

Fig. 3.

bidding an infinite price for the units. Because he was initially allocated them (giving him some form of property rights to the permits), he faces no penalties by bidding an infinite price to retain them; that is, the price he pays and the rebate he gets will cancel each other out if he chooses to repurchase all of his initially allocated units. This feature gives the RNA monopolist as much power as the MUDA monopolist, who simply withholds units, though, the former receives less information on equilibrium price levels than the latter.

Because of the special nature of experiments with monopolists, the results appear to be very sensitive to the attributes of the subject chosen to be the monopolist. We examined these individual effects by classifying monopolists as either "powerful" and "weak" categories. We defined relative strength in terms of the total profits earned. If the monopolist's earnings were closer to the predicted earnings at the competitive equilibrium, he was classified as "weak." Similarly, if his earnings were closer to the predicted earnings for the monopoly equilibrium, then he was termed "powerful". Using this classification scheme, we had two powerful and one weak monopolists for the MUDA experiments and one powerful and three weak monopolists for the RNA experiments (See Table 5). [34] The powerful monopolist in the RNA experiment was also one of the powerful monopolists in a MUDA experiment. He was the one exception to our rule of not

[34] We acknowledge that our ex-poste classification scheme may not be optimal for replication purposes, but it proved the best method for studying individual effects without biasing our choice of monopolist.

Table 5
Monopoly profits vs. efficiencies

Monopolist	Avg Profit/Period (in francs/period)	Avg Efficiency/Period
MUDA1 *	294.00	65.47%
MUDA2	244.88	75.15%
MUDA3 **	394.10	77.56%
RNA1	159.00	79.22%
RNA2	181.10	80.99%
RNA3	171.50	58.05%
RNA4 *	268.40	52.29%

* Same strong monopolist
** Price discriminator

allowing the same subject to participate in both the MUDA and the RNA under the same environment. [35] We felt it was important for comparative purposes to test the mechanisms at least once while keeping the monopolist as a constant. The results from the experiments were grouped and analyzed on the basis of the skill level of the monopolist.

Considering first the efficiency levels of the RNA and the MUDA, we see that our results differ greatly depending on the relative strength of the monopolist. The experiments with a weak monopolist have low efficiencies early but increase their efficiency levels quickly (Figure 4). [36] The difference in efficiency levels between the RNA and the MUDA is negligible – on average, MUDA performs at least as well as the RNA, if not better. The results are listed in Table 4.

Such is not the case in the experiments with a powerful monopolist (Figure 5). The MUDA outperforms the RNA in nine out of ten periods by substantial margins (ranging from 10 to 35 percentage points), and it achieves higher gains from trade efficiencies in earlier periods. An interesting point to note is that this gap in efficiency performance does not decrease over time (e.g., period 10 shows a 20 percentage point gap in efficiency between the MUDA and the RNA). The same holds true if we consider the gains from trade efficiency when the monopolist is held constant (Figure 8). The MUDA does as well as the RNA in nine out of 10

[35] When the same monopolist was used, he participated in the MUDA experiment first and then the RNA. Unfortunately, we did not run a similar test using another monopolist, reversing the order to see if any learning from mechanism to mechanism was occurring. Future research will consider this possibility more closely.

[36] We specify an efficiency level as "low" if it is below the average gains from trade efficiency generated randomly. For the non-monopoly and monopoly experiments, the average gains from trade efficiencies generated randomly are approximately 75% and 80%, respectively.

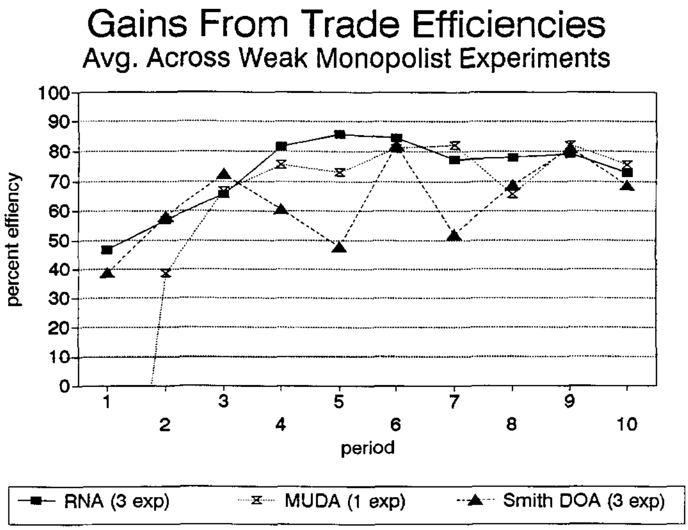

Fig. 4.

periods and strictly better (by at least a 10 point margin) in seven out of those nine periods. [37]

Equilibrium prices varied as much as efficiencies did between powerful and weak monopolists (Figures 6, 7). As one might expect, the more powerful the monopolist, the better able he was to keep prices high (and thus, volume traded low). The powerful monopolists (Figure 7) maintained the price above the predicted monopoly price of 100 francs; however, the MUDA experiments yielded lower prices consistently for nine of the ten periods. The weaker monopolists' equilibrium prices (Figure 6) followed the same pattern as those found in the non-monopoly experiments. Prices from the MUDA experiment declined to the competitive price, and prices from the RNA rose from below the competitive price, surpassing the MUDA prices by period 7. [38]

Prices across both the powerful and the weak monopolists did not fluctuate greatly except for the weak monopolist in the MUDA. The great drop in equilibrium prices from period 1 to period 4 was produced, in part, by the

[37] While in general we can make the statement that across both mechanisms, the more powerful the monopolist, the less efficient the results, we need to add one disclaimer. If a powerful monopolist makes effective use of price discrimination, then his efficiency may be high. This event occurred in experiment 3 of the MUDA. The monopolist submitted few asks for units he wished to sell. He primarily accepted bids posted by consumers; thus, he forced the subjects to sort themselves out along an aggregate demand curve, which he "marched down", picking off the highest bid for each subsequent unit. He attained both the highest efficiencies and profits from this strategy. (Figure 9).

[38] Average prices for the MUDA for periods 1 and 2 were 349 francs and 249 francs, respectively. They were not included on Figure 6 because we wanted to show the latter periods in greater detail.

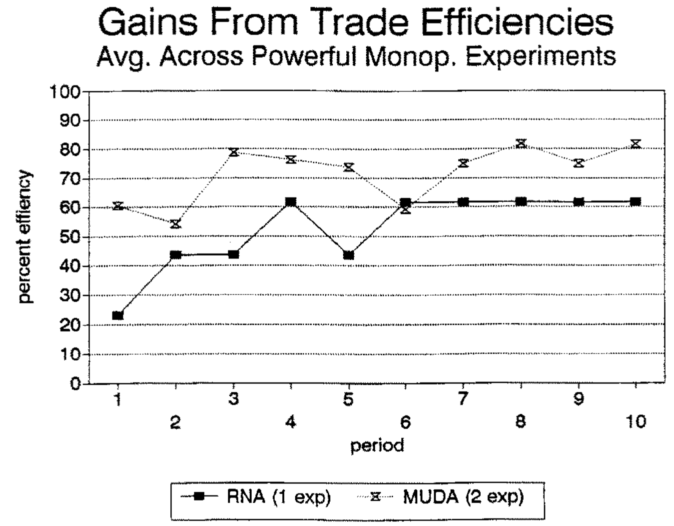

Fig. 5.

monopolist capitalizing on mistakes made by two subjects in periods 1 and 2. Both subjects misunderstood the instructions given them. One subject thought that the units purchased carried over from period to period and proceeded to purchase all the units the monopolist was willing to sell at prices higher than her value sheet

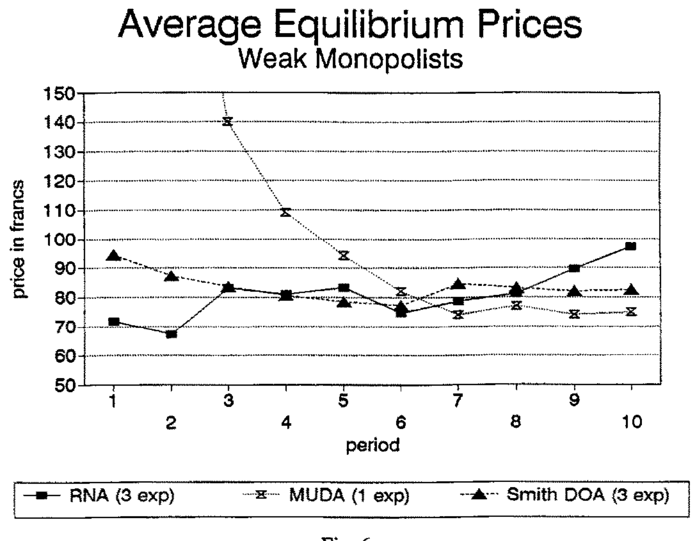

Fig. 6.

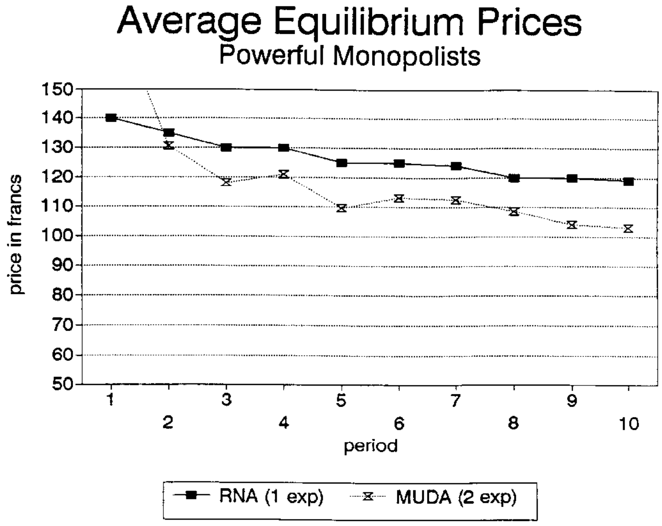

Fig. 7.

indicated. The other subject thought that trading would continue as long as the soft close rule was not invoked. He purchased units at prices higher than his redemption values for them in hopes of reselling them later in the period at even higher prices, but time ran out. Thus, in both cases, bids were placed at unusually high

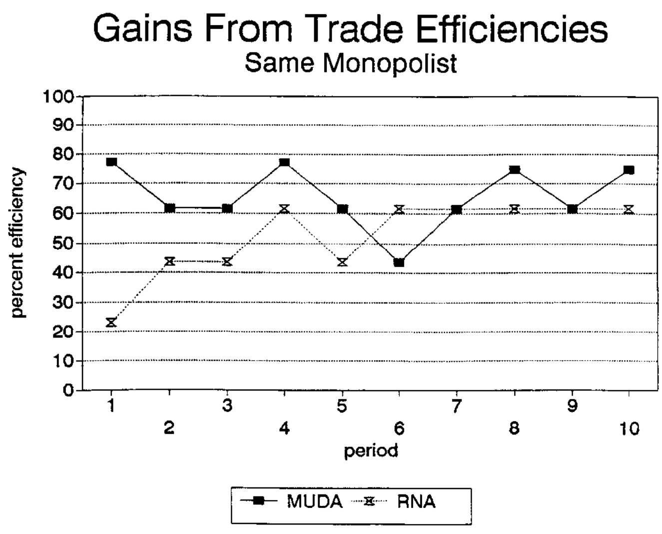

Fig. 8.

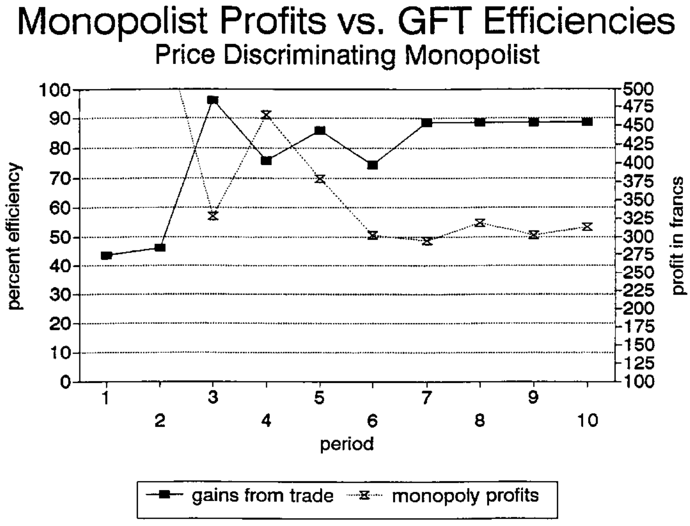

Fig. 9.

prices. The sharp drop in equilibrium prices for MUDA 2 after period 2 (Figure 6) reflects the subjects' realization of their mistakes and their unwillingness to purchase further units at unusually high prices.

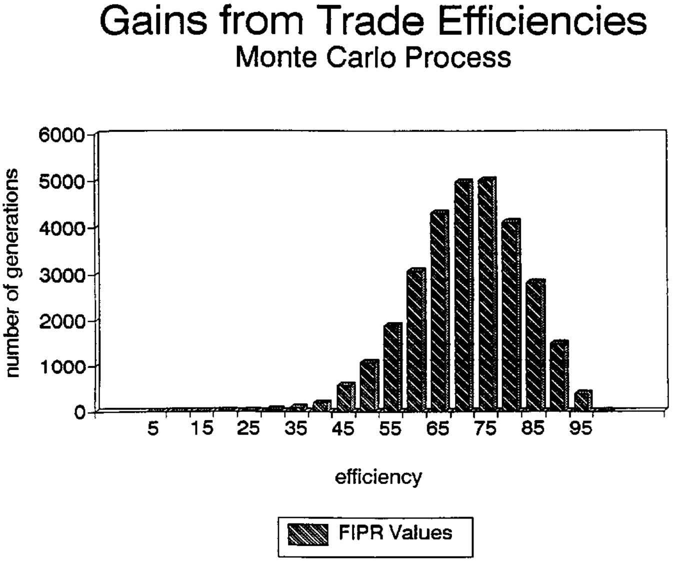

Fig. 10.

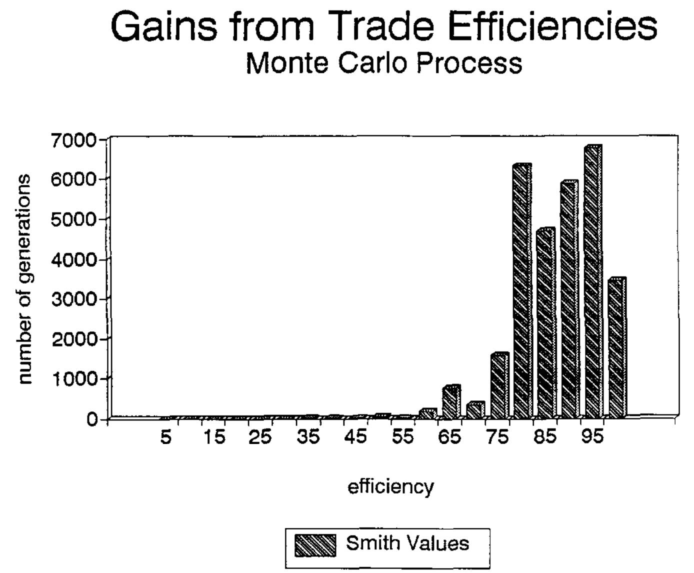
Gains from Trade Efficiencies
Monte Carlo Process
7000
6000
5000
4000
3000
2000
1000
0
number of generations
5
15
25
35
45
55
65
75
85
95
efficiency
Smith Values

Fig. 11.

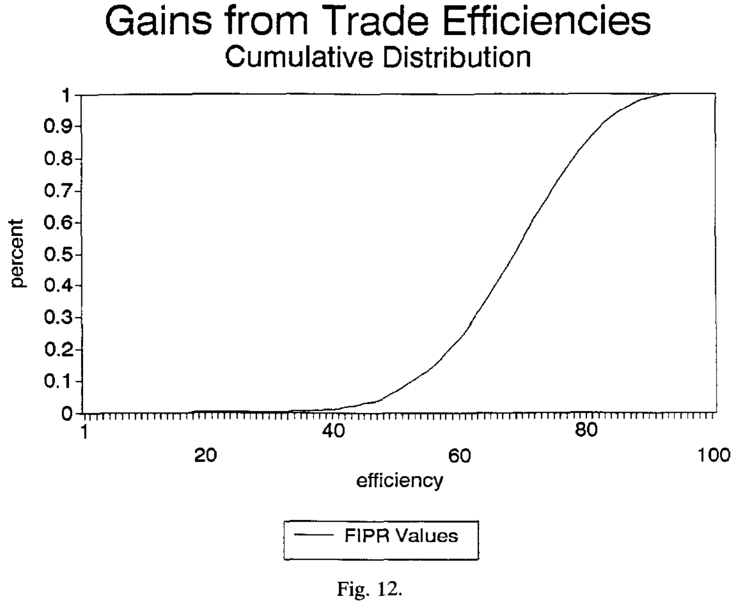
Gains from Trade Efficiencies
Cumulative Distribution
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
percent
1
40
80
20
60
100
efficiency
FIPR Values

Fig. 12.

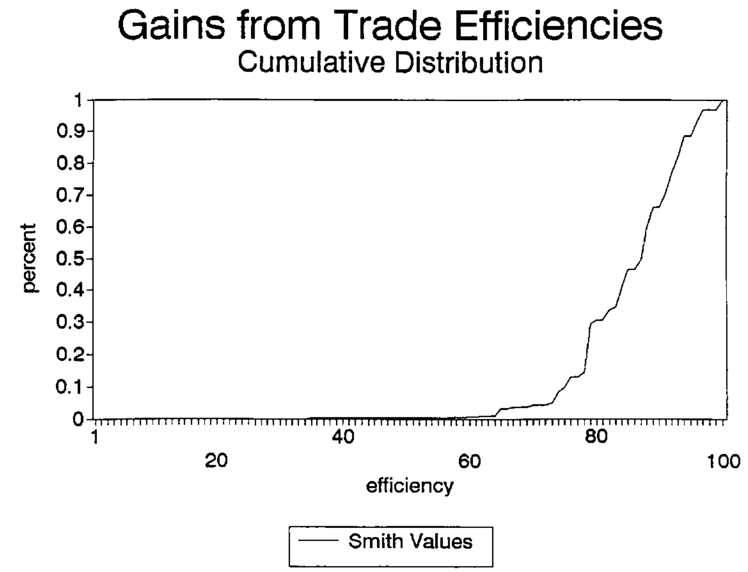

Fig. 13.

In the case of the strong monopolist experiment, the RNA yielded overall higher prices and lower trading volumes (1–3 units traded per period) than the MUDA (2–4 units traded per period). [39] Even the gains from trade efficiencies were higher in the MUDA than the RNA. Focusing on the weak monopolists, we see that neither mechanism allowed monopolies to prosper. Thus, an initial allocation followed by an aftermarket does not perpetuate monopolies any more than an initial allocation followed by an RNA.

In addition to efficiency and price stability, the final distribution of profits was observed. Once again, the relative strength of the monopolist determined how equitable was the distribution of gains from trade. In Table 6 we list the percentage of the final distribution of gains claimed by buyers and the monopolist and the amount lost from the system (the "dead weight" loss). Also listed are the theoretical percentage distributions at the monopoly price and at the competitive price. The powerful monopolists extract a noticeably larger portion of the wealth than the weaker monopolists across both mechanisms. With one exception, there are no significant differences in the equity distribution between the strong monopolists. The one exception to this assertion is the powerful monopolist from MUDA 3, whose price discriminating techniques earned him 75% of the total available gains from trade. The RNA, on average, appears to return more of the

[39] By "trading volumes" in the RNA experiment, we mean the number of permits not repurchased by the monopolist.

Table 6
Final distribution of the gains from trade

	Buyers %	Monopolist %	Loss %
Theoretical:			
at Competitive Price	70%	30%	0%
at Monopoly Price	38%	49%	11%
Experimental:			
MUDA 1 *	26%	51%	23%
MUDA 2	42%	32%	26%
MUDA 3 **	15%	77%	8%
RNA 1	62%	26%	12%
RNA 2	44%	23%	33%
RNA 3	69%	21%	10%
RNA 4 *	15%	44%	41%

* Same strong monopolist
** Price discriminator

gains from trade to the consumer under weak monopoly conditions, though the distribution under MUDA 2 was quite similar to that under RNA 2.

The results from our monopoly experiments show that the efficiency of both the RNA and the MUDA is a function of the relative strength of the monopolist. But, the efficiency achieved by randomly allocating units is higher than the efficiency of any of our monopoly experiments. Thus, neither the MUDA nor the RNA fully protect participants from monopoly power. One unique feature of the MUDA, however, is that it allows a discriminating monopolist to fully exercise his power on the system. This situation produces an interesting trade-off between efficiency and equity. Though gains from trade efficiencies are higher under the discriminating monopolist than any of the other powerful monopolists, he claims most of the surplus for himself. Thus, though he eliminates much of the ''dead weight'' loss from the system, the discriminating monopolist leaves a smaller percentage for other permit buyers.

5. Summary

Our results have shown that the use of markets for trading permits can be quite effective. Participants were always made better off under both mechanisms tested than under the initial allocation. Even with very clever monopolists, participants usually had positive gains from trade. [40]

[40] RNA 1 had two periods where the gains from trade efficiency was negative; that is, where the initial allocation was superior to the end of period allocation.

Overall, the MUDA dominated the RNA. In the early periods of the non-monopoly experiments, the gains from trade efficiencies of MUDA were higher and its prices more stable. On average across all three experiments, the MUDA's efficiency levels were higher and less volatile than the RNA's efficiencies. The monopoly experiments also yielded favorable results for the MUDA. In particular, if we kept the same monopolist across both the MUDA and the RNA, in 7 out of 10 periods the MUDA had higher gains from trade efficiencies (by more than 10 percentage points) than the RNA. The learning curve was steeper using the MUDA, as demonstrated by the higher gains from trade in both the non-monopoly and strong monopoly experiments for periods 1–4. Subjects received multiple price signals over the 3 minute 30 second periods and were able to adjust their bids/asks accordingly. In the RNA experiments, subjects were able to do the same only once per period.

Previous research done by Hahn and Noll and FIPR in the area of marketable permit systems reports misgivings regarding the use of aftermarkets as a trading mechanism. In particular, one concern echoed in both papers is that allocating permits and then running an aftermarket might perpetuate monopolistic behavior if one participant receives and hoards most of the permits. Our research has shown that is true to a lesser extent than predicted. Further, it is not solely an aftermarket phenomenon: to the extent that monopolists prevent efficiency gains, the effect is the same for both the RNA and the MUDA.

Finally, equity is controlled mainly by the initial endowment – not by the mechanism. The solution to monopoly effects is to change the initial distribution of rights if this is politically viable. We conducted our monopoly experiments under the most extreme anti-competitive condition – giving all of the initial allocation to one person. If this allocation could be adjusted only a little then others would receive a higher percentage of the distribution of equity.

Appendix

FIPR parameters for the non-monopolistic environment

	Unit #									
Person	1	2	3	4	5	6	7	8	9	Endowment
1	11.65	7.18	2.77	2.76	1.13	1.04	0.70			4
2	10.32	9.43	8.26	8.12	4.53	4.23	1.06			3
3	10.87	5.33	1.35	0.27	0.21	0.15				3
4	11.34	8.22	7.04	3.07	0.76	0.46				3
5	11.27	10.53	9.15	8.23	7.91	7.60	7.00	1.83	0.39	1
6	11.00	3.37	0.87	0.16						2
7	11.40	4.79	0.65							1
8	10.56	3.78	0.52							1
9	10.76	5.97	4.53	3.40	1.45	1.43	1.22			1
10	11.00	7.95	2.97	2.23	0.89					1

The competitive equilibrium price is 7.18.
The competitive equilibrium quantity is 20.
The competitive equilibrium allocation is:

Person	Allocation	Net Trade
1	1	−3
2	4	1
3	1	−2
4	2	−1
5	6	5
6	1	−1
7	1	0
8	1	0
9	1	0
10	2	1

Smith parameters for monopolistic environment

Unit #	1	2	3	4	5	6	7	8	9	10	Endow.
Monop.	90	85	80	75	70	65	60	60	60	60	10

Buyer #		
2	150	60
3	140	70
4	130	80
5	120	90
6	110	100

The competitive equilibrium price is 80.
The competitive equilibrium quantity is 10.
The competitive equilibrium allocation is:

Person	Allocation	Net Trade
MONOP.	2	−8
BUYER 2	1	1
BUYER 3	1	1
BUYER 4	2	2
BUYER 5	2	2
BUYER 6	2	2

The monopoly price is 100.
The monopoly allocation is:

MONOPOLIST	5	
BUYER	2	1
	3	1
	4	1
	5	1
	6	1

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