What Have We Learned From Emissions Trading Experiments?

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ABSTRACT

Emissions trading is a form of environmental regulation in which a regulatory body specifies the total allowable discharge of pollutants, divides this cap into individual permits assigned to individual polluters, and allows trading of the resulting permits. Laboratory experiments, in which paid subjects participate in controlled markets, can be used to test both proposals for emission trading and the theories on which they are based. This paper surveys the laboratory research that has investigated the efficiency of emission trading programs, role of alternative instruments and institutions, the effects of allowing firms to carry inventories of permits, and the extent to which market power can be exercised.

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INTRODUCTION

In the past thirty years, the concept of emissions trading has grown from a theoretical curiosity to a central idea in environmental regulation. The theory is well developed (Tietenberg, 1985, 1992) and case studies and summaries of actual practice are available widely (Hahn, 1989; Tietenberg, 1992). Attention has shifted from *whether* tradable emissions schemes should be implemented to *how* they should be implemented. This shift brings with it a need to examine closely details which may have been hidden in a broad overview but which need careful attention when designing and implementing emissions trading plans where millions of dollars are at stake.

This paper is concerned with one particular aspect of mechanism design: the use of laboratory techniques to testbed proposed market institutions and to test the theories on which the emission trading programs are based. Laboratory experimentation is a relatively new field in economics, but it is receiving greater acceptance both as a method for testing theories and a way of examining the performance of proposed market institutions before implementing them in the field (Smith and Williams, 1992; Davis and Holt, 1993).

A significant number of experiments related to emission trading have been reported over the past decade, and especially in the last five years. These experiments have taken place at many institutions in the United States and in the Experimental Economics Laboratory at McMaster University in Canada. This paper summarizes the results of the experiments with particular attention to what contribution they can make to rational policy formation. The paper begins with a brief overview of the experiments and continues to examine their findings in more detail. Evidence from laboratory markets will be presented to establish four points. First, emission permit markets tend to capture some but not all of the potential gains from trade in responsibilities for pollution control. Second, the market institutions governing trade in emission permit markets will have a significant effect on their efficiency. Third, the design features of emission permit markets, such as whether or not permits may be banked or whether or not time streams of permits may be traded, affect their performance. Last, concern about market power in emissions trading markets should not be dismissed lightly.

THE NATURE OF LABORATORY EXPERIMENTS

A laboratory experiment in economics is conducted with human subjects, usually university undergraduates. Typically about eight to twelve subjects are recruited for each market session. At the beginning of each session, participants are instructed about the rules of the experiment and assigned roles as buyers, sellers or traders. Usually they are told they will be participating in a market for an abstract product called a token. Buyers are given a schedule indicating the redemption value to them of one, two, or more tokens in each period. For example the first token may be redeemed for 100 lab dollars, the second for 50 lab dollars, the third for 45 lab dollars, and so on. The buyer's profit on each token is the difference between its redemption value and the price actually paid to the seller. Sellers are given marginal cost schedules indicating what each token they sell costs them. They compute their profit as the difference between the selling price and the marginal cost of the token.

Trading occurs for a number of market periods under rules specified by the experimenter. Trading may be done orally with manual record keeping or it may be mediated by computer programs of varying complexity and sophistication. In most of the experiments reported here, subjects entered bids and offers for tokens at a computer terminal. At the end of the experiment, subjects' earnings are converted from lab dollars to local currencies at a previously announced exchange rate and the subjects are paid in cash. A typical undergraduate may earn about $30 for a two-hour session.

One cardinal principle in experimental economics is to pay subjects sufficiently well to ensure their decisions are motivated by market payoffs. This is one reason for using university students as subjects; the opportunity cost of employed adults, especially senior decision makers, would be much higher. A second cardinal principle is never to deceive the subjects. All the rules of the experiment are announced in advance and strictly followed. Our interpretation of the data, however, may be different from the subjects'. For example, subjects are not told that the tokens they are trading represent permits to emit pollutants. In this way we hope to avoid biases induced by the nature of the commodity being traded.

EMISSIONS TRADING EXPERIMENTS

Plott

Plott (1983) reported the first laboratory experiment directly related to emissions trading. One of the questions Plott addressed was "how do the pollution tax, pollution standard, and pollution licenses compare as methods for correcting [an] externality?" Plott created a market for a product which conferred benefits on consumers who purchased the product, but also imposed spillover costs on all individuals in the market. The spillover costs were related to the number of units produced by the industry and were realized by buyers and sellers alike, regardless of how many units of the product they individually produced or consumed. Plott demonstrated that this externality could not be internalized by the double-auction pricing institution. Into this environment he introduced three alternative mechanisms to correct the market failure. When permits were used, the optimal number of permits were distributed among buyers and sellers of the product. Two double-auction markets operated simultaneously. Producers of the product had to acquire a permit before selling a unit of the product. Although the optimal theoretical distribution of permits and the optimal allocation of final product among consumers could easily be determined from the parameters underlying the laboratory environment, it was not obvious that this optimal distribution of permits and allocation of final product would emerge *behaviourally* when the permit mechanism was introduced into the laboratory. Plott's results were very impressive. The product market and permit market prices and quantities generally converged to, or very close to, the competitive equilibrium values. Participants in these markets realized on average more than 95 percent of the gains from using permits to regulate production. In the absence of the permit market net losses were realized by participants in this product market. Plott's laboratory sessions provided strong support for permit trading as a feasible mechanism for correcting externality problems such as pollution emission.

Hahn

Hahn (1988) tested his earlier proposal for a revenue neutral auction of emission permits (Hahn and Noll, 1982). One objection to emissions trading as originally proposed by Dales (1968) and others was that auctioning of emission permits by governments would both increase government revenues (a possibility viewed negatively by some) and impose a heavy financial burden on polluting industries. Hahn and Noll had proposed a revenue neutral auction in which current emissions would be grandfathered by distributing free permits to current polluters, but a market would be created by forcing the recipients to offer the permits for sale in a sealed bid auction. A market clearing price would be determined by aggregating all bids and offers and revenues from the auction would be redistributed to the firms offering permits for sale. Firms could retain their grandfathered permits by bidding a high value for them. This would be without financial consequence because they would in effect be buying the permits from themselves.

Hahn ran a series of seven experimental sessions using varying parameters. In six of the seven cases trading improved the efficiency of the market. Prices, however, did not always converge to the predicted values.

Several aspects of Hahn's research design were unsatisfactory. Most obviously, he did not run repeated trials of any of his experimental settings, so that the statistical significance of his various treatments cannot be gauged. His trading method, which involved collection of quantities offered at 10 prespecified prices may also have influenced his results. Nevertheless, Hahn's experiment represented a significant step in the direction of testbedding proposed emissions trading institutions in the laboratory.

U.S. Department of Energy Experiments

The U.S. Clean Air Act Amendments of 1990, which eventually led to the well-known Environmental Protection Agency (EPA) auction in sulphur dioxide emission allowances (the EPA's word for permits), provided an opportunity for further laboratory research into the properties of the revenue neutral auction. The U.S. Department of Energy first commissioned studies at the Universities of Arizona and Colorado and later followed them up with a systematic replication study at the Universities of Southern California and Mississippi. All of these studies have focussed heavily on the institutional features found in the U.S. sulphur dioxide emission permit program, in particular the revenue neutral auction, the reduction in the number of permits available to potential users, and the opportunity for banking permits.

Franciosi, Isaac, Pingry, and Reynolds

Franciosi *et al*. (1992) extended the Hahn experiment in a more conventional laboratory environment at the University of Arizona. They compared the performance of revenue neutral auctions with uniform price auctions in which revenues from the sale of permits were not redistributed to the subjects.[1] The prices and efficiencies generated in the revenue neutral markets and uniform price markets were quite similar, although substantial overbidding on infra-marginal units occurred in some of the revenue neutral cases.

The Arizona research group extended their examination of the revenue neutral auction in Franciosi *et al*. (1998). This experiment focussed on the interaction of the official revenue neutral auction market with a private, less regulated market for permits which was expected to develop beside the EPA auction. In this experiment each period is divided into two markets, conducted sequentially. In the first, subjects trade permits in a double auction market similar to a conventional asset market (such as the Toronto Stock Exchange). Subjects submit bids (offers to buy at a specified price), asks (offers to sell), or acceptances at a computer terminal. At the end of the double auction, subjects are required to surrender a fraction of their holdings to a revenue neutral permit auction. This auction is conducted as a sealed bid auction in which the traders effectively submit their entire demand schedule for permits and a market clearing price is determined by the intersection of the this demand curve with the fixed supply.

Eleven sessions were run, four with banking, four without, and three with banking and the Colorado parameters used by Cronshaw and Brown-Kruse (see below). They found a divergence in prices between the revenue neutral auction and the double auction. They also found that subjects are unable to exploit banking opportunities to increase efficiency.

Cronshaw and Brown-Kruse

Cronshaw and Brown-Kruse (1998) presented the results of a related experiment conducted at the University of Colorado. Their design focused primarily on the issue of banking. The Colorado subjects were told to allocate their permits over current and future periods, on the understanding that their production costs would vary with the number of permits used. Subjects were trained in a banking-only environment and then introduced to a revenue neutral auction in which they effectively submitted a demand or supply schedule for permits. The computer monitoring the experiment computed a market clearing price and enforced the implied trades. In contrast to Franciosi *et al*. (1998), who compared market equilibria with and without banking, Cronshaw and Brown-Kruse compared banking equilibria with and without trading. They found that market trading allowed subjects to improve over a banking-only equilibrium.

Cason, Elliott, and Van Boening

Cason *et al*. (1998) discuss a further study undertaken to reproduce the efficiency results and to reconcile the banking results of the two earlier studies by Franciosi *et al*. (1998) and Cronshaw and Brown-Kruse. They also investigate the opportunities for speculation opened up by the finding in the second paper by Franciosi *et al.* (1998) of a divergence between prices in the revenue neutral auction and the double auction.

Cason *et al*. investigate first whether the divergence between the Franciosi *et al.* (1998) and the Cronshaw and Brown-Kruse results reflect site-specific differences in performance rather than differences in experimental design and second whether opportunities for profitable speculation exist between periods and between the revenue neutral and private markets. They conduct a laboratory experiment in which there are four types of firm (high emissions/high abatement cost, low emissions/high abatement cost, high emissions/low abatment cost, and low emissions/low abatement cost). Subjects sequentially trade in a double auction and a revenue neutral call auction in each of twelve periods. There is a 50% reduction in permits allocated after the sixth period. The key treatment variable is location of the session: eight sessions were undertaken at each of the University of Mississippi and the University of Southern California.

The authors find efficiencies of 30.6% over all sessions, with no difference between mean values at the two sites.[2] These results are comparable to the efficiencies reported by Franciosi *et al*. (1998). The low efficiencies are associated with under-banking in earlier periods together with correspondingly low prices in early periods and high prices in late periods. This underbanking is consistent with earlier evidence of underbanking found using the same computerized environment and may be due to a serious bias induced by the presentation of data in it.[3]

The authors test for speculative opportunities by looking for systematic deviations from perfect foresight competitive equilibrium prices in the case of intertemporal speculation and statistically significant differences in mean prices by period in the double auction and the revenue neutral auction. They find that deviations from perfect foresight competitive equilibrium price are negatively related to deviations from optimal banking, both in early and late periods and conclude that speculative opportunities were indeed present. They also conclude that there were speculative opportunities present within the earlier periods, because there is a statistically significant difference in these prices. They find no evidence that net purchases of permits in early periods improved subjects' profits.

Other U.S. Experiments

Cason

Cason (1993, 1995) observes that the EPA auction is a discriminative price auction in which sellers with the lowest asking prices are matched with the buyers with the highest bids. He proceeds to demonstrate that the auction rules induce sellers to choose asking prices for permits which under-value their cost of emission control. Given the number of buyers, increasing the number of sellers increases the extend of under-valuation. The biased price signals which theory suggests will emerge in this market may reduce the efficiency of the market. Cason (1995) proceeds to demonstrate this bias in a laboratory market. These sessions suggest the EPA auction may be seriously flawed.

Cason and Plott

Cason and Plott (1996) report an experiment consisting of 12 sessions comparing the performance of the EPA style revenue neutral auction with the more conventional uniform price auction employed in many financial markets. Cason (1993) had pointed out that the EPA market contains important incentives for sellers to understate their true valuation of permits. This should lead to lower prices and efficiencies than might be obtained in a market with fewer biases. Cason and Plott find that the uniform price auction is more efficient, induces more truthful revelation of traders costs and values, generates more accurate price information, and is more responsive to changing market conditions than is the EPA style auction. The EPA style auction leads to lower clearing prices which in turn suggest the marginal abatement cost is lower than its true value.

Carlson and Sholtz

Carlson and Sholtz (1994) report an experiment undertaken at the California Institute of Technology which addressed the relationship between intertemporal trading opportunities in permits and the price stability of emissions markets. Uncertainty was introduced into a laboratory market by randomly adjusting the buyers' demands for permits. Two laboratory sessions were conducted. The first demonstrated there was a strong tendency for the prices of permits to become unstable when the demand for permits is uncertain and no banking is allowed. The second showed that a scheme of overlapping expiry dates on pollution permits could overcome this instability.

Ledyard and Szakaly-Moore

Ledyard and Szakaly-Moore (1994) extend the work of Franciosi *et al*. (1992a) by comparing the performance of the revenue neutral auction against the double auction. This is done in both competitive environments (five buyers and five sellers) and monopoly environments (one seller and five buyers). Ledyard and Szakaly-Moore find that the double auction performs better than the revenue neutral auction in both competitive and monopoly environments. The introduction of market power into the revenue neutral environment, however, does not lead to a great a reduction in market efficiencies as it does in the double-auction environment. In the competitive environment, prices adjust to the competitive equilibrium with both market institutions, but adjustment is much slower in the revenue-neutral market.

McMaster Experiments

A substantial program of laboratory research into tradable emission permits is underway at the McMaster Experimental Economics Laboratory. Three major experiments have been undertaken.

Mestelman, Moir, and Muller

Mestelman *et al*. (1998) and Muller and Mestelman (1993, 1994) report the outcomes of laboratory sessions which testbed proposals for nitrous oxide trading in southern Ontario (Nichols and Harrison, 1990a, 1990b; Nichols, 1992). The proposed institution differed from the U.S. EPA auction in a number of respects, notably the presence of two trading instruments, shares and permits, and the absence of a mandated auction with compulsory offers.[4] This experiment (hereafter identified as ET1) implemented trading for shares and permits in a multiple unit, open outcry, free-form market while using the Cronshaw and Brown-Kruse redemption values so as to allow comparison with the work by Franciosi *et al*. (1998) and Cronshaw and Brown-Kruse. This market structure was similar to open-pit trading for commodities but also provided traders with the opportunity to withdraw from the pit to negotiate private contracts. Contract prices were not made public systematically, and so price and quantity information was incomplete at best. ET1 demonstrated that an emission trading scheme such as the one described by Nichols and Harrison could effectively reduce abatement costs for a given emission cap. Banking was effective, but permit prices did not reflect system marginal abatement costs.

Godby, Mestelman, Muller, and Welland

Godby *et al.* (1997, hereafter ET3) was a large scale systematic test of the effects of bankable permits, tradable shares and uncertainty in a 2x2x2 factorial design. Trading was conducted in computer mediated double auction. This experiment confirmed the presence of price spikes in uncertain environments without banking and the ability of banking to eliminate the price instablility. It also revealed a significant impact on market efficiency through the interaction of banking and trading shares. The double-auction institution yielded permit prices that more closely reflected system marginal abatement costs than did the less organized market of ET1.

Brown-Kruse, Elliott, and Godby

Brown-Kruse *et al*. (1995, hereafter ETC) undertook an investigation into the potential for market power in emissions trading markets. The experiment consisted of twelve replications of a design originally proposed and piloted by Brown-Kruse and Elliott (1990). It involved groups of eleven subjects, one in the role of the dominant firm in an emission trading market and the others in the role of competitive fringe firms. Treatment variables were the initial allocation of permits (100% to dominant firm or fringe) and possibilities for manipulating a downstream product market. ETC displays striking results which suggest that market power can easily emerge in the presence of asymmetric information (when the dominant firm has information about the valuations of the competitive fringe).

THE FINDINGS

Overall, the experiments described above support several conclusions, which are reported below together with illustrative evidence.

Markets Work

Emissions trading markets work. Except for the market power experiments, all the reported experiments found increases in efficiency over the initial allocation. Moreover, prices in double auctions, revenue-neutral auctions, and uniform-price auctions tend to approximate the competitive prediction. Adjustment to these prices, however, may proceed differently for different institutions.

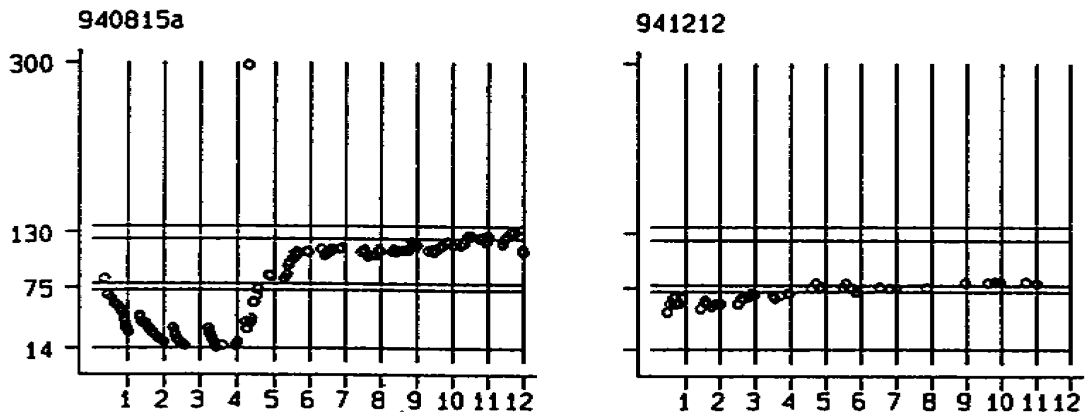
Table 1 presents efficiency results for the five studies which implemented a reduction in the emission permit cap during the laboratory session. Although trader characteristics and trading institutions differ across many of the sessions, on average each of the laboratory environments shows a reduction in abatement cost relative to what would be incurred under a command-and-control regime. In some environments the cost savings are nearly 90 percent of the potential savings (ET3), while in others the savings are slightly more than 25 percent of the potential. In all of the environments the system emission cap is maintained at the command-and-control level.

Figure 1 displays the contract prices generated in two ET3 sessions. In Panel A permits are traded, but banking is not permitted. The competitive price is 14 laboratory dollars during the first 4 periods, but increases to something between 123 and 136 during the final 8 periods. The price increase is the result of the reduction in permits following the crank-down of the emission cap. Note how well the prices generated by a double auction market with 8 traders converge to the price predicted by the competitive model. When banking is permitted, the price predicted by the competitive model is something between 72 and 78 laboratory dollars. The price path in Panel B is generated by a session in which permits may be traded as may entitlements to future permits (shares). This is relatively stable over the twelve trading periods *in spite of the crank-down in permits after period 4*. This is a dramatic example of the power of competitive markets to generate signals which will exhaust gains from trade (the efficiency of the market in Panel A, over the 12 periods, was 98 percent; in Panel B, it was 97 percent).

Market Institutions Matter

Low price incentives in the EPA auction

Market institutions affect market outcomes. Cason and Plott argue that the EPA auction rules bias both bids and asks downwards, and show that these results can be obtained behaviourally in a controlled market environment. Because the lowest ranked bid is matched with the highest offer, sellers have an incentive to ask a low price for further permits. Similarly, buyers have no incentive to bid above the competitive equilibrium price.



Panel A
No Banking, No Share Trading, No Uncertainty

Panel B
Banking, Share Trading, No Uncertainty

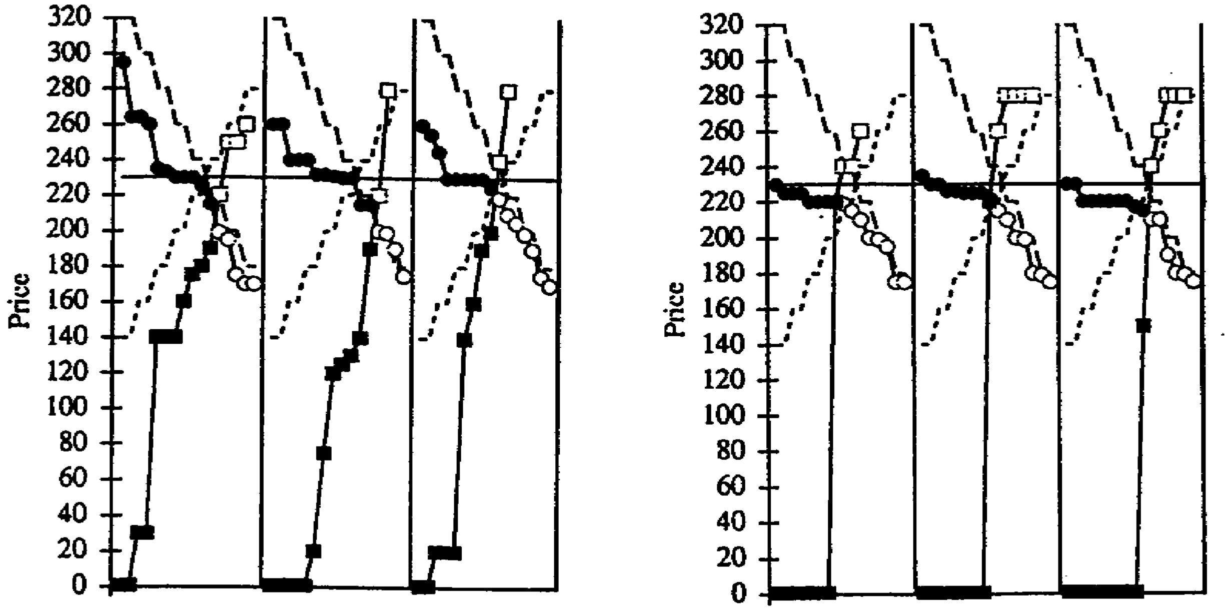
Figure 1 Permit Contract Prices

Source: Godby, Mestelman, Muller, and Welland (1996)

TABLE 1 EFFICIENCY OF PERMIT MARKETS WITH BANKING*

FIPR2A		FIPR2C		CBK		ET1		ET3		CEVB-USC		CEVB-UM	
Session	Percent of Abate-ment Cost Saved	Session	Percent of Abate-ment Cost Saved	Session	Percent of Abate-ment Cost Saved	Session	Percent of Abate-ment Cost Saved	Session	Percent of Abate-ment Cost Saved	Session	Percent of Abate-ment Cost Saved	Session	Percent of Abate-ment Cost Saved
R2	62.9	R10	24.7	1	29.9	1	74.1	1129	82.3	1	48.0	1	-37.3
R3	50.8	R11	7.5	3	54.8	2	82.8	1212	96.8	2	32.0	2	57.3
R4	46.4	R12	46.9	5	70.9	3	92.9	1220	92.4	3	59.3	3	65.3
R9	30.6			6	60.0	4	55.0			4	50.7	4	-12.7
				7	65.9	5	65.1			5	-26.7	5	41.3
										6	42.7	6	53.3
										7	34.0	7	34.0
										8	2.7	8	46.7
Mean	47.7	Mean	26.4	Mean	56.3	Mean	74.0	Mean	90.5	Mean	30.3	Mean	31.0

* The data for FIPR2A and FIPR2C are taken from Frnaciosi, Isaac, Pingry, and Reynolds (1992b), for CBK from Cronshaw and Brown-Kruse (1992), for ET1 from Muller and Mestelman (1994), for ET3 from Godby, Mestelman, Muller, and Welland (1996), and for CEVB-USC and CEVB-UM from Cason, Elliot, and Van Boening (1995). The FIPR2A sessions use a unique parameter set, but the same trading institution as FIPR2C. The FIPR2C, CBK, and ET1 sessions use a common parameter set, but different trading institutions. ET3 sessions use a unique parameter set and a unique trading iinstitution. The CEVB-USC and CEVB-UM sessions use a unique parameter set, but the same trading institutin as FIPR2A and FIPR2C.



Panel A
Periods 1, 2, 3

Panel B
Periods 9, 10, 11

Figure 2 Bids and Asks in EPA Auction

Source: Cason and Plott (1993)

Figure 2 illustrates Cason's and Plott's results. The dotted lines show the true marginal valuations for buyers and sellers. The dark lines connecting circles and boxes show actual bids and asks respectively (filled circles and boxes are bids and asks which were filled). At the beginning of the experiment, buyers and sellers are bidding close to their marginal values. By period 3, however, the sellers are asking prices well below their costs and the buyers are bidding well below their valuations. By period 9, sellers are asking zero and buyers are bidding at or below the competitive price. On average, prices are below the marginal cost of abatement for the industry

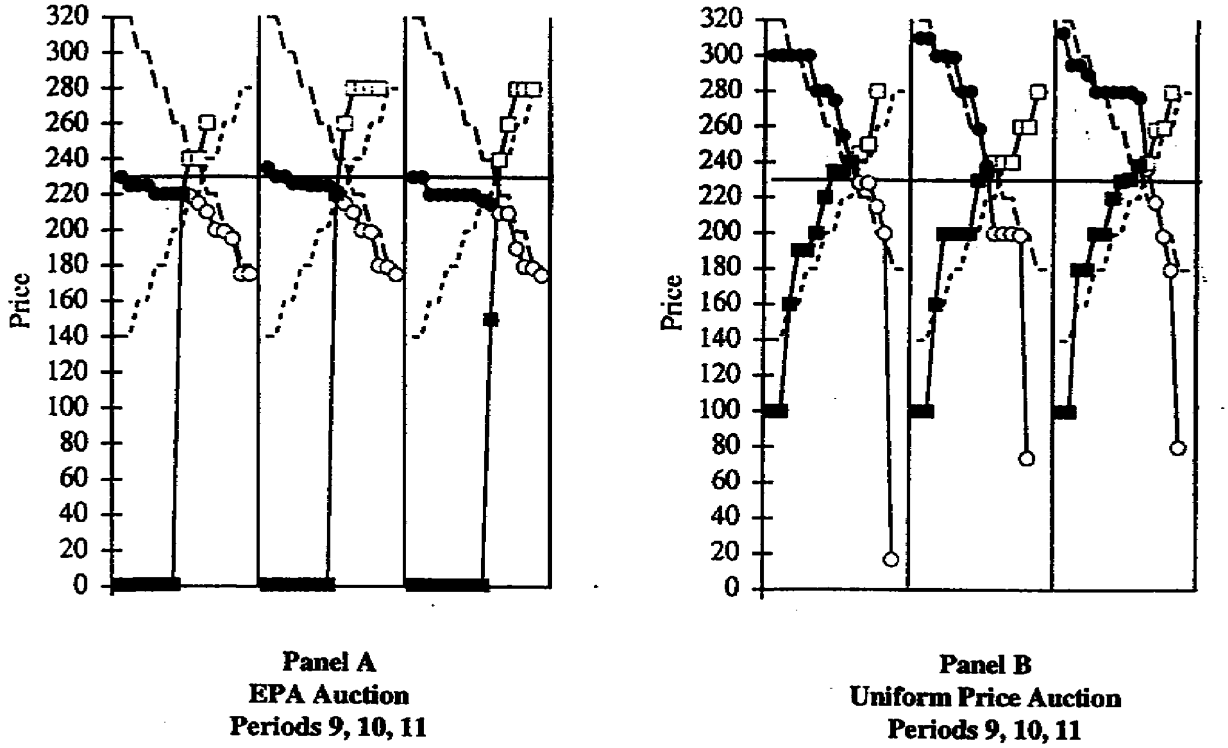


Figure 3 Bids and Asks in EPA Auction and Uniform Price Auction

Source: Cason and Plott (1993)

represented by this market.

Alternatives to the EPA Auction

Although the incentives built into the EPA auction may lead to behaviour which is not demand revealing and which results in lower than desirable prices, Cason and Plott provide evidence of an alternative trading institution with more desirable properties. Figure 3 shows periods 9, 10, and 11 from a session run under the laboratory EPA auction rules and periods 9, 10, and 11 from a session run under a uniform-price auction with the same parameters as the EPA auction. Notice how closely the bids and asks in the uniform-price auction track the actual valuations and costs, while in the EPA auction the bids and asks have fallen well below the respective valuations. There are other alternatives to the EPA auction than the uniform-price auction. None has been evaluated in a laboratory setting in the way Cason and Plott conducted their evaluation.

Another indication of the importance of institutions is shown in Table 1. The abatement cost schedules and permit allocations are the same for the traders in the ET1, Franciosi *et al*. (1998), and Cronshaw and Brown-Kruse. Permits may be traded and banked. The sessions lasted for 12 periods and the permit allocations were cranked down after period 4 in all cases. The trading institutions (described earlier) were very different. The performance of the trading schemes, as reflected by the abatement cost savings are also very different. Institutions clearly matter.

Design Features Matter

The abilities to trade shares and to bank permits have important and independent effects on permit markets. Moreover, these features interact with the degree of certainty about permit use.

Tradable Shares

Many Canadian proposals for emission trading have included formal trading in shares. A share is the right to receive a fixed percentage of the annual allowable emissions in the current and all future years. The McMaster experiments (ET1 and ET3) have shown that markets with tradable

TABLE 2 MEAN PERMIT VOLUME IN 12 PERIODS IN ET3 SESSIONS

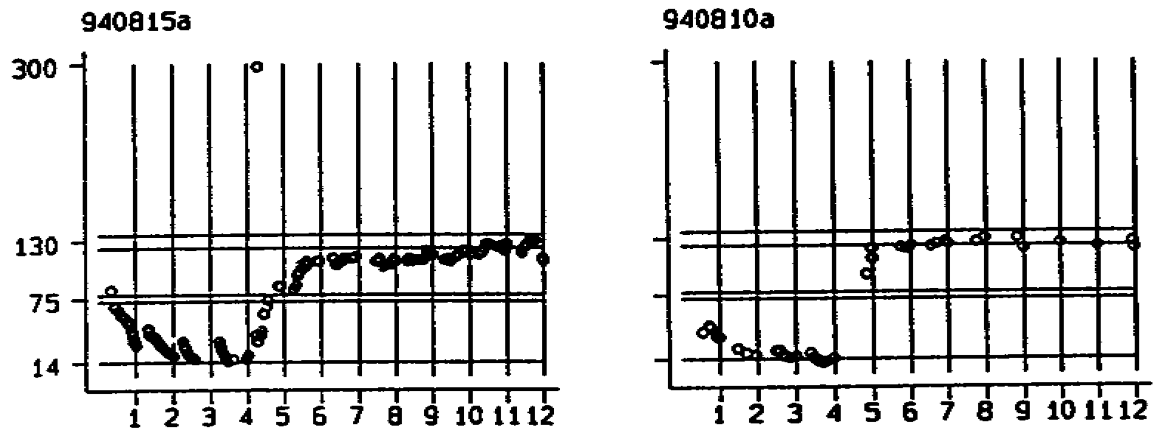
	Certain Production		Uncertain Production	
	No Share Trading	Share Trading	No Share Trading	Share Trading
No Banking	211.33	59.33	218.00	96.33
Banking	184.67	96.67	226.67	119.67

Source: Godby, Mestelman, Muller, and Welland (1996)

shares have less permit trading but a more rapid convergence of price to equilibrium levels than markets which exclude futures trading.

Table 2 presents the average permit volume per session in ET3 in each of different treatments. Whether the production of emissions is certain or uncertain or whether permits may be banked or not, the existence of share trading during a session leads to fewer permits being traded.

Figure 4 shows contract prices for two ET3 sessions. Banking is not allowed in either session, but in the session displayed in Panel B, shares are traded. In Panel A prices do not reach the upper equilibrium band until the end of the ninth trading period. In Panel B, prices are in the upper consistently by the seventh period. The frequency of the contracts is consistent with the mean trades reported in Table 2. Trades are fewer when shares are traded, and convergence is more rapid.



Panel A
No Banking, No Share Trading, No Uncertainty

Panel B
No Banking, Share Trading, No Uncertainty

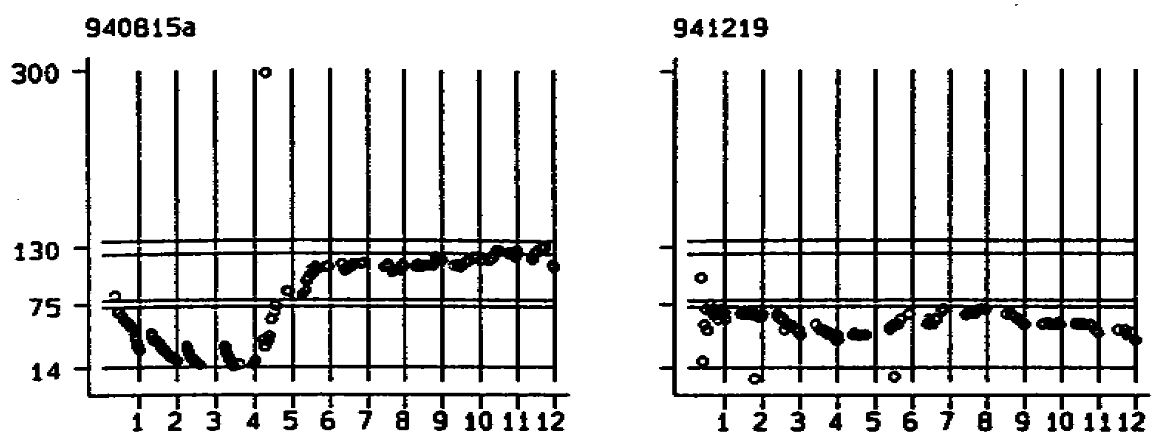
Figure 4 Permit Contract Prices

Source: Godby, Mestelman, Muller, and Welland (1996)

Banking

Another design feature is the ability to bank permits over time periods. The McMaster experiments confirm the results of the two sessions reported by Carlson and Sholtz (in a slightly different context) that permit banking smooths prices across time periods. We also found that banking reduced trading efficiencies relative to trade with no banking. This effect is eliminated, however, when trading in shares is permitted along with banking, and when traders acquire experience.

Panel A in Figure 5 is a repeat of Panel A in Figure 1. It shows permit prices in an ET3 session with no share trading and no banking. Notice the big jump in prices when the number of permits distributed each period is reduced in the fifth period. Panel B of Figure 5 shows permit prices in an ET3 session with banking, but no share trading. There is no abrupt price increase in period 5. Because the reduction in permits after the fourth period is known, it is anticipated. Decision-makers acquire permits and bank them as necessary. The reduction in permits after the fourth period is reflected by higher market prices for permits during the early periods of the session and lower prices in later periods of the session (compare the patterns of prices in Panels A and B).



Panel A
No Banking, No Share Trading, No Uncertainty

Panel B
Banking, No Share Trading, No Uncertainty

Figure 5 Permit Contract Prices

Source: Godby, Mestelman, Muller, and Welland (1996)

Panel B in Figure 1 shows prices when both share trading and banking are permitted. Compared with Panel A, prices are more stable over the course of the session and fewer trades are made.

Design Features Interact

Table 3 shows the effect of banking and share trading on efficiency. No-banking sessions have less potential for cost savings, since trade across time periods is prohibited. After adjusting for this, efficiency with banking but no share trading is lower than efficiency with neither banking nor share trading. Introducing share trading into a permit trading environment with no banking, has litte effect on efficiency. Share trading and banking, however, interact. The result is a market environment in which more than 90 percent of the potential cost savings are realized. This is a 20 percent increase beyond what can be achieved trading permits in the periods in which they will be used.*Design Features and Production Environment Interact*

It is possible that producers of pollution emissions are unable to accurately predict the amount of emissions that will actually be produced. If it is necessary to hold permits for emissions, or pay fines for not having sufficient permits, the behaviour of traders in emission permit markets will be different from that if permit needs were certain. If there is no opportunity for banking, uncertainty in emission control causes violent price spikes. This possibility was first demonstrated in the laboratory in two trading sessions with uncertainty at the Experimental Laboratory for Economics and Political Science at Caltech. The results are reported by Carlson *et al*. (1993) and Carlson and Sholtz. Uncertainty was introduced by randomly adjusting the subjects' planned use of permits. Subjects experiencing unexpectedly high permit use were forced into a reconciliation market. With

TABLE 3 MEAN NET (ADJUSTED NET) EFFICIENCY IN ET3 SESSIONS*

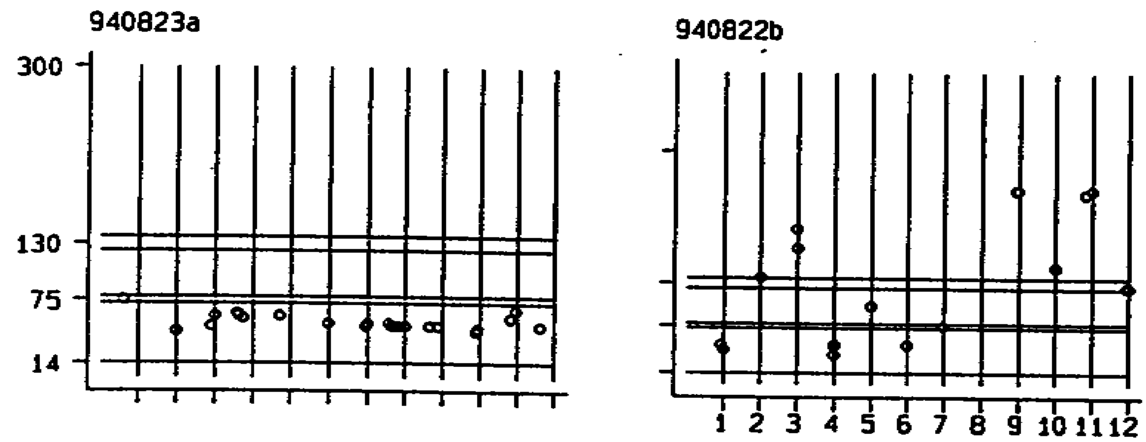
	Certain Production		Uncertain Production	
	No Share Trading	Share Trading	No Share Trading	Share Trading
No Banking	74.84 (93.79)	76.14 (95.41)	76.22 (95.44)	79.45 (97.98)
Banking	52.02 (52.02)	90.50 (90.50)	84.37 (84.37)	93.66 (93.66)

Source: Godby, Mestelman, Muller, and Welland (1996)

* Net efficiency is the ratio of the realized cost saving to the maximum potential cost saving with optimal banking. Adjusted net efficiency is the ratio of the realized cost saving to the maximum potential cost saving given that permits may or may not be banked.

no possibility of intertemporal trade, this led to very high price spikes in some periods and price troughs in others. Allowing staggered permits with overlapping expiry dates reduced these fluctuations. These results were convincing to the South Coast Air Quality Management Dirstrict and led to the inclusion of permits with overlapping expiry dates in the Regional Clean Air Incentives Market which was introduced in southern California in 1995.

This finding has been confirmed at McMaster. Panel B in Figure 6 shows a reconciliation market without banking but with share trading. The optimal time path of permit prices in this market is for them to rise from about 72 laboratory dollars to 130 laboratory dollars over the first five trading periods. Permit prices should be within the upper band shown in the diagram after the fifth trading period. Share trading is effective in reducing the number of trades which occur during the reconciliation portion of each trading period, but swings in permit prices are severe. Panel A shows a reconciliation market with both banking and share trading. Permit prices are much more stable (to some extent, the degree of fluctuation in permit prices in Panel B is underemphasized because the vertical scale of Panel B is compressed relative to that of Panel A).



Panel A
Banking, Share Trading, Uncertainty

Panel B
No Banking, Share Trading, Uncertainty

Figure 6 Reconciliation Permit Contract Prices

Source: Godby, Mestelman, Muller, and Welland (1996)

Market Power Matters

It is well known that the good efficiency properties of emissions trading markets can vanish if a dominant firm exercises its market power (see Ledyard and Szakaly-Moore). Market power is even more dangerous if it is exercised to raise the costs of rivals in downstream markets.

All of the laboratory markets that have been described here contain balanced distributions of producing units (for instance, Godby *et al*. have a market with eight producers, four of which have low abatement costs and four have high abatement costs; four emit half the pollution emitted by the other four in the pre-control environment). Brown-Kruse *et al*. (1995) set out to see if they could observe market power at work in the laboratory when the industry is asymmetric. Brown-Kruse *et al*. present an experimental design in which there are ten small fringe firms and one large dominant firm. Subjects trade permits, then decide how much output to produce in a downstream market. Permits were allocated either entirely to the fringe or entirely to the dominant firm. They discovered that experimental subjects do exercise market power and that efficiencies can actually be reduced below command-and-control levels when markets are vertically integrated. The ETC results are summarized in Table 4. When permits are allocated to the fringe firms, the large firm can hold the market price below the predicted competitive price giving the single buyer an advantage in the permit market. The reverse holds if the permits are allocated to the large firm. Whether there is a variable price in the product market or not, the large firm is able to exercise market power. Of particular note is that overall market efficiency is negative when the product market price is variable. This means that a command-and-control regime would lead to greater abatement cost savings than would result from permit trading. The Brown-Kruse *et al*. results clearly show the exercise of market power in vertically related markets.

TABLE 4 MEAN PRICES AND EFFICIENCY IN ETC SESSIONS

Treatment	Predicted Competitive Price	Predicted Market Power Price	Mean Market Price	Efficiency
Permits to Fringe; Fixed Product Price	105	90	87	0.71
Permits to Large Firm; Fixed Product Price	105	110	125	0.96
Permits to Fringe; Variable Product Price	105	75	64	-0.42
Permits to Large Firm; Variable Product Price	105	180	207	-1.40

Source: Brown-Kruse, Elliott, and Godby (1995)

CONCLUSIONS

Basic results

Laboratory markets, which capture many of the characteristics of the field, support advice arising from theoretical investigation and field research. A good emissions trading plan will have public information, some form of banking, and some form of secure trading in the rights to future permits such as is provided by trading shares. Because the rules governing permit trading matter, simply permitting trade in permits does not guarantee that efficient markets will emerge. Finally, laboratory results show that concerns about market power should not be quickly dismissed.

Future Laboratory Research

Future research in this area would be fruitful. Perhaps the most important line of research concerns market power. It is important to confirm the Brown-Kruse *et al*. results and to see whether they stand up in different trading environments. It may be that alternative market institutions, such as uniform price auctions, may be effective in controlling market power. Experimental research may also be important in related areas of environmental regulation, especially in testbedding alternative plans for monitoring compliance with environmental obligations, whether implemented through tradable permits or some other means.

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NOTES

1. In a uniform price auction subjects submit sealed bids from which the experimenter generates a demand curve. Bids are ranked and the available permits are distributed to the highest bidders at a price somewhere between the lowest accepted and highest rejected bids.

2. Efficiency in this context is a measure of the extent to which potential abatement cost savings are realized through trading and banking permits.

3. This environment program presents subjects with a table whose columns are permits redeemed and redemption value. The current holdings of permits are flagged; thus a subject holding eight permits in period one will believe that the marginal value of one more permit will be given by the ninth row in the table. But if the subject is banking optimally, some of his current holdings will be redeemed in later periods. Therefore, an additional permit redeemed in the current period will not be the ninth permit but some lower numbered permit with a higher redemption value. This presentation will lead subjects to undervalue current permits.

4. The proposed instruments were called shares and coupons. Permit is a generic term and replaces coupon and allowance in this paper.

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