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THE CHOICE OF INSTRUMENTS FOR POLLUTION EMISSION PERMIT TRADING: DESIGNING A LABORATORY ENVIRONMENT

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Abstract

Important decisions in designing markets for tradable pollution emission permits have focussed on whether to allow banking of permits and the selection of the trading institution for the transfer of permits. Recent studies in laboratory markets suggest that banking will be particularly important when uncertainty about actual emissions requires trading in a reconciliation period after the quantity of emissions has been determined and that the double auction trading institution tends to outperform others (such as revenue neutral discriminative auctions, revenue neutral competitive auctions, and open outcry free-form auctions). The existing laboratory work has not addressed the value of formal markets in permit futures. Such a market has been included in several proposals for emissions trading markets in Canada. This paper describes the laboratory environment created at McMaster University to evaluated the benefits of a market in entitlements for permits when the parameters characterizing the environment suggest theoretically that the existence of entitlement trading is redundant if permits are tradable and bankable. The results of laboratory testing of entitlement trading suggests that behaviourally the combination of emissions permit trading and entitlement trading can interact and increase the efficiency of the pollution emission trading program.

The choice of instruments for pollution emission permit trading: designing a laboratory environment

Stuart Mestelman and R. Andrew Muller[1]

Introduction (Main Heading)

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.

Often, proposed emissions trading plans contain elements whose effects are not clearly understood. For example, several reports prepared for Canadian governments have recommended trading two assets, coupons and shares. (Nichols, 1992; Nichols and Harrison, 1990a, 1990b). A coupon would permit its owner to emit a prescribed quantity of effluent (for example, one ton of nitrous oxide) during a prescribed period of time (for example, one year). A share would entitle the owner to a prescribed proportion of the coupons allocated each year. Unused coupons could be banked for use in future years. Because unrestricted coupon trading and banking allows firms to meet the total allowable discharge at minimum cost, the role of shares in the program is unclear. They may be justified on administrative grounds: creating and trading shares reduces transactions costs in disposing and acquiring time streams of coupons and may simplyify record keeping for the regulator. Their effect on the performance of the coupon market, however, is uncertain. They might improve efficiency by reducing transactions costs, reduce efficiency by introducing additional complexity or leave efficiency unchanged. The outcome cannot easily be predicted from economic theory.

Testbedding the proposed program in an economics laboratory is an ideal method for sorting out the effects of tradable shares and bankable coupons. Directly implementing the program with shares will make it impossible to determine whether or not share trading has affected performance. While field experiments might be feasible, they would be very expensive. Moreover , too many variables are uncontrollable in the field to guarantee that the field experiment would provide clear answers. In the laboratory, sufficient variables can be controlled to isolate the effect of share trading on system abatement cost saving.

A number of experiments related to emission trading have been reported over the past decade, and especially in the last five years. Most of this work has been directed at evaluating the performance of alternative trading institutions, specific trading institutions, or the role of banking (Carlson and Scholz, 1994; Cason, 1995 ; Cason, Elliott and Van Boening, 1995; Cason and Plott, 1996; Cronshaw and Brown-Kruse, 1992; Franciosi, Isaac, Pingry and Reynolds, 1993a, 1993b; Hahn, 1988; Ledyard and Szakaly, 1994; Muller and Mestelman, 1994; Plott, 1983). Alternative or multiple instruments have not been considered (the exceptions ares the work reported by Carlson and Scholz which compares the performance of markets in which non-bankable permits have common or overlapping expiry).

In this paper we present the laboratory environment that was designed as part of an investigation of bankable coupons and tradable shares.   The experiment suggested that tradable shares contribute positively and significantly to the efficiency of the coupon markets, in a manner which is not anticipated by conventional theoretical analysis and which reflects an intereaction between share trading and coupon banking and trading.

In the remainder of the paper we shall describe in detail the laboratory environment presented to our subjects. We will then more briefly discuss the predictions and results before concluding. A fuller discussion of the results appears in Godby, Mestelman, Muller and Welland (1996).

The Laboratory Environment (Main Heading)

The first laboratory investigation into emissions trading with shares and coupons was conducted in manual experiments run at McMaster University in 1993 (Mestelman, Moir and Muller,1993; Muller and Mestelman, 1994). Five sessions were run in which traders received physical shares and coupons, negotiated trades in an open outcry market, and made decisions on output and banking. This environment required that traders manually maintain all of their trading and production records, making it difficult for traders to concentrate on market transactions. In spite of the complex environment and tedious record-keeping requirements, the emissions trading program demonstrated substantial abatement cost savings. Because all the McMater sessions involved both tradable shares and bankable coupons, the individual contributions to efficiency could not be determined.

A field environment in which agents could bank coupons and trade both coupons and shares would be even more complex than our first experiment. In addition to making trading decisions and allocating coupons across time, agents would need to deal with uncertainty due to events external to the market. For example, a heat wave might increase demand for electricity and reduce the availablity of hydraulic power, causing electrcial utilities to burn more coal and release more suphur and nitrogen oxides. If a firm discharges more waste than planned, it must remit more coupons than it planned to use. The alternatives are to pay a large fine, acquire additional coupons from the market, or reduce its inventories of coupons. Carlson and Sholtz (1994) showed that overlapping the expiry date on permits greatly reduced the volatility of prices in such markets.

In extending our work to investigate systematically the separate effects of coupon banking, share trading and production uncertainty we decided to develop a computer mediated environment.[2] In this environment, agents trade shares in a double auction, entering their bids, asks and acceptances at their computer workstations. Coupon allocations, share and coupon trades, coupon use and inventories, and trader profits are all maintained on a computer and are available to the traders through their computer monitors. These monitors also provide public information about contract prices and volumes (for shares and coupons). Computerization also offered an opportunity to reduce the cognitive complexity of the environment by providing information about the marginal valuation of coupon and share inventories, as well as information about the cost minimizing allocation of coupon inventories (held or anticipated).

While we reduced the recordkeeping chores of the traders, we increased the complexity of the environment for traders by introducing production uncertainty. This additional complexity introduces the need for a third market. When traders discover that their production expectations are not realized, they may find it advantageous to enter into a reconciliation market. In this market traders may acquire or sell additional coupons to meet the changing circumstances created by the realization of the production uncertainty between the time that actual coupon needs are discovered and the delivery of coupons to the regulator (or the payment of fines) is required. In the remainder of this section we describe the decision-making environment that was presented to our subjects.

Parameters (Subheading)

We constructed a laboratory market in which eight subjects representing four types of firm trade coupons and shares. In every period each firm produces a fixed level of output and receives a fixed gross revenue. Gross emissions either are constant or vary randomly around an expected value. We refer to the latter as the case of uncertainty. Emissions may be abated at an increasing marginal cost. Net emissions equal gross emissions less abatement. Although abatement effort is chosen with certainty, net emissions are random when gross emissions are uncertain. We define complete abatement as the abatement effort required to reduce expected net emissions to zero. Abatement cost savings, the difference between the cost of complete abatement and the cost of the actual abatement effort, rise at a diminishing rate as expected net emissions increase.
The four types of firm differ in initial size (as measured by expected gross emissions) and by abatement cost. Expected gross emissions are 20, 20, 10 and 10 for firm-types A, B, C and D respectively. Types A and C have low marginal abatement costs relative to types B and D. Shares are distributed in proportion to expected gross emissions: 6, 6, 3 and 3 for firm-types A, B, C and D respectively. Each period firms receive a coupon dividend in proportion to their holdings of shares. A reduction in aggregate emissions is imposed by reducing this dividend from two to one coupon per share after the fourth period.

To remove the potential influence of the environmental aspect of the market, subjects are not told they will be trading emissions coupons, but rather that they are producing a product requiring a scarce input that is being rationed. They must surrender one coupon for each unit of input they actually use. Under conditions of certainty with no banking allowed, the marginal value of a coupon is equal to the marginal abatement cost savings shown in Table 1. Because subjects participated in more than one session (see below), these induced values were varied by a scale factor ranging from one to four to prevent subjects becoming familiar with the equilibrium values. The conversion rate from Laboratory to Canadian dollars was adjusted to yield approximately equivalent payoffs.

Table 1

Marginal Valuations by Type of Firm

Input Use	Type of Firm A	B	C	D
1	78	158	70	275
2	50	156	40	256
3	30	154	20	237
4	18	152	10	218
5	14	150	10	199
6	14	148	8	161
7	14	146	8	123
8	14	144	6	85
9	12	142	6	47
10	12	140	4	9
11	12	138	0	0
12	12	136	0	0
13	10	120	0	0
14	10	104	0	0
15	10	88	0	0
16	10	72	0	0
17	8	56	0	0
18	8	40	0	0
19	8	24	0	0
20	8	8	0	0

Notes:

The marginal valuation is the cost saving realized from having one more unit of input, i.e. permission to discharge one more unit of waste. Zero input use corresponds to 100% abatement.

The marginal abatement cost savings induce a demand curve for net emissions and hence for coupons. The supply of coupons is 72 coupons in each of periods one to four and 36 coupons in each of the remaining eight periods. If agents bank optimally, 48 coupons will be redeemed each period.[3] In the case of uncertainty, agents may find that they used one more or one fewer unit of input than they intended. Unexpected emissions must be covered by a coupon and so the supply of coupons available for redemption against expected use falls or rises each period by the sum of unexpected emissions in each period.

The trading environment (Subheading)

Our trading environment models much more of the actual complexity of a field market than has been the case in other emissions trading experiments. In our environment a session consists of 12 periods which are divided into six sub-periods or phases (share market, distribution, primary coupon market, production decision, production result, and reconciliation). In some treatments, one or more of these phases are omitted.

During the share market phase traders buy and sell shares in a computerized double auction market. This phase only occurs under treatments with tradable shares. The share market phase is followed by the distribution phase, in which subjects receive coupons according to their current holdings of shares and the previously announced coupon dividend rate for that period. The distribution phase does not require any intervention from the traders. During the primary coupon market phase, traders again buy and sell coupons in a computerized double-auction market.

During the production decision phase, traders choose the number of units of the input to use and consequently the number of coupons they will need. In the production result phase, which occurs once all production plans have been submitted, traders are informed of their actual input use and of the cash generated from current production. Under the uncertainty treatment, actual input use may differ from planned input use by an amount specified in advance by the investigators. In the present case these errors were drawn from a uniform distribution over the values (-1, 0, +1).[4]

During the reconciliation phase traders buy and sell coupons in a computerized double-auction market to eliminate any coupon deficit or unwanted coupon surplus. We chose not to allow traders to plan a coupon deficit during the production decision phase. Nevertheless, when uncertainty is present, it may be the case that actual use exceeds coupon holdings. In this case, the trader has a coupon deficit that must be cleared by purchasing more coupons. Similarly, traders may deliberately incur a coupon surplus (in the production decision phase) that they choose to sell rather than to bank. The reconciliation period allows such trades.

In the coupon-redemption phase, traders redeem the number of coupons corresponding to their actual input. Traders with a coupon deficit pay a penalty of 300 Lab dollars per unit, which is greater than any trader's marginal abatement cost. Eliminating the deficit becomes a first charge against any coupons acquired in the following period. The coupon-redemption phase does not require any intervention on the trader's part.

After the coupon-redemption phase the next period begins with a share market (if enabled) and a new distribution of coupons. There is no share market in the last period of the session. At the end of the session, traders' earnings are converted to Canadian dollars and paid privately in cash.

Table 2

Sample Marginal Abatement Cost Saving Schedule

	Period 1	Period 2	Period 3
Coupon 1	200	200	200
Coupon 2	190	190	190
Coupon 3	180	180	180
Coupon 4	170	170	170
Coupon 5	160	160	160
Coupon 6	150	150	150
Coupon 7	140	140	140

The planner and the wizard (Subheading)

Our trading institution places major cognitive demands on the traders. When banking is allowed, the marginal value of a coupon is not determined directly by the trader's abatement cost schedule for the current trading period, but rather by the place in the schedule that the coupon would occupy if all current coupons and anticipated coupon dividends are allocated optimally over the remaining periods of the session. Similarly, the marginal value of a share is derived from the incremental value of the coupons it bears. These values are the output of simple, deterministic maximization problems. In the field, the operations research department of participating firms could certainly compute these marginal values, given any trial holding of shares and coupons. Accordingly, traders are provided with a production planner that simulates an operations research department. The production planner is shown in a window on the computer screen. Traders can enter any trial quantity of coupons and shares. The production planner computes the abatement cost-minimizing allocation of current and anticipated coupons over time and reports both the allocation, the corresponding profit, and the change from the current holdings.

Even the production planner may be too time-consuming for traders to use in the course of the auction markets. Accordingly, traders are also provided with advice from trading and production wizards. The trading wizard uses the production planner to compute the marginal value of coupons or shares, depending on the phase of the market, and displays its advice in a window during the primary coupon market, the reconciliation market, and share market phases of the period. The production wizard simply displays the operating profit-maximizing number of input units to use during the production decision phase.[5]

An example (Subheading)

The environment is best understood by means of an example. Table 2 displays the marginal abatement cost saving schedule (in laboratory dollars, L$) for a trader in an emission permit trading environment. In this abbreviated example, the trader must plan over a three period time horizon. If this trader uses five coupons in period 1, the abatement cost saving is the sum of L$200, L$190, L$180, L$170, and L$160, for a total abatement cost saving of L$900. The trader has been given an entitlement of two shares, each of which pays a dividend of two coupons in periods 1 and 2 and one coupon in period 3.

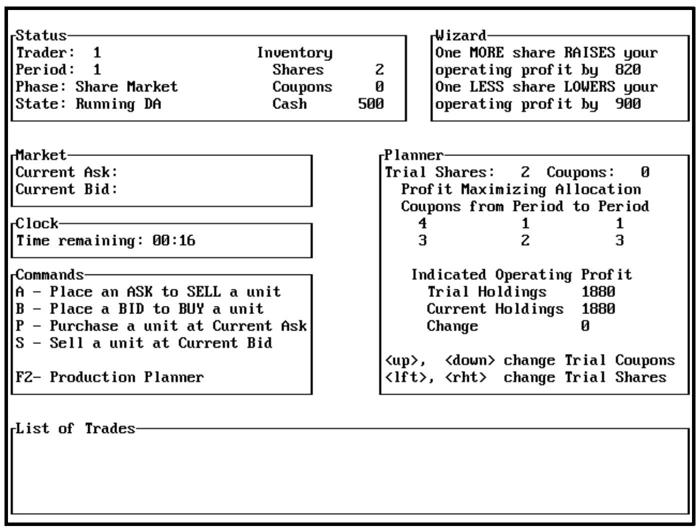

Figure 1 The Share Market

Figure 1 displays the information presented to the trader during the share phase. The **Status** window shows the trader's inventory of shares, coupons and cash at all times. A **Market** window displays the current **Ask** and **Bid**. The **Clock** window displays time remaining in the market. In the top right corner, the **Wizard** displays its trading advice. Traders should be able to infer from this their maximum willingness-to-pay for a coupon (i.e. their maximum bid) and their minimum willingness-to-accept payment for a coupon (i.e. their minimum ask). The **Planner**, which can be directly accessed during trading, allows traders to calculate their profits for any trial number of shares or coupons. The trial numbers are adjusted using the arrow keys. The **Planner** advises this trader to allocate 4 coupons in period 1 and three coupons in each of periods 2 and 3. The current allocation is 4 coupons in periods 1 and 2 and 2 coupons in period 2. Table 1 shows that by transferring one coupon from period 2 to period 3, the firm would save L$10 in abatement costs, since the abatement cost savings of L$180 in period 3 would outweigh the rise of L$170 in abatement costs in period 2.

Furthermore, if this trader purchased one more share at the start of period 1, there would be five additional coupons to allocate over the three periods. The 15 coupons would be most effectively allocated if 5 coupons were redeemed in each of the three periods. This would increase this trader's abatement cost savings by L$160 in period 1, L$330 in period 2, and L$330 in period 3. The total abatement cost saving of L$820 is reported by the **Wizard** in the top right-hand box. This trader could profit by paying up to L$820 for an additional share. The other value reported in the **Wizard** box is L$900. This is the abatement cost saving which would be lost if one of the two shares was sold in this first round of trading. By selling this share, only five coupons would be available for use over the three periods. Optimal coupon use would fall by two coupons in period 1, by one in period 2, and by two in period 3. The total reduction in abatement cost saving is L$350 in period 1, L$180 in period 2, and L$370 in period 3. The total of these values, L$900, is the minimum price the trader should accept for the sale of one share if the trader wanted to maximize profit. Once a share is purchased or sold, the **Wizard** amends its advise to reflect the value of the next transaction.

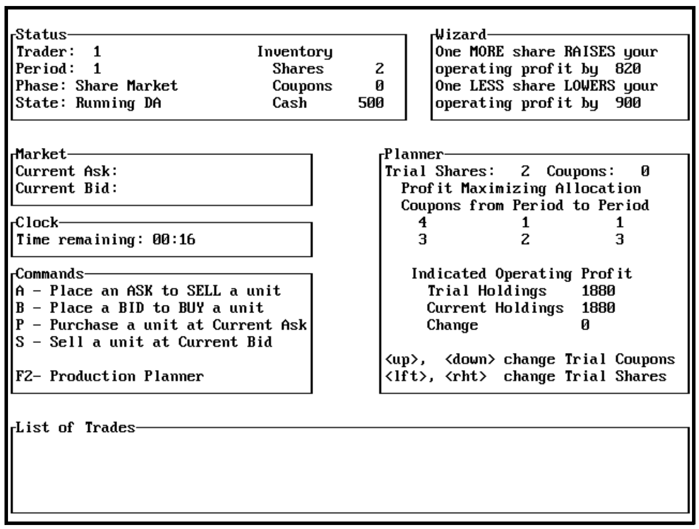

Figure 2 The Coupon Market

Figure 2 displays the information presented during the primary coupon market. Note that the **Wizard** now displays advice about the value of additional coupons rather than shares. Assuming no shares were bought or sold during the share market, this trader could increase abatement cost saving by purchasing one additional coupon and using it in period 2 or period 3. Abatement cost saving would increase by L$170. Similarly, by selling one coupon, the trader would reduce the number of coupons that can be redeemed in period 1 from four to three, and abatement cost saving would fall by L$170. This trader should neither pay more than L$170 for an additional coupon nor accept less than L$170 for the sale of one coupon. This is reported in the **Wizard** box. Once a coupon has been purchased or sold, the **Wizard** box is amended to reflect the value of the next transaction. As Figure 2 is presented, there are 31 seconds remaining for trading in Period 1, the outstanding bid is L$90 and the outstanding ask is L$300, both entered by trader 1 (whose screen is displayed). No trades have been made in period 1 because the **List of Trades** box is empty.

Figure 3 displays the information presented during the production decision phase. Note that the **Production Decision** window gives information on coupons owned and coupons intended to be used (**Planned Input**), together with the implied effect on this period's cash

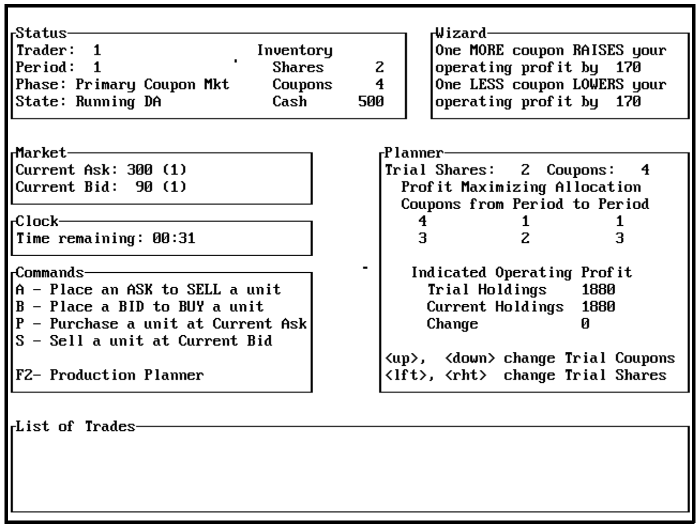

Figure 3 The Production Decision

balance. The **Planner** indicates the profit maximizing allocation of an alternative bundle of shares and coupons. The screen displayed in Figure 3 shows the **Wizard** recommending the use of 4 coupons in the first period. The **Production Decision** box shows the new cash position which would result if only 2 coupons are used. The **Planner** reflects the optimal allocation of coupons if this trader had two coupons available for the first period and 3 shares available for the remaining two periods. The recommended allocation is correct, but it is not a particularly meaningful scenario to describe, because this trader has 4 coupons available for the current period 1, not 2 coupons. Although the **Planner** is a useful planning tool, it is only as effective as the trader who asks the questions. If you ask inappropriate questions, you will get inappropriate answers!

Figure 4 displays the information given the trader during the reconciliation market. This trader chose to use 4 coupons in period 1 (as recommended by the **Wizard**). This trader's cash position has increased to L$1540 (L$500 is the Cash endowment shown in Figure 1, L$300 is the net sales revenue received by this trader for sales of output, which is fixed each period, and L$740 is the abatement cost saving realized by the use of 4 coupons in period 1). This trader, however, was unfortunate. Notice that the **Status** box in Figure 4 indicates a coupon deficit. Conditions were such that this trader must deliver an additional coupon to the regulator. If this coupon is not delivered, the trader will have to pay a L$200 penalty and give up a coupon in the next period. If the trader can purchase an additional coupon during the reconciliation market, the trader saves both the fine (L$200 in this case) and the coupon's value when used optimally in future periods (L$180 in period 3, given optimal banking). Therefore, the value of a coupon to this trader is up

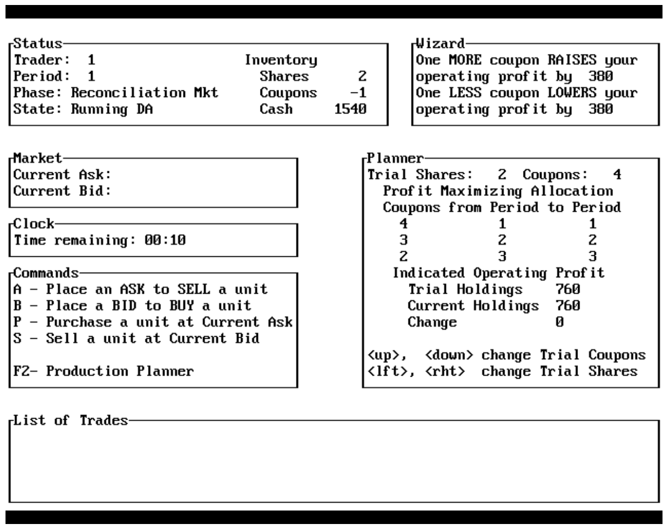

Figure 4 Reconciliation Market

to L$380 in the Period 1 reconciliation market. This is reported by the **Wizard** in Figure 4.

Benchmarks (Main Heading)

Our environment allowed us to run sessions with and without banking coupons, with and without trading shares, and with and without uncertainty in production. To examine the effect of bankable coupons and tradable shares we ran 24 experimental sessions in a 2x2x2 factorial design with three sessions in each cell. In a testbedding application, the main interest lies in the performance of the laboratory market in each combination of factors, rather than in the consistency of the results with theoretical predictions. It is useful to compare the laboratory outcome to benchmarks representing the minimum system abatement costs achievable under the constraints of each treatment. These benchmarks are reported in Table 3.

The command-and-control benchmarks represent the system abatement costs if neither trading nor banking occurs. Under these circumstances all firms use their entire coupon dividends in the period they are received. The system abatement cost is slightly higher in the case of uncertainty because the realized values of the random process effectively reduced the available coupons by 12, an average of one per period. The trading-only (TOC and TOU) benchmarks represent minimum system abatement costs when subjects may trade coupons, but they may not bank coupons. These benchmarks are computed by distributing the available coupons so as to equate the marginal abatement cost for each firm. Again, the case of uncertain abatement accounts for the net reduction in coupons due to the realization of the random disturbance. The banking-and-trading (BTC and BTU) benchmark represents minimum system abatment costs when subjects may both trade and bank coupons (and production is certain or uncertain). The certainty benchmark (BTC) is computed by equalizing coupon use at 48 coupons per period, distributed so as to equate marginal abatement cost. The uncertainty benchmark is computed each

Table 3

Benchmarks

Environment	Minimum System Abatement Cost[a]	Net Efficiency[b]	Share Trades[c]	Coupon Trades[c]	Coupon Balances: Period 4	Coupon Balances: Period 8
Certain Abatement						
Command-and-Control (CCC)	45376	N.A.	N.A.	N.A.	N.A.	N.A.
Trading Only (TOC)						
No Share Trading	22808	0.798	0	224	N.A.	N.A.
Share Trading	22808	0.798	18	64	N.A.	N.A.
Banking and Trading (BTC)						
No Share Trading	17088	1.000	0	264	96	48
Share Trading	17088	1.000	16	8	96	48
Uncertain Abatement						
Command-and-Control (CCU)	48992	N.A.	N.A.	N.A.	N.A.	N.A.
Trading Only (TOU)						
No Share Trading	24220	0.797	0	224	N.A.	N.A.
Share Trading	24220	0.797	18	64	N.A.	N.A.
Banking and Trading (BTU)						
No Share Trading	17928	1.000	0	264	95	44
Share Trading	17928	1.000	16	8	95	944

Notes:

[a] Lowest achievable abatement cost in lab dollars given the relevant constraints for the Benchmark. In the case of uncertain abatement, this accounts for the realization of the random error in emissions.
[b] The potential gain measured from the CCC or CCU benchmark as appropriate, expressed as a fraction of the potential gain under BTC or BTU.
[C] These are the minimum coupon and share trades consistent with an optimal allocation of coupons over the twelve trading periods.
N.A. indicates that a benchmark is not applicable to that case.

period by minimizing current and expected abatement costs given the current stock of coupons and the expected future dividend.

A natural performance measure for these markets is the reduction in system abatement cost actually achieved, expressed as a percentage of the total available gains from trading and banking. This is the Net Efficiency measure reported in Tables 3 and 4. Note from Table 3 that the net efficiency of the TOC benchmark is only 79.8 percent. The remaining 20.2 percentage points of the potential gain can only be achieved if subjects are allowed to reallocate coupons over time.

Notice that minimum system abatement cost and benchmark efficiency are unaffected by share trading. This reflects our inability to predict a priori how tradable shares will affect performance. It is intriguing, however, to compute the minimum number of trades that are necessary to achieve minimum costs under the various treatments. Here the potential effect of share trading is quite dramatic. In the case of certain abatement, minimum costs can be achieved with as few as 16 share trades and 8 coupon trades, compared to 224 coupon trades when share trading is not available. How this will affect the performance of the market is quite uncertain. It might be that the small number of necessary trades will make the market thin and non-competitive, alternatively the narrow spread between maximum bids and minimum asks for these units may reduce noise in the transactions prices. This is where testbedding becomes particularly important.

A final benchmark is provided by the coupon inventories that will develop if coupon banking is optimal. Table 3 reports these for periods 4 and 8. These periods are of particular interest because after period 4 the coupon dividend rate is reduced from two to one coupon per share, and by period 8, half of the announced trading periods with the lower coupon allotment have been completed.

Results (Main Heading)

We summarize our testbedding exercise in a series of four results based on Table 4. In this table, the net efficiency has been adjsted to reflect the constraints on the maximum attainable efficiency in the coupon-trading-only sessions (TOC and TOU). For example, Table 4 reports that the net efficiency in the TOC environment with no share trading is 0.748, while the adjusted net efficiency is 0.938. This indicates that when measured against the maximum attainable abatement cost saving (when coupons can be banked and traded), the TOC can at most yield about 80 percent of the abatement cost saving in the most efficient BTC setting. But when measured against the best that can be attained when coupons cannot be banked, the emissions trading program in the TOC environment achieves nearly 94 percent of the attainable cost savings. The latter measure is a better measure of the effectiveness of the emissions trading program conditioned on the environment in which it is used.

Result 1: When coupons cannot be banked, share trading has no effect on program efficiency.

The mean adjusted net efficiency of sessions with and without share trading is above 94 percent when coupons cannot be banked. When the individual observations for the cases with and without uncertain abatement are pooled according to whether they have share trading or no share trading, the null that their mean values are identical cannot be rejected (p = 0.295, using an exact randomization test).

Result 2: When coupons can be banked, share trading significantly increases program efficiency.

The mean adjusted net efficiency of sessions with share trading is greater than 90 percent when coupons can be banked, but is less than 80 percent when coupons can be banked but shares may not be traded. When the cases with and without uncertain abatement are pooled according to whether they have share trading or no share trading, the null that ehrie means are are identical can be rejected ($p = 0.011$, using an exact randomization test).

Result 3: Share trading reduces the volume of coupon trading.

Efficiency share trading is expected to reduce the volume of coupon trading. More than 200 coupon trades are necessary if system abatement cost savings are to be maximized. If the traders who will use greater numbers of coupons acquire them by purchasing the entitlements to the coupons, it will not be necessary for these traders to enter into the coupon market in later periods. The pattern in Table 3 is clear. The results reported in Table 4 are very close to the benchmarks for the TOC and TOU environments with and without share trading. The results do not conform as closely for the BTC and BTU environments, although the relative volumes are consistent. For both banking and no-banking environments, when the trading volumes by sessions are pooled across sessions with share trading and session without share trading, coupon trading volumes are significantly higher when shares are not traded than when they are traded ($p < 0.006$ for both banking and no-banking environments, using an exact randomization test).

Result 4: When share trading is possible, coupon banking is more effective.

The data in Table 4 show that in BTC environments with no share trading coupons are over-utilized relative to the benchmark use reported in Table 3 (coupon balances are 64 and 37 in periods 4 and 8 rather than the benchmarks 96 and 48 respectively). The results are reversed in the BTU environments with no share trading (115 and 83 coupons in periods 4 and 8 rather than the benchmarks 95 and 44 respectively). This misallocation is greatly reduced when shares are traded.

In the BTC and BTU environments with share trading, coupons are slightly over-utilized (under-banked) by the end of period 4 (86 and 82 for BTC and BTU sessions rather than the 96 and 95 coupon benchmarks respectively). However, by the end of period 8, both BTC and BTU environments with share trading exhibit average coupon balances very near to the benchmarks (48 and 45 versus 48 and 44).

Discussion (Subheading)

Our investigation into the effect of tradable shares was motivated by theoretical uncertainty about their effects. Nevertheless, it seemed clear that they were a redundant instrument, since minimum system abatement cost could be achieved simply by trading coupons. Our expectation was that they might degrade performance slightly by rendering the decision-

Table 4

Mean Session Performance

Environment	Net Efficiency[a]	Adjusted Net Efficiency[b]	Share Trades	Coupon Trades	Coupon Balances: Period 4	Coupon Balances: Period 8
<u>Certain Abatement</u>						
Trading Only (TOC)						
No Share Trading	0.748	0.938	0	211	N.A.	N.A.
Share Trading	0.761	0.954	18	59	N.A.	N.A.
Banking and Trading (BTC)						
No Share Trading	0.520	0.520	0	185	63	37
Share Trading	0.905	0.905	21	97	86	48
<u>Uncertain Abatement</u>						
Trading Only (TOU)						
No Share Trading	0.762	0.954	0	218	N.A.	N.A.
Share Trading	0.795	0.980	16	96	N.A.	N.A.
Banking and Trading (BTU)						
No Share Trading	0.844	0.844	0	227	115	83
Share Trading	0.937	0.937	14	120	82	45

Notes:

[a] The actual gain measured from the CCC or CCU benchmark as appropriate, expressed as a fraction of the potential gain under BTC or BTU.
[b] The actual gain measured from the CCC or CCU benchmark as appropriate, expressed as a fraction of the potential gain for the environment (TOC, BTC, TOU, or BTU).
N.A. indicates that a benchmark is not applicable to that case.

making environment even more complex. The big surprise of our experiment, therefore, was the positive effect of tradable shares on program efficiency.

Result 1 is consistent with a neutral effect of tradable shares. It provides support for the regulator's desire to track ownership of entitlements to future allotments of coupons, and at the same time it appears to be benign with regard to efficiency effects. It is Result 2 that is surprising. Based on the adjusted net efficiency results, banking alone (without share trading) leads to a reduction in the performance of the emissions trading program. When banking is permitted, only about 50 percent of achievable savings are realized (compared with over 93 percent when no banking is permitted) in the sessions with production certainty, while only 84 percent of these savings are realized (compared with over 95 percent when not banking is permitted) in the sessions with uncertain production. One possible explanation for this result is that when shares may not be traded, the introduction of coupon banking to an environment with coupon trading increases the complexity of the decisions which traders must make so much that overall efficiency suffers.[6] The introduction of share trading, however, interacts with banking to offset this effect and provide an justification for this second instrument on efficiency grounds.

The reasons for this unexpected effect of share trading are not obvious. A possible explanation is that the introduction of share trading reduces the noise in the coupon markets. When shares cannot be traded, more coupons are in the hands of traders who do not need the coupons to offset emissions. Reducing the number of traders and the number of coupons available for trading reduces the likelihood that noisy price signals will emerge. Fewer mistakes will be made. This will increase the efficiency of the allocation of coupons among agents. This is reflected by the convergence of average coupon balances towards benchmark balances, the significant reduction in coupon trades, and the higher efficiencies in the laboratory sessions with banking and share trading. Result 3 suggests that the generally positive effect of share trading may be associated with the reduction of coupon trading volumes. The benchmarks in Table 3 indicate that the minimum share trades for the TOC, BTC, TOU and BTU environments are 18, 16, 18 and 16 trades respectively. The mean number of trades over the TOC, BTC, TOU and BTU sessions (three of each) are 18, 21, 16 and 14 trades respectively (see Table 4). These are remarkably close to the benchmark values.

Conclusion (Main Heading)

The proposal for emissions trading with coupons and shares exemplifies the common phenomenon situation of policy overtaking theory. Although the theory predicts good performance for highly abstract emissions trading plans, practical designs are likely to include features, such as tradable shares, on which theory is essentially silent. Implementing these features in the laboratory permits us to verify theoretical predictions and to suggest empirical regularities which may justify or weaken specific policy proposals and suggest further research. In this paper we have shown how a laboratory environment can be constructed to testbed a specific set of proposals.

Some proposals may lead to simple experiments, but in our case we rapidly discovered that capturing significant featuires of the proposed trading plan introduced a high degree of complexity into the decision-making environment. Thus a central feature of our approach was the computerization of the main interactions among subjects. Not only was the computer network used to mediate trades, a common enough application at the present, but the computer was able to present a highly complex environment to the subjects in a manner that allowed them to achieve high laboratory efficiencies.

The planner and the wizard were important and innovative aspects of our experimental design. Introducing them allowed us to reduce training time considerably as well as to reduce subjects' mistakes. It is important, however, to distinguish between our planner and wizard and the "smart markets" reported on elsewhere in this volume. A smart market uses a central computer program to integrate bids and asks into a proposed allocation, which agents may accept or attempt to modify further. In contrast, our planner and wizard represent intelligence that would be found within any large corporation particpating in an emissions trading market.

Notes

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2. The software is adapted from RNA3, a computer program developed by Shawn LaMaster and colleagues at the University of Arizona.

3. Because cost schedules do not change over time and there is no discount rate on profits, the optimal banking-only strategy is to allocate the available coupons equally over the 12 periods.

4. The random element in gross emissions was common across sessions. Eight traders participated in each of the 12-period sessions. The sum of the 96 realized values was 12, thus over the entire session actual gross emissions were 12 greater than expected. This corresponds to an effective reduction of 12 in the number of coupons available in each uncertainty session.

5. The wizard avoids a potentially misleading presentation of the market value of coupons that may explain the poor banking performance found by Franciosi, Isaac, Pingry and Reynolds (1993b). Unlike our program, which presents marginal valuations of coupons assuming optimal banking, the original program (RNA3) used by Franciosi, et al. Presented subjects with a redemption value schedule uncorrected for banking decisions. This may have led subjects to undervalue and overuse coupons.

6. More detailed analysis presented in Godby, Mestelman, Muller and Welland (1996) shows that trader experience interacts with banking to offset this reduction in adjusted net efficiency. As traders become more experienced with banking and trading, their efficiency improves over what is realized by trading alone. The aggregate data presented in Table 4 do not reveal this result.

References

Carlson, Dale A. and Sholtz, Anne M. (1994), 'Designing Pollution Market Instruments: Cases of Uncertainty', Contemporary Economic Policy, 12 (4), 114-125.

Cason, Timothy N. (1995), ‘An Experimental Investigation of the Seller Incentives in the EPA’s Emission Trading Auction’, American Economic Review, 85 (4), 905-922.

Cason, Timothy N., Elliott, Steven R. and Van Boening, Mark V. (1995), ‘Speculation in Experimental Markets for Emission Permits’, University of Southern California, Department of Economics.

Cason, Timothy N. and Plott, Charles (1996), ‘EPA’s New Emissions Trading Mechanism: A Laboratory Evaluation’, Journal of Environmental Economics and Management, 30 (1), 133-160.

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

Davis, Douglas D. and Holt, Charles A. (1993), Experimental Economics, Princeton, NJ: Princeton University Press.

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

Franciosi, R., Isaac, R. Mark, Pingry, David E. and Reynolds, Stanley S. (1993b), ‘Extension of Research into Marketable Emission Permits’, University of Arizona, Department of Economics.

Godby, Rob, Mestelman, Stuart, Muller, R. Andrew and Welland, Douglas (1996), ‘Emission Trading with Shares and Coupons when Control over Discharges is Uncertain’, McMaster University, Department of Economics.

Hahn, Robert W. (1988), ‘Promoting Efficiency and Equity through Institutional Design’, Policy Sciences, 21, 41-56.

Hahn, Robert W. (1989), ‘Economic Prescriptions for Environmental Problems: How the Patient Followed the Doctor's Orders’, Journal of Economic Perspectives, 3 (2), 95-114.

Ledyard, John O. and Szakaly-Moore, Kristin (1994), ‘Designing Organizations for Trading Pollution Rights’, Journal of Economic Behavior and Organization, 25, 167-196.

Muller, R. Andrew and Mestelman, Stuart. (1994), ‘Emission Trading with Shares and Coupons: A Laboratory Test’, Energy Journal, 15 (2), 185-211.

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

Nichols, Albert L. and Harrison, David (1990a), Using Emissions Trading to Reduce Ground-Level Ozone in Canada: A Feasibility Analysis, Cambridge, MA: National Economic Research Associates, Inc.

Nichols, Albert L. and Harrison, David (1990b), The Impact on Ontario Hydro of Emissions Trading for Nitrogen Oxides: A Preliminary Analysis, Cambridge, MA: National Economic Research Associates.

Plott, Charles R. (1983), ‘Externalities and Corrective Policies in Experimental Markets’, Economic Journal, 93, 106-127.

Smith, Vernon L. and Williams, Arlington W. (1992), ‘Experimental Market Economics’, Scientific American (December), 116-122.

Tietenberg, Thomas (1985), Emissions Trading: An Exercise in Reforming Pollution Policy, Washington, D.C.: Resources for the Future.
Tietenberg, Thomas (1992), Environmental and Natural Resource Economics, 3rd Edition, New York: HarperCollins.