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Emissions Trading with Shares and Coupons when Control over Discharges is Uncertain

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Abstract

Two important decisions in designing markets for tradable emissions permits are whether to allow banking and whether to allow trading in entitlements to future permits Banking is predicted to reduce price instability when firms trade in a reconciliation market after the quantity of emissions has been determined Tradable entitlements ("shares") are a common feature in proposals for emissions trading in Canada We conduct a laboratory experiment to investigate how bankable coupons and tradable shares affect efficiency and prices under alternative conditions of certainty and uncertainty Cognitive demands on the subjects are reduced by computerized advice on the optimal allocation of coupons across periods and the implied marginal values of coupons and shares Banking, share trading and uncertainty conditions are introduced in a complete factorial design with 3 observations per cell High efficiencies are observed across all treatments Substantial price instability is observed when control of emissions is uncertain Coupon Banking reduces this instability Share trading reduces trading volumes, increases price stability and improves efficiency, particularly when combined with banking

Emissions Trading with Shares and Coupons when Control over Discharges is Uncertain

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1 INTRODUCTION

Two important decisions in designing markets for tradable emissions permits are whether to allow banking and whether to allow trading in entitlements to future permits Banking refers to the ability to carry unused emission permits forward from one compliance period to the next It is sometimes considered undesirable since it reduces the regulators' *control over the temporal distribution of emissions Banking might lead to a concentration of* emissions in one time period, thus increasing pollution damages if the damage function is convex Banking is particularly desirable when firms cannot control emissions precisely during a compliance period In this case, they may arrive at the end of the compliance period with a surplus or deficit of coupons An emission trading plan can provide for a reconciliation market in which firms clear these surpluses or deficits If the entire market is long, however, excess supply of permits in the reconciliation period may lead to extremely low prices for permits unless the permits can be banked for later use Alternatively, excess demand for permits may drive prices very high unless it can be met out of a stock of banked coupons Carlson *et al* provide experimental evidence supporting this proposition

Explicit trading in entitlements to future permits is a feature of several emission trading plans under discussion in Canada These proposals distinguish between *coupons* and *shares A coupon is the permission to discharge a unit quantity of waste (it thus corresponds* to the permit of economic theory or the allowance of the U S EPA Sulphur Dioxide market) A share is an entitlement to a specified fraction of coupons to be issued in future periods For example, a firm holding 10% of the shares in a emissions trading market would receive 10% of the coupons issued in any year, even if the absolute number of coupons is variable In a world of complete and perfect contingent future markets in coupons, shares would be redundant But in the practical world of environmental regulation, shares may have some advantages in allowing more secure long term planning for firms acquiring or selling coupons and in providing an explicit method for allocating any future variation in aggregate allowable emissions

Emission plans under discussion in Canada typically provide both for trading in shares and for banking coupons, while plans implemented in the United States tend not to provide a *formal mechanism for trading entitlements and have, in at least one case, restricted banking* [1] Neither design feature has been fully investigated in the laboratory

Previous experiments have shown that markets with bankable coupons achieve reasonable efficiency in a laboratory environment Nevertheless, this efficiency is less than that typically observed in markets with no intertemporal trading A possible explanation for this loss in efficiency is the significant cognitive complexity that banking adds to the experimental environment As for shares, an earlier experiment by some of us (Muller and Mestelman, 1994) has shown that a laboratory market with both shares and coupons achieves higher efficiency than that observed in otherwise comparable experiments [2] Nevertheless, no controlled investigation of the independent effects of banking or of trading in shares has been reported In light of the policy importance of emission trading, further experimentation that addresses these three issues seems warranted Any investigation of banking and share trading

[1] Recently, however, the Canadian government has announced an allowance trading plan for hydrogen bromide, in which banking is to be prohibited

[2] These experiments contained features approximating the revenue neutral auction employed in the tradable emission allowance program implemented in the United States under the Clean Air Act (Cronshaw and Brown-Kruse, 1992, Franciosi, Isaac, Pingry and Reynolds, 1993a, 1993b)

should take into account the work by Carlson *et al* (1993) which has shown that introducing uncertainty leads to price spikes in permit markets when banking is suppressed

This paper reports an experiment designed to examine more fully the contributions that bankable coupons and tradable shares make to efficiency and price stability in emission trading markets The design is noteworthy in two respects it incorporates uncertainty by explicitly modelling the sequence of decisions within each annual cycle and it reduces cognitive demands on subjects by providing computerized advice on intertemporal optimization of share and coupon holdings Section 2 provides a fuller motivation of the experimental design Section 3 reports our procedure Section 4 summarizes the data, Section 5 presents our preliminary results and Section 6 draws some conclusions

2. PREVIOUS LITERATURE

Increasing attention is being paid to the use of economic instruments to achieve environmental objectives at low cost (Canada, 1992, CCME, 1990, 1992, Economic Instruments Collaborative, 1993, Task Force on Economic Instruments, 1994) Such plans claim three advantages over traditional regulation methods First, coupon trading provides firms with a more cost-effective way of attaining a given aggregate reduction in emission of a specified pollutant Firms with low marginal abatement cost have an incentive to sell their coupons to high abatement cost firms For a given reduction in emissions, the aggregate cost of pollution abatement is thus reduced as dollars spent on abatement are used where they are most effective Second, the informational burden placed on regulators in traditional approaches is reduced as trading among firms in the market for emission coupons determines where pollution abatement efforts are most effective Third, the explicit price of coupons provides a continuing incentive for firms to develop and invest in new pollution control technologies

Approximations to emission trading schemes have been implemented with varying success in the United States (Hahn, 1989, Cropper and Oates, 1992) A variety of reasons

have been proposed as to why existing programs have not delivered the full cost savings theoretically predicted Among these are the high transaction costs imposed on participants through complex sets of trading procedures This problem also increased the level of uncertainty in the market The U S Clean Air Act Amendments of 1990 addressed some of these concerns and provided for a major program of sulphur oxide (SO_x) trading Central to this program is a revenue neutral discriminative price auction for coupons administered by the Chicago Board of Trade on behalf of the United States Environmental Protection Agency (U S EPA) The coupons traded in this market come either from a small fraction of the overall cap reserved for this purpose by the EPA or from voluntarily submissions by firms Interested parties submit sealed bids for these units The revenues from the auction are distributed to the firms offering units, sellers receive the bid price for any traded coupon voluntarily submitted and the average price of all reserved coupons for their share of the mandatory coupons

Laboratory investigations related to the EPA program have been conducted at the Universities of Colorado (Cronshaw and Brown Kruse, 1992) and Arizona (Franciosi, Isaac, Pingry and Reynolds, 1993a, 1993b) In general, these experiments show that the proposed U S market mechanism, as implemented in the laboratory, achieves only about one half of the potential cost savings Moreover, the University of Arizona experiments show incomplete arbitrage between the discriminative sealed bid auction and a computerized double auction market and some evidence of speculative bubbles in coupon prices

In further laboratory investigations, Cason and Plott (1993) have shown that the revenue neutral auction mechanism implemented by the U S EPA contains a perverse incentive encouraging both sellers and buyers of coupons to submit bids much below their true valuation of coupons Carlson *et al* (1993) have shown that the prohibition of coupon banking can lead to price spikes or troughs when firms are permitted to enter the market during a reconciliation period to clear outstanding obligations

Canadian governments are actively considering proposals for emissions trading, especially in nitrogen oxides (NO_x) One plan (Nichols and Harrison, 1990a, 1990b, Nichols, 1992) calls for a *Basic Emissions Trading Approach* (BETA) in which two assets are traded *coupons* allowing discharge of NO_x and *shares* entitling the holder to a proportionate share in future distributions of coupons Current discussion papers in Canada continue to adopt the coupons and shares formula (Economic Instruments Collaborative, 1993, Task Force on Economic Instruments, 1994), although a recently announced plan for methyl bromide emission trading refers to allowances and prohibits banking (Canada Gazette, 27 August 1994) Neither the theoretical properties nor the empirical performance of the BETA are well understood Only one laboratory experiment involving shares and coupons has been reported In earlier work two of us (Muller and Mestelman, 1994) compared a laboratory implementation of the BETA proposal to the results obtained by Cronshaw and Brown Kruse and by Franciosi, Isaac, Pingry and Reynolds Our laboratory market showed efficiencies significantly higher than those found by Franciosi, Isaac, Pingry and Reynolds and by Cronshaw and Brown Kruse for the same technical parameters We offered as possible explanations for this improvement the reduced complexity of our market environment and the more intensive training we provided our subjects

In summary, while emission trading programs continue on the regulatory agenda, many design issues remain unresolved Two of these are the desirability of tradable shares and bankable coupons Previous experiments suggest that the complexity of emission trading markets has reduced efficiency and that banking will be particularly important in the context of uncertainty Our problem, therefore, is to investigate the role of bankable coupons and tradable shares in a trading environment reflecting uncertainty, while attempting to ameliorate the cognitive demands placed on the subjects

3. PROCEDURE

3.1 Technological Parameters

We construct a laboratory market in which eight subjects representing four types of firm can trade coupons and shares Subjects are not told they will be trading emission coupons, but rather that they are producing a product requiring a certain scarce input that is being rationed The demand for (ration) coupons is induced by the marginal valuation schedules reported in Table 1 To prevent subjects from becoming familiar with the equilibrium values, the induced values were varied by a scale factor ranging from 1 to 4, and the conversion rate from Lab dollars to Canadian dollars was adjusted to yield approximately equivalent payoffs. All data reported in this paper have been normalized by deflation by the scale factor

There are four types of firm varying in initial size (as measured by emissions) and abatement cost Firm Types A and B have large uncontrolled emissions of twenty units Firm Types C and D have smaller uncontrolled emissions of ten units Types A and C have relatively low abatement costs Shares are distributed in proportion to uncontrolled emissions Firm types A and B receive 6 shares each, types C and D receive 3 shares each Firms receive coupons in each period in proportion to their holdings of shares A reduction in aggregate emissions is imposed by reducing the coupon dividend per share from two to one after the fourth period The resulting aggregate demand and supply curves for emission permits are shown in Figure 1 There are three supply conditions The rightmost vertical supply curve is located at the market supply of 72 coupons per period which obtains in high dividend condition experienced in periods 1 through 4 The corresponding equilibrium price is 14 laboratory dollars The leftmost curve is located at the market supply of 36 coupons which obtains during the low dividend condition which obtains in the remaining 8 periods The coresponding equilibrium price range is 123-136 lab dollars The middle vertical supply curve corresponds to a market supply of 48 coupons per period, which is the quantity that would be used if agents banked optimally The corresponding equilibrium price range is 72-78 lab dollars per coupon

3.2 Benchmarks

Following Cronshaw and Brown Kruse (1992), Franciosi, Isaac, Pingry and Reynolds (1993), and our own work (Muller and Mestelman, 1994) we define four benchmarks for assessing performance The *command-and-control (CC)* benchmark represents the performance of the market if neither trading nor banking occurs In this case all coupons are used by the subject to whom they are issued in the period when they are received The *perfect foresight competitive equilibrium (PFCE)* represents performance if subjects trade and bank optimally over the entire session The PFCE price is in the range 72-78 laboratory dollars (L$), indicated on Figure 1 by its midpoint L$75 The *banking-only equilibrium (BOE)* represents performance if subjects do not trade, but use their allocated coupons optimally over time Since 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

Again following Cronshaw and Brown Kruse (1992, 16) we also define an *adapted competitive equilibrium (ACE)* for each period in the session The ACE is the perfect foresight competitive equilibrium conditional on the current inventory of coupons This equilibrium can be readily calculated for any specific period by adding the total coupons remaining to be distributed to the current inventory, allocating them equally over the remaining periods, and reading the price off the aggregate demand schedule for coupons in the current period If coupons are overused in the early periods of a session, the ACE price will rise above the PFCE price Table 2 summarizes the system abatement costs for each of the first four benchmarks and the corresponding cost savings relative to the CC equilibrium The ACE cannot be reported independently of the laboratory sessions, because it changes as each session evolves

The cost savings reported in Table 2 can be used to define two measures of efficiency The raw efficiency measure expresses saving achieved in any session as a percentage of the PFCE cost saving Table 2 indicates that MCE achieves a raw efficiency of 79 8% It should be stressed that this is the best that can be achieved when banking is not allowed The remaining efficiency gains can only be achieved when there is intertemporal substitution of emissions via the banking of permits To compare the efficiency of the market institutions under banking and no banking treatments we also make use of an adjusted efficiency index This is defined as the cost savings achieved as a percentage of the maximum achievable savings, namely the MCE savings for no banking and the PFCE savings for banking treatments

3.3 The Market Institution

Each experimental session consists of 12 periods, divided into 6 sub-periods or *phases* share market, distribution, primary coupon market, production decision, production result, and reconciliation Not every phase occurs in every treatment

During the *share market phase* subjects trade 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 subjects During the *primary coupon market phase*, subjects again trade coupons in a computerized double-auction market During the *production decision phase*, subjects 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, subjects 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) The resulting errors are shown in Table 3

This feature models measurement error (as discussed by Carlson *et al*, 1993) or other errors in determining emissions Such other errors might include unforeseen changes in output or changes in the availability of a substitute for the rationed input

During the *reconciliation phase* subjects trade coupons in a computerized double auction market to eliminate any coupon deficit or unwanted coupon surplus We choose not to allow subjects 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 subject has a coupon deficit that must be cleared by purchasing more coupons Similarly, subjects 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 subjects to trade

In the *coupon-redemption phase*, subjects redeem the number of coupons corresponding to their actual input Subjects with a coupon deficit pay a per unit penalty which is greater than any firm's marginal abatement cost Subsequently, eliminating the deficit becomes a first charge against any coupons acquired in the following period[3] The coupon-redemption phase does not require any intervention on the subject'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, subjects' earnings are converted to Canadian dollars and paid privately in cash

[3] The penalty is set at L$300 This is greater than the highest marginal abatement cost of 275, and is equal to four times the PFCE coupon price

3.4 The Planner and the Wizard

The market institution just described clearly places major cognitive demands on the subjects When banking is allowed, the marginal value of a coupon is not determined directly by the schedule in Table 1, 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, we provide our subjects with a *production planner* that simulates an operations research department The production planner is shown in a window on the computer screen Subjects 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 subjects to use in the course of the auction markets Accordingly, we also provide subjects 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

3.5 Computer Implementation

The experiment was run in the McMaster Experimental Economics Laboratory, which contains a network of personal computers The program is adapted from RNA3, a computer program developed by Shawn LaMaster and colleagues at the University of Arizona for use in the experiments reported by Franciosi, Isaac, Pingry and Reynolds Major changes have been made in program control and in screen layouts, while preserving the core of the double auction mechanism

Figure 2 displays the information presented to the subject during the Share Phase The Status window shows the subject'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 Subjects 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 subjects to calculate their profits for any trial number of shares or coupons The trial numbers are adjusted using the arrow keys Figure 3 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 Figure 4 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 balance The Planner indicates the profit maximizing allocation of an alternative bundle of shares and coupons Figure 5 displays the information given the subject during the reconciliation market Notice that the subject in Figure 5 has a coupon deficit Because banking is allowed in the session shown, one additional coupon saves the subject both the fine (L$300 in this case) and the coupon's value when used optimally in future periods

3.6 Experimental Design, Subjects, and Training

The treatment variables are the presence or absence of banking, the presence or absence of trading in shares, and the presence or absence of uncertainty concerning actual input use We choose a complete 2x2x2 factorial design with three observations per cell to achieve the maximum information from our experimental budget (Table 4)

The sessions were run in July, August, November, and December 1994 In July, subjects were drawn from the summer population of the Hamilton region and for the most part were students Twenty-four subjects were recruited for training Subjects participated in four training sessions and approximately eight experimental sessions In the training sessions, subjects were introduced first to oral and then to computerized double auction markets Subjects then participated in an truncated oral version of the experimental market, in which they received shares and coupons in the form of slips of paper and in which they manually optimized coupon use over time Finally, each subject participated in two short training markets using the experimental software In November an additional thirty-two subjects were recruited for training from the McMaster University student population These subjects participated in training sessions comparable to the July sessions The results from twenty-four experimental sessions are reported here The 12 uncertainty sessions were conducted after the 12 certainty sessions had been run[4]

3.7. Predictions

Because it is essentially a conventional multiple unit double auction, we predict that the baseline treatment of no banking, no tradable shares, and no uncertainty will yield efficiencies close to the Myopic Competitive Equilibrium (79 8 percent) On the basis of the Colorado and McMaster experiments we do not expect the introduction of banking to increase efficiency significantly In an institution with complete set of futures markets for coupons, tradable shares would be redundant Because the laboratory institution has no futures

[4] The original schedule called for three sequences of eight sessions each In each sequence, the eight treatments were ordered randomly The twenty-four subjects were assigned randomly to each group of three consecutive sessions During practice, two trained subjects dropped out of the experiment and were replaced by other subjects Subjects were permitted to exchange sessions or to return for extra sessions Finally, difficulties with the computer program caused us to deviate from the original sequence of treatments Instead of following the planned schedule, the twelve sessions involving uncertainty were all run after the twelve sessions with no uncertainty The subjects in ten of the twelve uncertainty sessions were different from those in the certainty sessions

markets, however, share trading may play a role in reducing uncertainty about the terms of future exchanges We predict that shares will increase efficiency slightly On the basis of the McMaster and Arizona experiments, we do not expect close arbitrage between share and coupon prices

Introducing uncertainty concerning input use will expose subjects to penalties if they are caught with a coupon deficit We predict this will lead to higher inventories of coupons, a reluctance to trade, and reduced efficiency compared to the baseline On the basis of the Caltech experiments (Carlson *et al*) we predict more price instability and reduced efficiency (relative to the baseline of NB/NS/NU) in the no banking treatment. We expect these effects to be less pronounced in the banking treatment Because trading shares can substitute for plans to trade coupons later in the experiment, we expect higher efficiency and fewer coupon trades when shares are introduced

4 RESULTS

The basic results of the experiment are presented in Tables 5 through 10 Table 5 gives trading volume and efficiency results for each session Table 6 reports mean efficiency by treatment Note that both raw and adjusted efficiency are reported Tables 7, 8 and 9 report summary statistics for share prices, primary coupon market prices, and reconciliation market prices respectively Table 10 reports mean coupon balances by period for the 12 sessions involving banking In this section we concentrate on summary results related to trading volumes, price behaviour and efficiency

Result 1 *High efficiencies are obtained across all treatments.*

Efficiency data are reported in Tables 5 and 6 and graphed in Figure 6 Raw efficiency, as measured by the cost savings achieved as a percentage of cost savings under perfect foresight equilibrium, ranges from 29 5% to 96 8% with a mean of 74 4% The low observation of 29 5% is an outlier, the second lowest efficiency was 52 1% After dividing the data for the no banking sessions by the MCE efficiency of 79 8% the mean adjusted efficiency is found to be 83 9% These values are less than generally achieved in simple

double auction environments with buyers and sellers rather than traders and with no banking, but they are greater than achieved in our earlier study (Muller and Mestelman, 1994) and substantially above the efficiencies achieved in the most closely related experiments (Franciosi, Isaac, Pingry and Reynold, 1993a, and Brown Kruse and Cronshaw, 1992 If achieved in the field they would represent very substantial costs savings

Result 2: *The baseline treatment of no banking, no shares and no uncertainty exhibits*

- *a* *heavy volumes of coupon trading*
- *b* *coupon prices converging to MCE equilibria,*
- *c* *high efficiencies relative to MCE cost savings*

The mean number of coupon trades in the three baseline sessions was 211 (Table 5) This may be compared with the 224 trades that would be required to achieve all potential cost savings under this treatment The mean coupon prices of 41 and 103 during the early and late periods of the sessions were substantially above and below the respective MCE benchmarks (Table 8), however there seems to be some tendency for prices to converge on the MCE levels (Figure 7). The mean raw efficiency was 74 4%, which is 93 8% of the maximum achievable savings under this treatment

Result 3: *Compared to the baseline treatment, introducing uncertainty*

- *a* *does not affect trading volumes,*
- *b* *does not greatly affect convergence of coupon prices in the primary coupon market,*
- *c* *leads to price spikes and price instability in the reconciliation market, and*
- *d* *reduces efficiency*

Introducing uncertainty creates a reconciliation market following the primary coupon market in each period of the session The mean trading volume of 200 in the primary coupon market is not much below the baseline level of 211 The mean prices of 33 and 104 in early and late periods respectively are still substantially different from the MCE levels, but nevertheless show a clear response to the reduction in coupon dividends in Period 5 The pattern of price convergence toward MCE is very similar to the baseline treatment (Figure 7) The most dramatic effect of uncertainty, however, is shown in the reconciliation market There were an average of 18 reconciliation trades per session, or about 1 5 per period (Table 5) Mean prices were much higher than in the primary coupon market, 154 and 195 in early and late periods respectively, and many trades occurred at prices well above the MCE price of 150 Several trades occurred at prices close to the maximum penalty of 300 per coupon The mean adjusted efficiency falls from 93 8 to 79 1 (Table 6)

Result 4 *Compared to the no banking/ no shares sessions, sessions with banking exhibit*

- a *roughly comparable trading volumes,*
- b *much reduced variation in primary market coupon prices across periods, with significant deviations from PFCE,*
- c *virtually complete elimination of price spikes in reconciliation markets, and*
- d *comparable or reduced adjusted efficiencies*

The mean primary coupon volume in the banking /no shares sessions was 193, not significantly different from the mean volume of 206 in the no banking/no shares sessions (computed from Table 5) Much of the decline is associated with quite low volumes of 104 in one of the B/NS/NU sessions Banking clearly evens out the coupon prices over time In the certainty cases with banking, mean prices in early and late periods were essentially identical (33 5 and 34 1 respectively) while in the uncertainty cases mean prices actually declined after the reduction in coupon dividend (65 7 and 53 3 respectively The later values are not far from the PFCE range of 72-78, but the Figures CP3 and CP4 indicate that in 3 of the 6 sessions actual coupon prices converged rapidly to the low MCE price of 14 and stayed there throughout the session The same figures indicate that there was very little variation in mean coupon prices within each session The most dramatic effect of banking, however, is to virtually eliminate price spikes in reconciliation market trading The mean reconciliation market prices were 83 7 and 53 7 in early and late periods respectively, compared to 154 4 and 195 0 in the no banking/no shares sessions (Table 9) The standard deviation of

reconciliation market prices is much reduced under banking High price trades are virtually eliminated (Figure 8)

Introducing banking has little effect on adjusted efficiency in the sessions with uncertainty but a negative effect in the sessions without uncertainty In the former case, mean raw efficiency rises from 63 1 to 79 9 (Table 6) but the adjusted efficiencies for banking (79 9) and no banking (79 1) are almost identical, indicating that the gain in raw efficiency is entirely due to the intertemporal reallocation of coupons allowed by banking In the uncertainty case, Figure x indicates that efficiency was particularly low Inspection of Table 5 shows that the two lowest efficiencies observed in the entire experiment (29 5% and 52 1%) occurred under the banking/no share/uncertainty treatment The lower figure is clearly anomalous and is probably due to the behaviour of one particular subject Consequently we are inclined to discount somewhat the implication that the interaction of banking and certainty significantly lowers efficiency

Result 5 *Compared to sessions with no tradable shares, sessions with share trading exhibit*

- a *significantly lower trading volumes in the primary coupon market,*
- b *faster convergence of primary coupon prices to MCE when banking is not permitted,*
- c *closer approximation of primary coupon prices to PFCE when banking is permitted, and*
- d *generally increased efficiencies*

As would be expected, share trading dramatically reduces the volume of trading in the primary coupon market Mean coupon volumes were 93 7 and 68 2 in the banking and no banking cases respectively (Table 5) Inspection of Figure 9 suggests that coupon prices converged more rapidly towards the PFCE or the MCE in the presence of share trading than was the case in sessions without share trading This impression is confirmed by Table 8, which shows markedly reduced standard deviations for coupon prices in sessions involving shares In the case of no banking, mean coupon prices in sessions with share trading are noticeably closer to MCE benchmarks than in sessions without share trading In the case of banking, mean prices are relatively close to the PFCE benchmark and show no anomalies such as the ones which appeared in the Banking/No Shares/ Uncertainty case

Result 6 *In markets with tradable shares,*

a *share trading volumes approximate the minimum necessary for cost-minimization,*

b *coupon equivalent share prices are roughly comparable to coupon prices when banking is permitted,*

c *coupon equivalent share prices reflect future values rather than MCE prices when banking is not permitted*

If shares are tradable and banking is permitted, a cost minimizing allocation of coupons can be achieved with 18 share trades and 24 primary coupon trades per session [5] If banking is not permitted, a MCE allocation of permit can be achieved with 18 share trades and 64 coupon trades [6] The mean volume of share trades over the 12 share trading sessions was 17, almost exactly equal to the number required to minimize costs This suggests there was little speculative trading in shares Table 7 indicates that the mean share equivalent price across all share trading sessions was 74 0 in periods 1-4 and 102 1 in periods 5-12 These prices are consistent with the PFCE benchmark in early periods and with generalized underbanking in later periods Share equivalent prices were noticeably lower in the Banking/Shares/Uncertainty case Comparison with Table 8 shows that, in No Banking

[5]Under a PFCE, Firm Type A uses one coupon per period, Firm Type B uses 15, Firm Type C uses none, and Firm Type D uses 8 If banking is permitted, a cost minimizing solution can be achieved if firms of Type A sell their 6 shares to firms of Type B and firms of Type C sell their 3 shares to firms of Type D, if Firm Types B and D bank optimally, and if Firm Type B sells one coupon each period to Firm Type A Since there are two representatives of each type of firm, this would implies 18 share trades and 24 primary coupon trades per session

[6]During the first four periods firms of Type B and D sell and firms of Type A and C buy 5 and 3 coupons per period respectively

treatments, coupon equivalent share prices substantially exceed the corresponding primary coupon market prices, indicating that subjects were accounting for valuing their shares more at their PFCE equilibrium values than at the MCE prices Figure 10 graphs the share prices from all share trading sessions

5 DISCUSSION

Unlike an experiment designed to test a specific prediction, our experiment has been primarily an exercise in testbedding, that is, we wished primarily to observe the performance of a proposed market institution under closely controlled changes in institutional arrangements, in the hope of validating and improving upon the proposed design In this light, Result 1 is perhaps the most important We have shown that emissions trading plans can be implemented in a double auction laboratory environment and that they display a relatively high degree of efficiency under a wide range institutional choices Despite the relative complexity of our procedure, we have achieved higher levels of efficiency than reported by Franciosi, Isaac,Pingry and Reynolds (1993a) and by Cronshaw and Brown Kruse (1992) We attribute this partially to the more intensive training our subjects received and partly to assistance of the planner and wizard in guiding bidding and production decisions Both of these factors should reassure proponents of tradable emission permit plans that good results can be achieved when agents are well trained, well informed and have the requisite decision support

Results 3 and 4 confirm a finding by Carlson *et al* that emissions trading plans may experience severe price instability when control over emissions is imperfect and no provision is made for intertemporal substitution of emissions The Carlson *et al* finding is based on a single pair of laboratory sessions, our result demonstrates that their finding is replicable under more frequent repetitions and a wider variety of institutional arrangements Since control of emissions will almost always be less than perfect, the result itself provides strong support for including some form of banking or intertemporal substitution in the design of emissions trading programs These results also provide a useful reminder that 100% efficiency in trading is not to be expected as the decision making environment is made progressively more complex, as through the introduction of banking and uncertainty

Results 5 and 6 are the first reported laboratory results on the role of tradable shares in the context of emissions trading While most policy discussions of emissions trading plans envisage the development of futures markets in coupons, no previously reported laboratory experiments has implemented any form of trading future entitlements to permits We have shown that the introduction of shares tends to improve the performance of the market even though it reduces trading volume Our results, perhaps surprisingly, indicate that formal trading of future entitlements to discharge permits may improve both the price revealing and efficiency properties of emission trading plans

More generally, our results suggest that even though emissions trading markets are relatively complex, high efficiencies can be obtained provided participants are well trained and supported by software which reduces the computational complexity of the market They provide demonstrable support for emissions trading programs in comparison with other forms of regulation This conclusion should be qualified, however, by noting that the high efficiencies are obtained in a double auction environment, a market institution known to be highly efficient in other applications The efficiency properties of emission trading programs might be compromised by using alternative market institutions, such as private negotiation

The experiment reported here represents only part of a continuing program of laboratory research into the properties of emissions trading markets We plan to investigate systematically the effect of thin markets, large firms, and opportunities for strategic behaviour on the performance of these markets We believe our results demonstrate the value of laboratory research in testbedding alternative designs for new economic institutions Any practical innovation, such as emission trading, requires many specific design decisions Rather than choose among these on the basis of *a priori* reasoning, it is entirely practical to test the proposed design in a laboratory setting Although extrapolation of laboratory results

to the field is always difficult, some empirical basis for policy decisions is much better than none

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TABLE 1

Marginal Valuations by Firm Type

Input Use	Firm Type A	Firm Type B	Firm Type C	Firm Type 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

Note:

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.

TABLE 2

Benchmark System Abatement Cost Savings

Benchmark	Cost Savings Relative to 100% Abatement	Cost Savings Relative to Command-and-Control	Efficiency Index
Command-and-Control	C$ 163.90	C$ 0	0
Banking-Only Equilibrium	166.28	2.38	3.1
Myopic Equilibrium	224.84	60.94	79.8
Perfect Foresight Competitive Equilibrium	240.28	76.38	100.0

Note:

Cost savings are expressed in Canadian dollars.

TABLE 3

Error Structure for Uncertainty (Intended Use - Actual Use)

Period	Firm Number 1	2	3	4	5	6	7	8	Total
1	-1	1	-1	0	1	-1	0	-1	-2
2	-1	-1	0	1	0	0	0	0	-1
3	0	-1	0	1	0	-1	1	1	1
4	-1	1	-1	1	0	1	1	-1	1
5	1	0	1	-1	0	0	0	-1	0
6	-1	0	-1	-1	0	-1	0	1	-3
7	0	0	-1	-1	0	-1	1	0	-2
8	0	1	-1	1	-1	1	0	0	1
9	-1	-1	1	1	1	-1	0	0	0
10	-1	-1	-1	-1	-1	-1	1	0	-5
11	0	-1	1	1	0	0	0	-1	0
12	0	1	-1	-1	-1	-1	1	0	-2

TABLE 4

Number of Sessions by Treatment

Input Use	No Banking: No Shares	No Banking: Shares	Banking: No Shares	Banking: Shares
Certain	3	3	3	3
Uncertain	3	3	3	3

TABLE 5

Efficiency and Trading Volume by Session

Treatment	Session	Efficiency	Share Volume	Coupon Volume	Reconciliation Coupon Volume
B/ S/ U	940823a	94.23	8	153	32
B/ S/ U	941128	84.58	20	46	29
B/ S/ U	941213	91.40	13	73	26
B/ S/NU	941129	82.31	29	87	0
B/ S/NU	941212	96.77	16	50	0
B/ S/NU	941220	92.41	17	153	0
B/NS/ U	940824a	83.49	0	215	9
B/NS/ U	941130	72.08	0	163	31
B/NS/ U	941207	84.04	0	227	35
B/NS/NU	941205	29.54	0	104	0
B/NS/NU	941206	52.14	0	243	0
B/NS/NU	941219	74.39	0	207	0
NB/ S/ U	940818b	65.18	15	98	18
NB/ S/ U	940822b	70.34	17	74	19
NB/ S/ U	940823b	71.18	16	59	21
NB/ S/NU	940803a	75.32	18	56	0
NB/ S/NU	940810a	74.88	20	47	0
NB/ S/NU	940815b	78.21	15	75	0
NB/NS/ U	940819a	66.55	0	211	21
NB/NS/ U	940822a	65.81	0	208	18
NB/NS/ U	940824b	57.06	0	180	16
NB/NS/NU	940809b	72.78	0	211	0
NB/NS/NU	940811a	74.23	0	206	0
NB/NS/NU	940815a	77.52	0	217	0

Note:

B = Banking, S = Share Trading, U = Uncertainty, NB = No Banking, NS = No Share Trading, and NU = No Uncertainty.

TABLE 6

Efficiency by Treatment

Treatment	Mean	Std. Dev.	Frequency
B/ S/ U	90.07	4.96	3
B/ S/NU	90.50	7.42	3
B/NS/ U	79.87	6.75	3
B/NS/NU	52.02	22.43	3
NB/ S/ U	68.90	3.25	3
NB/ S/NU	76.14	1.81	3
NB/NS/ U	63.14	5.28	3
NB/NS/NU	74.84	2.43	3
Total	74.44	14.65	24

Note:

B = Banking, S = Share Trading, U = Uncertainty, NB = No Banking, NS = No Share Trading, and NU = No Uncertainty. The efficiency index is $\frac{\pi_a - \pi_{cc}}{\pi_{pf} - \pi_{cc}}$, where π denotes profit and the subscripts *a*, *cc*, and *pf* denote actual, command-and-control, and perfect foresight profits, respectively.

TABLE 7

Share Prices (in Coupon Equivalents) by Treatment and Stage

Treatment	Stage: Early	Stage: Late	Total
B/ S/ U	41.52 (23.63) [29]	61.44 (16.03) [12]	47.35 (23.36) [41]
B/ S/NU	84.83 (41.37) [39]	107.33 (34.69) [23]	93.18 (40.25) [62]
NB/ S/ U	85.39 (23.90) [32]	110.28 (31.86) [16]	93.69 (29.01) [48]
NB/ S/NU	78.07 (18.03) [37]	116.89 (25.26) [16]	89.79 (27.07) [53]
Total	73.97 (33.21) [137]	102.10 (34.63) [67]	83.21 (36.11) [204]

Note:

Numbers in parentheses are standard deviations; numbers in square brackets are observations. The early stage includes periods 1-4; the late stage includes periods 5-12.

TABLE 8

Coupon Prices by Treatment and Stage

	Stage		
Treatment	Early	Late	Total
B/ S/ U	55.66 (13.79) [156]	60.95 (15.96) [116]	57 91 (14.96) [272]
B/ S/NU	87.90 (15.38) [166]	89.31 (20.18) [124]	88.50 (17.57) [290]
B/NS/ U	65.67 (23.76) [314]	53.35 (25.91) [291]	59.75 (25.55) [605]
B/NS/NU	33.51 (22.67) [238]	34.11 (33.88) [316]	33.85 (29.56) [554]
NB/ S/ U	27.63 (13.29) [116]	111.84 (15.30) [115]	69.55 (44.55) [231]
NB/ S/NU	25.02 (8.52) [108]	114.78 (14.18) [70]	60.32 (45.34) [178]
NB/NS/ U	32.64 (13.11) [208]	104.61 (24.64) [391]	79.62 (40.39) [599]
NB/NS/NU	40.75 (34.32) [213]	102.98 (44.11) [421]	82.07 (50.51) [634]
Total	48.22 (28.89) [1519]	81.13 (42.40) [1844]	66.26 (40.38) [3363]

Note:

See the note on Table 7.

TABLE 9

Coupon Prices (reconciliation period) by Treatment and Stage

	Stage		
Treatment	Early	Late	Total
B/ S/ U	81.20 (29.69) [28]	69.35 (33.89) [59]	73.16 (32.90) [87]
B/NS/ U	83.71 (34.29) [30]	53.76 (31.66) [45]	65.74 (35.71) [75]
NB/ S/ U	131.36 (88.18) [23]	156.12 (93.40) [35]	146.30 (91.40) [58]
NB/NS/ U	154.37 (124.74) [22]	194.99 (181.38) [33]	178.75 (161.09) [55]
Total	108.76 (80.03) [103]	107.03 (108.45) [72]	107.68 (98.62) [275]

Note:

See the Note on Table 7.

TABLE 10

Mean Coupon Balances, By Period, By Treatment

	Treatment			
Period	B/NS/NU	B/NS/U	B/S/NU	B/S/U
1	24.33	35.00	21.67	26.67
2	34.00	65.33	43.67	45.67
3	47.33	92.00	64.67	62.33
4	62.67	115.33	86.33	81.67
5	53.33	107.67	77.33	74.00
6	48.00	103.67	67.00	66.33
7	42.00	96.00	58.00	57.33
8	37.33	82.67	47.67	45.00
9	33.67	64.00	36.33	33.67
10	25.67	50.67	26.00	26.67
11	16.33	29.00	14.00	12.67
12	0	5.67	0	3.33
Twelve Period Average	35.39	70.58	45.22	44.61

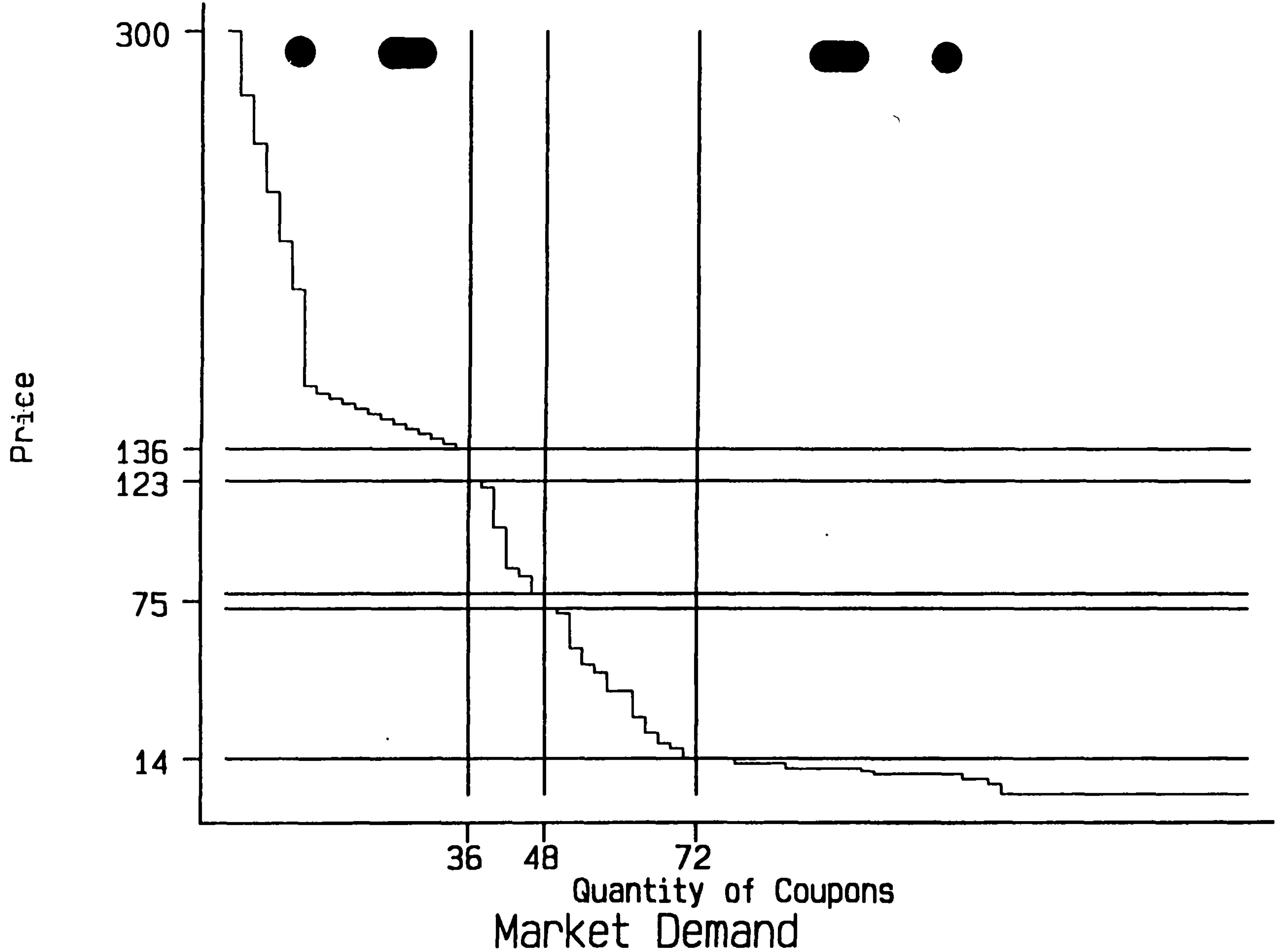

300
136
123
75
14
Price
36
48
72
Quantity of Coupons
Market Demand

FIGURE 1

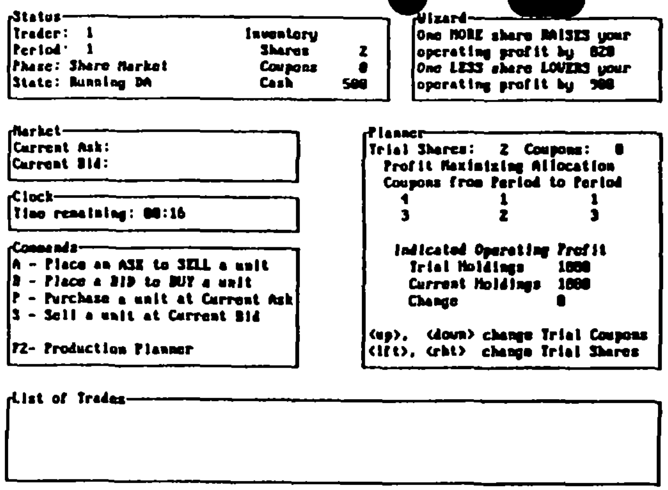


FIGURE 2

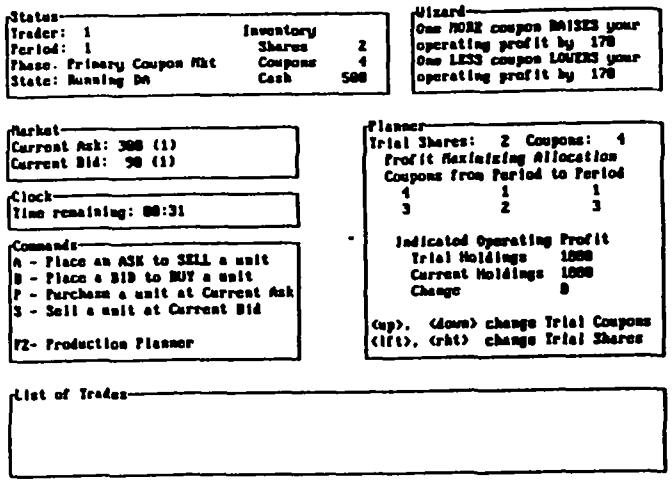


FIGURE 3

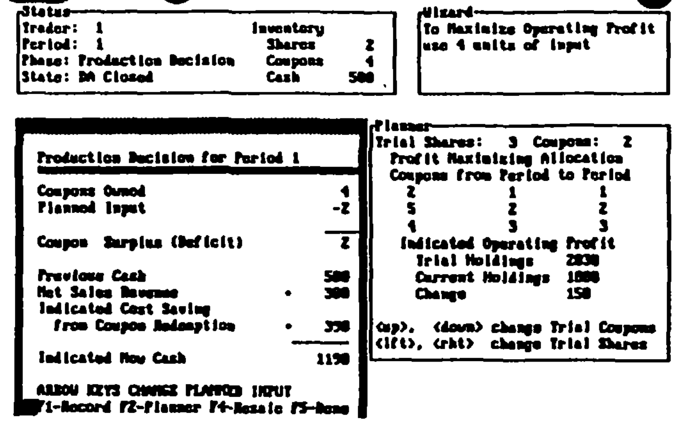


FIGURE 4

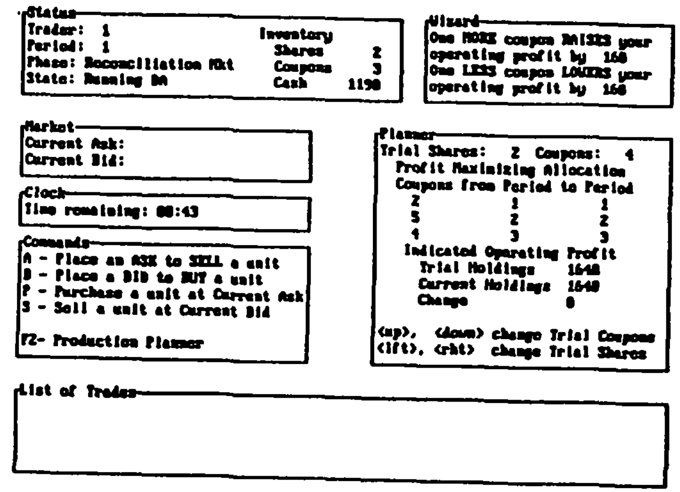
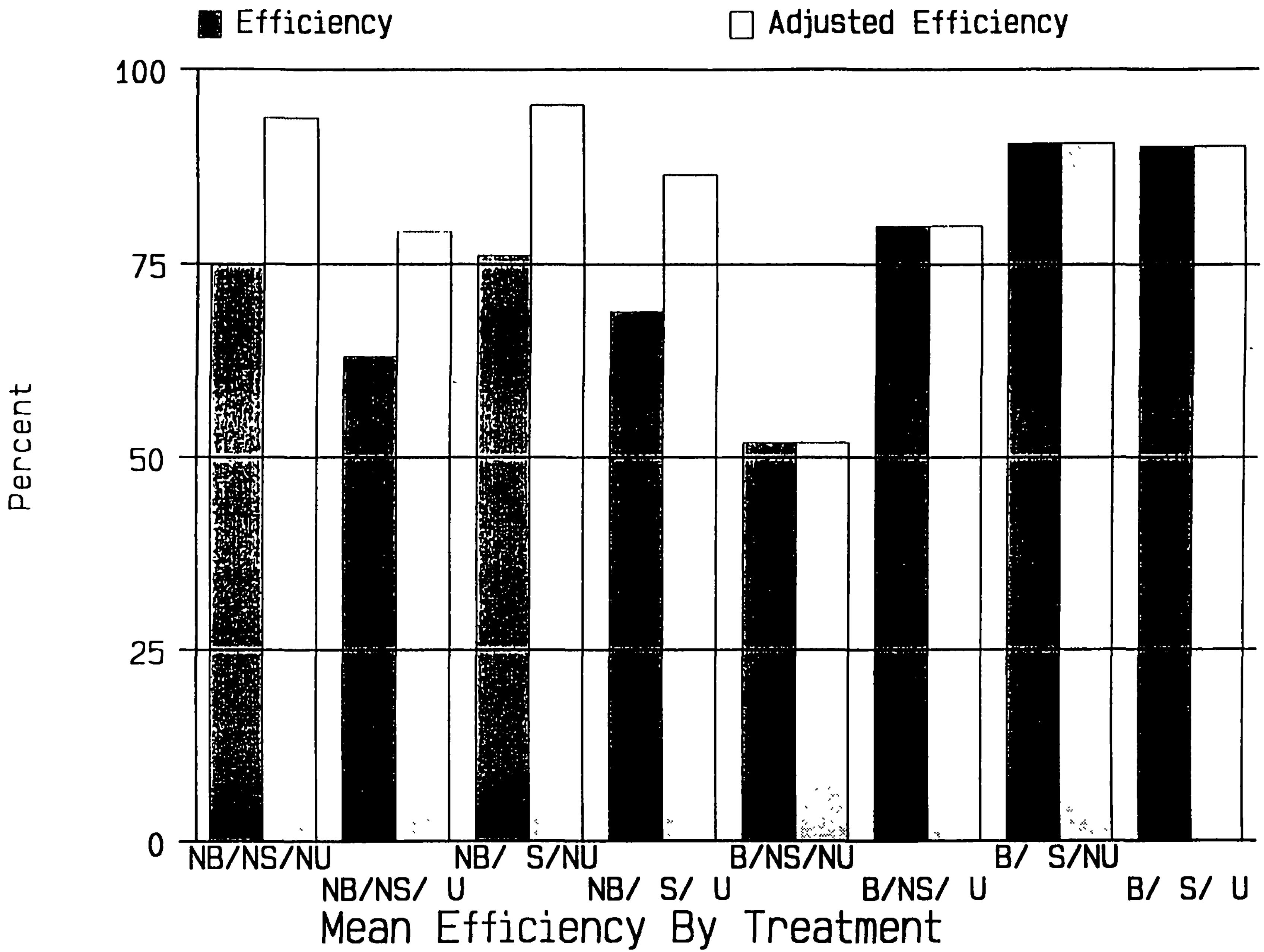


FIGURE 5



Efficiency
Adjusted Efficiency
100
75
50
25
0
Percent
NB/NS/NU
NB/NS/ U
NB/ S/NU
NB/ S/ U
B/NS/NU
B/NS/ U
B/ S/NU
B/ S/ U
Mean Efficiency By Treatment

FIGURE 6

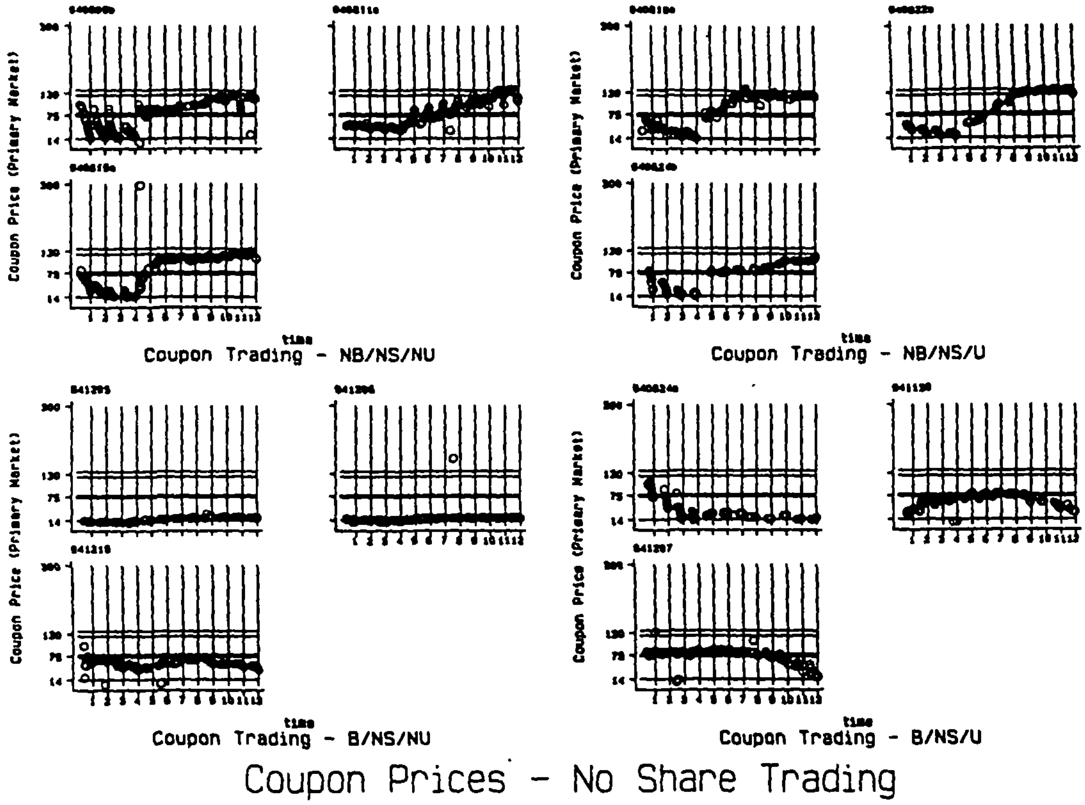


FIGURE 7

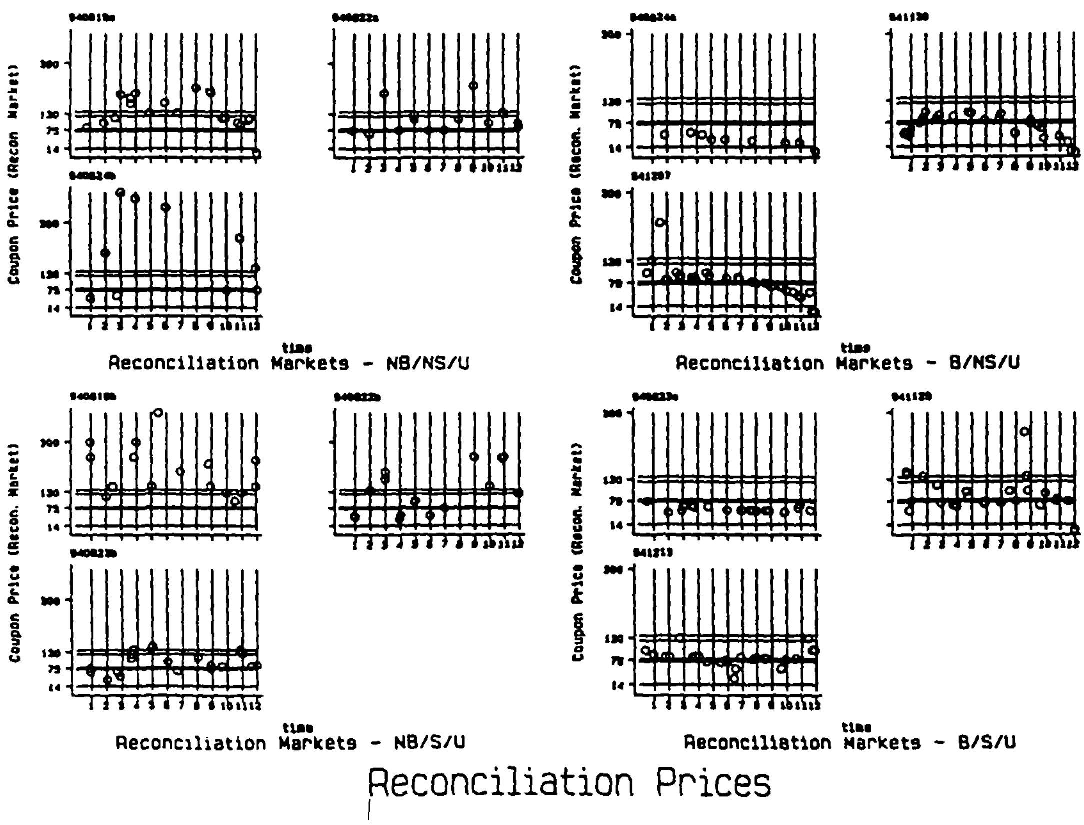
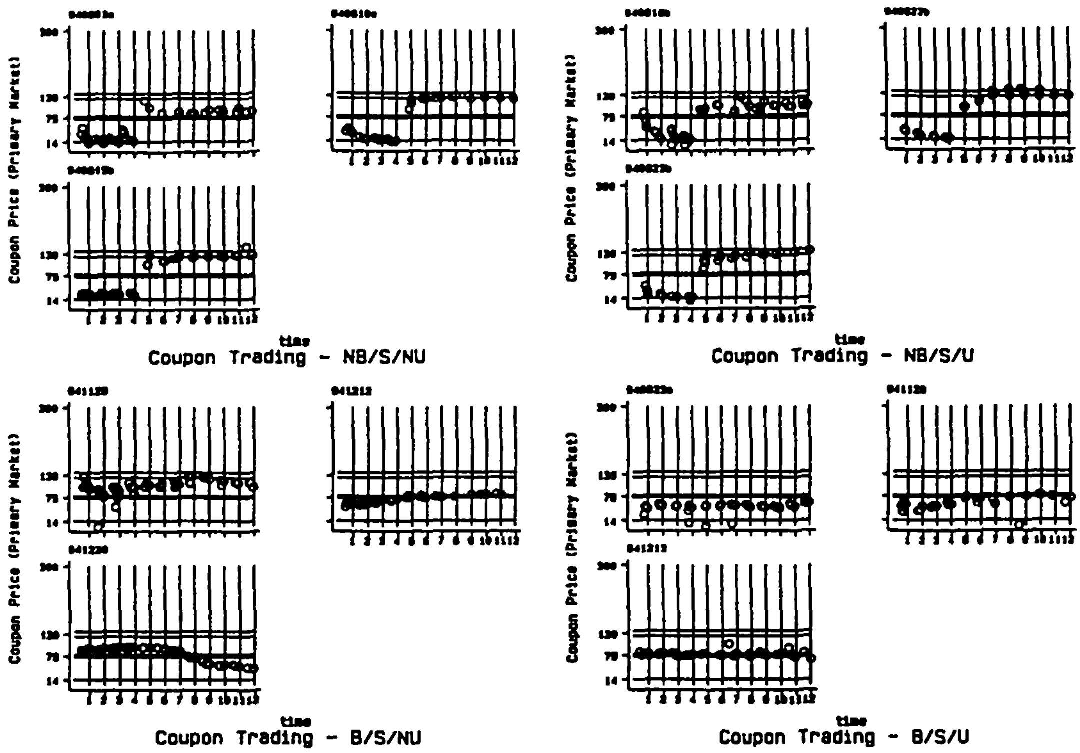
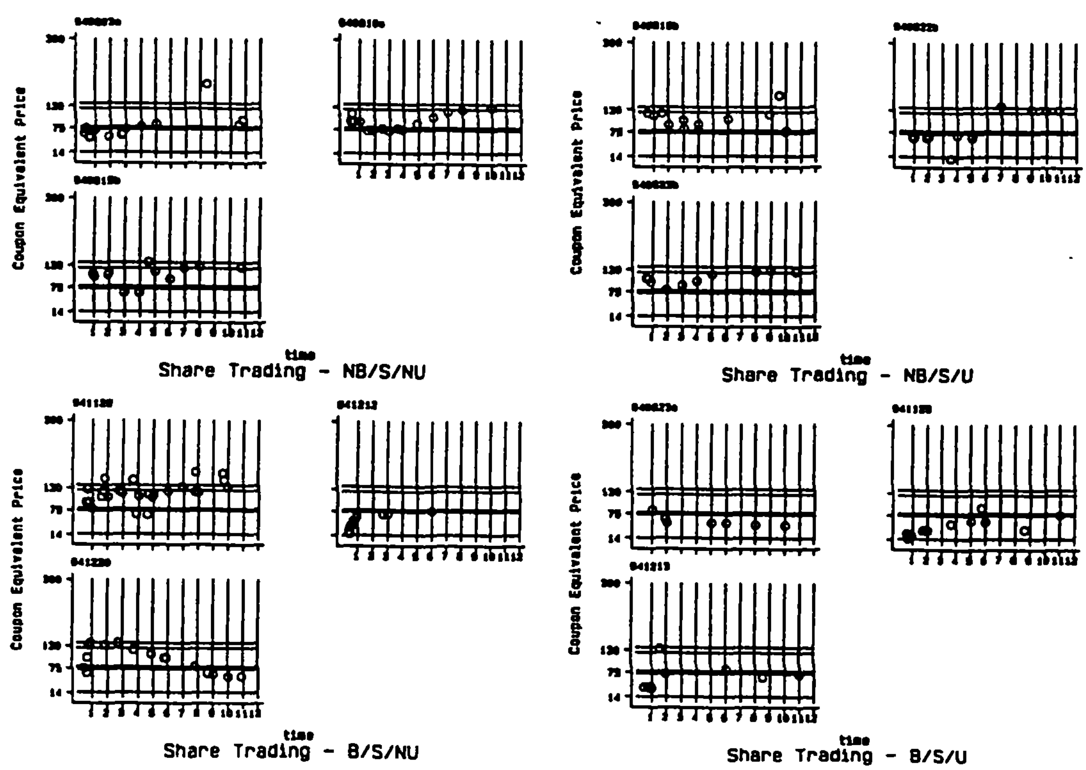


FIGURE 8



Coupon Prices - Share Trading

FIGURE 9



Share Prices

FIGURE 10