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Implications of Alternative Emission Trading Plans: Experimental Evidence

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Abstract

Two approaches to emissions trading are cap-and-trade, in which an aggregate cap on emissions is distributed in the form of emission allowances and baseline-and-credit, in which firms earn emission reduction credits for emissions below their baselines. Theoretical considerations suggest the long-run equilibria of the two plans will differ if baselines are proportional to output, because a variable baseline is equivalent to an output subsidy. To test this prediction we have developed a computerized environment in which subjects representing firms can adjust both their emission rates (per unit output) and capacity levels. Subjects buy or sell emission rights (allowances or credits) in a sealed bid call auction. The demand for output is simulated. All decisions are tracked through a double-entry bookkeeping system. This environment is to be used to compare short and long run responses to the alternative trading methods. Initial experiments in this environment will alternately hold emission rate and capacity choice constant. We report on six experimental sessions with variable emissions rates but fixed capacity and two pilot sessions with variable capacity but fixed emission rates.

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This paper reports on a long term research project on "Implications of Alternative Emission Trading Plans". Emissions trading is a method of assigning and trading the right to emit pollution so that the cost of pollution abatement is minimized. There are two basic methods of implementing emissions trading: cap-and-trade and baseline-and-credit. When production capacity is fixed these approaches should lead to identical results, but when firms can adjust capacity, output under a baseline-and-credit system is predicted to be higher than in a cap-and-trade system. We are trying to test this prediction experimentally. There is a relatively long history of laboratoy experimentation related to emissions trading, summarized in Muller and Mestelman (1998) and Bohm (2003). Recent papers include Cason and Gangadharan (2004), Murphy and Stranlund (2004) and Kusakawa and Saijo (2003). Most of these papers have abstracted from production decisions. Ben-David, Brookshire, Burness, McKee and Schmidt (1999) investigate technological choice in emissions trading, but hold output fixed. No previous published experiments have have focused on long-run adjustment of capacity in emissions trading markets.

In this paper we provide some brief background on alternative approaches to emissions trading and quickly review the theoretical basis for our predictions. We then present the experimental environment that we have designed, stressing the organization and sequencing of the various markets and the design of the computer program we have written. The present paper provides an overview of the program and highlights of early results. Fuller details are reported in Buckley, Muller and Mestelman (2003) and Buckley (2004). It turns out that the environment we have created is quite complex and we are implementing it step by step. We will review three sets of results we have obtained. The first is a set of simulated sessions using robot traders, which we used to test our program. The second is a recently completed experiment involving human subjects. It compares the two trading systems in the short run, when their outcomes should be identical. Finally, we will report long-run results from two pilot sessions in which capacity is variable.

1 Alternative Emission Trading Plans

Cap-and-trade is the textbook approach to emissions trading. It is best exemplified by the highly successful SO_2 trading program introduced by the US EPA in the mid-90s. In this approach, a fixed cap is placed on the aggregate emissions of a group of firms. The cap is divided into emission permits or allowances which are distributed or sold to the participating firms. Firms surrender one allowance for each unit of waste discharged. Unused allowances can be sold or banked for future use. Firms whose emissions exceed their holdings of allowances must buy more on the open market.

Many field implementations of emissions trading take a different approach. An example is the clean development mechanism proposed under the Kyoto Protocol. In these baseline-and-credit plans there is no concept of cap on aggregate emissions. Instead, each firm has the right to emit a certain baseline level of emissions. This baseline may be derived from historical emissions or from a performance standard that specifies the permitted ratio of emissions to output. Firms create emission reduction credits by emitting less than their baseline emissions. These credits may be banked or sold to firms who exceed their baselines.

Baseline-and-credit plans differ from cap-and-trade in a number of institutional details. For example, most baseline-and-credit plans are project based: credits are generated by specific projects which reduce emissions below predicted levels. Usually, the emission reductions must be actually realized before the credits can be registered and made available for trading. These and other features cause higher administrative costs. More importantly for our purposes, baseline-and-credit plans must specify a baseline for each firm. Although this could be a fixed amount, comparable to the distribution of allowances in a cap-and-trade plan, often the baseline is computed by mulitplying output or some other measure of scale by a performance standard in the form of a maximum rate of emissions per unit of output.

Under a variable baseline plan a firm can increase its baseline emissions simply by increasing output. This creates an implict subsidy which reduces the long run marginal cost of output. As a result, equilibrium output and emissions are predicted to be higher under baseline-and-credit than under cap-and-trade.

2 Theoretical Analysis

The prediction of higher output and emissions under a baseline-and-credit plan emerges very directly in a simplified version of our model. In this simplified version we assume output is always equal to capacity and that the regulator has set the performance standard under baseline-and-credit equal to the average emission rate for the industry under the optimal cap-and-trade plan. Under a cap-and-trade plan, each firm receives a fixed number of allowances, A_i. The firm's problem is to choose output, q_i, and emission rate, r_i, so as to maximize its profit. Profit is equal to the sales revenue $P(Q)q_i$ (where Q is industry output) less capacity costs, $c_i q_i$, variable costs, $w_i q_i$, and allowance costs. Allowance costs equal the price of allowances, P_a, times the net demand for allowances $(r_i q_i - A_i)$. This net demand is equal to the actual emissions minus the allowances received. Formally the firm must solve

$$\max_{\{r_i,q_i\}} \pi_i^a = P(Q)q_i - c_i(r_i)q_i - w_i q_i - P_a(r_i q_i - A_i) \tag{1}$$

Under a baseline-and-credit plan the firm's problem is almost identical. The only difference is in the last term, the cost of credits. Credit costs are equal to the price of credits P_c times the net demand for credits but in this case the net demand for credits is equal to the actual emission rate minus the performance standard, r^s, multiplied by output. Formally the firm solves

$$\max_{\{r_i,q_i\}} \pi_i^c = P(Q)q_i - c_i(r_i)q_i - w_i q_i - P_c q_i(r_i - r^s) \tag{2}$$

The difference in objective functions is reflected in the first order conditions. There are two: one for emission rates and one for output. The first order conditions on emission rates under cap-and-trade and baseline-and-credit are, respectively,

$$-c_i'(r_i^a) = P_a \tag{3}$$

$$-c_i'(r_i^c) = P_c \tag{4}$$

Equations (3) and (4) are identical. They require that marginal abatement cost equal the price of allowances or credits.

The first order conditions on output are (5) and (6) where Q^a and Q^c are industry output under cap-and-trade and baseline-and-credit respectively.

$$P(Q^a) = c_i(r_i^a) + w_i + r_i^a P_a \tag{5}$$

$$P(Q^c) = c_i(r_i^c) + w_i + r_i P_c - r^s P_c \tag{6}$$

Both conditions require that price of output equal the long run marginal cost. In the case of cap-and-trade long run marginal cost equals unit capacity cost, c_i, plus unit variable cost, w_i, plus the unit allowance cost, $r_i P_a$. In the baseline and credit case there is a fourth term, $r^s P_c$, which is the value of the credits displaced by the marginal increase in the firm's baseline. This term reduces long run marginal cost in the same way that a subsidy would do and consequently equilibrium output will be greater than in the case of cap-and-trade.

Note that in the cap-and-trade case private marginal cost is equal to social marginal cost because the private opportunity cost of allowances, P_a, is equal to the marginal damage cost whereas in the cap-and-trade case private marginal cost is below social marginal cost.

The long run competitive equlbrium can be illustrated by two interdependent diagrams (see Figure 1). Panel (a) depicts the aggregate emissions market. The demand for emissions is given by the aggregate marginal abatement cost curve. The social opportunity cost of emissions is given by the marginal damage curve, MD. The intersection of MD and MAC determines the optimal quantity of emissions, E^*. This

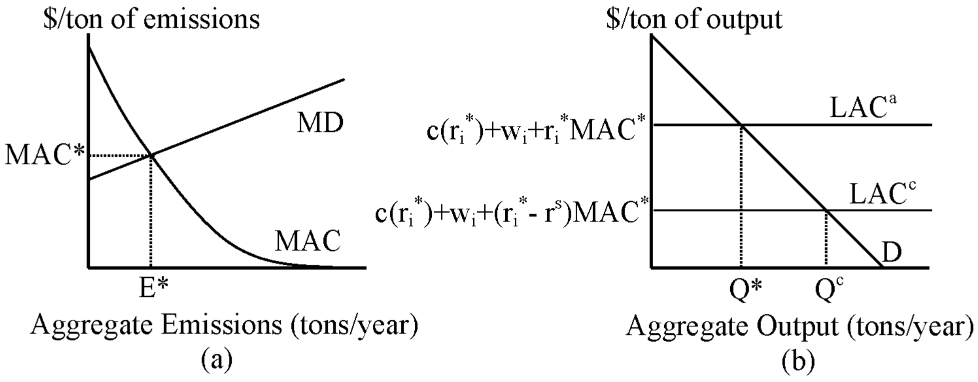

Figure 1: Long Run Competitive Equilibrium

intersection also determines the market clearing price for allowances if the socially optimal quantity of E^* allowances is created.

Panel (b) depicts the market for output. (It is assumed all firms are competitors in the downstream market.) The long run marginal cost curves (LAC^a and LAC^c for baseline-and-credit and cap-and-trade respectively) are both horizontal. Under a cap-and-trade plan equilibrium output is determined by the intersection of LAC^a and the demand curve at the social optimum, Q^*. Under a baseline-and-credit plan output Q^c is determined by the intersection of the demand curve with the lower, private marginal cost curve LAC^c. Clearly $Q^c > Q^*$

Note that the ratio of E^* to Q^* determines a unique emission rate, $r^s \equiv E^*/Q^*$, which we may call the optimal performance standard. Since the average emission rate under baseline-and-credit is equal to that under cap-and-trade, $Q^c > Q^*$ implies that emissions will also be greater under baseline-and-credit than they are under cap-and-trade.

Thus we have two key theoretical propositions.

Proposition 1 *Long run competitive equilibrium emissions and output* *are socially optimal under a cap-and-trade plan, provided the supply of allowances equals the socially optimal quantity of emissions.*

Proposition 2 *In long run competitive equilibrium, aggregate emissions and aggregate output under a baseline-and-credit plan are higher than the long run equilibrium levels of a cap-and-trade plan with the same aggregate emission rate.*

3 The Experimental Environment

We wish to test these propositions in a fully specified market environment. This is difficult, because it requires achieving equilibrium in two interrelated markets: the market for emission rights (allowances or credits) and the market for output. Consequently our subjects must make both a technological decision (on emission rate) and an output-determining decision (on capacity or output) each period. Such detail is rare in emission trading experiments. Only one published emission rate experiment (Ben-David et al. 1999) has included an explicit technological decision on emission rate and that experiment held the output of each subject constant. We also wish to capture the distinction between short-run production and long-run capacity decisions, although we have not fully implemented this feature in our experiments. Finally we wish to create a vehicle that can actually demonstrate the difference in plans to policy-makers and practicioners.

These considerations led us to develop a computerized environment in which subjects trade emission rights and sell output in multiple-unit uniform-price call markets. Demand in the output market is simulated. Due to the complexity of the environment and our desire to create a vehicle that could be used for training, we chose to use context-related rather than neutral language. Thus we explicitly use terms such as allowance and credit rather than abstract terms such as coupon.

We implemented our computerized environment with a fully specified accounting framework in which every action gives rise to both a debit and a credit. As a result we can provide subjects with a complete income statement at the end of each period.

The program operates as follows. At repeated intervals during the experiment subjects have the ability to choose their production capacity. Capacity may have a life of one or more periods. Subjects build capacity at the beginning of each period in which capacity adjustments are permitted. Following this subjects receive their periodic allotments of allowances if it is a cap-and-trade experiment. Otherwise they enter the emissions trading market with any credits they produced in the previous period. Then they may attempt to buy or sell more emission rights by entering up to three bids and three asks in a multiple-unit uniform-price auction. By emission rights we mean either allowances or credits as the case may be. Each bid or ask is a specifies both a price and quantity of rights demanded or offered at that price. After all bids and asks are received the market for emissions rights clears. Subjects then choose an emission rate which will be applied to their output for the period. Then they submit asks to the output market, which is a multiple-unit uniform-price market with simulated demand. Asks are constrained by available capacity and by the subject's inventory of emission rights. When the output market clears, subjects automatically produce the quantity sold and redeem the required number of rights. Finally, under baseline-and-credit treatments, subjects are credited with any credits they may have created by producing output with an emission rate below the performance standard. We then repeat the procedure. Algorithm 1 summarizes the process.

Algorithm 1 *Sequence of Events*

```
for each period in the session
  choose capacity if permitted
  receive  allowances if cap-and-trade
  submit bids or asks to emissions right market
  wait until the emissions rights market clears
  choose emission rate
  submit asks to output market
  wait until output market clears
  produce number of units sold in the output market
  redeem emissions rights
  create credits if baseline-and-credit
  bank excess rights;
```

Demand is simulated by a linear demand function. Unit capacity cost depends inversely on emission rates. We chose a functional form that would allow us to directly determine the minimum unit cost, u_0, the maximum unit cost, u_1, and the curvature of the marginal cost curve, α.

$$c_i(r_i) = u_0 + (u_1 - u_0)\big((r_{max} - r_i)/r_{max}\big)^{\alpha_i} \tag{7}$$

We convert the marginal cost curve into a step function by restricting r to integer values.

There are four types of firm ranging from dirtiest, with lowest u_0 but highest u_1, to cleanest, with highest u_0 and lowest u_1. Our experiments have been set up for eight subjects, two for each type of firm.

4 Robot Traders

We tested our model by programming clients to act as robot traders. Our primary interest was to determine whether the environment was

Firm Type	u_1	u_0	α	w_i	r_i^*	A_i	r^s
A-cleanest	76	65	3	0	0	2	1
B-cleaner	89	59	3	0	1	4	1
C-dirty	90	59	3	0	2	4	1
D-dirtiest	269	52	3	0	3	2	1

Table 1: Cost Parameters for Robot Traders

Trading Insitution	Uncontrolled	B&C	C&T
Price of Emission Rights	0	8	8
Price of Output	52	68	76
Aggregate Output	48	32	24
Aggregate Emissions	144	32	24
Active Firm Types	D	all	all

B&C - baseline-and-credit
C&T - cap-and-trade

Table 2: Predictions for Robot Traders

stable under reasonable assumptions about subjects' behaviour.

The robots were programmed to bid myopically and non-strategically. That is, they attempted to maximimze their short run profits at every decision point. However we did introduce a random error into their bidding decisions. Earlier simulations had become unstable when no restrictions were placed on the timing and size of capacity purchases. Consequently, for this experiment we imposed a capacity life of 8 periods. Capacity decisions were staggered, with one robot choosing new capacity each period. For the robot simulations we limited emission rate choices to the four integer levels between 0 and 3. The parameters and predicted outcomes are reported in Tables 1 and 2. We ran six simulations, with two institutional treatments (baseline-and-credit and cap-and-trade) and three levels of error in the bidding process (coefficients of variation of 0, 5% and 15%).

The results of some of these simulations are shown in Figures 2 to 5. Figure 2 shows the simulated adjustment when the robot baseline-and-credit traders begin with capacity and past prices consistent with the long-run cap-and-trade equilibrium. In this simulation there are no errors in the bidding process. The top left hand corner shows the evolution of output and capacity. Our key prediction concerning capacity is borne out. Capacity rises steadily from the cap-and-trade equilibrium of 24, overshoots the baseline-and-credit equilibrium of 32, then smoothly converges to the predicted level. Actual output is below capacity in a number of cases. These represent cases in which the robot traders were unsuccessful in obtaining sufficent credits to cover the output at full capacity and the chosen emission rate. The top right quadrant shows aggregate emissions. These oscillate widely over the first few periods and then settle down at equilibrium values.

The bottom left-hand quadrant shows the evolution of credit prices. After a sharp initial rise the credit price settles quickly back to the equilibrium level of 8. The bottom right-hand quadrant illustrates the emission rate chosen by each class of firm. All firms respond to the high initial price of credits by reducing their emission rates. This adjustment is promptly reversed when the price of credits falls. Figure 2 thus confirms that short-run myopic profit maximization will quickly lead to the predicted effects of the baseline-and-credit plan.

Figure 3 shows a simulated session when traders make larger errors in bidding. In these simulations the robot traders made bids equal to their optimal short-run profit maximizing bid plus a normally distributed error with coefficient of variation equal to 15% of the optimal bid. The quadrants of Figure 3 are laid out like those of Figure 2. The simulated results confirm our fundamental proposition, that baseline-and-credit trading will lead to an expansion of capacity relative to cap-and-trade. Capacity expansion is relatively steady, while output is marked by intermittent shortages caused by a failure to obtain sufficient credits on the market. The price of credits is generally close to equilibrium, but subject to significant price spikes. Emissions fluctuate wildly as emisison rates oscillate in response to credit prices.

Figure 4 shows a simulation of the cap-and-trade mechanism. In this simulation firms are started in the baseline-and-credit equilibrium and subjected to cap-and-trade rules. The prediction is that output and capacity should contract. In this no-error simulation, the price of allowances is remarkably stable, capacity declines smoothly, while output and emissions exhibit somewhat higher oscillations than in Figure 2. Figure 4 shows the same experiment with high bidding errors (coefficient of variation equal to 15% of the optimal bid). Once again we see relatively stable allowance prices, relatively smooth convergence of capacity, and increased oscillations in output, emissions and emisisons rates.

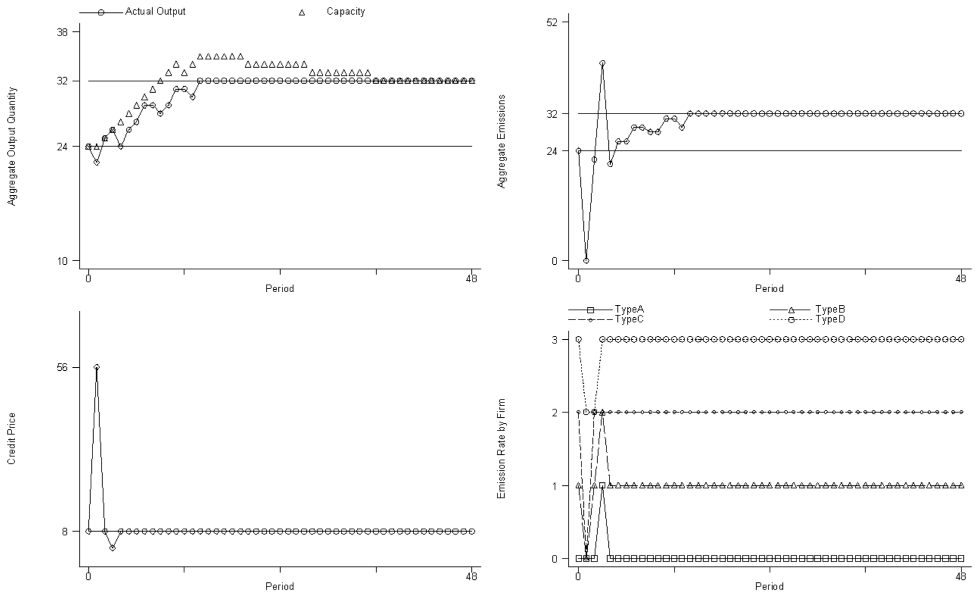

Figure 2: Allowance to Credit Equilibrium, Robot Traders, No Errors

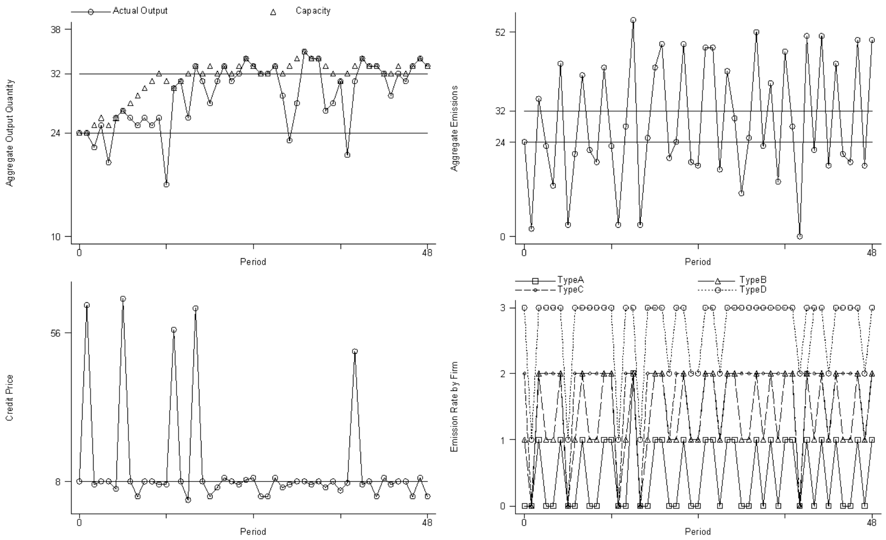

Figure 3: Allowance to Credit Equilibrium, Robot Traders, High Errors

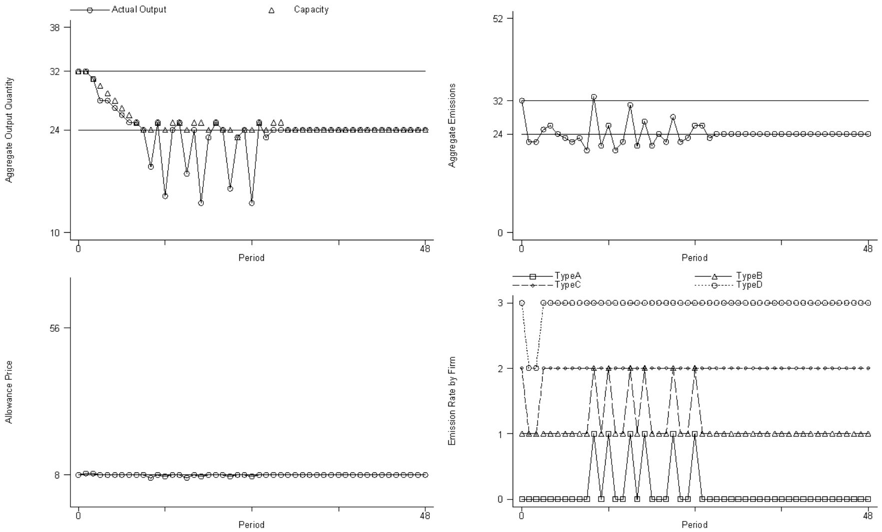

Figure 4: Credit to Allowance Equilibrium, Robot Traders, No Errors

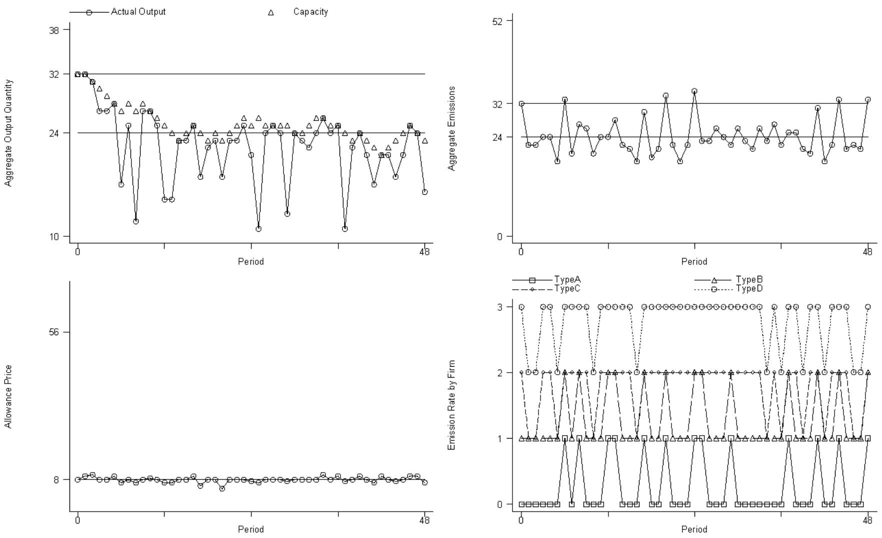

Figure 5: Credit to Allowance Equilibrium, Robot Traders, High Errors

Summary of Robot Trader Sessions

Our simulations with robot traders led to several conclusions which were helpful in designing our first sessions with human subjects.

First we discovered that the system became unstable when all robots could choose any level of capacity they wished. This was the motivation for staggering capacity expiry dates and constraining step sizes to unity.

Second, we discovered that the constrained system tracks the predicted output and capacity paths quite closely. It is true that output falls below capacity on a number of occasions. These occur when traders are unable to acquire sufficient emissions rights to produce at capacity.

Thirdly, errors in bidding generated large fluctuations in emission rates and total emissions. These fluctuations seemed largest in the baseline-and-credit simulations.

Finally, we determined that both the relative stability and high price spikes for emission rights were caused by a small number of large steps in the marginal abatement cost schedules. This lead us to modify the parameters for the fixed capacity sessions.

5 Fixed Capacity Sessions

The sessions with robot traders convinced us that we should proceed cautiously in experimenting with human subjects. Our general structure required subjects to optimize on 3 margins: the choice of output, choice of emission rate and the choice of capacity. When capacity is fixed, the outcome of baseline and credit trading should be identical to

Firm Type	u_0	u_1	α	w_i	r_i^*	A_i	r^s	k_i
A-cleanest	88	172	3	0	2	20	5	4
B-cleaner	64	249	3	0	4	20	5	4
C-dirty	52	375	3	0	6	20	5	4
D-dirtiest	29	1852	3	0	8	20	5	4

Table 3: Fixed Capacity Sessions - Cost Paramters

the outcome under cap-and-trade. We decided to test this prediction in our environment by running 3 cap-and-trade sessions and 3 baseline-and-credit sessions holding capacity fixed at 4 units per subject. To obtain a smaller equilibrium price tunnel we increased the number of emission rate steps to 10 (zero to nine).

After several pilot sessions indicated that the subjects were still finding the environment hard to understand we further simplified their task by automating the output decisions. Short run myopic profit maximization will lead subjects to offer their maximum output at a reservation price of zero, so we imposed this decision automatically.

We computed a set of parameters that would leave all types of firm operating in long run competitive equilibrium (see Table 3). The inverse demand curve for output was $P = 320 - 5Q$. All firms receive 4 units of capacity(k_i). The performance standard (r^s) is 5 tons of waste per ton of output. The equivalent endowment of allowances (A_i) is 20. Variable costs (w_i) are set equal to zero. Under uncontrolled conditions the dirtiest firms have lowest fixed cost per unit of capacity ($u_0 = 29$), and the cleanest firms the highest, 88. Under maximum control ($r_i = 0$) the cleanest firms have the lowest costs($u_1 = 172$) while the dirtiest have the highest (1852).

These parameters give rise to the four marginal abatment cost

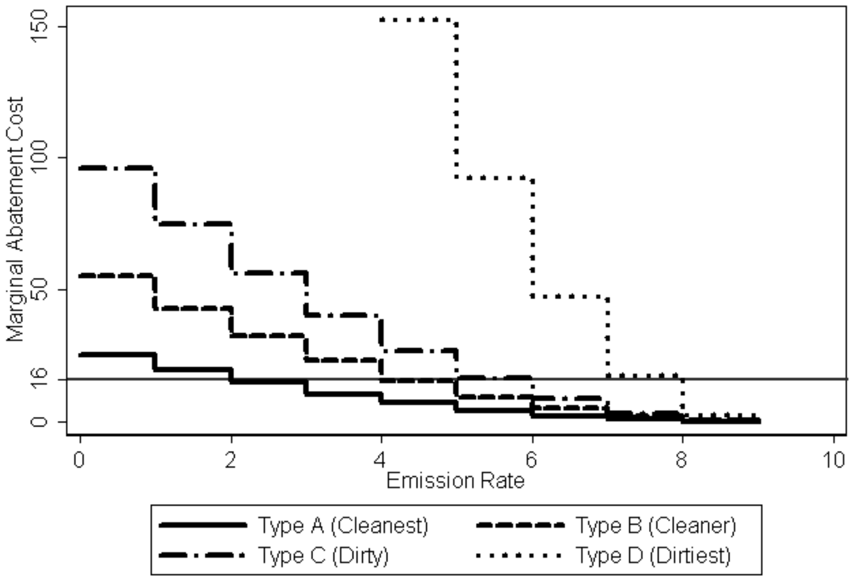

Figure 6: Marginal Abatement Costs

curves illustrated in Figure 6. The "dirty" firms have the steepest MAC curves, the "cleanest" the flattest. The equilibrium MAC of 16 is indicated by the horizontal line. In equilibrium the cleanest firms choose an emission rate of 2 while the dirtest choose 8. The remaining equilibrium predictions are reported in Table 4

As mentioned previously, under conditions of fixed capacity the equilibrium outcomes are the same in both treatments and both are equal to the social optimum provided marginal damage is 16. The price of emission rights is 16, output price is 160, aggregate output is 32, aggregate emissions are 5 times 32 or 160 and all firms have equal average costs in equilibrium.

We ran six sessions with untrained subjects. Figure 7 shows the mean price of emission rights by treatment, as indicated by the black

Trading Insitution	B&C	C&T
Price of Emisson Rights	16	16
Price of Output	160	160
Aggregate Output	32	32
Aggregate Emissions	160	160
Active Firm Types	all	all

Notes:
B&C - baseline-and-credit
C&T - cap-and-trade

Table 4: Fixed Capacity Predictions

dots. The shaded area spans the minimum and maximum observations for each period. It is immediately obvious that there are some systematic treatment effects. Under cap-and-trade prices are tightly clustered in a narrow band at or below the equilibrium band. There seems to be a clear downward trend across periods. Under baseline-and-credit prices are generally higher and much more variable, especially in the earlier periods of the session. Mean prices fall over the course of the session but are generally above the cap-and-trade prices for the comparable periods.

Figure 8 illustrates aggregate output by period. Recall that output can fall below equilibrium if firms fail to obtain sufficient credits or allowances to cover their emissions. Once again mean values are ndicated by black dots and the shaded area contains the range of the observations. Under cap-and-trade output is quite variable but systematically below the competitive equilibrium. Under baseline-and-credit output is closer to the competitive equilibrium, although still generally below it.

Despite the differences in output, aggregate emissions seem very

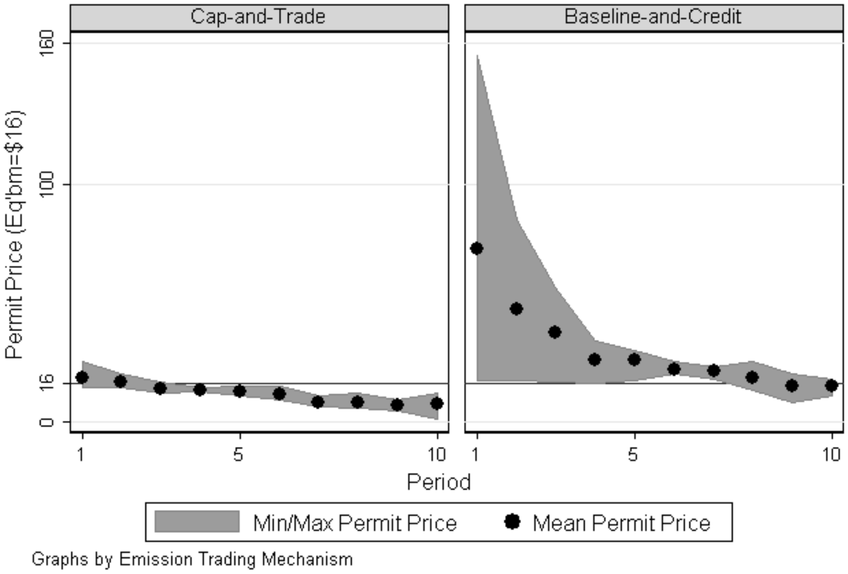

Figure 7: Fixed Capacity - Permit Prices

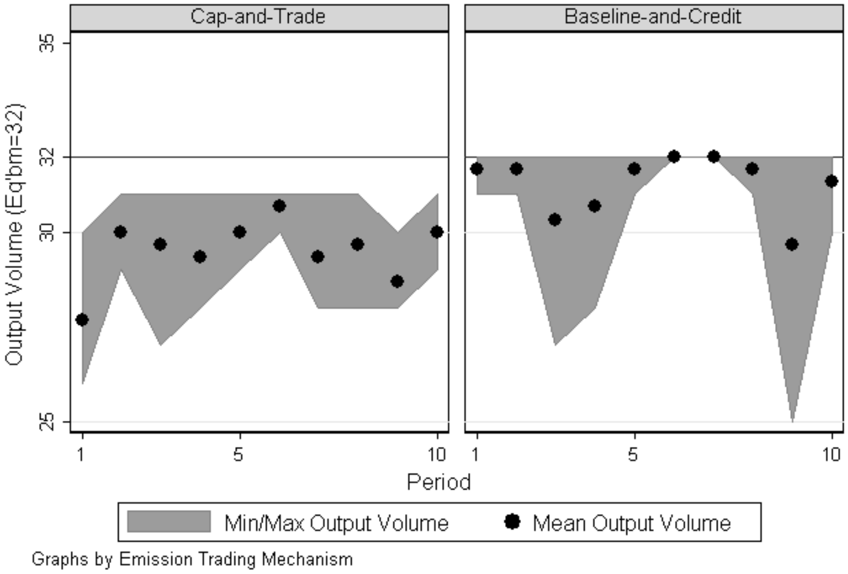

Figure 8: Fixed Capacity - Aggregate Output

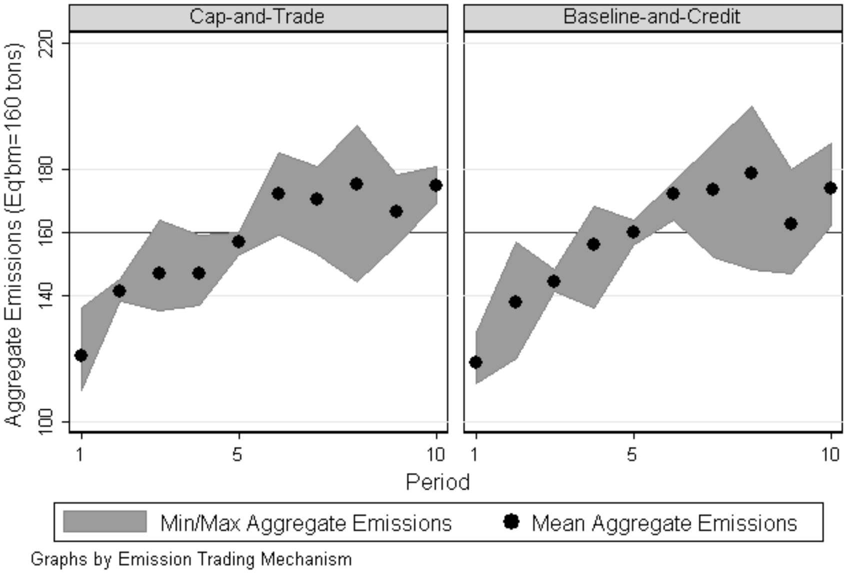

Figure 9: Fixed Capacity - Aggregate Emissions

similar under both treatments. There is a general upward trend in mean emissions. The emissions trend shown in Figure 9 reflects the behaviour of inventories over the course of each session. Under competitive conditions there is no need for firms to maintain inventories of emission rights. Perhaps surprisingly, every session demonstrated a substantial accumulation of emission rights inventories over the first five periods. Subjects began to work these off in the second half of the experiment.

Summary of Fixed Capacity Sessions

Simple statistics confirm the general impressions from the graphs. Table 5 presents means computed over periods 6 through 9. This avoids the learning and convergence effects observable in the early periods

	C&T	B&C	Prediction	Signif.
Permits				
Price**	8.42	18.92	16.00	c
Volume*	24.25	17.08	32.00	cb
Output				
Price*	172.08	163.33	160.00	c
Volume*	29.58	31.33	32.00	c
Emissions	171.00	171.58	160.00	
Inventory	59.00	48.00	0.00	cb
Efficiency	0.95	0.96	1.00	cb

B&C - baseline-and-credit
C&T - cap-and-trade
* - Treatment signficant at 10%, N=6
** - Treatment signficant at 5%, N=6
b - B&C significantly different from prediction at 5%
c - C&T significantly different from prediction at 5%

Table 5: Means by Treatment - Periods 6 to 9

and the possibility of end-game effects in period 10. Although there are only six observations it is possible to conduct parametric tests on the difference between treatment means and of the difference between the observed means for each treatment and the competitive prediction. We have also conducted non-parametric Mann-Whitney tests on these observations, with essentially the same results.

Examining the first row we see that predicted price of permits was 16. The mean price under baseline-and-credit was 18.92 compared to 8.42 under cap-and-trade. The difference between treatments is significant at the 5% level and the cap-and-trade observations are significantly different from the competitive equilibrium prediction of 16.

The volume of rights traded is slightly higher under cap-and-trade than under baseline-and-credit. The difference in means is significant at the 10% level. Both cap-and-trade and baseline-and-credit means are significantly below the predicted volume of 32.

Output volume is slightly lower and output price is slightly higher in cap-and-trade than in baseline-and-credit and the cap-and-trade values are significantly different from the predicted values of 32 and 160 respectively. On the other hand, aggregate emissions in the two plans are virtually equal. This implies a higher aggregate emission rate in the cap-and-trade plan. Inventories are higher in cap-and-trade than in baseline-and-credit, but in this case the difference is not significant. Efficiency, as measured by the sum of producer and consumer surplus, is essentially the same under both plans.

Summary of Fixed Capacity Results

We predicted that in this restricted environment there would be no difference between cap-and-trade and baseline-and-credit outcomes. Not surpisingingly, we found that both treatments deviated mildly from the predictions. Both exhibited some inefficient accumulation of permit inventories, below predicted volumes of trade and slightly lower product volumes. Somewhat surprisingly, we found some significant treament effects. In particular, cap-and-trade exhibits higher permit volumes and lower permit prices than baseline and credit. It also exhibits lower product volumes and higher product prices. All of these differences are significant at the 10% level. On the other hand, there is no significant difference in aggregate emissions nor in private efficiency. Private efficiency is quite high, with no significant treatment effect and no significant difference from the optimal level.

6 Variable Capacity

The last results we report here concern two pilot sessions for our next experiment. This is our first attempt to test the prediction that output and capacity will be higher under baseline-and-credit trading. In order to get as clear a reading as possible on this issue, we resolved to consider the case in which production capacity adjusts while emission rates remain constant. We used the same cost parameters as used in the fixed capacity experiment. We decided to start all subjects off in the cap-and-trade equilibrium from the fixed capacity experiments.

Because of the implicit subsidy on output created by the variable baseline we expect that subjects will expand aggregate capacity in the baseline-and-credit sessions while aggregate capacity under cap-and-trade should remain reatively constant. In both cases, however, the capacity of dirty firms should shrink and the capacity of cleaner firms should rise during the experiment. In order to prevent destabilizing adjustments we restrict changes in capacity to one unit per period. The output market is automated, as before.

We have run two pilot sessions for this experiment. We will compare the results to simulated results from myopic, profit maximizing robots. We have only begun to analyse the data from these sessions. Figure 6 graphs aggregate output in the two sessions. The large dots are the observed values. The smaller dots are simultated data from robot traders.

Consider first the simulated values. Under cap-and-trade there is a mild oscillation in volume as cleaner firms expand and dirtier firms contract. The observed values start below the predicted levels, pre-

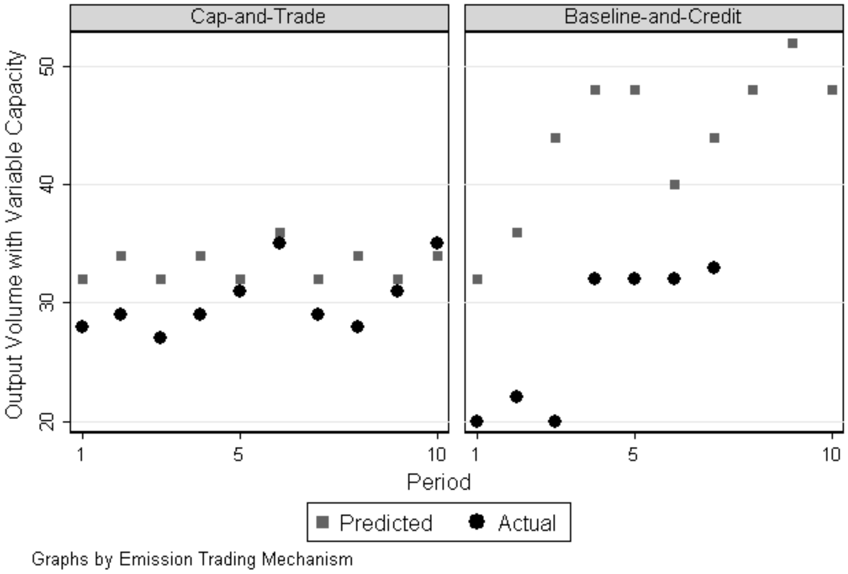

Figure 10: Variable Capacity Pilot Sessions Output Volumes

sumably because some firms were unable to obtain the allowances they required, given their capacity. Nevertheless, the pattern conforms quite closely to the predictions.

Under baseline-and-credit the predicted path is a gradual increase in output and capacity for all firms until product price is forced down sufficiently to drive some of the high cost firms out of the market. The actual path starts well below the predicted level but does rise over time. Unfortunately, the session ended early because of a computer malfunction.

It is too early to draw firm conclusions from these results. The one regularity seems to be that human subjects consistently produce less output than our robots do. The upward trend in output in the second session gives some hope that we will observe the predicted increase in capacity under baseline-and-credit.

7 Conclusion

This paper has reported our progress in developing a laboratory environment to examine long-run behaviour of alternative emission trading plans. In particular we wish to test the prediction that capacity, emissions and output will be higher under variable baseline-and-credit trading than under cap-and-trade. We have successfully developed an operational computerized environment suitable for short- and long-run experiments in emission trading. Simulations conducted in this environment suggest that there may be some difficuly in achieving a stable market equilibrium. Nevertheless, robot trades achieve the equilibria predicted by competitive theory. Experiments with human subjects and fixed capacity suggest there are some unanticipated differences between baseline-and-credit and cap-and-trade plans, even when the predicted short-run equilibrium is the same for both. Finally, our variable capacity pilot sessions demonstrate that experiments with variable capacity are feasible, and, with a generous eye, suggest that firms may be responding to the subsidy inherent in baseline and credit trading.

We will be continuing this work by running six variable capacity sessions this summer. By the fall we hope to progress to sessions in which allow adjustment at both margins: emission rate and capacity. That should be sufficient to provide at least provisional evidence on the long run differences in the performance of baseline and credit and cap and trade systems.

The environment we have created lends itself to a number of further applications. There are at least three possible projects on our to-do list.

First would be to testbed the performance of credit-for-early action plans. These plans allow firms to earn credit for emissions reduction below a baseline which is not yet mandatory. The issue is whether this would encourage reductions in emissions that would not otherwise take place.

A second area for work lies in the impact of alternative accounting rules on the behaviour of subjects in these environments. There is no firm agreement on how the distribution of allowances should be treated. In our experiment they have been entered into firm's inventories at estimated market value. This, however, has the result of raising a firm's income above its cash flow when the allowances are received and reducing income below cash flow when sold at a loss. It is entirely possible that production decisions could be affected by changing the reporting method.

Finally, variable baseline and credit plans are most commonly proposed in a hybrid form, where the credits generated by the uncapped firms are sold to firms in a capped sector (Fischer 2001). Our environment should be ideal for investigating the behavioural implications of such arrangements.

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