

# Baseline-and-Credit Style Emission Trading Mechanisms: An Experimental Investigation of Economic Inefficiency \*

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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 allowance permits, 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. This paper reports on a laboratory experiment designed to test the prediction in a laboratory environment in which subjects representing firms choose emission technologies and output capacities. A computerized environment has been created in which subjects participate in markets for emission rights and for output. Demand for output is simulated. All decisions are tracked through a double-entry bookkeeping system. Our evidence supports the theoretical prediction that aggregate output and emissions are inefficiently high under a baseline-and-credit trading plan compared to a corresponding cap-and-trade plan.

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# 1 Introduction

Emissions trading is now well established as a method of regulating emissions of uniformly mixed pollutants. The classic analysis assumes that the regulatory authority sets an aggregate cap on emissions from a set of sources and then divides the cap into a number of tradable permits (frequently called allowances), each of which authorizes the discharge of a unit quantity of emissions. Although the allowances could be sold at auction to raise revenue, the most frequently discussed plans assume that the permits will be distributed to the regulated firms on some ad hoc basis. Firms then trade the allowances, establishing a market price. In equilibrium, individual firms choose emissions such that the marginal cost of abating pollution equals the allowance price. They redeem allowances equal to the emissions discharged, selling or banking the remainder. If emissions exceed the initial distribution of allowances the firm must purchase allowances to cover the excess. Such plans are generally known as *cap-and-trade* plans. A good example is the U.S. EPA's sulphur dioxide auction.

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 explicit 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 fewer than their baseline emissions. These credits may be banked or sold to firms who exceed their baselines. The effect is to limit aggregate

emissions to an *implicit* cap equal to the sum of the individual baselines. Typical baseline-and-credit plans also differ from classic cap-and-trade in a number of institutional details. For example, credits are often computed on a project-by-project basis rather than on the basis of enterprise-wide emissions. They must be certified and registered before they can be traded and there are generally restrictions that credits cannot be registered until the emission reductions have actually occurred.

Baseline-and-credit plans are theoretically equivalent to a cap-and-trade plan if the cap implicit in the baseline-and-credit plan is fixed and numerically equal to the fixed cap in a cap-and-trade plan. In many cases, however, the baseline is computed by multiplying a measure of firm scale (energy input or product output) by a performance standard specifying a required ratio of emissions to input or output.<sup>1</sup> In this case, the implicit cap on aggregate emissions varies with the level of aggregate output. Fischer (2001, 2003) refers to such plans as tradable performance standards.

The variable baseline in a baseline-and-credit plan introduces a critical difference in long-run performance compared to cap-and-trade with the same implied performance standard.<sup>2</sup> Specifically, the variable baseline acts as a subsidy on output. Firms receiving this subsidy will tend to expand their capacity to produce output. This introduces two potential inefficiencies. If the performance standard remains the same in both plans, the baseline-and-credit plan will exhibit higher output, emissions, and external costs. If, instead, the performance standard under baseline-and-credit is tightened so as

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<sup>1</sup>This ratio is often called the *emission intensity* or *emission rate*.

<sup>2</sup>A cap-and-trade plan with aggregate cap on emissions may be said to imply a performance standard of  $r^s = E/Q$  where  $E$  and  $Q$  are respectively aggregate emissions and output in long run equilibrium.

to meet the aggregate emissions specified under cap-and-trade, then industry costs will increase due to unnecessarily tight restrictions on emitting firms (Muller 1999; Dewees 2001; Fischer, 2001, 2003). It should be noted that this reasoning presumes that firms are adjusting to pollution regulation on two margins: the emission rate of output and the level of output itself. Moreover the reasoning is essentially long-run in that output is changed by firms' investing or divesting themselves of productive capacity and equilibrium is computed by imposing a zero-profit restriction on firms in the market.

Currently, both cap-and-trade and baseline-and-credit plans are being implemented at similar rates at the international level (Hasselknippe 2003). However, the predictions on the relative performance of baseline-and-credit versus cap-and-trade have not been tested in the laboratory. Thus far, experiments have been fruitful in shaping cap-and-trade public policy (Cason 1995; Cason and Plott 1996), but as of yet no baseline-and-credit laboratory studies have been published. Laboratory implementation of baseline-and-credit trading would serve several goals: it would verify that market processes are sufficient to drive agents to competitive equilibrium, demonstrate the contrast between baseline-and-credit and cap-and-trade to policy makers, and possibly create a vehicle for training policy-makers and practitioners in the nature of alternative emission trading plans.

We have undertaken a long-term research project to compare the properties of baseline-and-credit and cap-and-trade plans in the lab. In previous work (Buckley, Muller, and Mestelman 2005b) we have developed a tractable model with constant returns to scale in production and multiple firm types. We have implemented a computerized lab environment with explicit capac-

ity and emission rate decision, fully specified markets for emission rights and output, and a complete accounting framework. We have demonstrated that predicted results hold in simulated markets with robot traders adjusting on both the output and emissions intensity margins. However, market instability occurs when capacity is freely adjustable, so we have implemented work with human subjects slowly, examining the emissions rate margin and the output market margin one at a time.

Buckley (2004) reports on six sessions comparing baseline-and-credit with cap-and-trade when firm capacities are fixed and firm adjustment is limited to emission rate. The investigation seeks to confirm the prediction that the outcome of the two approaches would be the same when the output subsidy inherent to the baseline-and-credit plan can not possibly lead to productive expansion. Any deviation from parallel results could be then laid to the institutional differences between the two plans rather than the implied subsidy on output and emissions. The study confirms that the overall predictions on emissions hold. Efficiency in the market was improved, although only about one-half the available gains from trade were realized. However there were some deviations from the benchmark values computed under the assumption of a perfectly competitive equilibrium. Emission permit prices were higher under baseline-and-credit trading and inventories of permits were irrationally high in both treatments.

Buckley, Muller, and Mestelman (2005a) report on six sessions investigating the complementary problem of adjustment on the capacity margin. That is, firm emission technologies are held constant at their optimal levels and firms are allowed to change their productive capacity each decision

period. The study confirms that when firms can make adjustments only on the margin of output capacity, baseline-and-credit trading exhibits higher output and emissions and lower efficiency than a comparable cap-and-trade plan. However, as reported in Buckley (2004), emission permit prices were found to be higher under baseline-and-credit trading than under cap and trade. Unlike in the environment reported by Buckley (2004), inventories of permits were extraordinarily high only in the baseline-and-credit treatments when output capacity was variable.

In this paper we investigate the full long-run model in which firms make choices on both the emission technology and output capacity margins. We have three objectives. First we wish to see whether market forces are sufficiently strong as to generate and maintain a competitive equilibrium. Secondly, we are particularly interested in demonstrating that the baseline-and-credit policy leads to higher emissions and output than occur under cap-and-trade. Thirdly, we wish to test whether the relatively high permit prices and inventories found under baseline-and-credit trading in the previous single margin experiments, persist in a more realistic long-run setting in which firms make decisions on both margins.

## **2 Experimental Design**

We ran six laboratory sessions (three cap-and-trade and three baseline-and-credit), each involving 8 subjects, in February and March of 2005. Subjects were recruited from the general population of undergraduates at McMaster University. Each session of the experiment was conducted in two separate parts. During the first two hour part of each session, students received in-

structions and participated in 4 training periods using an alternate set of parameters. This training exercise was rewarded by a flat fee of \$45. Subjects then returned a week later to complete the second two hour part of the session in which they participated in 20 paid rounds using the parameters reported here. After 20 rounds they were informed of their results and paid privately in cash. Subjects earned between \$12.00 and \$71.25 with a mean of \$46.14, not including the \$45 training fee from the week earlier. The software implementation of the environment detailed below was programmed at McMaster University using Borland's Delphi programming environment and the MySQL open source database.<sup>3</sup>

Testing the two competing trading mechanisms requires a relatively complex experimental environment. Unlike most emission trading experiments which tend to focus on individual aspects of the trading mechanism (e.g. Cason 1995; Cason and Plott 1996), our experiment is conducted within a fully specified institutional framework, much like previous cap-and-trade work by Godby, Mestelman, Muller, and Welland (1997), Ben-David, Brookshire, Burness, McKee, and Schmidt (1999) and Muller, Mestelman, Spraggon, and Godby (2002). To date, there has been no work published on baseline-and-credit experiments outside of those generated by this project. Also, there has been no published cap-and-trade experiments involving firms making both emission technology and output capacity decisions. Given this, environments reported by Ben-David et al. (1999) and Murphy and Stranlund (2005) are most relevant to this study, as the former involves firms with fixed output choosing explicit emission technologies, and the latter involves

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<sup>3</sup>See Appendix A and B posted at <http://www.economics.mcmaster.ca/econ/mceel/> for the laboratory instructions and screenshots of the computerized environment, respectively.

firms with fixed emission technologies choosing output levels (albeit under an exogenous capacity constraint).

Other than Ben-David et al. (1999), most fully specified experimental emission trading environments assume fixed output levels and implicitly defined emission abatement technology choices. In these experiments, subjects trade emission permits; their permit holdings at the end of each period (divided by their exogenous output) implicitly determine their firm's emission rate. In these environments, the difference between choosing a sub-optimal emission rate and an error made while trading permits can not be identified. Ben-David et al. (1999), however, examine a model with exogenously fixed output in which firms with differing and chosen abatement technologies attempt to achieve an optimal allocation of abatement and permits. Their objective is to test hypotheses regarding how abatement and cost heterogeneity affect efficiency and permit trading volume and price. This environment involves subjects making an explicit choice of emission rate: subjects trade permits and then choose one of three possible abatement technology levels. Despite adding to the complexity of the experimental environment, the authors implement an explicit emission rate choice to allow them to distinguish between emission rate/technology choice errors and permit trading errors.<sup>4</sup>

The experimental environment created for the work presented in this paper is similar to that described in Ben-David et al. (1999) with the addition of a market for output, the introduction of an output capacity decision, and an increase in the range of possible emission technologies from 3 to 10. A fully

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<sup>4</sup>The authors model their abatement technology decision as being “irreversible”. Once a cleaner technology, or lower emission rate, has been chosen, the firm cannot revert back to a dirtier technology at a later decision period.

specified environment with an emission permit market, an output market, an explicit emission technology choice and an output capacity choice is required to test our theoretical predictions concerning the alternative emission trading plans in a long-run setting. In order to focus on market features important to our theoretical predictions, the experimental setting necessarily abstracts from many additional market characteristics which would exist in a naturally occurring setting. Failure to abstract would possibly make the experimental setting too complex. Thus, we impose full compliance, abstracting from issues of penalties and monitoring. Compliance is enforced by restricting output by the fixed capacity level and the current holding of emission permits. Firms are not able to sell output if they do not have the required amount of permits to redeem.

Subjects were told that they represented firms which create emissions while producing output and selling it on a simulated market. We chose not to present the experiment in neutral terms, because we believed that the explicit emissions trading environment would help subjects understand the nature of the decisions they were making. We employed a design using four types of firms, from A to D, possessing different marginal abatement cost (MAC) schedules. The type D “dirty” firms have the steepest MAC curves, the type A “cleanest” have the flattest. There were two subjects of each type in each session. Subjects were presented with MAC curves represented by step functions. These functions are broken down into nine steps corresponding to emission rate possibilities ranging in integer values between 0 and 9. While Ben-David et al. (1999) implement an explicit emission rate choice with three possible levels, results from robot simulations

reported in Buckley et al. (2005a) provide evidence that MAC functions with a limited number of steps may contribute to volatility of permit prices, emission rates and aggregate emissions. MAC functions for this experiment are implemented with nine steps so as to make the function more continuous without making the environment too complex.

Each firm was initially given four units of productive capacity,  $k$ , which they could raise or lower by one unit at the end of each decision round. During each decision round, output could be produced at zero marginal cost up to the fixed capacity. Each firm created external costs proportional to its emissions, although the instructions did not explicitly inform subjects of this. The marginal damage of emissions (not provided to the subjects) was assumed constant at \$16 per unit of emissions. These parameters were chosen to equate the marginal social cost ( $MSC$ ) of each firm so that all could be present in final equilibrium.<sup>5</sup> Figure 1 illustrates the short- and long-run cost curves for a typical firm and Figure

There were two treatments: Cap-and-Trade and Baseline-and-Credit. In both treatments subjects were started off at the cap-and-trade equilibrium, which was chosen to coincide with the social optimum. In the cap-and-trade treatment, 160 permits were distributed each period and aggregate production capacity began at 32 units of output. This implies an average emission rate of five at the social optimum. We expect the system to remain stable at the equilibrium point. In the baseline-and-credit, treatment we imposed a tradable performance standard of 5, equivalent to the average emission rate in the cap-and-trade treatment. In this treatment we expect

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<sup>5</sup>Marginal social cost equals unit capacity cost plus the external costs created by each unit of output. For our parameters  $MSC$  equals 160 for all four firm types.

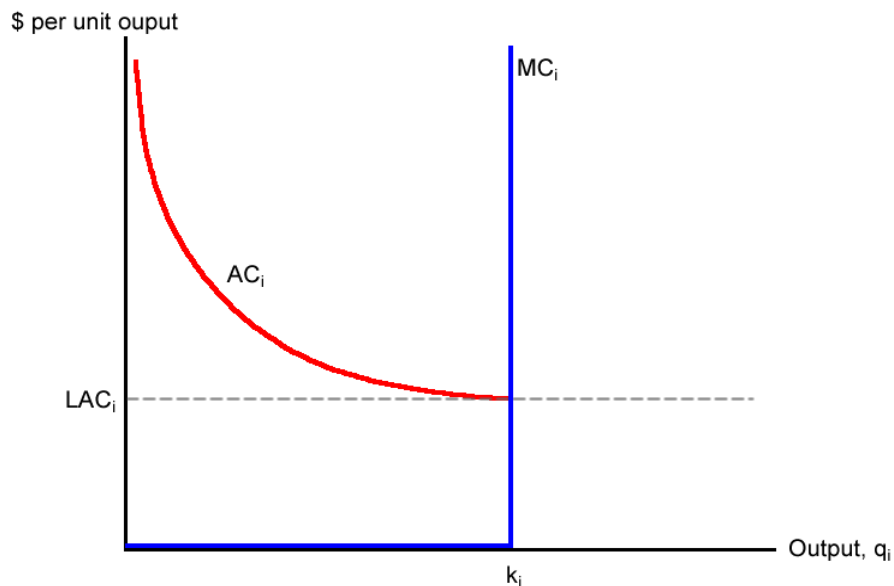


Figure 1: Firm Cost Curves

the output and emissions to increase due to the inherent subsidy to output.

The treatments differed slightly in the sequence of decisions. A flowchart is provided as Figure 2. In the cap-and-trade treatment subjects begin with capacity and allowance holdings determined in the previous period. They receive an endowment of allowances. Their first action is to trade allowances in a multiple-unit uniform-price sealed bid-ask auction (call market).<sup>6</sup> Subjects were permitted to place up to three bids for additional permits. Each

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<sup>6</sup>For our purposes, keeping the market institution constant across treatments is essential. A multi-unit uniform price sealed bid-ask auction was chosen because of the relatively quick trading time and high efficiency associated with it. As discussed by Smith, Williams, Bratton, and Vannoni (1982), while traders have incentives to bid below values and ask above costs, traders of infra-marginal units near the margin that determine price should fully reveal costs and values to avoid being excluded from the market by extra-marginal units. Therefore, misrepresentation is not expected to affect the uniform market clearing price.

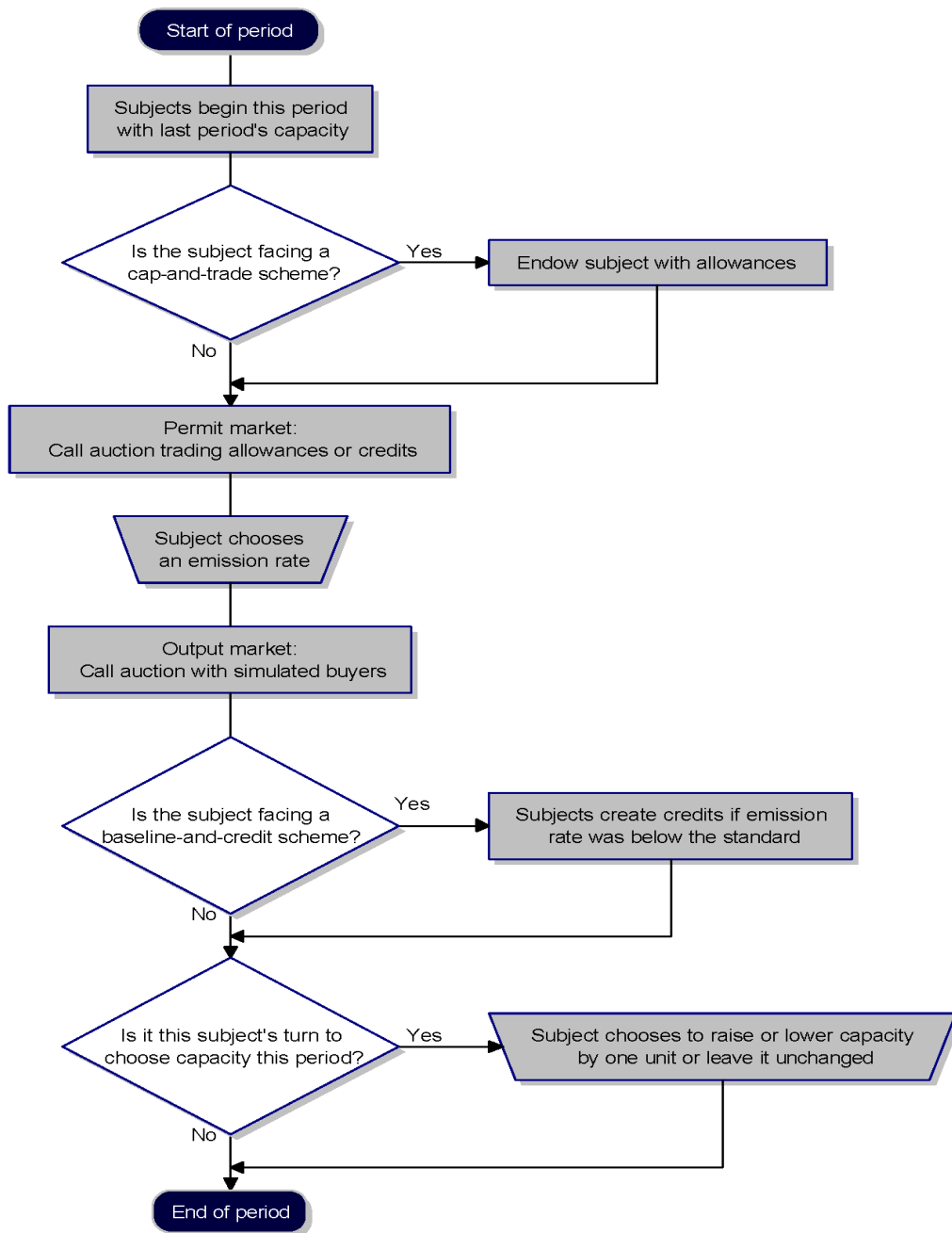


Figure 2: Sequence of Events in a Typical Period

bid was accompanied by a specified number of units. Subjects were also allowed to place up to three asks: each specified a number of units the subject was willing to sell at a specified price. This action required subjects to estimate the price they are willing to pay for additional permits and the price at which they are willing to sell their permits. They were provided with extensive on-screen help to aid them in this decision. Once all bids and asks were submitted, the allowance market cleared, determining a price of permits and a quantity bought or sold for each subject. Each subject was then required to produce and offer for sale as much output as possible, given output capacity and permit holdings. This amount was computed and submitted to the output market automatically. Demand for output was represented by an exogenous demand function with known intercept and slope. The output market then cleared, determining a common output price and an individual quantity sold and revenue earned for each subject. After reviewing their financial report for the period, subjects decide whether to increase or decrease capacity by one unit.

The baseline-and-credit sequence was identical to cap-and-trade except that subjects do not receive any emission permits before the credit market opens. Consequently, they can only trade credits which were produced in previous periods. The quantity of credits created in the current period is determined by the firm's emission rate and its quantity of output sold, and so can only be credited after output for the current period was determined.<sup>7</sup>

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<sup>7</sup>As mentioned in the introduction, this lag in credit supply mimics the institutional framework found in most real-world baseline-and-credit systems.

### 3 Parameterization and Benchmarks

In this section we derive benchmark equilibria for the two treatments under the assumption of perfect competition. These benchmarks are derived from a static model even though our experimental environment is inherently dynamic. This will allow us to investigate whether these models, which are typical of the field, are useful in predicting the outcomes in real emission trading markets. We first introduce some notation and describe the general model which allows adjustment on both the emission rate and output margins. Secondly we report on the parameterization of the model for this experiment, and finally present the benchmarks.

#### 3.1 Theory

This theoretical model is a multi-firm partial equilibrium model based on the representative agent model used by Fischer (2003). At the basis of the model is an industry with a fixed number of perfectly competitive price-taking firms. Quality of output is fixed and homogeneous between firms. We begin by assuming constant marginal costs of output. The predictions do not require more realistic and complicated assumptions so the experimental environment is kept as simple as possible.

Consider an industry with  $N$  firms. Each firm  $i \in [1, \dots, N]$  produces  $q_i$  units of output at an emission rate of  $r_i = \frac{e_i}{q_i}$ , where  $e_i$  represents quantity of emissions. Industry output is  $Q = \sum_{i=1}^N q_i$ . Aggregate emissions are  $E = \sum_{i=1}^N e_i = \sum_{i=1}^N r_i q_i$ . Environmental damages are assumed to be a positive and weakly convex function of total emissions:  $D = D(E)$ ,  $D'(E) > 0$  and  $D''(E) \geq 0$ . Willingness-to-pay for the output is a weakly concave

function of aggregate output,  $WTP = \int_0^Q P(z)dz$ , where  $P = P(Q)$  is an inverse demand curve with positive ordinate ( $P(0) > 0$ ) and negative slope ( $P'(Q) < 0$ ). The private cost of production is a linear homogenous function of output and emissions:  $C_i = C_i(q_i, e_i) = q_i C_i(1, r_i)$ . Unit cost  $C_i(1, r_i)$  can be separated into unit capacity cost  $c_i(r_i)$ , which is a positive and declining function of the emission rate with  $c_i(r_i) > 0$  and  $c'_i(r_i) \leq 0$ , and unit variable cost  $w_i$ , which is a constant function of output. Consequently, total cost is  $C_i = c_i(r_i)q_i + w_i q_i$ . Note that the marginal cost of output is  $c_i(r_i) + w_i$  and the marginal cost of abating pollution is  $MAC = -\frac{\partial C_i}{\partial e_i} = -c'_i(r_i)$ . The general form for the unit capacity cost function<sup>8</sup> is,

$$c_i(r_i) = u_0 + (u_1 - u_0)[(r_{max} - r_i)/r_{max}]^{\alpha_i}. \quad (1)$$

An omnipotent social planner would choose an emission rate and output for each firm in order to maximize total surplus,  $S$ . The total surplus is composed of the consumer's willingness-to-pay for the output minus firm costs and environmental damage caused by output production. The social planner's welfare maximization problem can be expressed as

$$\max_{\{r_i, q_i\}} S = \int_0^Q P(z) - \sum_{i=1}^N c_i(r_i)q_i - \sum_{i=1}^N w_i q_i - D\left(\sum_{i=1}^N r_i q_i\right). \quad (2)$$

The first order conditions for an interior maximum are

$$-c'_i(r_i^*) = D'\left(\sum_{i=1}^N r_i^* q_i^*\right) \quad \forall i \in N \quad (3)$$

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<sup>8</sup>As previously mentioned, firms can choose emission rates from 0 to 9 in our environment, so  $r_{max}$  is set to 9. Steps of the relevant MAC function can be found by calculating the cost differences between integer emission rate values between 0 and 9 (i.e.  $c_i(r_i = j) - c_i(r_i = j + 1) \quad \forall j \in [0, 8]$ ).

and

$$P(Q^*) = c_i(r_i^*) + w_i + r_i^* D' \left( \sum_{i=1}^N r_i^* q_i^* \right) \quad \forall i \in N \quad (4)$$

with  $q_i$  and  $r_i$  greater than zero.

These conditions require that each firm's operations be optimized on two margins. The *efficient abatement* condition (3) ensures that abatement is both cost minimizing, since the marginal abatement cost (MAC) is equated across firms, and surplus maximizing, since MAC equals marginal damage. Let  $MAC^* = D'(\sum_{i=1}^N r_i^* q_i^*)$  denote the common value of the  $-c'_i$ 's. The *efficient output* condition (4) ensures that output is surplus maximizing because each firm's marginal social cost equals marginal willingness-to-pay. Note that, although condition (3) determines a unique emission rate for each firm, condition (4) determines only the aggregate level of output. Any combination of  $q_i^*$ s and  $r_i^*$ s such that the  $q_i^*$ s sum to  $Q^*$  and the  $r_i^* q_i^*$ s sum to  $E^* = \sum_{i=1}^N r_i^* q_i^*$  is a solution to the surplus maximization problem.<sup>9</sup>

The social optimum can be supported as a competitive equilibrium under cap-and-trade regulation. The regulator distributes  $A_i$  allowances to each firm so that the sum of allowances granted equals the optimal level of emissions,  $\sum_{i=1}^N A_i = E^*$ . Letting  $P_c$  denote the price of allowances under cap-and-trade, firm  $i$ 's profit maximization problem is

$$\max_{\{r_i, q_i\}} \pi_i^c = P(Q)q_i - c_i(r_i)q_i - w_i q_i - P_c(r_i q_i - A_i). \quad (5)$$

The two first order conditions for an interior maximum are

$$-c'_i(r_i^c) = P_c \quad (6)$$

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<sup>9</sup>This feature of the model is a direct result of the constant marginal cost of output assumption. Unit cost,  $c_i(r_i^*)$ , is a function of emission rate but not output. If this assumption were relaxed, condition (4) would imply a firm specific output level but would result in a more complicated laboratory environment.

if  $q_i$  is greater than zero, and

$$P(Q^c) = c_i(r_i^c) + w_i + r_i^c P_c. \quad (7)$$

Equation (6) ensures cost minimizing abatement and defines each  $r_i^c$ . Equation (7) requires that each firm earn zero marginal profit, and identifies  $Q^c$ . The system (6) and (7) can be obtained from the optimal conditions (3) and (4) by replacing  $D'(\sum_{i=1}^N r_i^* q_i^*)$  with  $P_c$  and  $r_i^*$  with  $r_i^c$ . The optimal solution to the surplus maximization problem can be sustained as a cap-and-trade competitive equilibrium and vice versa.

Under a baseline-and-credit plan, the regulator sets an industry-wide performance standard,  $r^s$ . This performance standard characterizes a relative emission target mechanism. Firm  $i$ 's net demand for credits is  $(r_i - r^s)q_i$ , with negative values signifying a supply of credits. If the price of credits under a baseline-and-credit plan is  $P_b$ , firm  $i$ 's profit maximization problem is

$$\max_{\{r_i, q_i\}} \pi_i^b = P(Q)q_i - c_i(r_i)q_i - w_i q_i - P_b q_i (r_i - r^s). \quad (8)$$

The first order conditions for an interior maximum are

$$-c'_i(r_i^b) = P_b \quad (9)$$

if  $q_i$  is greater than zero, and

$$P(Q^b) = c_i(r_i^b) + w_i + r_i^b P_b - r^s P_b. \quad (10)$$

Equation (9) is the usual efficient abatement condition which defines each  $r_i^b$ . Equation (10) is the usual zero marginal profit condition which determines  $Q^b$ . Let us assume that the regulator sets the emission rate standard equal to the average emission rate under the social planner scenario,

$r^s = (\sum_{i=1}^N r_i^* q_i^*)/Q^*$ .<sup>10</sup> If the emission standard is binding and net demand for credits in equilibrium equals zero, then

$$\sum_{i=1}^N r_i^b q_i^b = \sum_{i=1}^N r_i^s q_i^b. \quad (11)$$

Substituting for  $r^s$  we can calculate that

$$\sum_{i=1}^N r_i^b \frac{q_i^b}{Q^b} = \sum_{i=1}^N r_i^* \frac{q_i^*}{Q^*}. \quad (12)$$

Equation (12) implies that, if market shares are equal under baseline-and-credit and cap-and-trade plans, any set of emission rates satisfying the socially optimal abatement condition (3) also satisfies the corresponding baseline-and-credit equilibrium condition (9).

The baseline-and-credit zero marginal profit condition (10) is similar to optimal equation (4) with  $P_b$  playing the role of marginal damage,  $D'()$ . If emission rates are the same under the two cases ( $r_i^b = r_i^*$ ), then  $P_b = D'(E^*)$  and the right hand side of (10) is equal to the right hand side of (4), except for the term  $-r^s P_b$ . This negative cost term derives from the  $P_b r^s q_i$  term of the firm's profit function and represents a subsidy on output causing the output price under baseline-and-credit trading to be less than optimal. Consequently, because the demand curve for output is assumed to be downward sloping ( $P'(Q) < 0$ ), aggregate output  $Q^b$  will be higher than aggregate output  $Q^*$  chosen by the social planner. Since equal average

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<sup>10</sup>As mentioned in the introduction, we will find that setting the performance standard equal to the optimal average emission rate will result in quantities of emissions and output that are inefficiently high. We could set a stricter standard so that quantities of output and emissions are optimal but then firm costs will be inefficiently high. Considering that both methods yield inefficiency we choose to focus on the case comparing cap-and-trade with a baseline-and-credit system with a performance standard equal to the average emission rate from the optimal scenario.

Table 1: Firm Cost Parameters

| Firm Type | Optimal Unit |      |    |          |       | Optimal Emission |           | C&T         | B&C                  | B&C             |
|-----------|--------------|------|----|----------|-------|------------------|-----------|-------------|----------------------|-----------------|
|           | Cost         | u1   | u0 | $\alpha$ | $w_i$ | Rate             | Endowment | Each Period | Performance Standard | Initial Credits |
| A         | 128          | 172  | 88 | 3        | 0     | 2                | 20        | 20          | 5                    | 12              |
| B         | 96           | 249  | 64 | 3        | 0     | 4                | 20        | 20          | 5                    | 4               |
| C         | 64           | 375  | 52 | 3        | 0     | 6                | 20        | 20          | 5                    | 0               |
| D         | 32           | 1852 | 29 | 3        | 0     | 8                | 20        | 20          | 5                    | 0               |

Note: B&C is Baseline-and-Credit and C&T is Cap-and-Trade.

emission rates are imposed under both trading plans, this higher aggregate output implies that aggregate emission levels will be also be higher under the baseline-and-credit plan.

Note from (8) that, if a firm chooses an emission rate equal to the performance standard,  $r_i = r^s$ , it will not create, nor be required to redeem, any permits. Therefore, its output and emissions will be unconstrained by the regulatory program. While cap-and-trade imposes a fixed upper limit on emissions, a baseline-and-credit plan implies that emissions will vary with output.

### 3.2 Parameterization

Table 1 presents firm-specific parameters used in the sessions reported in this paper. Figure 3 presents the four firm types' marginal abatement cost curves and their equilibrium emission rates of 2, 4, 6 and 8 associated with the equilibrium permit price of \$16. Firm types A, B, C and D have optimal equilibrium unit costs of 128, 96, 64 and 32, respectively. Figure 4

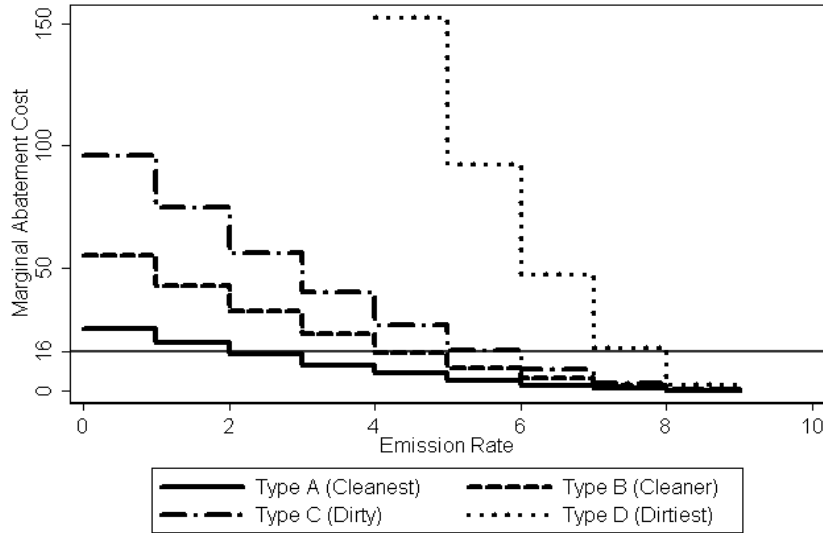


Figure 3: Marginal Abatement Cost Curves

illustrates how the marginal social cost is equated across all firm types when the marginal damage of emissions is equal to \$16 and each firm chooses its optimal equilibrium emission rate.

In the experiment, the demand for output is exogenous and is represented by the inverse demand function  $P = 320 - 5Q$ , where  $P$  is the output price and  $Q$  is the quantity demanded. Table 2 summarizes the associated equilibrium predictions under the alternative emission trading mechanisms. It is useful to illustrate the equilibria diagrammatically.

Figure 5 illustrates the cap-and-trade output equilibrium when only type A and D firms are in the market and they are choosing their optimal equilibrium emission rates of 2 and 8, respectively. The dirty firms have long-run average costs (LAC) of 32 and create damages of  $r_D MD = 8 \times 16 = 128$  per

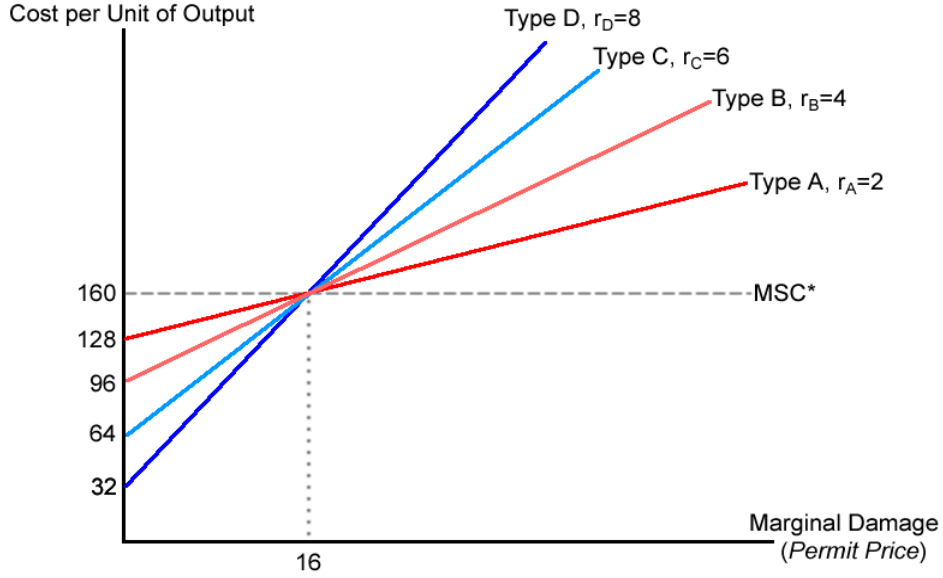


Figure 4: Marginal Social Cost (and *Long-run Average Cost*) by Firm Type

Table 2: Variable Capacity Predictions

| Trading Institution | Price of Allowances or Credits | Output Price | Aggregate Output | Aggregate Emissions | Active Firm Types |
|---------------------|--------------------------------|--------------|------------------|---------------------|-------------------|
| B&C                 | 16                             | 80           | 48               | 240                 | A,B,C,D           |
| C&T                 | 16                             | 160          | 32               | 160                 | A,B,C,D           |

Note: B&C is Baseline-and-Credit and C&T is Cap-and-Trade.

unit of output. Marginal social cost is 160. Firm type A has a higher unit capacity cost at \$128 but lower damages of  $r_A MD = 2 \times 16 = 32$  per unit of output, yielding the same marginal social cost. Optimal output  $Q_C^* = 32$  is determined by the intersection of the demand curve and marginal social cost. At the optimal output, type A firms earn  $160 - 128 = 32$  in rent per unit of

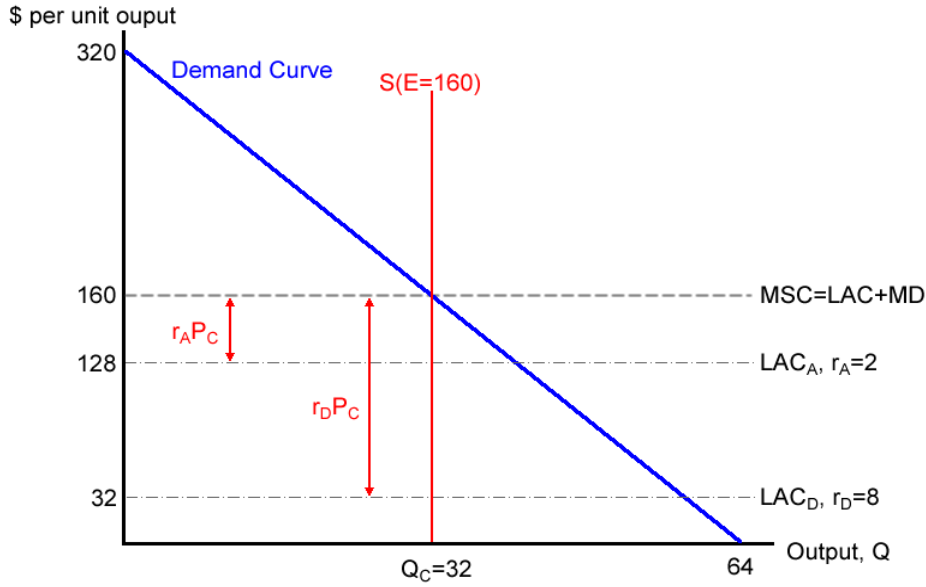


Figure 5: Cap-and-Trade Equilibrium

output, or  $32/2 = 16$  per unit of emissions. Type D firms earn  $160 - 32 = 128$  in rent per unit output, or  $128/8 = 16$  per unit of emissions. Both types of firms are willing to pay \$16 per permit. Under cap-and-trade, the regulatory authority allocates 160 allowances and the allowance market clears at \$16 per permit. Long-run average cost is now \$160 for each firm type. Equilibrium at a price of \$160 implies output of 32 units, and an average emission rate of 5. The only way to achieve an average emission rate of 5 with type A ( $r_A = 2$ ) and D ( $r_D = 8$ ) firms is to have equal output capacity of each firm type. This equilibrium implies the presence of 16 units of capacity from type A and 16 units of capacity of type D in the market.

Figure 6 shows the equivalent baseline-and-credit output equilibrium, again assuming that the emission permit market is also in equilibrium. The

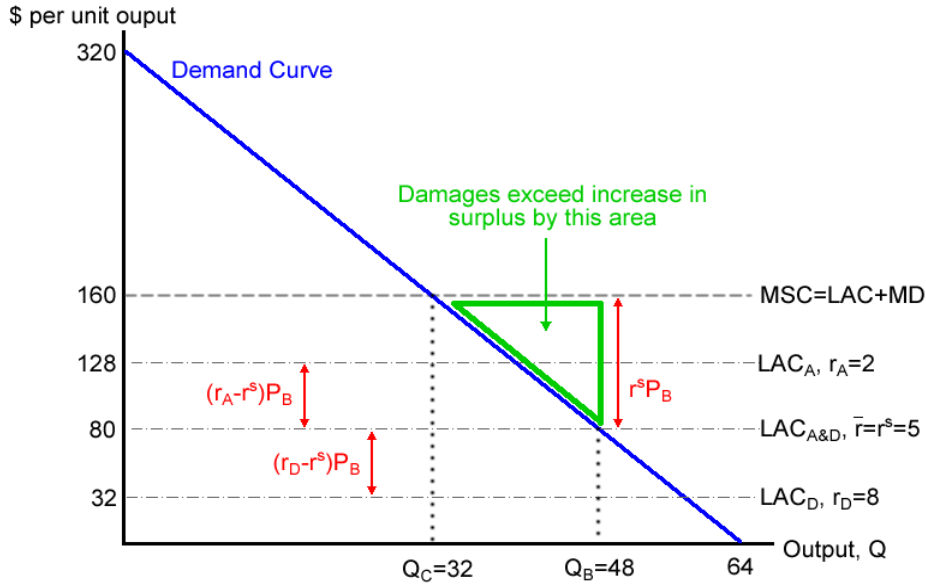


Figure 6: Baseline-and-Credit Equilibrium

performance standard is  $r^s = 5$  units of emissions per unit of output. Restricting attention to type A and D firms, we see this implies that there must be equal capacity of each firm type. The effect of baseline-and-credit trading is to equate the LAC of both firm types. Given equal capacity shares, average  $LAC = (128 + 32)/2 = 80$ . This determines the inefficient equilibrium output of 48 units, 24 from each firm type. At this point, type D firms must buy  $r_D - r^s = 3$  credits per unit of output and they are willing to pay  $(80 - 32)/3 = 16$  per credit. Type A firms create  $r^s - r_A = 3$  credits per unit of output. They must receive at least  $(128 - 80)/3 = 16$  per credit to earn non-negative profits under baseline-and-credit. Since there is equal capacity of type A and D firms (24 units for each type), the supply of credits equals demand for credits at a price of \$16.

### 3.3 Efficiency

We compute the efficiency of baseline-and-credit and cap-and-trade equilibria relative to the maximum surplus available. The social surplus is equal to the sum of consumers' surplus and producers' surplus less any environmental damage. In computing the environmental damages we assume constant marginal damages of \$16 per unit of emissions. From Figure 5 it is clear that under cap-and-trade consumers' surplus in equilibrium is  $0.5(320 - 160)(32) = \$2560$ . Producers' Surplus is  $(160 - 80)(32) = \$2560$ , the same amount. External damages are equal to total emissions multiplied by the marginal damage,  $160 \times 16 = 2560$ . Note that this exactly offsets the producers' surplus, so that total social surplus is equal to the consumer surplus of \$2560. Because the emissions cap was set to the socially optimal level of 160 units of emissions, the cap-and-trade surplus values are optimal. Using Figure 6, the corresponding consumers' surplus, producers' surplus, external damages and total social surplus under baseline-and-credit are \$5760, \$0, \$3840 and \$1920, respectively.

Given these definitions we can compute an efficiency index

$$\text{Efficiency} = \frac{\text{Actual Total Surplus}}{\text{Optimal Total Surplus}}. \quad (13)$$

It is convenient to decompose efficiency into components associated with consumer surplus, producer surplus and external costs. Thus the consumer surplus component of the efficiency index is

$$\text{Consumer Surplus Component} = \frac{\text{Actual Consumer Surplus}}{\text{Optimal Total Surplus}}. \quad (14)$$

Table 3 reports the equilibrium values for total surplus and its components under the two treatments.

Table 3: Equilibrium Surplus and Efficiency

|                                  | Efficiency<br>= | Components of Efficiency |                          |                               |
|----------------------------------|-----------------|--------------------------|--------------------------|-------------------------------|
|                                  |                 | Consumer<br>Surplus<br>+ | Producer<br>Surplus<br>+ | Environmental<br>Damages<br>- |
| Cap-and-Trade Equilibrium:       |                 |                          |                          |                               |
| C&T Surplus                      | \$2560          | \$2560                   | \$2560                   | \$2560                        |
| Efficiency Index                 | 100%            | 100%                     | 100%                     | 100%                          |
| Baseline-and-Credit Equilibrium: |                 |                          |                          |                               |
| B&C Surplus                      | \$1920          | \$5760                   | \$0                      | \$3840                        |
| Efficiency Index                 | 75%             | 225%                     | 0%                       | 150%                          |

Note: B&C is Baseline-and-Credit and C&T is Cap-and-Trade.

## 4 Results

Figures 7 to 12 provide an overview of the data.<sup>11</sup> We have three independent series in each treatment. The figures show the range and mean of observations for each period. Many series show a distinct time trend and general convergence to equilibrium values over the first half of each session. Moreover, the fact that there was no payoff to subjects' inventory of permits held at the end of the session may have induced an end-game effect in Period 20. Accordingly, we drop the first 9 periods and the last 2 periods in summarizing the results numerically and report mean values for periods 10 through 18 in Table 4. We test for treatment effects using parametric (t-tests based on robust OLS regression techniques) and non-parametric methods (Mann-

<sup>11</sup>Appendix C posted at <http://www.economics.mcmaster.ca/econ/mceel/> provides analysis of the bid and ask data from each period to investigate whether subjects fully comprehended the trading environment.

Table 4: Mean Values over Periods 10 to 18 by Treatment

|                      | Output<br>Capacity* | Output<br>Volume* | Aggregate<br>Emissions* | Permit<br>Price | Market<br>Volume | Permit<br>Inventories |
|----------------------|---------------------|-------------------|-------------------------|-----------------|------------------|-----------------------|
| Cap-and-Trade:       |                     |                   |                         |                 |                  |                       |
| Session 1            | 43.00               | 35.11             | 162.89                  | 14.89           | 22.56            | 68.89                 |
| Session 2            | 31.67               | 30.00             | 159.78                  | 18.44           | 40.33            | 36.11                 |
| Session 3            | 33.22               | 33.22             | 162.44                  | 15.72           | 35.11            | 31.89                 |
| Treatment Mean       | 35.96               | 32.78             | 161.70                  | 16.35           | 32.66            | 45.63                 |
| Prediction           | 32.00b              | 32.00b            | 160.00b                 | 16.00b          | 32.00            | 0.00cb                |
| Baseline-and-Credit: |                     |                   |                         |                 |                  |                       |
| Session 4            | 47.33               | 47.33             | 239.89                  | 17.61           | 31.11            | 81.44                 |
| Session 5            | 45.33               | 45.22             | 230.44                  | 20.44           | 24.56            | 42.67                 |
| Session 6            | 46.44               | 45.89             | 224.56                  | 20.83           | 27.33            | 39.00                 |
| Treatment Mean       | 46.37               | 46.15             | 231.63                  | 19.63           | 27.67            | 54.37                 |
| Prediction           | 48.00cb             | 48.00cb           | 240.00c                 | 16.00b          | 48.00cb          | 0.00cb                |

\* Treatment effect is significant using a t-test and a Mann-Whitney U-test at a 5% critical level.

c The cap-and-trade treatment is significantly different from the prediction using a t-test at the 5% level.

b The baseline-and-credit treatment is significantly different from the prediction using a t-test at the 5% level.

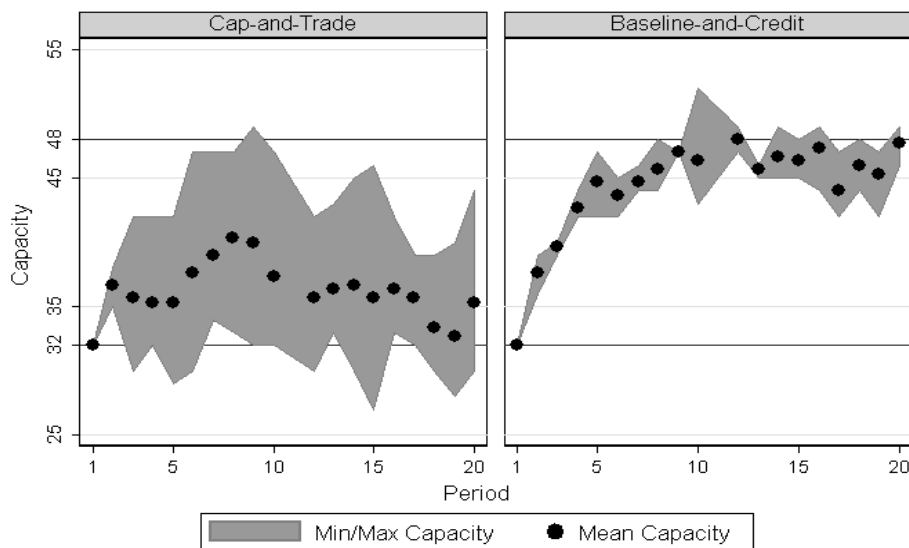


Figure 7: Capacity

Whitney U-statistics). However these tests have extremely limited power, even adopting a critical level of 10%, so they should not be taken too seriously.<sup>12</sup>

#### 4.1 Capacity, Output and Emissions

Consider first the key predictions on capacity, output and emissions. Figure 7 shows the evolution of capacity. Under baseline-and-credit trading, capacity rises steadily to reach the predicted level, and stabilizes between 45 and 48 by period 9. Under cap-and-trade, capacity is highly volatile and fluctuates between 32 and 45 throughout the entire 20 periods. The treatment

<sup>12</sup>With a critical level of 10% there is about a 45% chance of detecting a true difference in means of 1.5 standard deviations. We would need a critical level of 25% to get a 70% chance of detecting this large a difference in means (two-tailed tests, common variance).

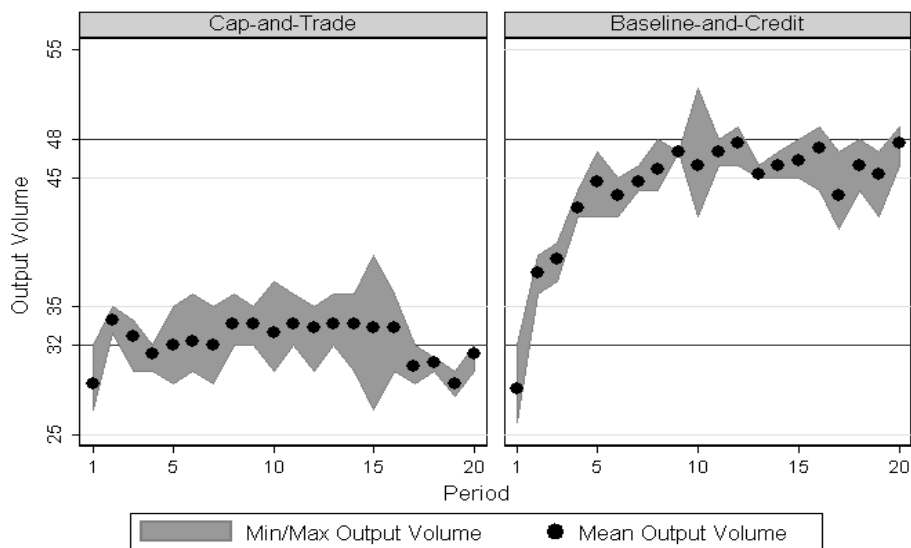


Figure 8: Output Volume

effect is strongly significant as output capacities are significantly higher under baseline-and-credit trading. Figure 8 shows a similar pattern for output, except that under cap-and-trade output exceeds the benchmark level of 32 by only a small amount and much of the volatility has diminished. This suggests pervasive underutilization of capacity under cap-and-trade due to inability to acquire permits or super-optimal emission rate choices. As we will find below, this over-capacity under cap-and-trade yields an unexpected source of inefficiency. Emissions in Figure 9 follow the same pattern as output.

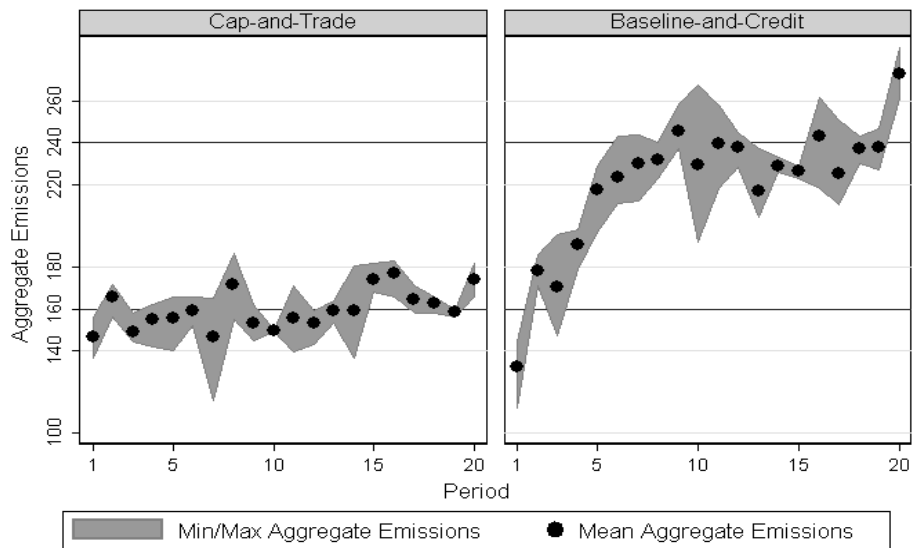


Figure 9: Aggregate Emissions

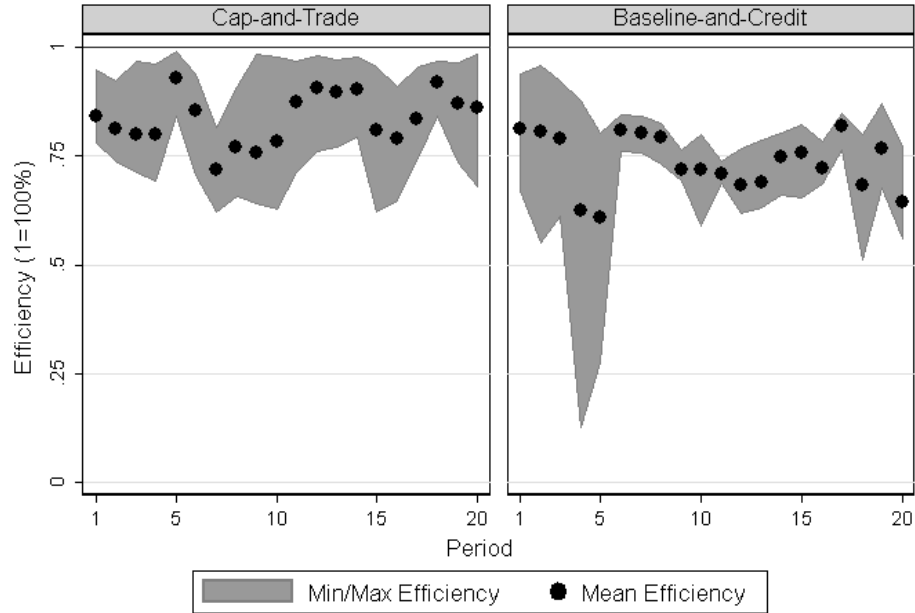


Figure 10: Efficiency

Aggregate emissions under both treatments do not deviate significantly from their own benchmark equilibria. Emissions under baseline-and-credit trading are significantly greater, in terms of magnitude and precision, than emissions under cap-and-trade regulation. In total, these observations conform well to the underlying theory.

These results imply that the efficiency losses from baseline-and-credit trading will be similar to those predicted by theory. Figure 10 reports the evolution of efficiency over the 20 periods. Table 5 reports the numerical results. Efficiency was variable across the cap-and-trade sessions but was more stable across the baseline-and-credit sessions. Two of the cap-and-trade sessions attained above 90% efficiency, while the third achieved only

Table 5: Mean Efficiency over Periods 10 to 18

|                      | Efficiency** | Components of Efficiency |                   |                        |
|----------------------|--------------|--------------------------|-------------------|------------------------|
|                      |              | Consumer Surplus*        | Producer Surplus* | Environmental Damages* |
|                      | =            | +                        | +                 | -                      |
| Cap-and-Trade:       |              |                          |                   |                        |
| Session 1            | 76%          | 121%                     | 57%               | 102%                   |
| Session 2            | 91%          | 88%                      | 102%              | 100%                   |
| Session 3            | 96%          | 108%                     | 90%               | 102%                   |
| Treatment Mean       | 88%          | 106%                     | 83%               | 101%                   |
| C&T Equilibrium      | 100%b        | 100%b                    | 100%b             | 100%b                  |
| Baseline-and-Credit: |              |                          |                   |                        |
| Session 4            | 72%          | 219%                     | 3%                | 150%                   |
| Session 5            | 74%          | 200%                     | 18%               | 144%                   |
| Session 6            | 73%          | 106%                     | 7%                | 140%                   |
| Treatment Mean       | 73%          | 209%                     | 9%                | 145%                   |
| B&C Equilibrium      | 75%b         | 225%cb                   | 0%c               | 150%c                  |

\* Treatment effect is significant using a t-test and a Mann-Whitney U-test at a 5% critical level.

\*\* Treatment effect is significant using a t-test and a Mann-Whitney U-test at a 10% critical level.

c The cap-and-trade treatment is significantly different from the prediction using a t-test at the 5% level.

b The baseline-and-credit treatment is significantly different from the prediction using a t-test at the 5% level.

76%. Mean efficiency in the three cap-and-trade sessions was just below the predicted level of 75%. Due to the variation in cap-and-trade efficiency levels, the difference in treatment means is significant at the 5% level using a Mann-Whitney U-test but only at the 10% level using a t-test. Treatment effects were significant at the 5% level for each of the three components of surplus, however. Under cap-and-trade consumer surplus, producer surplus and damage were not significantly different benchmark predictions. Under baseline-and-credit trading producer surplus and emission damages were close to the benchmarks while consumer surplus was significantly less than expected, although still higher than in the cap-and-trade treatment.

## 4.2 Credit and Allowance Markets

Figure 11 shows similar trends in permit prices across treatments over the entire 20 periods. In cap-and-trade permit prices are consistently very close to the benchmark and not significantly different from it. While the variance in prices is high in the first few periods, this quickly disappears by the fifth period. In baseline-and-credit, credit prices start just above the predicted equilibrium level of 16 and remain fairly stable at this level over the 20 periods. Although the prices in each treatment are not significantly different from each other, the fact that credit prices consistently stay 3-4 dollars above the predicted equilibrium price leads to credit prices differing significantly from the predicted level. It is interesting to note that the extremely high initial credit prices found in the partial experimental environments reported in Buckley (2004) and Buckley et al. (2005a) are not exhibited in the full long-run environment investigated here.

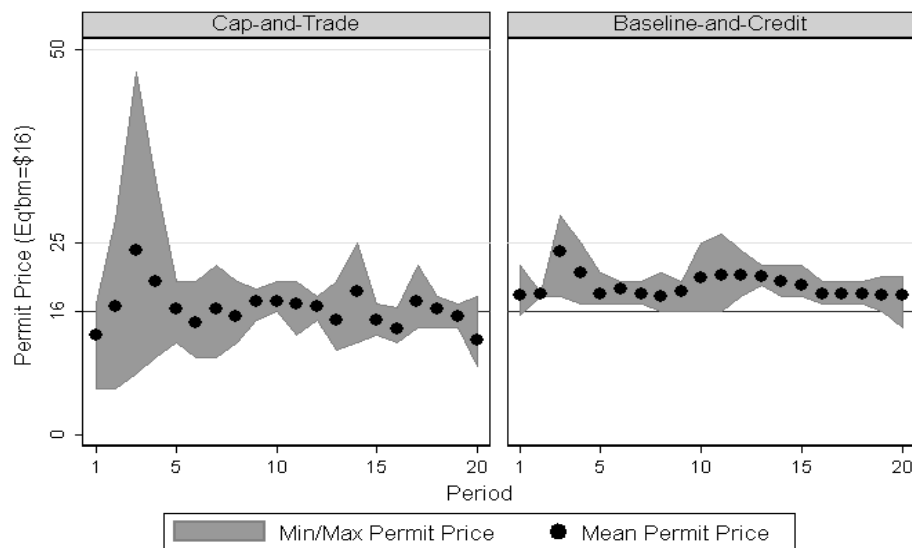


Figure 11: Permit Trading Prices

Unlike the extraordinarily high permit inventories held in the baseline-and-credit treatments reported by Buckley, Muller, and Mestelman (2005a), Figure 12 shows a build-up and general working off of permit inventories over the 20 periods under both trading plans. While Table 4 provides evidence that inventory levels are significantly above the predicted level of zero over periods 10 to 18, it also shows that inventories are not significantly different between the two trading plans.<sup>13</sup>

## 5 Discussion and Conclusions

Theory predicts higher aggregate output and emission under baseline-and-credit than under cap-and-trade when the former imposes a performance

<sup>13</sup>Positive inventories in periods 1 to 19 can be consistent with risk-averse preferences.

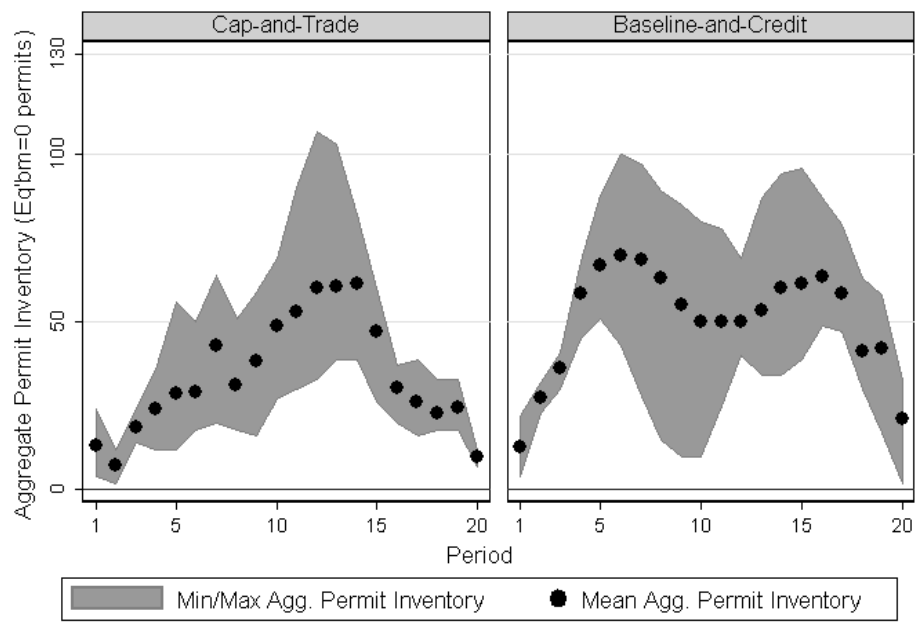


Figure 12: Aggregate Inventory

standard consistent with the cap under the latter plan. This is because a performance standard acts as a subsidy on output. Despite this prediction, baseline-and-credit emission trading systems currently being used around the globe. The question remained, however, whether the theoretical predictions regarding the two mechanisms would hold in real markets. This paper reports results on controlled laboratory sessions in an environment involving variable emission technologies and variable output capacities.

Results from the experimental sessions reported here support the theory. Using graphical and tabular data, we have confirmed that, while cap-and-trade emission and output levels stay close to their predicted equilibrium values, emissions and output soar and converge to their predicted higher levels under baseline-and-credit. Despite firms building super-optimal capacities under cap-and-trade, these capacities do not deviate enough from the optimal level to lead to significant differences in the realized cap-and-trade efficiencies from their optimal levels. However, the inefficient levels of environmental damages under baseline-and-credit are significant enough to render baseline-and-credit trading significantly less efficient than cap-and-trade emission trading.

An experimental has now been designed and tested. This paper reports sessions involving variable emission rates and capacities, building on previous experiments which held capacity or emission rate fixed. With the theoretical framework and corresponding experimental environment in place, future work can now assess the long-run properties of these alternative trading plans in more realistic environments involving firm compliance, "credit for early action" regulation and output demand volatility and growth.

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