Short-Run Implications of Cap-and-Trade versus Baseline-and-Credit 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 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 instituted in the form of an emission technology performance standard because this creates a subsidy to output that results in increased emissions. This is in opposition to the prediction that, when firm output capacity is fixed, the short-run equilibria of the two plans will be identical. As a first step towards testing the long-run model, this paper reports on a laboratory experiment designed to test the short-run prediction. A computerized environment has been created in which subjects representing firms choose emission technologies under fixed output capacity and participate in markets for emission rights and for output. Our evidence supports the theoretical prediction that the two trading mechanisms yield similar aggregate emissions, however significant differences between plan outcomes are discussed and both plans exhibit significant deviations from the predicted equilibrium.

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1 Introduction

Policy and research interest in emission trading systems have increased during the last decade and a half, even though economists have long advocated market-based environmental regulations (Dales 1968). Researchers often support incentive-based regulation over traditional command-and-control methods on the basis of its superior cost-effectiveness (Montgomery 1972; Hahn and Hester 1989). It is the potential cost savings of tradable emission schemes that has likely led to their prominence in the United States 1990 Clean Air Act Amendments and in the 1997 Kyoto Protocol.[1]

Title IV of the 1990 Clean Air Act Amendments led the Environmental Protection Agency (EPA) to enact a trading program for sulphur dioxide emissions from power plants. In addition to theoretical scrutiny, valuable incite into EPA-style trading schemes has come from economists using laboratory methods (e.g. Cason and Plott 1996; Cason 1997). The EPA's sulphur dioxide trading market is a form of *cap-and-trade* emission reduction program which, until recently, has been the predominant focus of research. There has been very little theoretical and experimental analysis on alternative forms of emission trading. This lack of research is surprising, considering that past environmental regulation in Canada (PERT 1997) and the U.S. (e.g. regulations surrounding the new source performance standards enacted in the 1970s) employed a different trading mechanism: *baseline-and-credit*.[2]

Given the cost savings ability of emission trading schemes, it is not surprising that they are currently being used around the world as part of various forms of environmental regulation. Hasselknippe (2003) presents a comprehensive overview of the myriad of systems for emission trading used by various national governments. In addition to categorizing emission trading plans as being either suspended, active, planned or proposed, the author also categorizes them as being either mandatory or voluntary and, even more importantly for our purposes, cap-and-trade or baseline-and-credit based. In his international survey of emission trading, Hasselknippe finds that credit schemes are just as prevalent as capped schemes, with 20 out of 42 national schemes using a baseline-and-credit system. Moreover, many governments, such as the Ontario Ministry of the Environment (OMOE 2003) in Canada, have recently implemented hybrid emission trading schemes using elements from both cap-and-trade and baseline-and-credit mechanisms. This paper reports on the

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[1] Article 17 of the 1997 Kyoto Protocol describes emission trading as part of an overall strategy to achieve strict greenhouse gas targets.

[2] See Tietenberg (2000, Ch. 16) and Dewees (2001) for a more detailed discussion on the historical use of these two systems in North America.

first laboratory study to compare these two policy instruments.

Under a cap-and-trade plan, an aggregate cap is placed on emissions. A corresponding quantity of emission permits, often called *allowances*, is created. Firms must surrender an allowance for every unit of emission discharged over a given period of time. Firms may sell allowances that they expect not to use, or purchase allowances to cover emissions in excess of the original distribution. Under a rate-based baseline-and-credit plan, firms are prescribed a performance standard specifying the target industry *emission rate*. An emission rate represents the emission technology level of a firm and is the amount of pollution that is emitted per unit of output. This concept is sometimes referred to as *emission intensity*.[3] Simply put, "clean" firms with emission rates below the performance standard create permits, in this context often referred to as *emission reduction credits* (ERCs). On the other hand, "dirty" firms possessing emission rates above the performance standard are required to purchase and redeem ERCs. The quantity of credits created or redeemed is calculated by multiplying *output* by the difference between a firm's emission rate and the industry performance standard. This type of baseline-and-credit plan is often called a rate-based system of "tradable performance standards". Consequently, the cap-and-trade mechanism uses an *absolute* framework, in that an allowance must be redeemed to the authorities for every unit of pollution produced, while rate-based baseline-and-credit trading uses a *relative* frame, where firms must account for only deviations from their performance standard baseline.

To be clear, by "cap-and-trade" we refer to an emission trading system in which permits are endowed by the regulator, rather than auctioned, using a grandfathering approach based on historical data.[4] These permit endowments enforce a fixed cap on emissions. We compare this typical cap-and-trade setup to a rate-based baseline-and-credit system which implements a regulated emission rate performance standard which causes the inherent emission cap to be linked to output.

Under these assumptions, theoretical considerations suggest the long-run equilibria of the two plans will differ because an ERC plan with an instituted performance standard creates a subsidy to output. Compared to an optimal cap-and-trade plan with the same average emission rate, the baseline-and-credit plan will exhibit higher output and emissions. Compared to an optimal cap-and-trade plan with the same emissions, the

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[3] Most government documents refer to this concept as *emission intensity*, likely due to the common use of the term *rate* to convey the notion of occurrences per unit of time. This paper, however, will use the term *emission rate*, as it more closely resembles the common use of the term in the Economics discipline.

[4] For a detailed discussion on auctioning permits versus grandfathering them, see Cramton and Kerr (2002) and Fischer, Parry, and Pizer (2003).

baseline-and-credit plan will exhibit a lower and more costly average emission rate. Thus, baseline-and-credit plans entail an inherent efficiency loss, even before considering costs of administration. In the short-run, when output capacity is fixed, theory predicts identical outcomes for the two schemes since the output subsidy cannot possibly lead to an expansion of output. In this paper we compare the two plans under the assumption of equal average emission rates.

By using the terms *long-run* and *short-run* we intend to differentiate a scenario in which all factors of production are variable to one in which output is fixed. Thus, the short-run could be viewed as a time frame in which a firm can quickly change pollution technology but cannot influence its capacity for producing output. One example is the ability some factories may possess to add or upgrade "end-of-pipe" pollution technology, such as adding scrubbers to industrial smokestacks, in a time frame in which output expansion is not possible. A short-run time frame is also one in which output cannot be expanded but the switch to cleaner fuel inputs is possible.

Although the short- and long-run theoretical predictions are reasonably straightforward, they rely on competitive equilibria being realized in two interrelated markets: the market for output and the market for emission permits. Although some market institutions, such as the double auction and the uniform price sealed bid/ask auction, are highly effective in achieving equilibrium in a single market, it is less evident that competitive markets can achieve efficient outcomes when firms must optimize in two or more markets. If the theoretical predictions are not to be considered a mere curiosity, it would be useful to demonstrate whether the hypothesized potential gains from trade under the two schemes will actually be achieved in real markets. Laboratory markets are ideal for this purpose. They can be designed to reflect a substantial level of institutional detail while exerting careful control over a wide range of factors which are uncontrolled in a natural setting. This is frequently called "testbedding".

Other than the theoretical analyses of Dewees (2001), Ellerman and Wing (2003) and Fischer (2001, 2003), little work, and no experimental economic evidence, has been published comparing baseline-and-credit and cap-and-trade market-based mechanisms. While this paper presents results from the first baseline-and-credit experiment, the only cap-and-trade experimental environment to involve explicitly chosen emission rates was studied by Ben-David, Brookshire, Burness, McKee, and Schmidt (1999, 2000). While Ben-David et al. (1999) uses explicit emission rate choices to investigate the effect of cost heterogeneity on market volatility, the Ben-David et al. (2000) environment involves uncertain reductions in permit endowments to study attitudes on risk and compliance. Because we are not currently interested in researching the effect of uncertainty on baseline-and credit trading, we reserve comparison of our work to the earlier Ben-David et al. paper. Due to the complexity involved in setting up an experimental environment rich enough to test for differences between these two alternative emission trading mechanisms, our research program has split up the investigation into first testing the theoretical prediction in a short-run setting and later testing it in a more complicated long-run setting.

This paper reports progress on a laboratory experiment designed to testbed basic forms of cap-and-trade and baseline-and-credit methods of emission trading and to test whether the predicted short-run identical emission levels will actually be realized. This is a necessary step in order to properly attribute, in future work, any differences in long-run emission levels between the two mechanisms to the different underlying incentives instead of to the frames themselves. The paper is organized as follows. First, we present the theoretical framework. Secondly, we describe the experimental design we have implemented. We then describe the laboratory decision making sequence and discuss the predictions of the model. Subsequently, we report the experimental results and, lastly, we discuss and conclude our work.

2 Theoretical Framework

In this section we motivate the experiment by demonstrating that long-run equilibrium emissions and output are optimal under a cap-and-trade plan and are higher than optimal under a baseline-and-credit plan with the same industry-average emission rate. We also establish that emissions and output are identical for the two plans in the short-run. The theoretical model presented below is a multi-firm partial equilibrium model based on the representative agent model used by Fischer (2001, 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 $i \in [1, ..., N]$ 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 $MAC = -\frac{\partial C_i}{\partial e_i} = -c_i'(r_i)$.

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

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

The first order conditions for an interior maximum are

$$-c_i'(r_i{}^*) = D'(\sum_{i=1}^{N} r_i{}^* q_i{}^*) \quad \forall i \in N \tag{2}$$

and

$$P(Q^*) = c_i(r_i{}^*) + w_i + r_i{}^* D'(\sum_{i=1}^{N} r_i{}^* q_i{}^*) \quad \forall i \in N \tag{3}$$

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 (2) 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 (3) ensures that output is surplus maximizing because each firm's marginal social cost equals marginal willingness-to-pay. Note that, although condition (2) determines a unique emission rate for each firm, condition (3) 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.

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

$$\max_{\{r_i,q_i\}} {\pi_i}^c = P(Q)q_i - c_i(r_i)q_i - w_i q_i - P_c(r_i q_i - A_i). \tag{4}$$

The two first order conditions for an interior maximum are

$$-c_i'({r_i}^c) = P_c \tag{5}$$

if q_i is greater than zero, and

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

Equation (5) ensures cost minimizing abatement and defines each ${r_i}^c$. Equation (6) requires that each firm earn zero marginal profit, and identifies Q^c. The system (5) and (6) can be obtained from the optimal conditions (2) and (3) 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

$$\max_{\{r_i,q_i\}} {\pi_i}^b = P(Q)q_i - c_i(r_i)q_i - w_i q_i - P_b q_i(r_i - r^s). \tag{7}$$

The first order conditions for an interior maximum are

$$-c_i'({r_i}^b) = P_b \tag{8}$$

if q_i is greater than zero, and

$$P(Q^b) = c_i({r_i}^b) + w_i + {r_i}^b P_b - r^s P_b. \tag{9}$$

Equation (8) is the usual efficient abatement condition which defines each ${r_i}^b$. Equation (9) 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, $r^s = (\sum_{i=1}^{N} {r_i}^* {q_i}^*)/Q^*$.[5] If the emission standard is binding and net demand for credits in equilibrium equals zero, then

$$\sum_{i=1}^{N} {r_i}^b {q_i}^b = \sum_{i=1}^{N} r^s {q_i}^b. \tag{10}$$

Substituting for r^s we can calculate that

$$\sum_{i=1}^{N} {r_i}^b \frac{{q_i}^b}{Q^b} = \sum_{i=1}^{N} {r_i}^* \frac{{q_i}^*}{Q^*}. \tag{11}$$

Equation (11) 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 (2) also satisfies the corresponding baseline-and-credit equilibrium condition (8).

The baseline-and-credit zero marginal profit condition (9) is similar to optimal equation (3) 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 (9) is equal to the right hand side of (3), 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.

Note from (7) 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. The welfare implications of variable emissions are discussed ably by Weitzman (1974) in the context of quantity instruments (cap-and-trade) versus price instruments (baseline-and-credit).

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[5] 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 this would require a stricter performance standard and resulting firm costs would be inefficiently high. Since both methods yield inefficiencies, we choose to focus on the comparison between cap-and-trade and a baseline-and-credit system associated with a performance standard equal to the average emission rate from the optimal scenario.

Thus, in a long-run scenario where firms can choose emission rates and change their output capacity, the baseline-and-credit scheme will produce higher emissions and output compared to a cap-and-trade scheme with the same average emission rate. In a short-run scenario, where firms can change their emission rates but cannot change their capacity for producing output, only the emission rate first order conditions define the equilibria. According to equations (2), (5) and (8), the price of permits and each firm's marginal abatement cost equaling the optimal marginal damage is a short-run equilibrium under both schemes ($P_c = P_b = D'(E^*)$). If output is fixed at its optimal level ($Q = Q^*$), the subsidy to output inherent to the baseline-and-credit plan has no effect other than increasing marginal profits. Therefore, in the short-run when output is fixed at the optimal level, cap-and-trade and baseline-and-credit emission trading mechanisms will produce identical results: optimal levels of emissions and output. The predictions of our short-run model discussed above are consolidated in the following propositions.

In the short-run, when firm output capacities are fixed at their optimal levels. . .

Proposition 1 *the cap-and-trade competitive equilibrium outcome is identical to the baseline-and-credit competitive equilibrium outcome. Therefore, aggregate emissions are identical under both plans.*

Proposition 2 *the cap-and-trade and baseline-and-credit competitive equilibria are identical to the socially optimal equilibrium.*

3 Experimental Design

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 et al. (1999) and Muller, Mestelman, Spraggon, and Godby (2002). To date, there has been no work published on baseline-and-credit experiments. Of the cap-and-trade experiments cited above, the Ben-David et al. (1999) environment is most relevant to this work as it is the only cap-and-trade experiment to involve an explicitly chosen emission technology.

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 traded emission permits; their permit holdings at the end of each period (divided by their exogenous output) implicitly determined their firm's emission rate. In these environments, the difference between choosing a sub-optimal emission rate and an error made while trading permits could 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. The 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.[6]

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 and the introduction of output capacity. A fully 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 short- and 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.

To test our propositions regarding cap-and-trade and baseline-and-credit emission trading schemes in a controlled short-run laboratory setting, we require only a very basic experimental design. Given that this paper is part of a larger research agenda using the same basic framework, we chose to run 3 experimental sessions involving cap-and-trade regulation and 3 experimental sessions involving baseline-and-credit regulation. Each of these 6 sessions involves 8 subjects and was run between March and April 2004. All 48 recruited subjects were McMaster University undergraduates who had passed a standard

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[6] 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.

first year Economics course. Due to the relatively complicated experimental setting, subjects were paid a flat rate to undergo training in an environment similar to the one in which they were to participate.[7] The training consisted of instructions being read aloud, a basic questionnaire to ascertain participant understanding, and a 4 period practice experiment with a unique parameterization. Afterward, subjects participated in the ten period experiment reported in this paper. Sessions lasted between 2 and 3 hours including a break. Experiment earnings were based on each firm's cash holdings at the end of the experiment. Subjects earned between \$10 and \$81.75 with a mean of \$42.69, including the training fee of \$10.

The software implementation of the laboratory environment was programmed at McMaster University using Borland's Delphi programming environment and the MySQL open source database. All sessions were run at the McMaster University Experimental Economics Laboratory. The fully specified environment contains an emission permit market, an output market and an explicit emission technology choice. The program also allows for an output capacity choice, which is not used for the short-run experiments presented in this paper. Screen shots of the software are provided in Appendix A.

Unlike most experiments, the software for this project is framed using terminology from the pollution abatement context. Preliminary pilot sessions with human subjects were discovered to be hampered by instructions and software which framed the experiment in neutral terms. A neutral framing was rejected so as not to complicate an already complex trading environment. With a complicated environment, experimenters stand the chance of losing control if subjects are forced to create their own, possibly faulty, context for understanding the underlying economic incentives. Framing the experiment in context not only allows for more control over subjects' interpretation across treatments, but allows for an environment in which the operation of alternative emission trading plans could be demonstrated to students and policy makers. Experimental instructions are provided in Appendix B.

During the experiment, we presented a short-run frame in which each subject is told that he or she represents a firm producing output at a constant cost up to a fixed capacity level of 4 ($k = 4$). The variable cost of production, w_i, is set to zero.

We employed a design using eight firms per session. Two firms have one of four different marginal abatement cost schedules, from A to D. The type D "dirty" firms have the steepest MAC curves, the type A "cleanest" have the flattest. Subjects were presented with MAC curves represented by step functions. These functions are broken down into

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[7] This flat rate allows subjects to test different strategies without affecting their remuneration.

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 by Buckley, Muller, and Mestelman (2003) 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. The general form used for the unit capacity cost function is,

$$c_i(r_i) = u_0 + (u_1 - u_0)[(r_{max} - r_i)/r_{max}]^{\alpha_i}, \tag{12}$$

with r_{max} 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. $c_i(r_i = j) - c_i(r_i = j+1) \quad \forall j \in [0, 8]$). A graphical illustration and discussion of each firm type's MAC curve is provided in the discussion below on the laboratory decision making sequence.

Under cap-and-trade regulation, subjects receive an allotment of 20 allowance permits at the beginning of each period. Under baseline-and-credit regulation, subjects are assigned a common emission rate performance standard of $r^s = 5$. This is the average overall emission rate in the cap-and-trade treatment equilibrium.[8] 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 1 presents firm-specific parameters used in the short-run sessions reported in this paper. Table 2 summarizes the associated short-run equilibrium predictions under the alternative emission trading mechanisms.

4 Decision Making Sequence

The laboratory environment created for this project transforms the simultaneous decision framework presented in Section 2 into a sequential decision making process. The first action to be taken in a period involves allowances and credits to be traded in a call

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[8] Since the average emission rate under cap-and-trade is equal to 5 and output capacity is equal to 4, firms generate 20 units of pollution on average in equilibrium, using up the total endowment of permits. Under baseline-and-credit, the performance standard of an emission rate of 5 enforces that the average emission rate per firm is also 5. However, in this case without endowments, some firms create supplies of permits by choosing low emission rates and later sell them to other firms with emission rates above the performance standard.

Table 1: Short-Run Cost Parameters

Firm Type	u1	u0	α	w_i	Optimal Emission Rate	C&T Endowment Each Period	B&C Performance Standard	B&C Initial Credits
A-cleanest	172	88	3	0	2	20	5	12
B-clean	249	64	3	0	4	20	5	4
C-dirty	375	52	3	0	6	20	5	0
D-dirtiest	1852	29	3	0	8	20	5	0

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

Table 2: Short-Run Predictions

Trading Institution	Price of Allowances or Credits	Output Price	Aggregate Output	Aggregate Emissions	Active Firm Types
B&C	16	160	32	160	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.

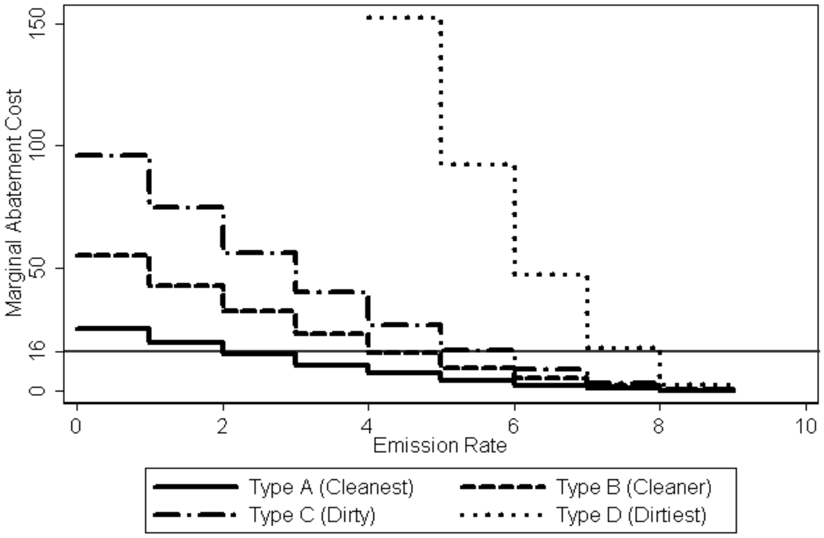

Figure 1: Marginal Abatement Cost Curves

market. This occurs immediately following the endowment of allowances upon firms under cap-and-trade regulation. The permit call market is held as a uniform price sealed bid-ask auction in which submitted bids and asks are ordered in descending and ascending order, respectively. A market clearing price is then determined and all successful orders are traded at the market clearing price. Production of output generates emissions at a rate of r emission-units per unit of output q. Knowing that output is constrained by capacity and permit holdings, each firm, once the permit market is cleared, can choose its own emission rate ranging from zero to nine. The ten possible choices give an acceptable approximation to a continuous variable. Figure 1 presents the 4 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. Because the computer software only allows emission rates to be integer values, the effective marginal abatment cost curves are step graphs. Total fixed cost, $c(r)k$, depends on the emission rate chosen.

Given that the demand for output is assumed to be exogenous to the participating firms, the output market offers a relatively simple strategic environment compared to the permit market. To keep the environment simple, we impose a straightforward output pricing rule in which minimal asks are entered in the output market on behalf of all firms. Effectively, this forces firms to sell the maximum amount of output possible, constrained by capacity and permit holdings, at the market-bearing price. At the end of each period, allowances are redeemed and credits are created/redeemed by the governing authority. Any permits held over at the end of the period are automatically banked until the proceeding period. The number of credits created or redeemed under an ERC plan cannot be computed until all decisions have been made for the current period due to the fact that the quantity depends on a firm's emission rate choice and the amount of output produced and sold. This creates a lag in sellers' inventories of permits under baseline-and-credit that does not exist under cap-and-trade.[9] Financial results for each trading period are reported in a conventional double-entry accounting framework allowing for realistic accounting statements not often found in controlled laboratory settings. The sequence of events detailed above is summarized in the flow chart in Figure 2.

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.[10] As discussed by

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[9] The inherent lag in credit creation mimics an important characteristic of many real world baseline-and-credit style emission trading systems. In systems such as the OMOE (2003) ERC plan, credits are not created until they have actually been realized and regulator verified on a project-by-project basis.

[10] The uniform price auction is very similar to the one used by the New York Stock Exchange to set

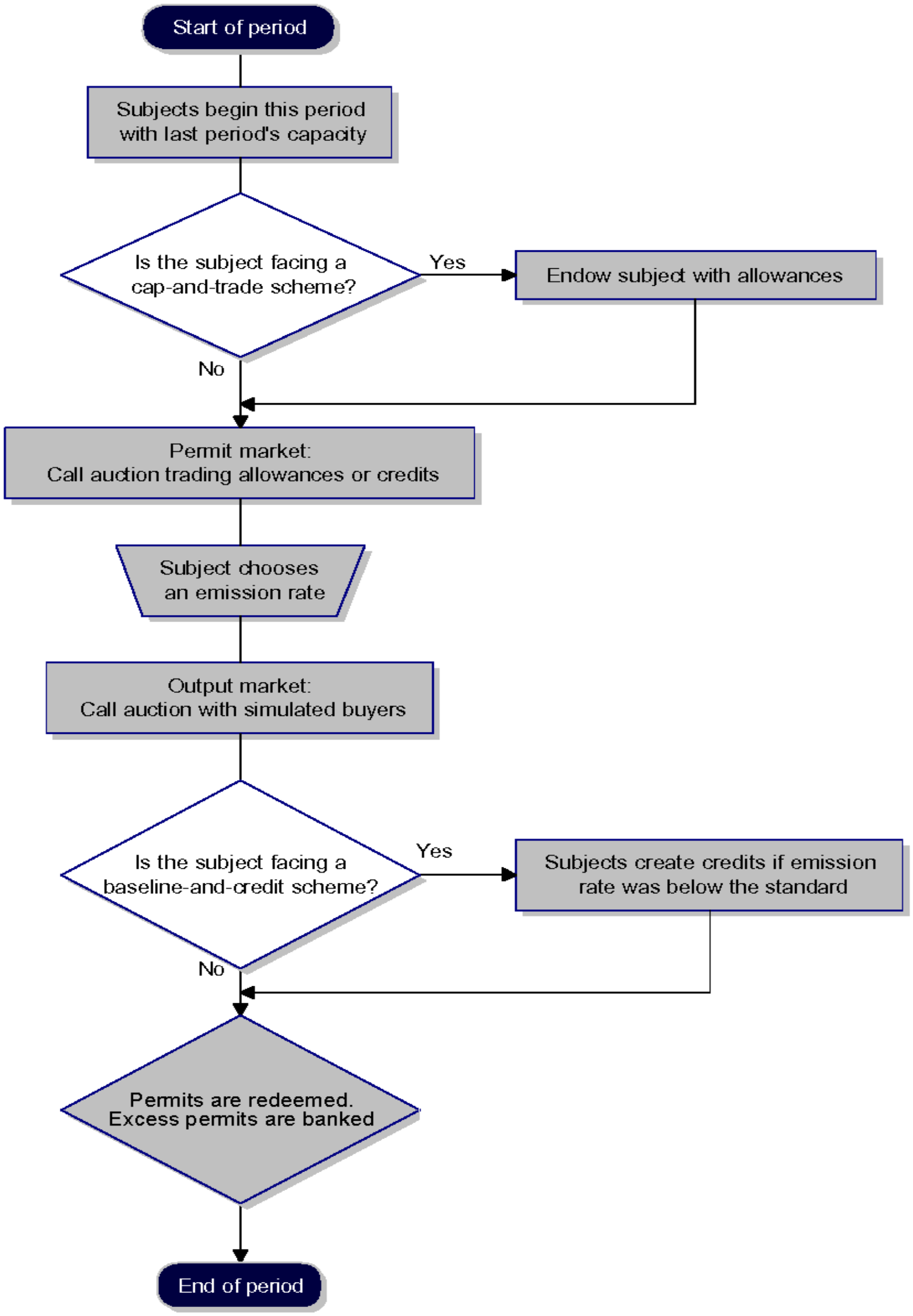

Figure 2: Sequence of Events in a Typical Period

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.

The lag inherent to the baseline-and-credit mechanism in this framework reveals a major operational difference between cap-and-trade and baseline-and-credit systems. Only permits currently held in inventory can be sold in a given period, creating a "production-to-demand" setting under cap-and-trade and an "advance production" setting under baseline-and-credit. By choosing lower emission rates, cap-and-trade firms can effectively increase their supply of permits for sale in the current period. This increase in supply can be valued at the marginal abatement cost of having to lower their emission rate in the first place. In "production-to-demand" fashion, a firm can ask its marginal abatement cost for its supply of permits and subsequently choose an emission rate consistent with the amount sold. On the other hand, the permit market for ERCs is akin to an advance production model because a firm that decreases its emission rate below the performance standard in the current period will not increase the amount of permits it can sell until the next period, at which point the cost of creating the permit supply is technically sunk. It remains to be seen whether this lag will create behavioural differences in the laboratory, even though the theoretical equilibrium discussed above is not affected. Evidence from experimental advance production markets points to advance production inventory being priced close to marginal cost. Mestelman and Welland (1991) find minor support for lower prices under advanced production markets than under production-to-demand markets in an environment with costless inventory carryover which is similar to our own.[11] However, the authors conclude that the two production models generate similar price distributions and prices under production to demand are significantly higher than the price of zero suggested by the sunk cost theory.

Simulations reported by Buckley et al. (2003) provide evidence that this lag will create permit market volatility at the start of each experiment if firms are not initially given credits to sell in the first period. To eliminate this fabricated disturbance, it was decided that baseline-and-credit firms with equilibrium emission rates below the performance standard would start the first period of the experiment with the number of credits that they produce in equilibrium. Initial credit inventories are presented in Table 1.

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daily opening prices based on bid and ask offers submitted prior to the market opening.

[11] The authors' work investigates both double auction and posted offer market trading institutions.

5 Experimental Predictions

Because the trading mechanisms, one absolute and one relative, will be tested under identical firm and environment specifications, theory predicts no difference in outcomes when capacity is fixed and emission rates are variable. However, there are reasons to raise doubts around this prediction in the laboratory market. Below is a discussion of four reasons why cap-and-trade and baseline-and-credit outcomes may differ in the short-run. One must keep in mind that inefficiency in this environment is a dynamic phenomenon. A choice made by one firm will impact the optimal action that all other firms should take in the following decision period. The beauty of incentive-based market solutions to emissions control is that the market price for permits provides information to guide future decisions.

The first reason why the mechanisms may produce short-run discrepancies is that the relative permit trading framework of baseline-and-credit could easily be perceived as more complex than the absolute frame of the cap-and-trade mechanism. Previous experimental work in the area of research and development externalities has demonstrated significant behavioural differences caused by subsidies that are framed in an "absolute" fashion when compared to those framed in a "relative" manner (Buckley, Mestelman, and Shehata 2003). On the other hand, the relative framing of baseline-and-credit regulation might inadvertently lend more stability to firms that make errors. For example, if a baseline-and-credit firm mistakenly sells all of its permits, this does not preclude the firm from choosing a relatively high emission rate equal to the performance standard to sell output. A cap-and-trade firm with no permits, however, cannot sell any output unless it chooses a costly emission rate of zero.

Secondly, the relative framing implies that firms hold fewer permits in a baseline-and-credit plan. Fewer permits in baseline-and-credit trading markets could have important repercussions for out-of-equilibrium behaviour. The relative framing may cause more instability under baseline-and-credit as less permits make for thinner markets. When the same absolute number of permits is accidentally traded or not traded, the emission trading institutions may be affected differently. In addition, the reduced stock of permits may lead to market power for low abatement cost firms which supply most of the permits in this thin market.

An additional reason why one might expect a difference between the two schemes hinges on the fact that the total supply of permits is fixed under cap-and-trade but not under baseline-and-credit. In a cap-and-trade scheme, out-of-equilibrium behaviour might temporarily decrease aggregate emissions but, eventually, they can increase to compensate due to the regulating authority distributing a fixed number of permits which can be carried in inventory from period to period. However, in a baseline-and-credit plan, the supply of permits is linked to output and each firm's chosen emission rate. If errors are made in choosing an appropriate emission rate, potential credit supplies, and thus emissions and output, could be lost forever. Therefore, in the short-run when output capacity is fixed at its optimal value, lifetime credit supplies might be affected due to the possibility for potential credits to never be realized in the first place. It is assumed that the optimal number of permits is distributed under an appropriate cap-and-trade plan, implying that any decrease in the variable permits supply under the comparable baseline-and-credit mechanism will result in inefficiency.

Lastly, the lag in baseline-and-credit permit creation could cause the supply of permits to lag behind demand in out-of-equilibrium play, creating a timing difference between the two institutions. For instance, if a cap-and-trade firm intends to choose a very low emission rate in the current period, this will allow it to sell more of its permits this period. Under baseline-and-credit, however, the firm would have to wait until the following period to sell those permits. While this feature may be specific to our baseline-and-credit scheme implementation, it mirrors characteristics of many real world credit systems. This is a requirement in our sequential decision making environment (that does not contain any "forward" permit markets) since the quantity of emission reduction credits created cannot be computed until after the credit market has cleared, an emission rate is chosen and output quantity for the period has been determined.

6 Experimental Results

Although the primary objective of this paper is to compare basic cap-and-trade emission trading with baseline-and-credit trading, whether behaviour under either system falls within acceptable bounds of the predicted equilibrium is also of importance. Accordingly, the analysis of experimental results that follows focuses on mean per session values of the chief market indicators: permit trading price and volume, output trading price and volume, aggregate emissions, permit inventory and overall efficiency.

6.1 A First Look

A natural question to ask when running an experiment involving an environment as complicated as the one in this work is whether the subjects understood the underlying incentives. In this short-run environment where subjects participated in a permit market and chose an emission rate based on the results of the permit market every period, examining the permit market behaviour will provide a good indication of subject behaviour. An obvious benchmark to compare the bid-ask behaviour of subjects in this experiment is the behaviour from a similar uniform price auction presented by Cason and Plott (1996).

The uniform price auctions investigated by Cason and Plott (1996) occur in a solitary auction setting less complicated than the fully specified environment presented here. The Cason and Plott environment is a static repeated game with fixed cost and redemption values, not one where past permit market and emission rate decisions made by all subjects affect the underlying permit market values possessed by each subject during the current period. In addition, the subjects in the Cason and Plott study are in fixed roles as either buyers or sellers, while the environment presented in this paper involves traders that will have incentives to buy and sell, at different prices, depending on current permit inventory. The Cason and Plott auctions are applicable, however, since they involve 4 buyers and 4 sellers, identical to the equilibrium values in our 8 subject environment. While the buyers and sellers in Cason and Plott (1996) implicitly had a fixed output equal to 1 and an implicitly defined emission rate with 5 possible values, the environment presented in this work imposes a fixed output equal to 4 with an explicit emission rate choice between 10 possible values.

In the Cason and Plott (1996) static uniform price auction sessions, subjects tend to reveal their true costs and values, especially for units near the margin that decide price. Figure 3 presents results of our experiment that are similar to those presented by Cason and Plott, graphing actual bids and asks against the underlying incentives for periods 2 and 9 for each of the 6 short-run sessions. In each graph in Figure 3, light grey circles denote actual asks, dark grey squares denote actual bids and the thin lines illustrate the underlying incentives. One must remember that, as previously discussed, there is an incentive for subjects to misrepresent their true values in a multi-unit uniform price bid-ask auction, although traders of infra-marginal units near the margin that determines price are expected to fully reveal underlying values. Looking at the six session graphs in Figure 3, one can ascertain that subject behaviour appears very rational: bids and asks, especially those close to the price margin, tend to reveal the true underlying values, and this disclosure becomes more accurate over time. It appears as if subjects facing baseline-

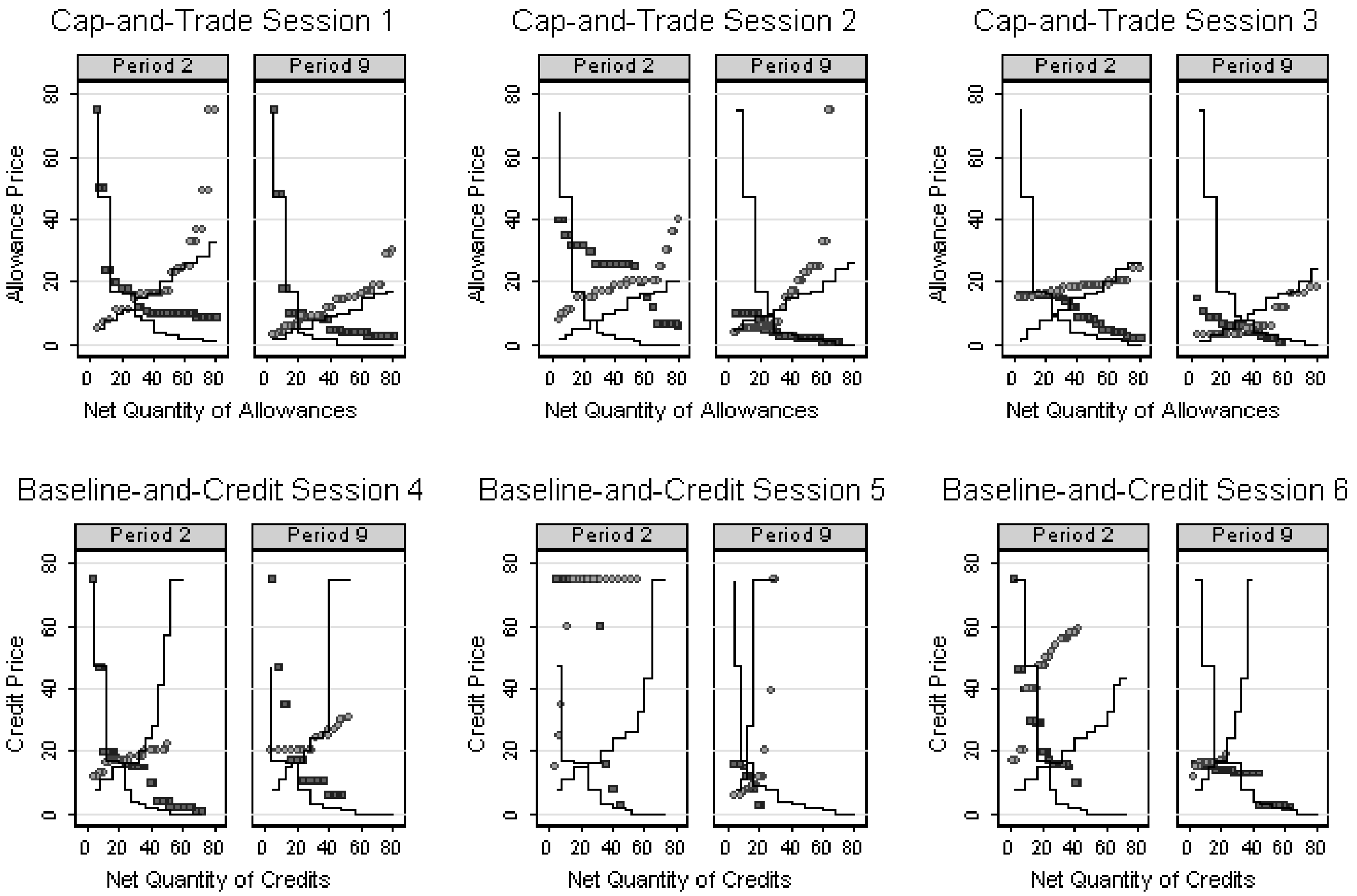

Figure 3: Actual Bids and Asks for Permits by Session

and-credit make larger bid-ask pricing errors at the beginning of the experiment than subjects facing cap-and-trade. Comparing the period 2 to period 9 results for both plans, this difference disappears over time. It is remarkable how similar the results illustrated in Figure 3 are to those found in the simpler Cason and Plott environment. We acknowledge this as evidence that the subjects in our short-run experiment were not overwhelmed by the complex environment and were acting in accordance to the underlying incentives.

6.2 Permit Market, Output Market and Aggregate Emissions

The overall data analysis strategy adopted for this work and presented in this section was decided before running any sessions. Because of the dynamic nature of the experiment whereby subjects' decisions in one period can directly affect the optimal decision a subject should take in the next period, each experimental session only provides one truly independent observation. This implies that, with the six session design used, we can only compute our statistical tests using six independent observations. Due to data convergence typically found in laboratory experiments with multiple periods, it was decided that, while figures

Table 3: Mean Values over Periods 6 to 9 by Treatment

	Permit Market		Output	Aggregate	Permit
	Price**	Volume**	Volume*	Emissions	Inventories
Cap-and-Trade:					
Session 1	11.75	29.00	29.00	155.25	56.00
Session 2	6.88	20.50	30.25	178.00	60.25
Session 3	6.63	23.25	29.50	179.75	60.75
Treatment Mean	8.42	24.25	29.58	171.00	59.00
Baseline-and-Credit:					
Session 4	22.00	18.75	32.00	161.00	34.00
Session 5	14.75	14.00	30.00	177.75	59.00
Session 6	20.00	18.50	32.00	176.00	51.00
Treatment Mean	18.92	17.08	31.33	171.58	48.00
Prediction:	16.00c	32.00cb	32.00c	160.00	0.00cb

* Treatment effect is significant using a t-test at a 10% 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.

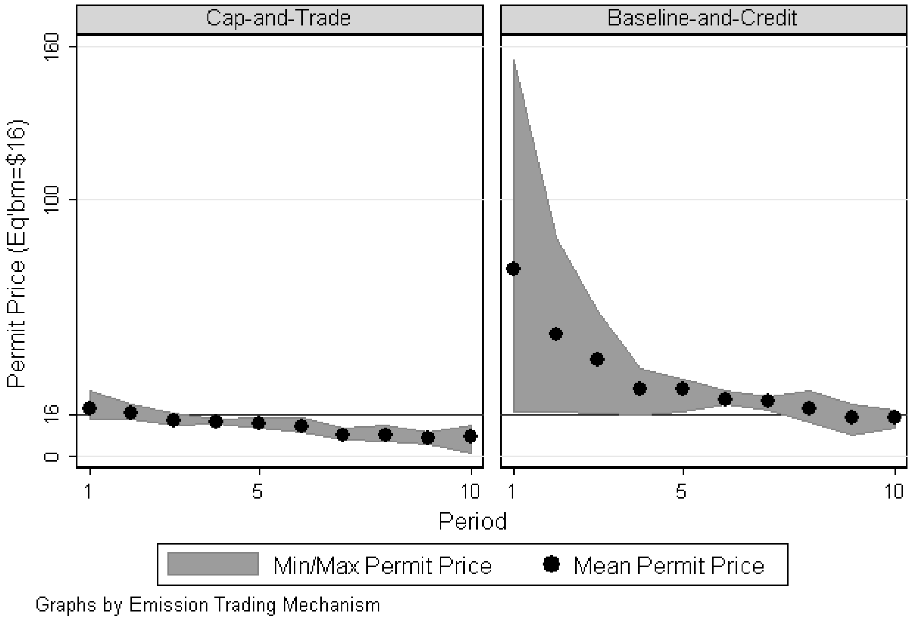

Figure 4: Permit Trading Prices

would be provided illustrating summary results from periods 1 to 10, all statistical tests would be based on the mean market indicators over periods 6 to 9 only. This will account for any learning effects or decision errors made in the initial periods of the experiment.[12]

Predicted equilibrium values of the main market indicators, based on the theoretical model presented in Section 2, are provided with the experimentally observed values in Table 3. The results from significance testing using t-tests on the six cap-and-trade and baseline-and-credit independent observations are also provided in Table 3. A non-parametric Mann-Whitney U-test was conducted in parallel with each parametric t-test. Due to small sample sizes involved in testing, the exact distribution function of "U" was used (Mendenhall, Reinmuth, and Beaver 1993). Our strategy is for each hypothesis to be tested using the above parametric and nonparametric methods at the 5% and 10% level.

Figure 4 illustrates the minimum, maximum and mean session permit price under each emission trading mechanism. This indicates that the observation at the top edge of

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[12] Period ten is dropped from all analyses due to an end game effect introduced by the experimental environment. Subject payoffs were calculated using firm cash holdings at the end of the experiment. It was decided that subjects' payoffs would not be influenced by permit inventory held at the end of the experiment, as differences between any imposed conversion value and the cost of creating or buying the permits in the first place may ambiguously influence subject strategies earlier in the session.

the shaded range represents the session with the highest permit price in each period, the observation at the bottom edge of the shaded range represents the session with the lowest permit price in each period and the third and final session's permit price will determine where the mean permit price 'bullet' is placed within the shaded range. According to Table 3 and Figure 4, the observed trading price for permits appears to be higher under baseline-and-credit than with cap-and-trade. A t-test comparing the 6 independent mean trading price observations under the two schemes rejects the null hypothesis of the means being equal across emission trading treatments at the 10% level. This result appears to be consistent over the length of the experiment.

In summary, the mean cap-and-trade permit price was \$8.42 and the mean baseline-and-credit permit price was \$18.92 over periods 6 to 9. The graphical and tabular data show that, while initial credit prices are quite high, only the cap-and-trade prices are found to be significantly different from the equilibrium prediction of \$16 at the 5% level using a t-test on the period 6 to 9 data. This large early deviation from equilibrium prices under baseline-and-credit is consistent with our earlier proposition that the more complicated framing of the credit scheme might lead to greater deviations from equilibrium. The cap-and-trade permit price converging to levels below the equilibrium prediction is an unexpected result. Unto itself, a deviation in permit trading price from its equilibrium value does not necessarily breed inefficiency, as it could simply result in a redistribution of wealth if firms still choose appropriate emission rates and trade the proper number of permits.

Figure 5 illustrates frequent shortfalls in permit trading volumes from equilibrium predictions. Evidence from Table 3 supports the notion that both permit trading programs result in permit trading volumes that are significantly below the predicted equilibrium level. The per period graphical analysis demonstrates average trading volumes of approximately 24 units for the capped scheme and under 20 units for the credit scheme, volumes that are significantly below their prediction of 32 units. A formal test on all mean session trading volumes proves that the deviation from the equilibrium is significant for both schemes, using a t-test at a 5% level. Evidence regarding a possible treatment effect is less clear. Although the volumes in Figure 5 appear to be similar across treatments, Table 3 shows the three mean session volumes to be significantly higher under cap-and-trade than baseline-and-credit. Setting the question of a treatment effect aside, the significantly lower trading volumes indicate that not all gains from trade are being realized and must cause, or be caused by, inefficiently chosen emission rates or output levels. Low trading volumes and higher trading prices of credits over allowances could be caused by the thin

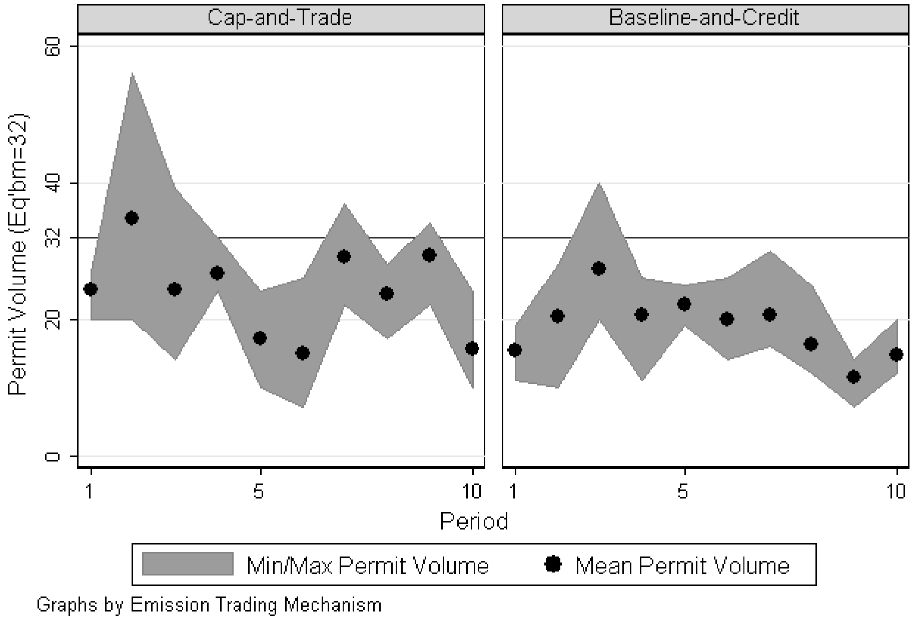

Figure 5: Permit Trading Volumes

market for credits created by the nature of the relative framing of the baseline-and-credit trading institution, as discussed in Section 5.

Given that, in this environment, the demand side of the output market is represented by an exogenous demand curve, output price and volume will be perfectly correlated as per the formula $P(Q) = 320 - 5Q$. Due to the straight line demand function that was implemented for output, one need only focus on output trading volume to investigate the output market as a whole. One must remember that the experimental environment is a short-run setting in which each of the 8 firms can only produce and sell a maximum capacity of 4 units of output. Figure 6 confirms the results from the statistical tests reported in Table 3. Only the cap-and-trade treatment displays significantly different (lower) output volumes from the equilibrium prediction (according to a t-test at the 5% level) but support for a treatment effect is weak. While the trading plan treatment effect is significant at the 10% level using a parametric t-test, the output volumes under the two plans are not significantly different at the 10% level using a non-parametric Mann-Whitney U-test. This result is consistent with the prediction that, if firms commit permit trading errors, firms under baseline-and-credit are able to choose emission rates at or below the performance standard of five in order for the errors to not affect output; baseline-and-credit firms can ensure that they will not be required to deliver any permits

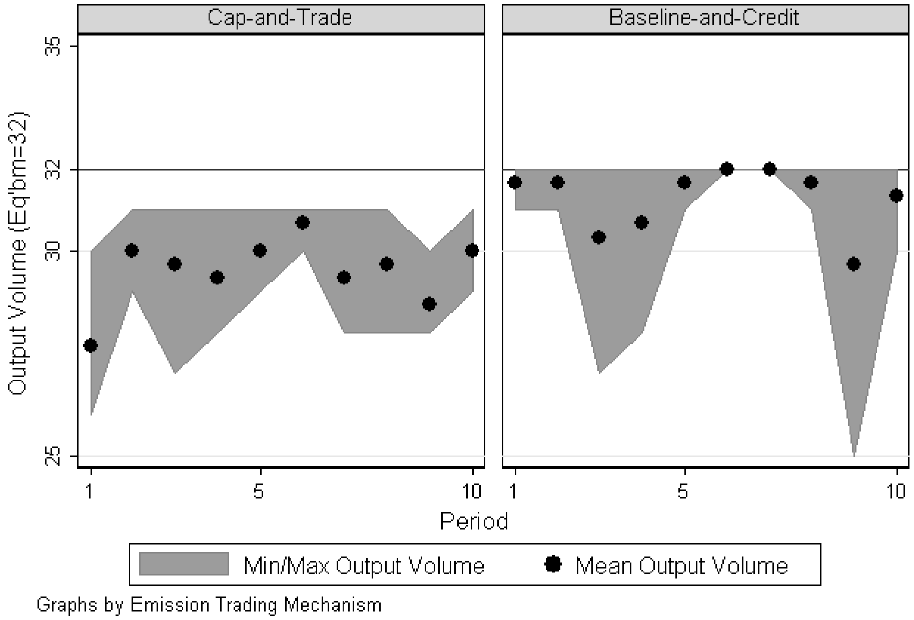

Figure 6: Output Volume

to the regulator by choosing emission rates at or below the performance standard. Cap-and-trade regulation requires that all firms with emission rates above zero must deliver a positive quantity of permits. This regulation difference allows firms that made permit trading errors to produce output at full capacity with lower cost consequences under a baseline-and-credit system compared to a cap-and-trade plan. This output shortfall in the cap-and-trade case implies significant profit and consumer surplus loss that will emerge in our calculation of overall efficiency. Obviously, if baseline-and-credit firms tend to make more permit trading errors, they might experience a greater efficiency loss than firms in the cap-and-trade case.

The above evidence yields weak support that the two emission trading mechanisms are different. Since the difference is most pronounced over the initial periods of each session, this is most likely a consequence of the more complicated relative framework of the baseline-and-credit institution. However, the evidence regarding aggregate emissions demonstrates strong support for the theory. Figure 7 highlights an almost identical upward trend of aggregate emissions under cap-and-trade and baseline-and-credit trading. Table 3 cites mean cap-and-trade emission levels at 171 over periods 6 to 9 and comparable baseline-and-credit emission levels at 172 over the same time period. The mean aggregate per period emission levels under cap-and-trade and baseline-and-credit are not

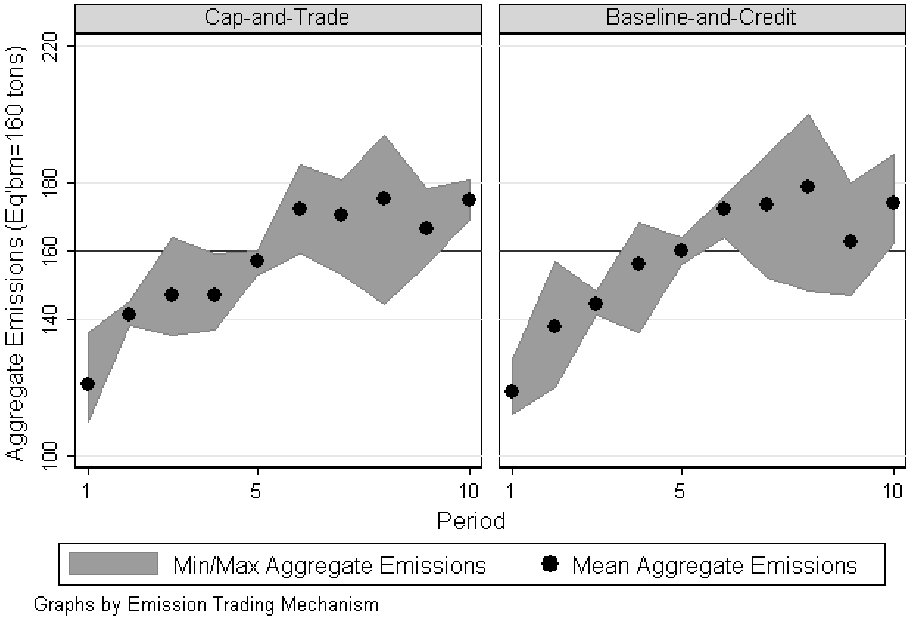

Figure 7: Aggregate Emissions

significantly different from each other (t-test and Mann-Whitney test at the 10% level) or from the equilibrium prediction of 160 (t-test at a 5% level). As stated in Propositions 1 and 2, there is no difference in short-run aggregate emission levels in industries under cap-and-trade or baseline-and-credit regulation, nor are they different from the optimal levels.

One might note that, although not statistically different from 160, Figure 7 illustrates that during the first half of the experiment, emission rates are far below 160 and, over the second half, are above 160. The only explanation for this trend is that permits are being banked in the first half of the experiment and carried in inventory to be later redeemed to contribute towards producing emissions and output. Is the initial under-polluting and inventory build-up due to inexperience or strategy/preferences (e.g. risk aversion)? To help shed light on the issue, we shall examine permit inventories period by period. Figure 8 displays the aggregate inventory held at the end of each period. The diagram shows how inventories are built up over the first half of the experiment, only to be expended in the second half. Table 3 provides statistical support that there is no significant difference in these inventories under the two mechanisms, but that in both cases inventories are significantly above the predicted rate of zero.

The definition of inventory used when comparing cap-and-trade and baseline-and-

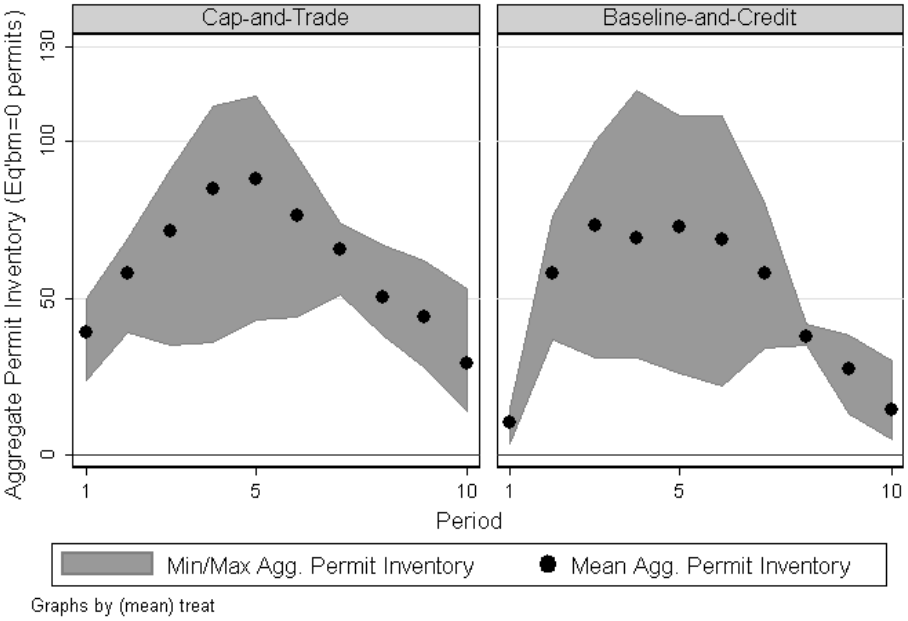

Figure 8: Aggregate Inventory

credit outcomes excludes credits created at the end of a period when defining the current period's inventory. For example, credits created at the end of period 5 are defined as entering inventory at the beginning of period 6. This definition of permit inventory allows for a consistent expectation of zero permit holdings in both cap-and-trade and baseline-and-credit. Risk neutral, profit maximizing agents are predicted not to carry any inventory from period to period. Risk averse agents have no incentive to carry permit inventories past period 10, as subject payoffs are solely determined by firm cash holdings at the end of the last period. Notice that even though there is no reason to keep an inventory at the end of the experiment, Figure 8 illustrates that subject inventories are still irrationally above zero at the end of the final period. It is impossible to assess the reason for the apparent irrationality of carrying inventory by looking at the data alone. Subjects may bank permits due to misunderstanding the environment or by making permit trading and emission rate choice errors during the session. Of course, this behaviour may also be the result of legitimate preferences: subjects might hold inventories in efforts of risk aversion or for speculative trading. If inventories were brought about by general decision error, one might think that the more cognitively difficult baseline-and-credit scheme would exhibit higher inventories and the fact that it actually does not (as evidenced by Figure 8) would support a "preference" explanation. However, one must also remember that the relative frame of the baseline-and-credit scheme creates thin permit markets with potentially lower permit supplies than under cap-and-trade. These potentially lower permit supplies, evidenced by the low credit trading volumes in Figure 5, would induce permit inventories to be lower under baseline-and-credit regulation compared to a cap-and-trade scheme.[13]

While the exact cause of the high inventory may be indeterminate in the current experimental design, breaking down the inventory by firm type may shed light on the matter. If only few subjects dominate the inventory results, or if a specific firm type accounts for the majority of the inventory holdings, this might provide meaningful information. Figures 9 and 10 illustrate mean inventory holdings by firm type over the three cap-and-trade sessions and over the three baseline-and-credit sessions.

It must be pointed out that the values underlying the mean treatment results presented in Figures 9 and 10 are indicative of the separate session results in that all 6 sessions involved most of the 8 subjects carrying nontrivial quantities of inventories; in other words, permit inventories were not driven by a few outliers. To investigate whether some firm types dominate the inventory holdings, we calculated the percentage of total inventory carried by type A and B firms averaged over periods 1 to 9 in each session. Similar to our other statistics reported in this section, the aforementioned inventory percentage provides us with 6 truly independent observations. Type A and B firms are predicted to be the sellers of permits in the short-run equilibrium and are represented by the darkest segments in Figures 9 and 10. The mean percentage of inventory held by type A and B cap-and-trade firms is 71.4% (3 observations), while the corresponding mean for baseline-and-credit firms is 63.9% (3 observations). Using this statistic, type A and B firms do not carry a significantly different proportion of total inventory under cap-and-trade than they do under baseline-and-credit (t-test, 6 observations, p-value>0.10). Only the cap-and-trade percentage of 71.4% is significantly different from 50% using a two-tailed t-test at a 10% level of significance. Type A and B firms might carry relatively more inventory because they have the lowest marginal abatement costs and so are predicted to be sellers in equilibrium. If subjects misrepresent their true costs in the uniform price permit market by bidding below their values and asking above their costs, this could lead buyers (type C and D) to purchase fewer permits, lowering their inventories, and lead sellers (type A and B) to sell fewer permits, causing them to maintain high inventory levels.

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[13] Having the experiment end after a random number of periods could have possibly been used as a strategy to eliminate some of the previously mentioned causes of inventory build-up. A random end game rule was not imposed in our design as we believe that, after the extensive training the subjects were given in this environment, we could not afford to lose even a single period of decision making data.

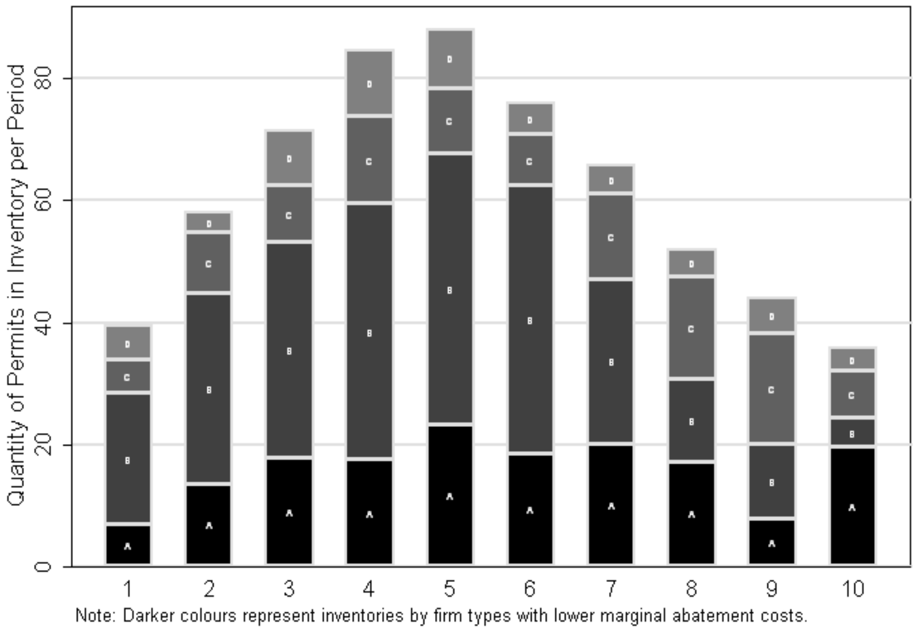

Figure 9: Cap-and-Trade Mean Inventories at End of Each Period

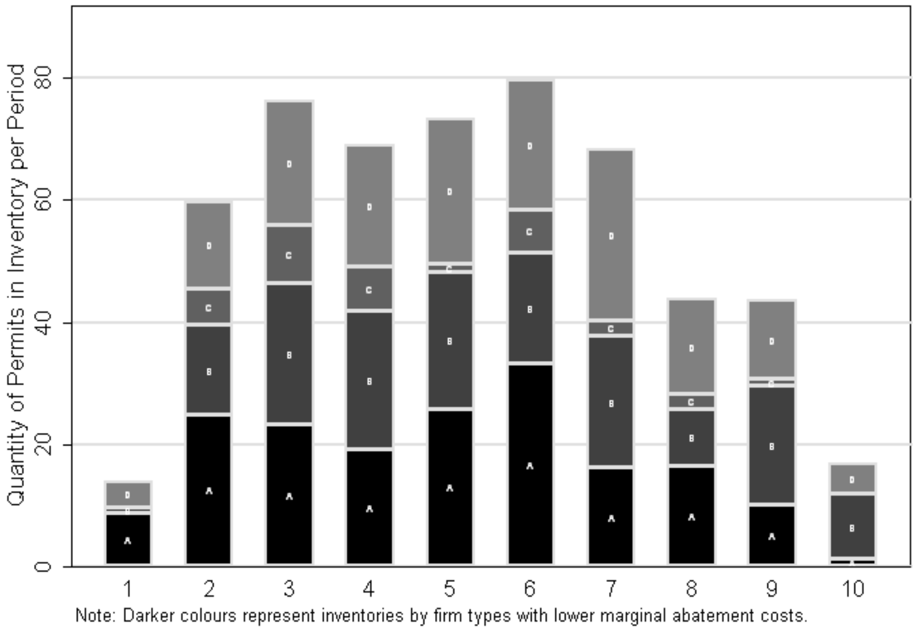

Figure 10: Baseline-and-Credit Mean Inventories at End of Each Period

6.3 Efficiency: Gains from Trade

The typical measure of market efficiency is not appropriate for this fully specified experimental environment involving a consumer output market and environmental damages in addition to the emission permit market. It is important the efficiency measure used be based on the realized consumer surplus, producer surplus and environmental damages. These three components constitute the social planner's total surplus function maximized in the optimal equilibrium. We therefore define total social surplus, S, as

$$\begin{aligned} S = Total\,Social\,Surplus = Consumer\,Surplus + Producer\,Surplus \\ + Environmental\,Surplus \end{aligned} \tag{13}$$

where the environmental surplus in our model is negative since it is solely the result of environmental damages from emissions. In the emission permit trading regulatory framework, a mechanism's efficiency is framed as the actual (realized) gains from trade expressed as a percentage of the potential gains from trade. To measure "gains from trade", a surplus is computed relative to the benchmark surplus inherent to the command and control outcome in which the optimal mechanism is imposed but permit trading is prohibited. Thus, command and control output and emissions will be optimal, however this will not be achieved at minimum cost in the industry. Therefore, actual gains from trade are calculated as the difference between actual total surplus and command and control total surplus, while potential gains from trade are equal to the difference between the optimal total surplus (given by the social planner's equilibrium) and the command and control equilibrium. This results in the efficiency measure given by

$$\text{Efficiency} = \frac{S^{actual} - S^{command/control}}{S^{optimal} - S^{command/control}} \tag{14}$$

where S is defined in equation (13). The environmental damage function is assumed to be weakly convex in our assumptions stated in Section 2. The statistics on efficiency reported in this section assume that environmental damages are expressed by a straight line, with marginal damage being flat and equal to the optimal marginal damage in the environment which is equal to 16. Although not reported here, a sensitivity analysis was conducted assuming a highly convex damage function in which increasing emissions by 50% above the optimal level corresponds to 3 times the environmental damages. The values presented in the analysis below changed very little under this extreme assumption and none of the qualitative conclusions were affected.

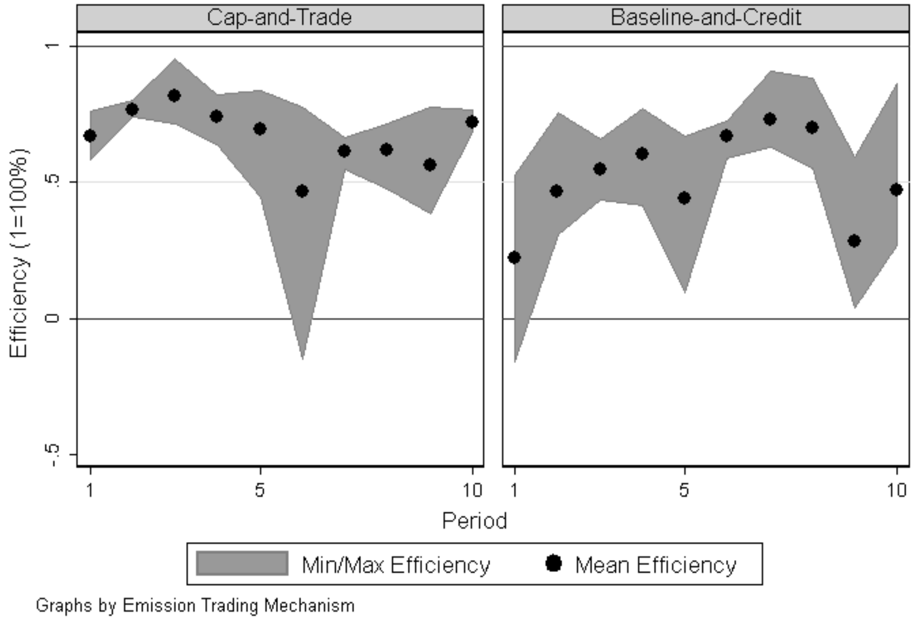

Figure 11: Efficiency (Gains from Trade)

Figure 11 illustrates minimum, maximum and mean session efficiencies over periods 1 to 10, based on gains from trade as discussed above, for all three sessions under both emission trading schemes. The graphs show remarkably similar efficiencies under both trading mechanisms. While the percentage of realized gains from trade compared to the potential gains from trade is below 100%, one must realize that this formulation of efficiency provides a much tougher benchmark (because it is based on deviations from the command and control outcome) than traditional efficiency measures (usually calculated by actual surplus divided by optimal surplus).

Table 4 presents the quantitative results supporting Figure 11, averaged over periods 6 to 9. In addition, the mean efficiency percentage for each session is decomposed into its primary components according to surplus type. This allows one to verify the driving forces behind the realized gains from trade compared to the potential gains from trade, using the command and control outcome as a benchmark. All three component surplus percentage points sum to the overall efficiency of each session. For example, the consumer surplus component is defined as

$$Consumer\,Surplus\,Component = \frac{CS^{actual} - CS^{command/control}}{S^{optimal} - S^{command/control}} \tag{15}$$

Table 4: Decomposition of Mean Efficiency over Periods 6 to 9

	Efficiency =	Components of Efficiency Consumer Surplus* +	 Producer Surplus +	 Environmental Surplus +
Cap-and-Trade:				
Session 1	68.55%	-45.03%	106.06%	7.52%
Session 2	56.56%	-26.53%	111.60%	-28.50%
Session 3	43.82%	-37.73%	112.82%	-31.27%
Treatment Mean	56.31%	-36.43%	110.16%	-17.42%
Baseline-and-Credit:				
Session 4	77.61%	0.00%	79.19%	-1.58%
Session 5	55.29%	-28.58%	111.98%	-28.11%
Session 6	45.50%	0.00%	70.84%	-25.33%
Treatment Mean	59.47%	-9.53%	87.33%	-18.34%

* Treatment effect is significant using a t-test at a 10% critical level.

where CS denotes the level of consumer surplus. Again, the environmental surplus will be negative if environmental damages are positive. For instance, Table 4 contains negative environmental surplus components for most sessions. This is indicative of aggregate emission levels above the command and control outcome of 160, a result confirmed by the evidence in Figures 7 and 8 which illustrate inventories being used forcing aggregate emissions to be above the equilibrium prediction over the second half of the experiment.

Also, the consumer surplus components are never greater than zero because output can never exceed the fixed output capacity which is imposed in the command-and-control benchmark. To provide an example of how to interpret the values in Table 4, an explanation of the first line will be provided. The first line states that the mean efficiency in periods 6 to 9 in cap-and-trade session 1 was 68.55%, meaning that 68.55% of the potential gains from trading emission permits was actually realized. 45.03 percentage points of this efficiency were lost due to actual consumer surplus falling below the benchmark, while 106.06 and 7.52 percentage points were due to gains in actual producer and environmental surplus above the command and control benchmark values, respectively.

Statistical testing indicates that there is no treatment effect on overall efficiency. While the mean cap-and-trade producer surplus is much higher than under baseline-and-credit over the last four periods (110% compared to 87%), this difference is not significant at the 10% level using a t-test or Mann-Whitney U-test. There is, however, a long lasting treatment effect causing the consumer surplus component to differ between the cap-and-trade and baseline-and-credit sessions. Table 4 provides support that, over the last 4 periods, consumer surplus is the only component to significantly differ between the two plans, but this result is supported by a t-test at the 10% level only (the corresponding nonparametric Mann-Whitney test p-value is above 10%). Over these periods, efficiency levels under both schemes are close to 60% of the potential gains from trade, using the command and control outcome as a benchmark. That both schemes should produce such similar efficiencies is surprising, considering the permit and output market discrepancies noted in the above paragraphs; however, it is not surprising given our basic theoretical prediction that both schemes should produce identically optimal results in the short-run.

7 Discussion and Conclusions

The potential cost savings from an emission trading program stems from firms with different marginal abatement costs reallocating effort between abating and buying permits, until the marginal abatement costs are equalized and total abatement costs are minimized in the regulated industry. On their own, neither a cap-and-trade nor a baseline-and-credit emission trading scheme will decrease emissions. The regulator must continually set lower and lower caps (under cap-and-trade) or set stricter and stricter performance standards (under baseline-and-credit) to achieve aggregate emission reduction goals over time. The question remained, however, whether the theoretical predictions regarding the two mechanisms would hold in real markets.

Theory predicts identical short-run outcomes between an appropriate cap-and-trade plan and a baseline-and-credit plan when the latter imposes a performance standard consistent with the cap under the former plan. Theory predicts that emissions will be greater under baseline-and-credit in the long-run because a performance standard acts like a subsidy on output. This study reports results on controlled laboratory sessions in a short-run environment.

Despite the host of reasons cited in Section 5 as to why the theoretical predictions may not be realized, our experimental results suggest otherwise. Although we have observed statistically significant differences in prices and volumes of permits and output under the two schemes, we have also found evidence that aggregate emission levels and overall system efficiency are not statistically different. Using graphical and tabular data, we cannot reject the null hypothesis that aggregate emission levels under cap-and-trade and baseline-and-credit are identical and we cannot reject the hypothesis that emissions under either scheme are different from the theoretically optimal equilibrium prediction. While market efficiency levels are very high, both schemes achieve almost 60% of the potential gains from trade, using the command and control levels of consumer surplus, producer surplus and environmental damage as a benchmark. Despite differences in permit trading prices and permit and output volume levels, the fact that overall system efficiency and aggregate emission levels are not significantly different between the two schemes suggests that cap-and-trade and baseline-and-credit will perform equally well as emission control programs in scenarios involving fixed output capacities. This supports the two propositions we first introduced in Section 2.

One caveat is that the cause of large early permit pricing errors under baseline-and-credit cannot be identified. If these errors were caused by a general misunderstanding of the mechanism, one would not expect this to affect long-run policy considerations. However, the current experimental design cannot rule out the possibility that experienced baseline-and-credit traders might exhibit similar pricing errors every time underlying parameters change in the model or the economy. We leave this important policy question for further research.

Permit inventories were an essential focus of our short-run analysis. Our initial interest was simply to investigate whether subjects carried inventories at all, and if they did, whether they would use them all before the end of the the experiment, as predicted. Results show that while a great deal of inventories were being carried under both trading plans, these inventories were generally redeemed over the last few periods of the experiment. Our analysis indicates a significant firm type effect under cap-and-trade, whereby the firms with the lowest marginal abatement costs tended to carry more than their share of the inventories, a reasonable result considering that permits are not as directly valuable to these types of firms.

With a theoretical framework and corresponding experimental environment having been designed and tested in the short-run, future work can now assess the long-run theoretical prediction of higher output and emissions under baseline-and-credit trading. The policy implications of work in this area are substantial considering the prevalent use of both alternative trading mechanisms at the international level.

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