Implications of Alternative Emission Trading Plans

Implications of Alternative Emission Trading Plans

By

Neil J. Buckley, B.Arts Sc., M.A.

A Thesis

Submitted to the School of Graduate Studies

in Partial Fulfilment of the Requirements

for the Degree

Doctor of Philosophy

McMaster University

DOCTOR OF PHILOSOPHY (2004) McMaster University
(Department of Economics) Hamilton, Ontario

TITLE: Implications of Alternative Emission Trading Plans

AUTHOR: Neil J. Buckley, B.Arts Sc., M.A.

SUPERVISORS: R. Andrew Muller, Stuart Mestelman and David Bjerk

NUMBER OF PAGES: xviii, 163

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. Theory suggests the long-run equilibrium of the cap-and-trade plan is socially optimal, whereas the corresponding baseline-and-credit equilibrium is inefficient, since the baseline creates a subsidy to output. In the short-run, however, when output capacity is fixed, the two plans are predicted to be identical. Surprisingly, despite the long-run predictions, both approaches are used around the world.

To test whether these predictions hold in real markets, we developed a computerized laboratory environment in which subjects, representing firms, can adjust their emission technology and capacity levels. Subjects trade emission rights in a uniform price sealed bid-ask auction. The demand for output is simulated. All decisions are tracked through a double-entry bookkeeping system. Full documentation of the software is attached as an appendix.

Primarily, this dissertation presents results from the first ever experimental economic analysis comparing the two most commonly proposed and implemented emission trading policy instruments: cap-and-trade and rated-based baseline-and-credit emission permit trading. After creating a laboratory implementation of the theoretical setting, we report results from simulations with robot traders in a long-run environment. These simulations verify the long-run predictions. Simulations and pilot experiments provide interesting evidence on permit market volatilities and effects of various accounting rules. As a first step towards testing the long-run model with human subjects, this dissertation

reports on a laboratory experiment designed to test the short-run predictions. The short-run experiments support the theoretical prediction that the two mechanisms yield similar outcomes, however both exhibit significant deviation from the predicted equilibrium.

Acknowledgements

I would like to acknowledge the helpful comments made by my thesis supervisory committee: Andrew Muller, Stuart Mestelman and David Bjerk. This thesis was made possible from a SSHRC grant received by Andrew Muller (Grant # 410001314). I would also like to thank participants at two McMaster graduate seminars and discussants from the various conferences where the content of this thesis was presented. Thank you to my parents, Jim and Jean, and other family members who have always supported me, especially my loving wife, Gioia, for all her help and encouragement.

Table of Contents

[1]Appendix C is found on the CD-ROM enclosed in the pouch on the inside cover at the back of this thesis.

[2] Appendix D is found on the CD-ROM enclosed in the pouch on the inside cover at the back of this thesis.

[3] Appendix E is found on the CD-ROM enclosed in the pouch on the inside cover at the back of this thesis.

List of Figures

List of Tables

Preface

The material contained in this thesis was originally drafted as three independent papers. The substance from these three papers was reorganized into the chapters found within this dissertation to provide a more comprehensive overall narrative which reduced much duplication. The material now primarily located in Chapters 3 and 4 was presented at the Canadian Economics Association meetings in May 2003, at the Economic Science Association Meetings in October 2003 and at the Southern Economics Association meetings in November 2003 under the title "Long-run Implications of Alternative Emission Trading Plans: An Experiment with Robot Traders". The material primarily found in Chapter 5 was presented at the Canadian Economics Association meetings in June 2004 under the title "Short-run Implications of Cap-and-Trade versus Baseline-and-Credit Emission Trading Plans: Experimental Evidence". A previous paper focusing on effects of various emission trading accounting rules was disseminated throughout all chapters contained in this dissertation.

Since no existing experimental laboratory software could be modified for the needs of this project, it was decided that a major requirement of this dissertation was to program the necessary economic laboratory software from scratch, and provide it with full documentation. Appendix E contains thorough documentation of the "ERC" software, so that it can be easily used for further laboratory work in the public domain. The "ERC" software and experimental data discussed in Chapters 4 and 5 are provided on the CD-ROM accompanying this dissertation. Appendices C, D and E, containing the laboratory instructions for both trading schemes and the documentation of the experimental software, are not provided in this manuscript. They can be found on the CD-ROM enclosed in the pouch on the inside cover at the back of this thesis.

Chapter 1

Introduction and Background

1.1 Introduction

Policy and research interest in emission trading systems has increased during the last decade and a half, even though economists have long advocated market-based environmental regulations. Crocker (1966) and Dales (1968) were the first researchers to publish details on how a system of tradable pollution quotas could efficiently control air pollution from stationary sources through the establishment of a market for emission rights. This idea was revolutionary as it provided the foundation for various breeds of incentive-based regulation in an area dominated by traditional command-and-control governance. Since then, researchers have often supported incentive-based emission trading regulation on the basis of its superior cost-effectiveness (Montgomery 1972). It is the potential cost savings of tradable emission schemes that has likely led to their prominence in discussions of environmental regulation in North America and around the world.

1.2 Background of Alternative Emission Trading Systems

The 1990 Clean Air Act Amendments of the United States of America and the 1997 Kyoto Protocol are arguably the most popular pieces of environmental regulation currently being discussed in the press and academic journals.

Title IV of the U.S. 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 insight 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 and present environmental regulation around the world has generally employed a different trading mechanism: *baseline-and-credit*. For example, Article 12 of the Kyoto Protocol proposes the Clean Development Mechanism, a mechanism aimed at achieving strict greenhouse gas targets using a baseline-and-credit approach. Before investigating the historical use of these two alternative mechanisms, a brief explanation of their operation is in order.

Under a cap-and-trade plan, an aggregate cap is placed on emissions. A corresponding quantity of emission permits, often called *allowances*, is created. The permits may be sold at auction or distributed to incumbent firms. 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 baseline-and-credit plan, firms are assigned a baseline emission level. If their actual emissions are below the baseline, they earn permits, in this context often called *emission reduction credits* (ERCs). These credits may be sold to firms whose emissions exceed their baselines. 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 baseline-and-credit trading uses a *relative* frame, where firms must account for only deviations from an emission baseline.

The two plans are theoretically equivalent if the emission baseline in a baseline-and-credit plan is fixed and numerically equal to the quantity of allowances allocated under a cap-and-trade plan. In many cases, however, the baseline is proportional to the regulated firms' output. As in the case of our baseline-and-credit implementation, the emission baseline can be computed by multiplying output by a prescribed performance standard specifying the target industry *emission rate*. An emission rate represents the emission technology level of the firm and is the amount of pollution that is emitted per unit of output. It is sometimes referred to as *emission intensity*.[1] This type of baseline-and-credit plan is often called a rate-based system of "tradable performance standards". Simply put, "clean" firms with emission rates below the performance standard create ERCs, while "dirty" firms possessing emission rates above the performance standard are required to purchase and redeem ERCs. While cap-and-trade regulation places an explicit upper limit on the quantity of aggregate emissions, there is no strict emission cap under rate-based baseline-and-credit regulation: it is linked to output.

[1]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 dissertation, however, will use the terminology *emission rate*, as it more closely resembles the common use of the term in the economics discipline.

North American use of these two approaches to environmental regulation has been quite extensive. Tietenberg (2000, Ch. 16) reviews the history of U.S. environmental regulation and Dewees (2001) provides a detailed discussion on the historical use of cap-and-trade versus baseline-and-credit rate-based systems in the U.S. and Canada. Some historical facts found in these two studies warrant mention.

The U.S. Clean Air Act Amendments of 1970 were passed to set a new direction for American environmental policy and the EPA was created to oversee its implementation. This gave rise in the early 1970's to the New Source Performance Standards (NSPS), which governed new and modified sources of industrial pollution. Throughout the 1970s, modifications were made to the U.S. system allowing for emission trading, offsets, bubbles, netting, and banking, with the NSPS regulation as a foundation. The most important characteristic of the institutions surrounding the NSPS during this time period was that they shared many similarities to a baseline-and-credit rate-based program since they linked regulation to current activity levels (e.g., fuel input, power output, product output etc.) of the source.[2] It is interesting to note, however, that in many cases a pollution limit was placed on the source, essentially creating a cap on emissions. In order to receive certification for an ERC under the policies surrounding the NSPS, the emission reduction had to be permanent. The result of this policy was that a firm could generate ERCs by permanently reducing emissions, including shutting down operations, but not by temporarily reducing emissions. While most estimates place the cost savings of the entire program over its lifetime at over $10 billion, many claim this is much lower than what was anticipated upon inception (Tietenberg 2000; Hahn and Hester 1989). More recently, Title IV of the 1990 Clean Air Act

[2]See Tietenberg (2000, Ch. 16) for a detailed description of how these policies integrate with the concept of emission reduction credit trading.

Amendments instituted a cap-and-trade brand of emission trading regulation. This instituted a cap on emissions of sulphur dioxide that is based, using a multiplier, on a firm's activity in a fixed historical year. Researchers have also found that this cap-and-trade system has already produced considerable cost savings (Ellerman, Schmalensee, Joskow, Montero, and Bailey 1997).

In Canada there has been much less experimentation with the use of baseline-and-credit and cap-and-trade instruments compared to that in the United States. The Pilot Emission Reduction Trading (PERT) program developed by Ontario Hydro and various government officials and environmental stakeholders used a baseline-and-credit ERC framework (PERT 1997). The program ran from 1996 to 2000 and was voluntary, the regulation was not enforced. Under PERT, ERCs were created by firms undertaking an identifiable action to reduce emissions. The quantity of ERCs created was equal to the amount of output produced multiplied by the difference between the baseline emission rate and the new lower emission rate. Unlike the U.S. system, shutting down a plant would not generate ERCs under PERT. However, temporary shifts to cleaner technologies and inputs would generate ERCs. Where U.S. regulation has been shifting towards cap-and-trade regulation, Canadian regulation seems to be merging the two styles. The Ontario Ministry of the Environment (OMOE 2003), for example, has recently implemented a hybrid emission trading scheme using elements from both cap-and-trade and baseline-and-credit mechanisms. The program regulates nitric oxide and sulphur dioxide produced by coal and oil-fired electricity generators. Mandatory cap-and-trade regulation for the aforemention industry is coupled with a voluntary ERC-based system.

Given the cost savings ability of emission trading schemes, it is not surprising that they are 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 greenhouse gas emission trading used by various governments throughout the world. In addition to categorizing emission trading plans as being either suspended, active, planned or proposed, the author also categorizes them as being mandatory or voluntary and, even more importantly for our purposes, cap-and-trade or baseline-and-credit based. In his survey of international emission trading, Hasselknippe finds that credit schemes are just as prevalent as capped schemes, with 20 out of 43 schemes based on an ERC-type system.

That both instruments are so prevalently used begs the question why so little economic theory, empirical analysis or laboratory research has been conducted on baseline-and-credit with respect to cap-and-trade. Specifically, laboratory methods are unique in that they can be used to test different mechanisms in a controlled environment. While theory often says little regarding the market institutions surrounding a regulation, laboratory methods are ideal for investigating how institutions affect behaviour. This dissertation reports on the first economic laboratory study of baseline-and-credit emission permit trading.

1.3 Cap-and-Trade versus Baseline-and-Credit Emission Trading

This dissertation considers "cap-and-trade" emission trading systems in which allowances are endowed by the regulator, using a *grandfathering* approach based on historical data, rather than being auctioned. "Grandfathering" is the term used to indicate when the number of permits endowed upon a firm does not depend on current activity and when these permits are given costlessly to the firm by the regulator. The quantity of permits endowed is usually based on a fixed and regulated percentage of past historical activity (e.g. 80% of yearly firm emissions averaged from 1987 to 1990). In contrast to grandfathering, some real-world cap-and-trade systems auction permits to firms instead of endowing them. While not the focus of this research, Cramton and Kerr (2002) and Fischer, Parry, and Pizer (2003) provide a theoretical discussion on auctioning permits versus grandfathering them. The Cramton and Kerr (2002) study examines the advantages of auctioning permits on the grounds of reduced tax distortions (the "double-dividend" argument) and greater incentives for innovation. The authors also discuss the political pros and cons of auctioning, ranging from the ability of government to offer lower tax levels to the inevitable political backlash from the industry forced to pay for the auctioned permits. The Fischer et al. (2003) study uses a simulation of a more formal model to demonstrate that under different circumstances each permit allocation method could be welfare maximizing. There has also been some experimental evidence published on this topic. An interesting example is the laboratory study by Cason (1995) which provided evidence of the inefficiencies inherent to the permit auction originally suggested by the EPA to operate under the 1990 Clean Air Act. Since it is not necessary to incorporate an auction in the assumptions of a cap-and-trade system in order to measure the difference between it and baseline-and-credit, for simplicity a grandfathering approach is assumed for the cap-and-trade permit endowment.

Another relevant aspect of our assumed cap-and-trade system is that the permit endowment is fixed since it is based on historical activity. This enforces a fixed cap on emissions. We compare this typical cap-and-trade setup to an output-based baseline-and-credit system which uses a regulated emission rate performance standard. As opposed to the former, a rate-based baseline-and-credit system does not set a fixed cap on emissions, as emissions will be linked to output activity. Fischer (2001), on the other hand, provides an in-depth discussion on the theoretical implications of converting traditional tax and cap-and-trade regulation schemes into output-based instruments like the rate-based baseline-and-credit system by rebating tax revenues based on market share in the former and allocating permit endowments proportional to output in the latter. Her main conclusion is that, for any given targeted level of abatement, these output-based instruments all result in higher marginal costs of control or higher output and emissions compared to the social optimum.

Assuming the typical cap-and-trade and baseline-and-credit setup described above, theoretical considerations suggest the long-run equilibria of the two plans will differ because an ERC plan using an emission rate performance standard creates an inherent subsidy to output. Compared to a cap-and-trade plan with the same average emission rate, the baseline-and-credit plan will exhibit higher output and emissions. Compared to a cap-and-trade plan with the same emissions, the baseline-and-credit plan will exhibit a lower and more costly average emission rate. Thus baseline-and-credit plans entail an inherent efficiency loss compared to an equivalent cap-and-trade plan. In the short-run however, theory predicts identical outcomes for the two schemes. In this case, the output subsidy cannot cause output expansion because output capacity is fixed. The details behind these theoretical predictions are provided in Chapter 2.

In this dissertation we contrast *long-run* and *short-run* scenarios. The long-run refers to cases in which all factors of production are variable. Thus, in the long-run a firm can change its emission rate and its output capacity. We assume the short-run time frame is one in which a firm can rapidly modify its pollution technology but cannot influence its capacity to produce 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. Of course, the definition of a short-run time frame also includes any case in which a firm could easily replace heavily polluting technology but would not be able to modify output capacity.

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".

To date, other than the theoretical analyses of Thomas (1980), Helfand (1991), Dewees (2001), Fischer (2001, 2003) and Ellerman and Wing (2003), little work, and no experimental economic evidence, have been published comparing baseline-and-credit and cap-and-trade market-based mechanisms. The first two studies cited above do not directly address tradable emission permits, but they investigate the advantages and disadvantages of limiting emissions directly (similar to cap-and-trade) versus limiting the rate of emissions per unit of input/output (similar to baseline-and-credit). In both these articles, the authors use theoretical estimates to conclude that direct regulation of emissions is the least costly, and profit maximizing, alternative.

The work conducted by Dewees (2001) is more pertinent to this dissertation than the previous two studies in that it focuses explicitly on the efficiency of a cap-and-trade emission trading program versus an ERC trading program. The author conducts an excellent analysis of these emission trading markets using simulation analysis, in an electricity generating context, to determine key factors such as the marginal and average costs of a typical regulated firm. Dewees (2001) concludes that the cap-and-trade system is more efficient than the rate-based baseline-and-credit system.

The theoretical work by Fischer (2001, 2003) is innovative in that it focuses on cap-and-trade and baseline-and-credit trading using a partial equilibrium framework. As previously stated, Fischer (2001) analyzes the properties of a tax, cap-and-trade, and baseline-and-credit scheme when all three are linked to output, and supports the contention that output-based instruments are inherently inefficient. Fischer (2003) assumes a combined cap-and-trade and rate-based regulation. The paper finds that unrestricted trade between these programs always raises combined emissions. These two studies compare cap-and-trade to baseline-and-credit schemes in a simple, partial equilibrium model employing the use of a representative firm. This model's simplicity is its strength as it allows for theoretical predictions that are easily testable using laboratory methods in an environment with multiple markets (one for emission permits and one for output) and many margins of choice (emission rate choice, output choice etc.). The theoretical model presented in Chapter 2 is based on Fischer's model.

Lastly, Ellerman and Wing (2003) conduct quite a different study from the others mentioned above. The authors provide a non-technical description of the differences between cap-and-trade and rate-based baseline-and-credit regulation with a focus on the macroeconomic picture. In their discussion, the authors identify the properties of each system in a world where future emissions and GDP are unknown. They conclude that there is a divergence between the plans under uncertainty. While not closely related to the topic of research this dissertation focusses on, it is important to note that recent publications, such as the Ellerman and Wing (2003) study, have been interested in descriptively comparing different characteristics of our alternative trading plans.

As mentioned, to date, there has been no work published on baseline-and-credit laboratory experiments but many have examined characteristics of cap-and-trade schemes. One of the first published laboratory studies on emission trading was Plott (1983), who investigated cap-and-trade pollution licences in his study on corrective policies for externalities. Some of the more recent cap-and-trade experiments focus on individual aspects of the trading mechanism (e.g. Franciosi, Isaac, Pingry, and Reynolds 1993; Ledyard and Szakaly-Moored 1994; Cason 1995), and others are conducted within a fully specified institutional framework (e.g. Muller and Mestelman 1994; Godby, Mestelman, Muller, and Welland 1997; Ben-David, Brookshire, Burness, McKee, and Schmidt 1999; Muller, Mestelman, Spraggon, and Godby 2002). Much of the latest research on emission trading has been focussing on different aspects of compliance (Cason and Gangadharan 2004; Murphy and Stranlund 2004).

Of the many published cap-and-trade experiments, the Ben-David et al. (1999) environment is most relevant to this work since it is the only study to involve an explicitly chosen emission rate technology by experimental subjects. However, while this dissertation requires an explicitly chosen emission rate because it is a distinguishing institutional detail in the theoretical modeling of cap-and-trade versus rate-based baseline-and-credit instruments, Ben-David et al. use an explicitly chosen emission rate technology because their focus is on how firm technological heterogeneity impacts the market for permits. The paper's results suggest that increased technological heterogeneity may lead to reduced trading volumes and decreased production efficiency. However, the Ben-David et al. environment is not adequate to compare cap-and-trade to baseline-and-credit since it only involves permit trading and an emission rate technology choice, leaving output exogenously fixed at a constant level over the duration of the experiment. The experiment forces compliance by automatically changing a firm's emission technology to a cleaner alternative if the firm does not hold a sufficient number of permits to meet the requirements of the subject's chosen emission technology for the period. Although this environment may be sufficient to test cap-and-trade versus baseline-and-credit trading in the short-run, a more elaborate environment involving an output market and an output capacity choice is required to test our long-run prediction.

It should be noted that the above authors use the same basic laboratory environment to study attitudes towards risk and compliance in cap-and-trade emission trading markets by investigating behaviour under various treatments involving uncertain permit endowment reductions (Ben-David, Brookshire, Burness, McKee, and Schmidt 2000). Although the two environments are almost identical, the Ben-David et al. (2000) environment involves a reduction in permit endowments over the course of the experiment. Because this dissertation is not focused on investigating uncertainty and regulatory compliance, we will only use the original Ben-David et al. (1999) environment as a basis of comparison for our own work.

Laboratory studies of emission trading conducted by Elliott, Godby, and Kruse (2003) and Murphy and Stranlund (2004) are also noteworthy to the current context. While both studies involve implicitly chosen emission rates in the context of cap-and-trade permit trading, both studies also allow output to fall short of an exogenously fixed capacity. This differs from most emission trading environments in which output is often entirely exogenous. The capacity limit on output inherent to these two environments is not unlike that required to test our short-run predictions. Elliott et al. (2003) require endogenous output since the focus of their study concerns market power and whether a dominant firm can use the permit market to exert control over the associated output market. On the other hand, Murphy and Stranlund (2004) allow for possible output shortfalls from capacity in their investigation of compliance, to allow subjects who did not purchase enough permits the possibility of decreasing output in order to comply with regulation. Despite the above considerations, both the Elliott et al. and the Murphy and Stranlund implementations lack explicit emission technology choices.

It was quite clear that new laboratory software had to be programmed and an original experimental environment created to achieve the goals of this dissertation. After running early pilot[3] experiments, we realized that implementing cap-and-trade and baseline-and-credit trading was fairly complex. We therefore decided to build the framework of the experiment on an accounting infrastructure involving a double-entry system of debits and credits for every possible action and event. This would allow experimental subjects to be presented with familiar terms and expressions, in addition to providing a robust system to track decisions.

1.4 Accounting for Emission Permits

Emission permit trading is a relatively young regulatory instrument. In his international survey on emission trading plans, Hasselknippe (2003) reports 5 active cap-and-trade programs and 17 active baseline-and-credit programs, as of September 2003. This is in comparison to only 1 cap-and-trade plan and 5

[3]We use the term *pilot* to denote a paid test session used to assess whether a full complement of experimental sessions is feasible with a particular design. Our pilot sessions also involved a private de-briefing with each subject after the session was finished.

baseline-and-credit type plans that were active in the year 2000.[4] These statistics provide evidence of just how young emission rights trading really is. One issue that often arises in new and innovative regulatory frameworks is the question of how accounting rules should be applied by firms to take account of the new circumstances created by the regulation. The International Accounting Standards Board (IASB) is an independent accounting standard setter with the goal to provide high quality enforceable global accounting standards. The IASB foundations date back to 1973 as a result of an agreement by accountancy bodies in Australia, Canada, France, Germany, Ireland, Japan, Mexico, Netherlands, United Kingdom and the United States of America. Specifically, the Financial Reporting Interpretations Committee (IFRIC) of the IASB is responsible for addressing accounting issues that are likely to receive conflicting or unacceptable treatment in the absence of authoritative guidance.

Recently, the IFRIC has drafted an interpretation of how to account for emission rights. After this comment was publicly posted in May 2003, the committee received many letters of concern expressing that the interpretation may misrepresent and cause artificial volatility of profits and losses. In light of these events, the IFRIC decided to explore alternative interpretations to the emission right accounting issue. Since the laboratory software created for this dissertation is built on a double-entry accounting framework, results from the sessions reported herein can shed light into the concerns brought to the IFRIC.

[4]These statistics involve only active plans, while the statistics quoted earlier from Hasselknippe (2003) aggregated over active, planned, proposed, and suspended plans.

1.5 Overview

Because of the complexity involved in setting up and programming an experimental environment rich enough to test for differences between cap-and-trade and baseline-and-credit emission trading mechanisms, progress must necessarily be incremental. This dissertation reports a series of contributions towards the ultimate goal of testing long-run theoretical predictions in a fully specified economic laboratory environment. Primarily, this dissertation presents results from the first ever experimental economic analysis comparing the two most commonly proposed and implemented emission trading policy instruments: cap-and-trade and rate-based baseline-and-credit emission permit trading.

Chapter 2 outlines the details of a fully testable theoretical model. Predictions are described comparing a traditional Pigovian pollution tax, a cap-and-trade emission trading system and baseline-and-credit emission trading system to the optimal solution within a multi-firm partial equilibrium framework.

Chapter 3 describes the creation of our experimental environment. Care is taken to implement an environment representative of the theoretical model from Chapter 2. Details of the accounting implementation and its relation to the IFRIC recommendations will be highlighted.

Chapter 4 presents results from simulations involving robot traders in the environment created for a long-run setting. We demonstrate that the theoretical predictions provided in Chapter 2 are realized by profit maximizing myopic robots. The chapter is concluded with a summary of the lessons learned through the use of robot traders.

Chapter 5 presents results from the first laboratory experiment comparing baseline-and-credit and cap-and-trade emission trading. The chapter reports results from a laboratory experiment designed to test whether the short-run prediction of identical outcomes under both trading plans will actually be realized. This chapter discusses six experimental sessions involving fixed output capacity. Human behaviour in both the output and permit markets under the two regulations is compared. Particular emphasis is placed on the effect of an accounting rule change that occurred between three pilot sessions and the six regular sessions. Although some differences between the alternative plans are noted, results generally indicate support for the theoretical prediction of equivalence. This chapter provides a first look at the short-run behaviour of the two plans, in anticipation of testing them in a long-run environment.

Chapter 6 summarizes this dissertation, offers conclusions and discusses options for future research.

Chapter 2

Theoretical Model and Predictions

2.1 Theoretical Model

There are three general approaches to designing economic incentives for emission reduction instruments: a traditional tax, a cap-and-trade emission trading scheme and a rate-based baseline-and-credit emission reduction trading scheme. The latter two involve emission trading, with the cap-and-trade being based on an absolute target and the baseline-and-credit using a relative target.

In this chapter, we provide the theoretical analysis underlying our predictions and our experimental environment, providing motivation for the simulations and experiments discussed in later chapters. We demonstrate short-run equivalence and long-run divergence of the two emission trading plans. The long-run model and predictions involving both emission rate and output as choice variables will be presented in detail, after which the short-run predictions will be discussed. 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 of perfectly competitive price-taking firms with no entry or exit allowed from the industry.

2.2 Theoretical Assumptions

We begin by assuming constant marginal costs in terms of output. The predictions do not require more realistic and complicated assumptions, so the experimental environment based on the theory 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 is 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 $MAC = -\dfrac{\partial C_i}{\partial e_i} = -c_i'(r_i)$. The notation is summarized in Table 2.1.

2.2.1 Optimal Social Planner's Solution

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

Table 2.1: Theoretical Notation

Symbol	Description	Properties
q_i	Firm output	$q_i \geq 0$
Q	Aggregate output	$Q = \sum_{i=1}^{N} q_i,\ Q \geq 0$
r_i	Firm emission rate	$r_i \geq 0$
e_i	Firm emissions	$e_i \geq 0,\ e_i = r_i q_i$
E	Total emissions	$E = \sum_{i=1}^{N} e_i = \sum_{i=1}^{N} r_i q_i$
w_i	Firm unit variable cost	$w_i \geq 0$
$P(Q)$	Inverse demand function	$P(Q) \geq 0,\ P(Q) < 0$
$c_i(r)$	Firm unit capacity cost	$c(r) \geq 0,\ c'(r) < 0,\ c''(r) > 0$
MAC	Marginal abatement cost	$MAC = -\dfrac{\partial C_i}{\partial e_i} = -c_i'(r_i)$
$D(E)$	External damage function	$D(E) \geq 0,\ D'(E) > 0, D''(E) \geq 0$
P^c	Permit price (cap-and-trade)	$P^c \geq 0$
P^b	Permit price (baseline-and-credit)	$P^b \geq 0$

Note: Variables above can be denoted with superscripts u, $*$, c , and b for uncontrolled, optimal, cap-and-trade and baseline-and-credit cases, respectively.

and environmental damage caused by output production. The social planner's welfare maximization problem can be expressed as

$$\max_{\{r_i, q_i\}} S = \int_0^Q P(z) - \sum_{i=1}^{N} c_i(r_i) q_i - \sum_{i=1}^{N} w_i q_i - D(\sum_{i=1}^{N} r_i q_i). \tag{2.1}$$

The first order conditions for an interior maximum are

$$-c_i'(r_i{}^*) = D'(\sum_{i=1}^{N} r_i{}^* q_i{}^*) \quad \forall i \in N \tag{2.2}$$

and

$$P(Q^*) = c_i(r_i{}^*) + w_i + r_i{}^* D'(\sum_{i=1}^{N} r_i{}^* q_i{}^*) \quad \forall i \in N \tag{2.3}$$

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 (2.2) 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 (2.3) ensures that output is surplus maximizing because each firm's marginal social cost equals marginal willingness-to-pay. Note that, although condition (2.2) determines a unique emission rate for each firm, condition (2.3) 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. Proof that this solution is indeed a maximum, and not a minimum, is provided in mathematical Appendix A.

2.2.2 Uncontrolled Outcome

The uncontrolled outcome is the result of an unregulated industry and is an interesting case as a benchmark against which to compare the optimal social planner's solution. In the uncontrolled case firms can pollute as much as they want with no interference. Each unregulated competitive firm's profit maximizing problem is

$$\max_{\{r_i, q_i\}} {\pi_i}^u = P(Q)q_i - c_i(r_i)q_i - w_i q_i. \tag{2.4}$$

The two first order conditions for an interior maximum are

$$-c_i'({r_i}^u) = 0 \tag{2.5}$$

as long as q_i is greater than zero, and

$$P(Q^u) = c_i({r_i}^u) + w_i. \tag{2.6}$$

Equation (2.5), which states that each firm sets its marginal abatement cost to zero, will ensure that each firm chooses an emission rate higher than its optimal rate, ${r_i}^u > {r_i}^*$, since $-c'({r_i}^u) = 0 < -c_i'({r_i}^*) = D'(E^*)$ and marginal abatement cost is monotonically decreasing in r. Because $c_i({r_i}^u) < c_i({r_i}^*)$ and equation (2.6) is missing the positive marginal damage term contained in the social planner's condition (2.3), the right hand side of equation (2.6) must be less than the right hand side of equation (2.3). This implies that the uncontrolled price of output is lower than the optimal output price, $P(Q^u) < P(Q^*)$. The assumption of downward sloping output demand leads to the prediction that $Q^u > Q^*$.

Since only the total quantity of output is identified in the uncontrolled equilibrium, any set of q_is that sum to Q^u will be equilibrium quantities in the uncontrolled case. Notice in this general case that there are no conditions on aggregate emissions: the sum of the individual ${r_i}^u {q_i}^u$ firm emissions is unknown because the distribution of output between firms is unknown. Since every firm has a higher uncontrolled emission rate than its optimal rate, aggregate emissions in the uncontrolled case must be higher than in the optimal case, $E^u > E^*$.

2.2.3 Tax on Emissions

Perhaps the most commonly proposed economic instrument of environmental policy is the traditional emission tax first described by Pigou. The idea behind the Pigouvian tax is to place an appropriate price on emissions so as to internalize the social cost of pollution. Although emission taxes are not directly within the scope of this dissertation on alternative emission trading schemes, they nonetheless complete the regulatory framework and provide an interesting reference point.

An optimal emission tax that will internalize the externality is set such that $t^* = D'(E^*)$. This tax will generate the optimal result if each firm must pay t^*, the marginal value of damage to the environment, for each unit of pollution it emits. Under this Pigouvian tax, firm i's profit maximization problem is

$$\max_{\{r_i, q_i\}} \pi_i{}^t = P(Q)q_i - c_i(r_i)q_i - w_i q_i - t^*(r_i q_i). \tag{2.7}$$

The two first order conditions for an interior maximum are

$$-c_i'(r_i{}^t) = t^* \tag{2.8}$$

if q_i is greater than zero, and

$$P(Q^t) = c_i(r_i{}^t) + w_i + t^* r_i{}^t. \tag{2.9}$$

Equation (2.8) ensures cost minimizing abatement and defines each $r_i{}^t$. Equation (2.9) requires that each firm earn zero profit in equilibrium, and identifies Q^t. Because the system of equations (2.8) and (2.9) can be obtained from optimal equations (2.2) and (2.3) by replacing $D'(\sum_{i=1}^{N} r_i{}^* q_i{}^*)$ with t^* and replacing $r_i{}^*$ with $r_i{}^t$, a solution to the surplus maximization problem is also a competitive equilibrium under an optimal tax and vice versa.

2.2.4 Cap-and-Trade Theory

The social optimum can also be supported as a competitive equilibrium under cap-and-trade regulation. Cap-and-trade is an emission trading instrument involving a fixed cap on pollution that constitutes an absolute emission target. The regulator distributes a quantity of allowances, A_i, to each firm so that the sum of allowances granted equals the optimal level of emissions, that is, $\sum_{i=1}^{N} A_i = E^*$. The regulation states that firms must redeem one allowance for each unit of pollution they emit. Firms with extra allowances can sell them and firms with a quantity of emissions greater than allowances can buy them. Letting P_c denote the price of allowances under cap-and-trade, firm i's profit maximization problem is

$$\max_{\{r_i, q_i\}} \pi_i{}^c = P(Q)q_i - c_i(r_i)q_i - w_i q_i - P_c(r_i q_i - A_i). \tag{2.10}$$

The two first order conditions for an interior maximum are

$$-c_i'(r_i{}^c) = P_c \tag{2.11}$$

if q_i is greater than zero, and

$$P(Q^c) = c_i(r_i{}^c) + w_i + r_i{}^c P_c. \tag{2.12}$$

Equation (2.11) ensures cost minimizing abatement and defines each $r_i{}^c$. Equation (2.12) requires that each firm earn zero marginal profit, and identifies Q^c. The system (2.11) and (2.12) can be obtained from the optimal conditions (2.2) and (2.3) by replacing $D'(\sum_{i=1}^{N} r_i{}^* q_i{}^*)$ with P_c and $r_i{}^*$ with r_i^c. A solution to the surplus maximization problem can be sustained as a cap-and-trade competitive equilibrium and vice versa. Note that an optimal cap-and-trade plan, that is, one that allocates a socially optimal number of allowances, can achieve the optimal social planner's outcome as an equilibrium, just as in the Pigouvian tax case. Section 2.3 will illustrate this solution graphically to provide insight on how the price of allowances, P_c, equates to the optimal marginal damage, $D'(E^*)$.

2.2.5 Baseline-and-Credit Theory

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. Firms with emission rates below the performance standard create credits which can be sold or used in the future, and firms with emission rates above the standard are required to purchase and redeem credits. 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, then firm i's profit maximization problem is

$$\max_{\{r_i,q_i\}} \pi_i{}^b = P(Q)q_i - c_i(r_i)q_i - w_iq_i - P_bq_i(r_i - r^s). \tag{2.13}$$

The first order conditions for an interior maximum are

$$-c_i'(r_i{}^b) = P_b \tag{2.14}$$

and

$$P(Q^b) = c_i(r_i{}^b) + w_i + r_i{}^bP_b - r^sP_b. \tag{2.15}$$

Equation (2.14) is the usual efficient abatement condition which defines each $r_i{}^b$. Equation (2.15) 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,

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

$$\sum_{i=1}^{N} {r_i}^b {q_i}^b = \sum_{i=1}^{N} r^s {q_i}^b. \tag{2.16}$$

Substituting for r^s we can calculate that

$$\sum_{i=1}^{N} {r_i}^b \frac{{q_i}^b}{Q^b} = \sum_{i=1}^{N} {r_i}^* \frac{{q_i}^*}{Q^*}. \tag{2.17}$$

Equation (2.17) implies that, if market shares are the same under baseline-and-credit and cap-and-trade plans, any set of emission rates satisfying the socially optimal abatement condition (2.2) also satisfies the corresponding baseline-and-credit equilibrium condition (2.14).

The zero-profit condition for baseline-and-credit equilibrium (2.15) is similar to optimal equation (2.3) 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 (2.15) is equal to the right hand side of (2.3), 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. Section 2.3 illustrates the baseline-and-credit case with the use of a diagram and demonstrates why the

[1] As mentioned in Section 1.3, 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 of cap-and-trade with a baseline-and-credit system with a performance standard equal to the average emission rate from the optimal scenario.

Table 2.2: Table of Long-run Theoretical Predictions

Variable	Predictions
Emission Rate, r	$r^* = r^c = r^b < r^u$
Output Quantity, Q	$Q^* = Q^c < Q^b < Q^u$
Output Price, P	$P(Q^u) < P(Q^b) < P(Q^c) = P(Q^*)$
Total Emissions, E	$E^* = E^c < E^b < E^u$
Emission Permit Price, P_c or P_b	$P_c = P_b = D'(r^*Q^*)$

Note: '*', 'c', 'b' and 'u' denote the optimal, cap-and-trade, baseline-and-credit and uncontrolled cases, respectively.

price of credits will converge to the optimal marginal damage and how long-run output and emissions will be greater than optimal.

Note from (2.13) 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 versus price instruments. If marginal damages rise steeply with emissions, quantity instruments like cap-and-trade regulation would be preferred. Conversely, if marginal abatement costs rise more steeply than marginal damages, a price instrument like a rate-based baseline-and-credit instrument would be preferred.

Table 2.2 provides an overview of the relative ranking of the predictions associated with the various treatments described above.

2.3 Graphical Analysis

Figure 2.1 illustrates the theoretical solutions discussed above. The marginal abatement cost curve, MAC, is obtained by (1) inverting the expression $MAC = -c_i'(r_i)$ to obtain emission rates as a function of MAC, $r_i = r_i(MAC)$; (2) computing total emissions over all firms by multiplying by q_i and aggregating; and (3) reinverting to obtain MAC as a function of total industry emissions. Optimal emissions and optimal marginal abatement cost are determined in Panel (a) by the intersection of the marginal damage curve, MD, and the aggregate marginal abatement cost curve, MAC. This intersection point is optimal since it is the point at which the private cost of lowering emissions is equal to the social cost saved by reducing emissions. Optimal output, Q^*, and product price, P^*, are determined in Panel (b) by the intersection of the product demand curve, D, and the long-run unit social cost curve, $LAC_c = c_i r_i{}^* + w_i + r_i{}^* MAC^*$. The curves in the two panels are interdependent. The position of MAC is conditional on the optimal outputs $(q_i{}^*)$, as detailed in the definition of the MAC function above; the position of the LAC curve is conditional on the optimal emission rates $(r_i{}^*)$, as determined by MAC^*.

The cap-and-trade equilibrium is illustrated by a simple reinterpretation of Figure 2.1. The MAC becomes the aggregate demand for emission allowances, since each firm's willingness-to-pay for an allowance is equal to the cost saved by emitting the one additional unit of pollution authorized by the allowance. The aggregate supply curve of allowances is vertical at E^*, as it is assumed that the regulator allocates a number of allowances equal to the optimal amount of emissions. The price of allowances determined by the intersection of the aggregate demand and supply curves is $P_c = MAC^* = D'(\sum_{i=1}^{N} r_i{}^* q_i)$. The cap-and-trade long-run equilibrium output at Q^* is determined by the intersection of the demand curve for output with the long-run supply curve for output, which is horizontal at LAC_c.

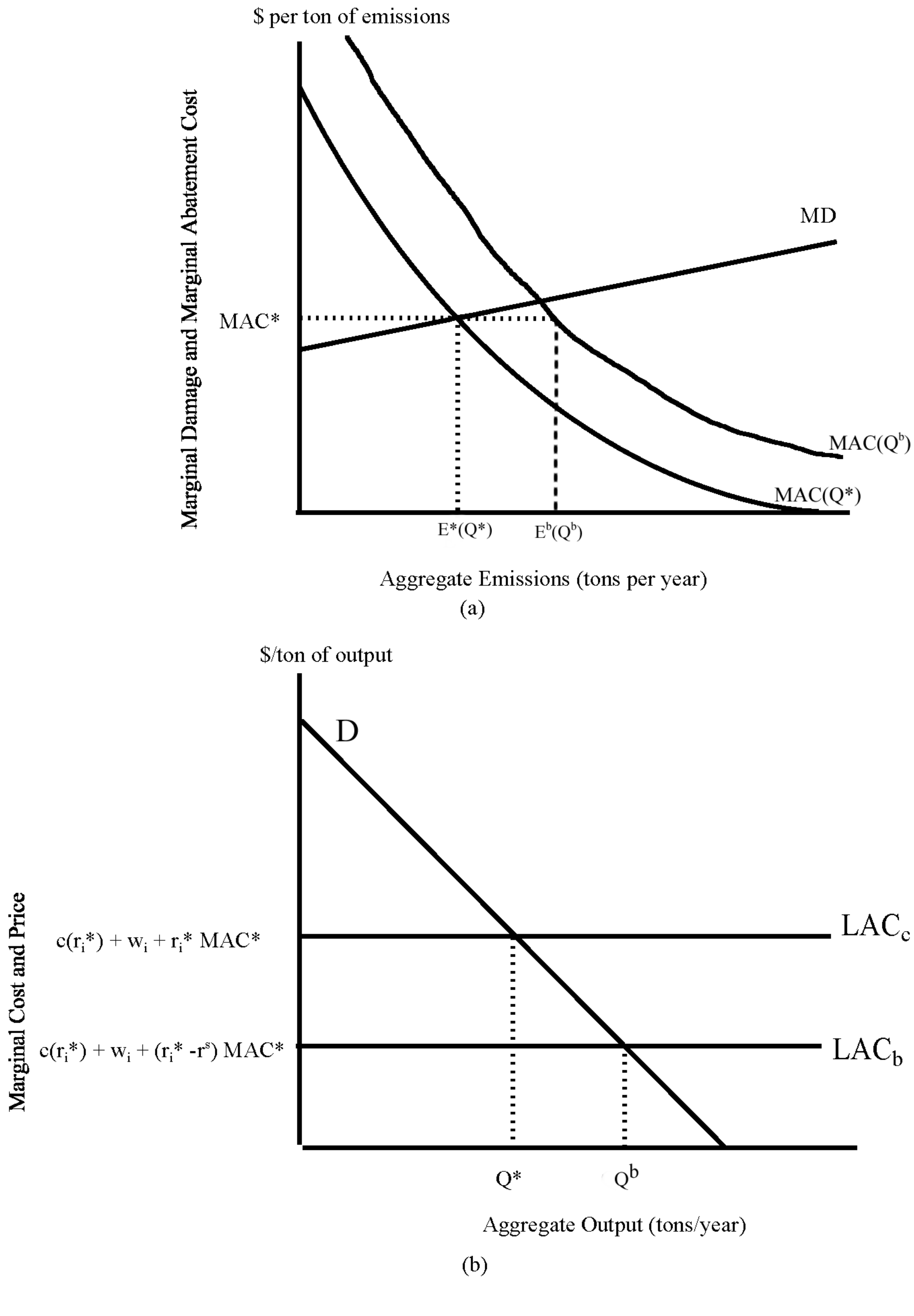


Figure 2.1: Alternative Equilibria

The baseline-and-credit equilibrium operates in a similar fashion except the performance standard acts like a subsidy in that it lowers marginal costs, producing a lower long-run average cost curve, LAC_b, as shown in Figure 2.1. This lower output supply curve generates a lower equilibrium output price and greater equilibrium output quantity under baseline-and-credit than under the optimal cap-and-trade case. Because the performance standard is assumed to be equal to the average emission rate under an optimal cap-and-trade scheme, this greater output quantity implies higher aggregate emissions under baseline-and-credit regulation than under cap-and-trade regulation. The output increase under baseline-and-credit shown in Panel (b) causes the MAC curve in Panel (a), which represents aggregate demand for credits, to shift to the right since higher output leads demand at each price to increase because of the relative target embodied by the fixed performance standard.[2] This shift in the "demand" is mirrored by an equal shift to the right of the vertical aggregate supply curve for credits which, due to the increase in output to Q^b, is now at $E(Q^b)$. Since emission rates have not changed, the output expansion under a fixed performance standard causes demand and supply of credit to increase by the same proportion. Notice that, since the aggregate demand and supply curves for credits both shift to the right by an equal amount, the intersection of these curves implies a change in emission permit quantity but not price. The long-run credit market equilibrium price will equal the optimal marginal damage, just as in the cap-and-trade case ($P_c = P_b = D'(E^*)$). This occurs despite the fact that Figure 2.1 indicates that emissions and marginal damage are both clearly higher than optimal under the new baseline-and-credit equilibrium ($E(Q^b) > E(Q^*)$ and $D'(E^b) > D'(E^*)$).

[2]The effect of output on the MAC curve is explained in the first paragraph of this section.

2.4 Short-run versus Long-run

Using our terminology introduced in Chapter 1, we found that in a long-run scenario where firms can choose emission rates and change their output capacity, the baseline-and-credit scheme generates 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 efficient abatement first order conditions stated above are applicable.

According to the short-run first order conditions, (2.2), (2.11) and (2.14), 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 quantity cannot vary, the subsidy to output inherent to the baseline-and-credit plan has no effect other than increasing marginal profits. If output levels are fixed at the optimal cap-and-trade quantities, there is an incentive for baseline-and-credit firms to increase output; however, firms will be unable to do so. Therefore, in the short-run, when output is fixed at the optimal quantity, comparable cap-and-trade and baseline-and-credit emission trading mechanisms are predicted to have identical equilibria involving optimal levels of emissions and output. The answer to whether behaviour will steer firms into this equilibrium cannot be answered by theory alone. Permit and output market volatilities could conceivably result in troubled dynamics. Laboratory research is required to shed light on the predictions of the model.

It is important to realize that the term 'long-run' is not being used in the context of this work to infer the meaning commonly associated to it by economists. Typically, the long-run is a time frame during which entry to, and exit from, the industry is possible. The model presented in this chapter is set up to inform the first laboratory comparison of cap-and-trade emission trading with baseline-and-credit emission trading. The potential laboratory environment is sufficiently complex that entry and exit possibilities are unneeded at this initial stage. Future work in this area may be fruitful, however, as entry and exit of firms from a cap-and-trade regulated industry raises many questions concerning the institution of how permit endowments are allocated.[3]

Although not the focus of this dissertation, a brief discussion of the implications of our model with entry and exit is warranted. The entire theoretical model builds on the assumption of constant marginal costs in terms of output. This allows for a simple but rich model that can be tested in a laboratory setting. This constant marginal cost assumption implies that industry size, and hence associated firm size, is indeterminant in our model. Our model predicts only aggregate outcomes. While we know that the optimal equilibrium level of output is Q^* and that firms produce optimal aggregate emissions of $E^* = \sum_{i=1}^{N} {r_i}^* {q_i}^*$ in this equilibrium, we could have two firms in equilibrium, or two thousand. Most long-run economic models involve entry of firms until profits get driven to zero, but this model is quite different. Even though the theory in this chapter does not explicitly address entry and exit, the possibility of expansion and contraction of output capacity, in this constant marginal output cost environment, inherently considers the effects of entry and exit. Again, because of constant marginal costs, the firm's profit maximizing behaviour in selecting an output level will drive *marginal* profits to zero, as expressed by equations (2.12) and (2.15) for the respective plans. Under baseline-and-credit, this will also result in reducing *total* profit to zero. To obtain proof of this, substitute (2.15) into (2.13).

Cap-and-trade profits, on the other hand, are never driven to zero, even in the long-run. This can be demonstrated by substituting equation (2.12)

[3]The possibilities of auctioning or grandfathering permits, as discussed in Section 1.3, would surely have different repercussions in a regulated industry with firms entering and exiting as opposed to one without entry and exit.

and $P_c = D'(E^*)$ into equation (2.10), to find that equilibrium profit for firm i equals $D'(E^*)A_i$. This positive profit constitutes a windfall experienced by firms receiving grandfathered permit endowments.[4] Even with unimpaired entry to the cap-and-trade industry, the aggregate equilibrium windfall profit of $D'(E^*)E^*$ will never be affected in the model.

It should be highlighted that, in a short-run environment, when firm output is fixed at the optimal level (which is equal to the cap-and-trade long-run equilibrium level), aggregate equilibrium profit under both schemes will be identical. We have already demonstrated that $P_c = P_b = D'(E^*)$ is an equilibrium in the short-run permit market. The aggregate profit in the cap-and-trade industry will still remain at the level quoted in the paragraph above, i.e. $D'(E^*)E^*$, given that the short-run equilibrium is identical to the long-run equilibrium under cap-and-trade regulation. We have previously brought attention to the subsidy term inherent to all baseline-and-credit firm profit functions which implies that ERC firms are making positive marginal profit in the optimal equilibrium. The subsidy of $P_b q_i r^s$ per firm (derived earlier from equation 2.13) is aggregated to $D'(E^*)E^*$ once $r^s = \frac{E^*}{Q^*}$ and $P_b = D'(E^*)$ are substituted into firm i's subsidy equation. This suggests that, when output is fixed at the optimal level, aggregate accounting profits in the short-run cap-and-trade equilibrium are predicted to be equal to the aggregate accounting profits in the short-run baseline-and-credit equilibrium.

The fact that short-run profits are equal under both plans is not a coincidence and can be attributed to the imposition of an ERC performance standard equal to the average emission rate under the optimal cap-and-trade plan. This imposition causes the rents inherent to the induced supply of permits to be equal under both plans when output is fixed at the optimum.

[4] Auctioning the permits can potentially drive the windfall, and total profits, to zero.

Chapter 3

Creation of the Laboratory Environment

3.1 The Laboratory Environment

This chapter provides details on how the theoretical environment is implemented in a laboratory setting. Although the theory presented in Chapter 2 is based on a simultaneous decision of emission rate and output quantity, the laboratory environment detailed in this chapter is founded on a sequential decision-making model created in the spirit of the theory presented in Chapter 2. After raising the general issues surrounding implementation, details of the decision-making sequence, ERC implementation, accounting methods and graphical user interface will be discussed.

3.2 General Setup

To reiterate, we wish to investigate whether the theoretical predictions stated in Section 2.4 will hold in a laboratory trading environment characterized by greater institutional detail than the simple competitive theory of Chapter 2. In particular, our challenge is to test whether long-run equilibrium results will be obtained when both output and emission rights (allowances or credits) are traded in a fully specified institutional environment. From the onset of this work, we expressed the desirability of investigating behaviour, not only in the long-run, but also in a short-run setting where emission rates are variable but output capacity is fixed. We also identified the need to create a laboratory environment in which the operation of alternative emissions trading plans could easily be demonstrated to students and policy-makers. This lead us to reject the context-free framing of the typical laboratory experiment in favour of a context-laden framing in which subjects are told explicitly that they are trading emission rights and making output decisions.

Previous to Ben-David et al. (1999), fully specified experimental emission trading environments assumed fixed output levels and implicitly defined emission abatement technology choices (Muller and Mestelman 1994; Godby, Mestelman, Muller, and Welland 1997; Mestelman, Moir, and Muller 1999; Godby 1999).[1] 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) 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, permit volume and permit 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 add an explicit emission rate choice to allow them to

[1] Although some authors use the abstract concept of production technology that is *clean* or *dirty*, we attribute the general notion of a firm's emission abatement technology level to a firm's *emission rate*: the amount of pollution emitted for every unit of output produced.

distinguish between emission rate/technology choice errors and permit trading errors. This is crucial for attributing reasons for trading volume fluctuations.[2]

The experimental environment required to test our long-run and short-run predictions will need to be more complex than those from previously published work. It must be similar to the explicit emission technology implementation reported in Ben-David et al. (1999) with the addition of a market for output and the introduction of the concept 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.

At first, it might appear to be puzzling why both an output market and an explicit output capacity choice are required to test the long-run predictions declared in Chapter 2. These are both required in order to discern between outcomes originating from strategic actions and outcomes resulting from decision error. Simply adding an output market to the Ben-David et al. (1999) implementation results in an environment in which deviations in output quantity can be caused by strategic decision making, by emission rate choice errors or by permit trading errors. The latter two possibilities are associated with the fact that the quantity of permits required to be redeemed to the regulator depends on the firm's emission rate and output. If a firm makes an error and chooses a higher emission rate than intended, it may not have enough permits in inventory to produce its expected quantity of output. If a firm mistakenly purchases too few permits, or sells too many, this might also affect the output when the firm does not have sufficient permits in inventory to redeem.

[2]Ben-David et al. (1999) 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.

In order to focus on market features important to our theoretical predictions, the experimental setting necessarily abstracts from many additional market characteristics which exist in a naturally occurring setting. Failure to abstract could render the experimental setting too complex. Thus, we impose full compliance, abstracting from issues of penalties and monitoring.[3] For investigations of compliance in laboratory emission trading markets, the studies of Cason and Gangadharan (2004) and Murphy and Stranlund (2004) provide useful examples. We also assumed that quality of output is fixed and homogeneous between firms. Entry to and exit from the industry are not permitted.

In our framework, subjects are told that they represent firms producing output at a constant variable cost up to a fixed capacity of k units. Production of q units of output generates emissions at a rate of r emission-units per unit of output. Total emissions, e, are equal to rq. Total fixed cost, $c(r)k$, depends on the amount of capacity and the emission rate chosen. Therefore, actual output quantity determines how much pollution a firm emits, while output capacity influences a firm's total fixed cost. Emissions can be subject to cap-and-trade or baseline-and-credit regulation. Under the former, subjects receive a periodic allotment of allowances (an endowment). Under the latter, subjects are assigned a common emission rate performance standard, r^s.

The general form used for the unit capacity cost function, $c(r)$ is

$$c_i(r_i) = u_0 + (u_1 - u_0)[(r_{max} - r_i)/r_{max}]^{\alpha_i}. \tag{3.1}$$

[3]We impose compliance by not allowing firms to sell output if they do not own enough permits to cover the associated pollution. This is different from the method of forced compliance in the cap-and-trade experiment reported by Ben-David et al. (1999), who force the emission rate to change to the cleanest alternative that would allow the subject to fully comply. This method of forced compliance was not used in our implementation as it would distort the subject's emission rate choice, which is the focal variable in our rate-based baseline-and-credit treatment.

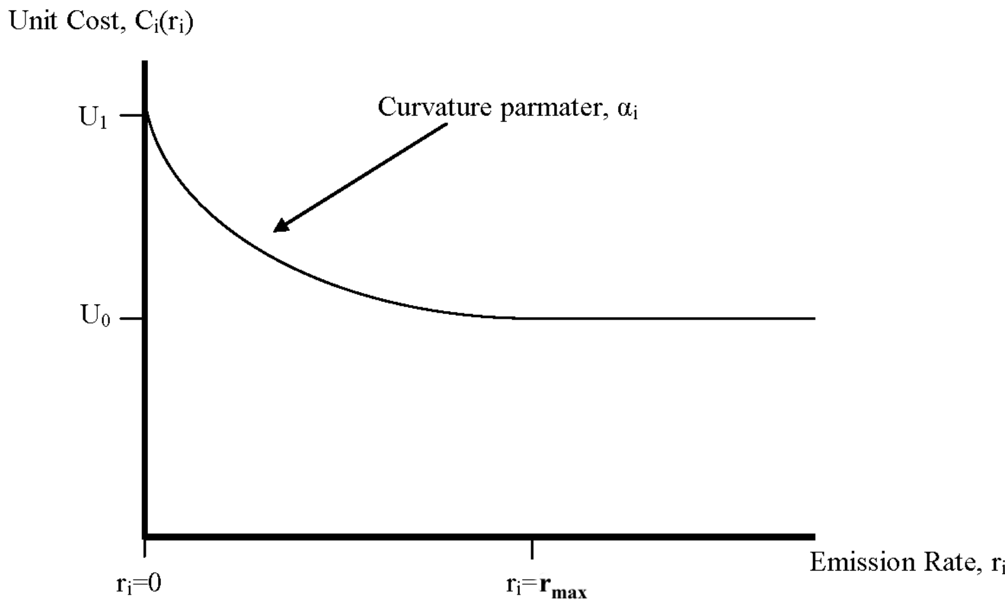


Figure 3.1: Unit Capacity Cost Function

This functional form meets the requirements of $c(r) \geq 0$, $c'(r) < 0$ and $c''(r) > 0$. Parameters u_1 and u_0 specify maximum and minimum unit costs, respectively, and α_i determines the curvature of the unit MAC curve. The functional form of the unit cost function is illustrated in Figure 3.1. To simplify the choices facing subjects, emission rates are restricted to *integer* values in the range $[0, ..., r_{max}]$, where r_{max} is the maximum emission rate. This restriction implies that the smooth cost curves of Figures 2.1 and 3.1 are replaced by step functions with steps equal to the difference in costs at consecutive integer values.

The laboratory environment is based on a population of eight firms, two of each of four cost types. Each firm has the same cost structure, but the parameters of the function itself are different for the four firm types. A spectrum of firm types rated on a scale from A, using the cleanest technology, to D, using the dirtiest technology, is defined. The dirty firms have lower uncontrolled unit costs compared to firms with the cleaner technology, $c_{dirty}(r_{max}) < c_{clean}(r_{max})$, but it is cheaper for the clean technology firms to abate pollution than it is for the dirty firms. This results in dirty firms having higher unit costs than the cleaner ones at the lowest emission rates, $c_{dirty}(0) > c_{clean}(0)$. To keep things simple, the unit variable cost is assumed to be zero, $w_i = 0 \ \forall i$ in our implementation. Exact parameter specifications and associated cost curves will be provided in Chapters 4 and 5.

In the environment created to test our theoretical propositions, allowances and credits are traded in a call market. The call market is a sealed bid-ask auction in which bids and asks are ordered in descending and ascending order respectively, a market clearing price is determined and all successful orders are traded at the market clearing price. Output is traded in a similar call market, except that the demand side is represented by a simulated demand curve. Financial results for each trading period are reported in a conventional accounting framework. Capacity has a fixed life of a specified number of periods, after which it must be replaced. Subjects can adjust the amount of output capacity at replacement time.

Even though emission trading theory is silent on the effect of market institutions, laboratory evidence demonstrates that market institutions affect market performance (Cason and Plott 1996).[4] 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.[5] Smith, Williams, Brat-

[4]See Davis and Holt (1993) and Kagel and Roth (1995) for a more extensive survey of the auction literature in general.

[5]The uniform price auction is very similar to the one used by the New York Stock Exchange to set daily opening prices based on bid and ask offers submitted prior to the market opening.

ton, and Vannoni (1982) report high efficiencies for this type of uniform price auction in the context of the traditional double-auction institution. Cason and Plott (1996) espouse the use of the uniform price auction with the EPA sulphur dioxide emission trading program. Since only marginal traders affect the market clearing price, this institution provides transparent incentives for most traders to reveal their true abatement costs. As discussed by Smith et al. (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.

3.3 Decision Making Sequence

Our theoretical framework, presented in Chapter 2, uses a simultaneous decision model where firms are expected to simultaneously select an output and an emission rate to maximize their profit in continuous time. Our original idea when creating a laboratory environment was to mimic this by having subjects choose a capacity level *and* an emission rate at capacity replacement time, but to hold emission rates constant over the life of the capital stock. This would reflect the idea that emission control is built into process design and that it can only be changed by major reinvestment. Subjects would then follow the decision pattern outlined as Algorithm 1.

Algorithm 1 *Simultaneous markets for emission rights and output*

```
repeat until end of experiment
    choose capacity (k) and emission rate (r)
    for each period in lifetime of capacity
```

```
submit bids and asks to emission right market
submit asks to output market
wait until output and emission rights markets clear
produce number of units sold in the output market
redeem emission rights
bank excess rights
```

We quickly concluded that this algorithm would be difficult to implement in a testbedding environment. There were at least two challenges. First, a firm's ability to produce output is constrained by the quantity of emission rights which it holds, but this amount depends on the result of the emissions rights market, which is unknown at the time output asks are submitted. To avoid default, subjects would have to hold a large inventory of rights or else have some means of obtaining rights in a reconciliation market. Second, and more importantly, fixing both capacity and emission rate renders the short-run demand curve for permits perfectly inelastic over the interval $0 \leq p_c \leq (P - c_i(r_i) - w_i)/r_i$. Small variations in capacity will then lead to rapid oscillations in allowance or credit prices and consequent instability in the output market. This algorithm is predicted to lead to behaviour contradicting the spirit of the model presented in Chapter 2 in which a firm's demand curve for permits is driven by their marginal abatement cost schedule.

To remedy these problems, we choose to operate the emission rights and output markets sequentially. We also allow emission rate to vary in every period even though capacity still has a fixed, multi-period lifetime. It is as if emissions could be controlled by short-lived capital investments in end-of-pipe treatment. Even with these modifications, we learned that the sequencing of events within each period must be conducted with care. For example, we tested a version of the model in which subjects sequentially chose their emission rates, bought and sold emissions rights, and then offered contracts in the output market. This sequence is captured in Algorithm 2.

Algorithm 2 *Sequential markets following emission rate choice*

```
repeat until end of experiment
    choose  capacity (k)
    for each period in lifetime of capacity
        choose emission rate
        submit bids and asks to emission right market
        wait until the emission rights market clears
        submit asks to output market
        wait until output market clears
        produce number of units sold in the output market
        redeem emission rights
        bank excess rights
```

Early simulations with robot traders quickly revealed that this sequence led to the same kind of unstable results we had obtained from Algorithm 1 because capacity and emission rate technology were already fixed when subjects were constructing bids and asks for the emission rights market. Consequently, we decided to reorder the sequence so that emission rates were set after the permit market was closed, as shown in Algorithm 3.

Algorithm 3 *Sequential markets, emission market precedes emission rate choice*

```
repeat until end of experiment
    choose capacity (k)
    for each period in lifetime of capacity
        emission rights are endowed if cap-and-trade
```

```
submit bids and asks to emission right market
wait until the emission rights market clears
choose emission rate
submit asks to output market
wait until output market clears
produce number of units sold in the output market
redeem emissions rights
emissions rights are created if baseline-and-credit
bank excess rights
```

Algorithm 3 is the basis for the final long-run simulations, which are reported in Chapter 4, and the short-run experiment with human subjects reported in Chapter 5. This algorithm was chosen because the emission permit market preceding the emission rate choice provides subjects with the incentive to bid and ask for permits using values along their marginal abatement cost curves, as suggested by the simultaneous choice model presented in Chapter 2. Early simulations also indicated capacity volatility due to every firm choosing capacity levels at the same time in an environment with constant marginal costs of output. Thus, capacity choice was staggered across firms in the long-run simulations presented in Chapter 4 so that only one firm decided if it wanted to change capacity each period. To further limit volatility and cycling behaviour in the environment, we restricted the ability to modify capacity to the possibilities of adding one to existing levels, subtracting one from existing levels, or leaving capacity unchanged. Figure 3.2 illustrates how the algorithm was implemented in detail.

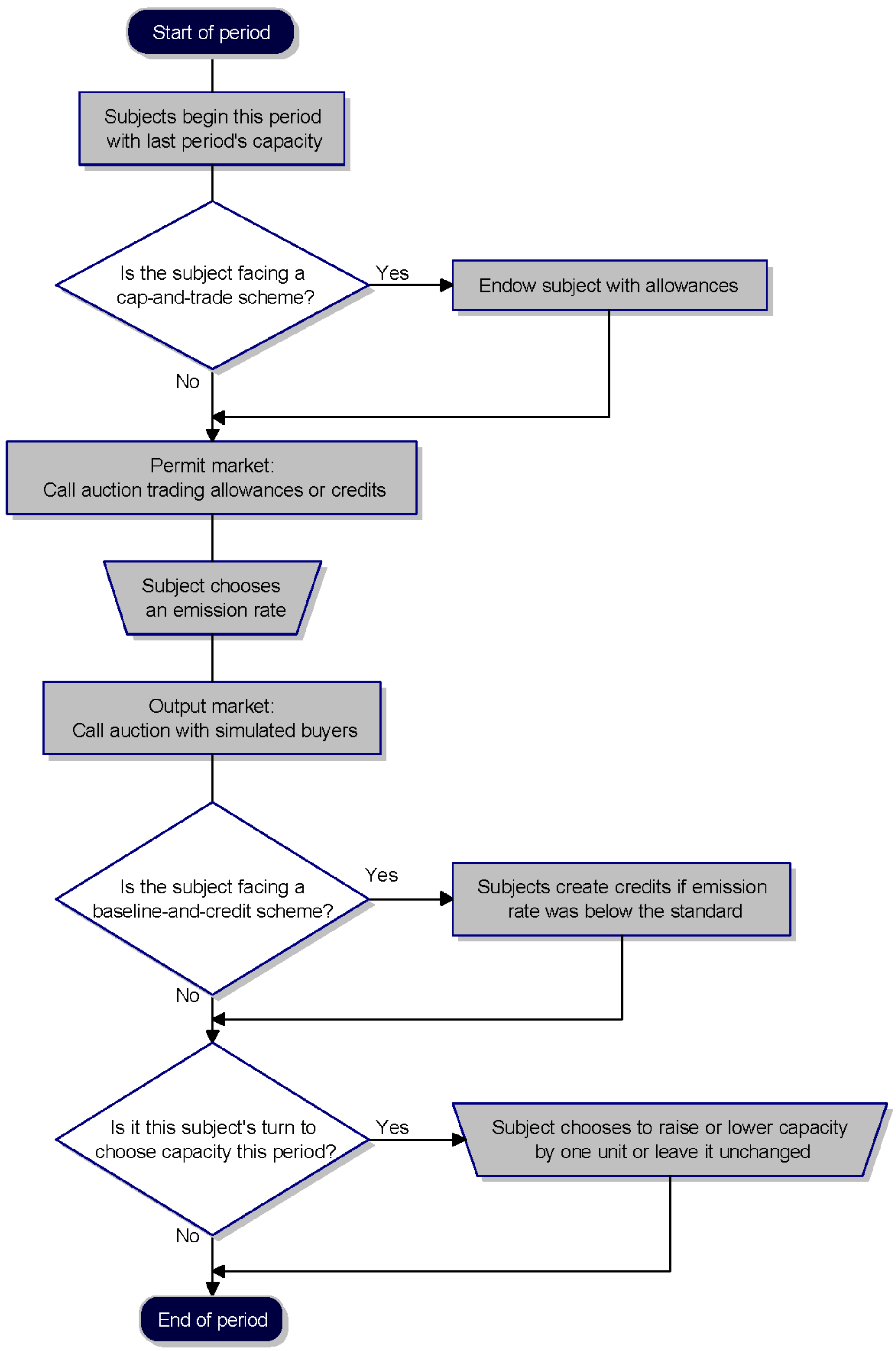


Figure 3.2: Sequence of Events

3.4 Eccentricities of ERCs

Algorithm 3 and Figure 3.2 also provide details of the sequencing of the endowment of allowances and the creation of emission reduction credits. Under our cap-and-trade implementation, a constant quantity of allowances is given to each firm at the very beginning of each period. This sequencing allows subjects to buy and sell allowances before choosing an emission rate. The relative framing imposed by the performance standard of baseline-and-credit regulation implies that emission rate must be decided before it is known whether the firm will be required to redeem credits or if, instead, it will create them. Furthermore, the emission rate and quantity of output sold must be known before the quantity of credits redeemed or created can be determined. The prerequisites of ERC regulation require that credits created by choosing emission rates below the standard can only be created at the end of the period, at the time when permits must be redeemed. This creates a fundamental difference in the way these schemes can be implemented. For instance, a cap-and-trade firm that expects to choose a low emission rate this period can sell unneeded permits (those made available by intending to choose a low emission rate) this period. However, a baseline-and-credit firm with the same intentions cannot create credits (by choosing a low emission rate) until the end of the period, and the credits created by this period's action cannot be sold until next period. Thus the baseline-and-credit implementation must possess an inherent lag that does not exist under cap-and-trade.

While a fabricated lag could be added to our cap-and-trade implementation to make the two plans comparable, we decided that mimicking real-world regulation was of greater importance. While international cap-and-trade systems have been implemented, or plan to be implemented, in a fairly straightforward manner, emission reduction credit schemes are often project-based. That is, firms must get the regulator to validate credit creation on a project-by-project basis by convincing them that a specific action taken by the firm has resulted in reduced emissions from baseline levels. The PERT project (PERT 1997) and the recent "cap, credit and trade" hybrid trading program in Ontario (OMOE 2003) both require validation of a firm's identifiable action to reduce emissions before credit creation is realized. The credit creation lag generated by the logistics of sequential decision making in our laboratory environment is an unforseen benefit since it mimics an important attribute of real-world baseline-and-credit emission trading regulation not found in cap-and-trade regulation.

One last noteworthy point regarding credit creation is the implication of a permanent versus a temporary reduction in emissions. As discussed in Section 1.2, some trading regulations, such those surrounding the U.S. NSPS in the 1970s, only give credit to permanent reductions in emissions while others, such as recent baseline-and-credit plans in Ontario, allow credits to be created from temporary emission reductions. Our laboratory emission trading implementation involves subjects choosing emission rates every period and each period's credit creation depends on the emission rate chosen that period only. Whether the emission rate is permanently lowered or only temporarily lowered for a few periods is irrelevant. Thus, the implemented baseline-and-credit environment is similar to the ERC program instituted in Ontario in that temporary emission reductions qualify for created credits.

3.5 Accounting Rules for Emission Permits

As introduced in Section 1.4, the IFRIC of the International Accounting Standards Board has drafted an interpretation of how firms should account for emission rights. After this comment was publicly posted in May 2003, the committee received many letters of concern indicating that the interpretation may misrepresent and cause artificial volatility of profits and losses. In response, the IFRIC explored alternative interpretations to the emission right accounting issue and posted details behind the drafting of a revised accounting interpretation. However, with the European Union emissions trading scheme coming into force at the beginning of 2005 and given the need for standardized accounting practices for that scheme, the IFRIC later decided that the advantages of providing timely accounting guidance outweighed the disadvantages associated with the original drafted interpretation. At its September 2004 meeting, the IFRIC decided to forego drafting a revised interpretation in order to quickly finalize the original interpretation it had drafted in May 2003.[6]

Although, as mentioned, the IFRIC posted some details on an unofficial revised accounting method that did not possess the disadvantages of the original accounting interpretation, it is the original accounting method that was programmed into our laboratory software. From a policy perspective, this allows us to comment in later chapters on behaviour in an emission trading environment that uses accounting methods similar to those that will be used in the European Union, and around the world, as of 2005. The subsections below provide details on the original IFRIC interpretation, provide examples of how it was implemented in our environment and highlight some potential problems with the method.

3.5.1 Accounting Implementation and the IFRIC

Table 3.1 provides a listing of the various accounts used by the emission trading software created for this dissertation. The asset, liability, and net worth accounts are balance sheet items, while income and expense accounts,

[6]The full details of the IFRIC interpretation are attached as Appendix B (Source: International Accounting Standards Board Website, www.iasb.org.)

Table 3.1: List of Accounts

Account Number	Account Name	Account Type
11	Cash	A
12	Allowance Inventory	A
13	Credit Inventory	A
14	Fixed Plant	A
15	Accumulated Depreciation	A
21	Bank Loans	L
31	Net Worth	Q
41	Output Sales	I
42	Allowance Sales	I
43	Allowances Received	I
44	Credit Sales	I
45	Credits Received	I
51	Materials Expenses	E
52	Allowance Expenses	E
53	Credit Expenses	E
54	Depreciation Expenses	E
55	Cost of Allowance Sales	E
56	Cost of Credit Sales	E
61	Net Income	S

Note: A, L, Q, I, E and S denote asset, liability, net worth, income, expense, and summary accounts, respectively.

along with the net income account, are income statement items. Actions and events that occur in the experimental environment translate into debit and credit double-entry bookkeeping records that are inserted into a ledger database. These entries not only provide a means for the software to keep track of subject decisions but they also provide a familiar way to present subjects with relevant information regarding the status of the experiment at any given time. This allows us to provide subjects with helpful tools such as income statements and inventory flow breakdowns (i.e. quantity endowed, bought, sold, created, redeemed) in each period.

Accounting entries that do not directly involve emission permits are relatively straightforward. For instance, if a subject decided on an output capacity and emission rate for the period and total fixed cost associated with the decision was $c(r)k = 900$, then the accounting entry

Action	Account	Amount
DEBIT	FIXED PLANT	900
CREDIT	CASH	900

would be entered into the ledger table for that subject during that period.

Accounting entries related to emission rights are a little more complicated. Do emission permits have any value if they are held in inventory? Should permit inventories be valued at the price paid for them? How should endowed allowances and created credits be treated? To answer these questions, in May 2003 the IFRIC drafted an interpretation of how to account for emission permits. The draft interpretation suggested that emission rights be treated as *intangible assets*. This entails that endowed allowances and created credits should enter the books as an asset at *fair value*.[7] It is also implied that, when emissions are generated, each required permit should be surrendered at the average value of permits in inventory.

The intangible asset rule suggested by the IFRIC is actually a little more complicated than summarized above. The interpretation also calls for periodic re-evaluation of the permit inventory on the balance sheet when value fluctuations between the book value and the current market value for permits occur. The re-evaluation is recorded as a ledger entry adjustment to the permit inventory and equity accounts that appear on the balance sheet. Table 3.2 illustrates a simple example of what ledger entries in our environment might

[7] We interpret fair value to be the current market price of permits.

Table 3.2: IFRIC Draft Interpretation Example

Period	Action	Account	Statement*	Amount	Balance
1.1	DEBIT	Allowance Inventory	B	900	900
	CREDIT	Allowances Received	I	900	900
	Endowed with 90 permits, last market price was 10 each.				
1.2	DEBIT	Allowance Inventory	B	200	1100
	CREDIT	Cash	B	200	-200
	Purchased 20 permits at a price of 10 each this period.				
1.3	DEBIT	Cash	B	1000	800
	CREDIT	Output Sales	I	1000	1000
	DEBIT	Allowance Expenses	I	900	900
	CREDIT	Allowance Inventory	B	900	200
	Sold/produced output causing 90 units of emissions for 1000.				
1.4	DEBIT	Allowances Received	I	900	0
	DEBIT	Output Sales	I	1000	0
	CREDIT	Allowance Expenses	I	900	0
	CREDIT	Net Income	I	1000	1000
	Close all income and expense accounts to net income.				

*Note: 'statement' values of 'B' and 'I' denote whether the account appears on the balance sheet or income statement, respectively.

look like over a few periods under a cap-and-trade plan. The example assumes total fixed cost to be zero in order to focus on the permit accounting.

With reference to Table 3.2, let us suppose that the market price for permits was 15 in period 1 instead of 10, and 20 permits were still purchased. This would cause line 1.2 to change to the entry shown in Table 3.3. If permit inventories were re-evaluated every period using accounting standards associated with intangible assets, we would need to insert a journal entry like the one on line 1.25 in Table 3.3. Since this adjustment only involves balance sheet items, the income statement is left unaffected by this entry.

Table 3.3: Additional Entries for IFRIC Example

Period	Action	Account	Statement*	Amount	Balance
1.2	DEBIT	Allowance Inventory	B	300	1200
	CREDIT	Cash	B	300	-300
	Purchased 20 permits at a price of 15 each this period.				
1.25	DEBIT	Allowance Inventory	B	450	1650
	CREDIT	Net Worth (Equity)	B	450	450
	Adjusted inventory due to price change from 10 to 15.				

*Note: 'statement' values of 'B' and 'I' denote wether the account appears on the balance sheet or income statement, respectively.

3.5.2 Problems with the IFRIC Implementation?

As anticipated earlier, the balance sheet focus of an intangible asset could create misleading income statements due to a mismatching in the accounting of assets with profits and losses. The specific concern was that changes in the value of permit inventory is recognized in equity while changes in the value of permit redemption obligations influences profits and losses on the income statement. This asymmetry was predicted to create artificial volatility of reported profits and losses. This will not be a problem with our laboratory implementation since changes in the value of permit obligations are not possible: firms in our environment are forced to redeem permits immediately upon sale of output and hence permit price cannot change between the time the obligation is created and the time at which it must be rendered.

At its meeting in December 2003, the IFRIC posted intentions to draft an amendment that emission rights should instead be reported in a fashion similar to currency (since they have value only to be used to settle an obligation), in that they should be measured at fair value with changes in value recognized as profit or loss on the income statement. This revision would imply that the credit to net worth for 450 in line 1.25 of the example in Table 3.3 above, should instead be a credit of 450 to net income. This rule change would make changes in inventory value apparent on the income statement. As mentioned above, the IFRIC has decided to abandon this proposed amendment and finalize the interpretation as originally drafted.

Although not documented by the IFRIC, there appears to be another factor, inherent to both the intangible asset and currency proposals, which could potentially cause a misrepresentation of profits and losses due to differences between income statement items and balance sheet items. Buying permits and adding them to inventory without redeeming them during a period does not affect the income statement, though it undoubtedly lowers cash balances. This is simply a redistribution of cash assets to intangible inventory: a simple shift of equity from one asset to another. According to both accounting interpretations documented above, initial purchases of permits are entered into the balance sheet at fair value. For an example, see Table 3.2. The accounting entries show that net income is 1000 at the end of the period (900 from the endowment plus 1000 from the sale of output minus 900 for the value of permits redeemed to the government), which is unaffected by the purchase of 200 worth of permits that are kept in inventory for the next period.

The alarming fact about this mismatching between balance sheet and income statement items is that it might adversely affect firm behaviour. For instance, according to the income statement generated in Table 3.2, the firm might believe that its actions were a success; after all it generated 1000 in net income. This could potentially cause the firm to continue adopting the same strategy every period which could very likely result in the firm holding large amounts of permit inventories for no reason. Even if the firm later identifies the problem and sells these inventories on the market, the permits, due to the increased supply, will likely sell at prices much lower than the firm had initially paid for them.

To clarify, profits or losses associated with purchased permits will not appear on the income statement until the period they are either sold or used (at which point an entry similar to lines 1.3 and 1.4 in Table 3.2 will be made). Therefore, a subject who repeatedly purchases permits and keeps them in inventory each period will appear to be doing nothing wrong according to the income statement; however, if the subject does not use or sell the entire inventory for an extended period of time, large losses could occur. Of course, buying permits and not using or selling them will also affect cash holdings but, again, this asset account is not part of the income statement.

The possible problem discussed over the last few paragraphs is a behavioural one. Subjects who rely on the income statement for guidance without paying attention to balance sheet items, like permit inventories and cash, might be mislead by the accounting rules implemented based on the IFRIC standards. Although, the computer software created for this dissertation does provide subjects with all the information needed to make informed rational decisions. Whether the accounting rules that influence the income statement will influence human behaviour in our emission trading environment is a question left to be answered by the laboratory sessions reported in Chapter 5.

3.6 Computer Software and Graphical User Interface

In order to meet the needs of this research project we needed to create a program that was flexible enough to implement our short-run and long-run environments and be open to new possibilities stemming from different streams of research into alternative emission trading plans and the institutions surrounding them. The software was programmed at the McMaster Experimental Economic Laboratory, using Borland's Delphi object-oriented programming language. The software uses a common client-server distinction passing networking messages using the standard internet protocol. The client and server programs were written with a modular design so that components could be easily interchanged. Both client and server programs store data in a common MySQL database. MySQL provides a robust open source database that can handle concurrent accessing of data within many tables. To guide subjects through a relatively complex series of decisions and events, an elaborate user interface was programmed into the laboratory software created for this dissertation.

Figure 3.3 shows the Allowance Order Form. On the right hand side of the window, the Dataview Form allows the subject to view tables recording capacity, permits, market data and income statements. The Planner tab, shown in the figure, reports details on the subject's capacity and emission rate in the previous period, as well as results from the output market and cash holdings. The planner tab also contains a Cost Calculator Panel which can be used to compute the various components of cost at different levels of output and emission rates. On the left hand side, the Allowance Order Form allows subjects to enter bids or asks for emission rights. Up to three bids and three asks can be specified, each for a different price.

Figure 3.4 presents the Output Order window and the Income Statement tab of the Dataview Form. The income statement shows the financial results reported at the end of each period. Revenues from sales of output and of emission rights are booked at transaction value. Revenues also include the implied value of allowances received. These have been booked at the latest market price. The cost of goods sold includes materials costs, the cost of emission rights used in production and the book value of emission rights sold.

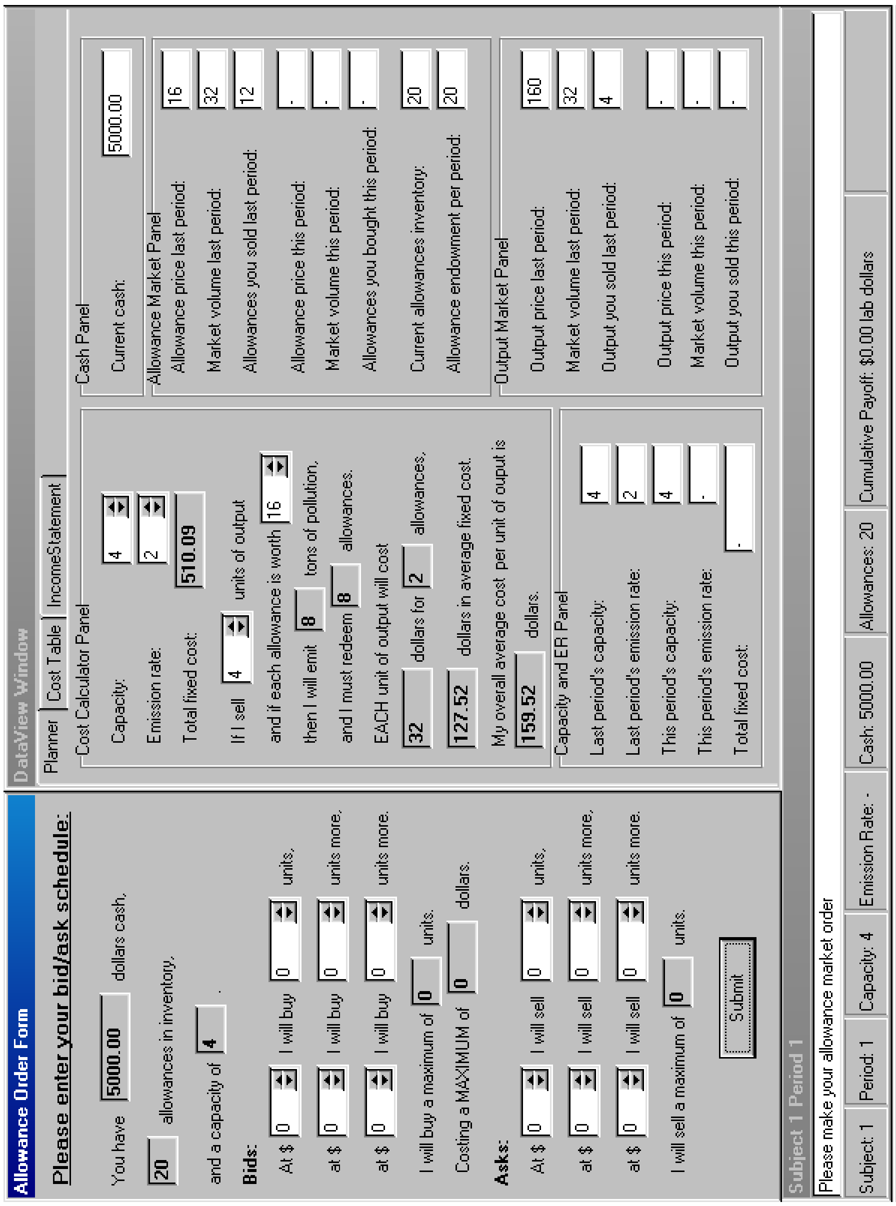


Figure 3.3: Allowance Order Form

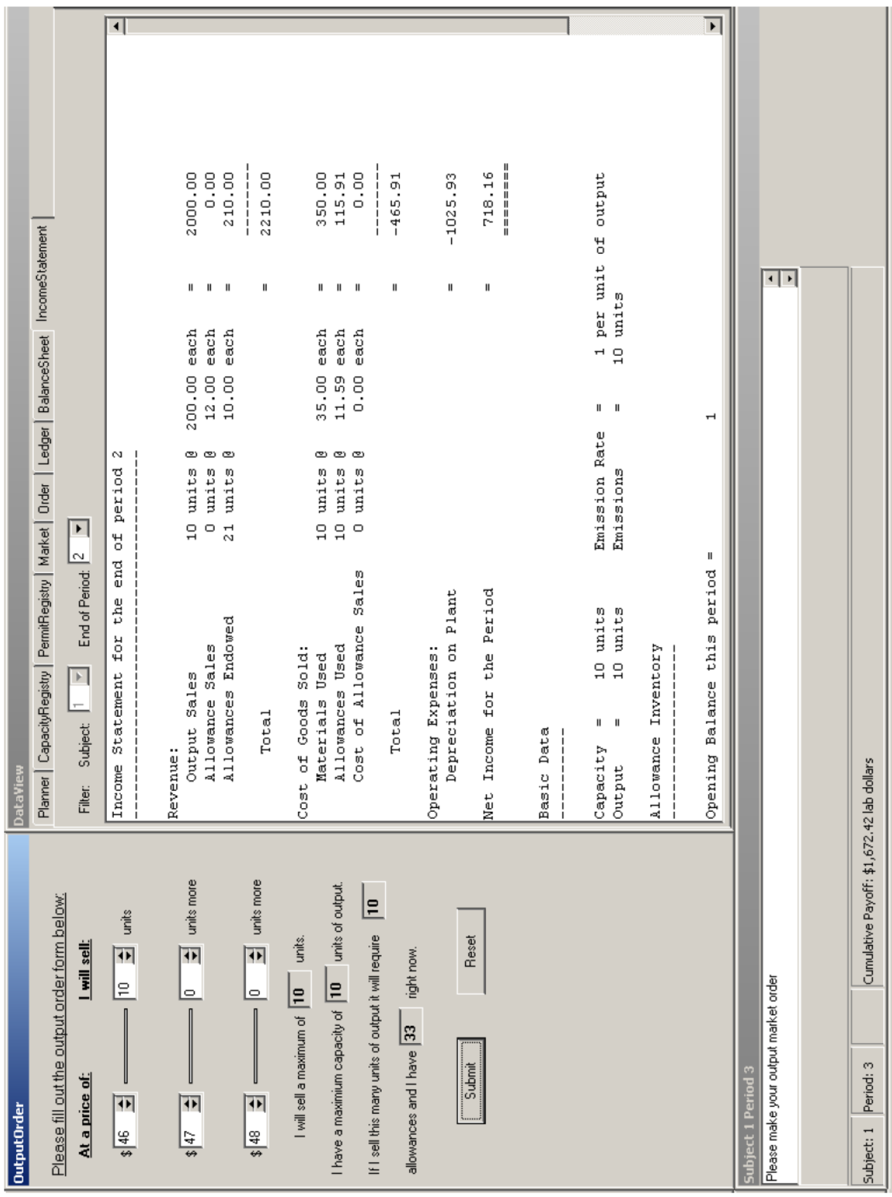
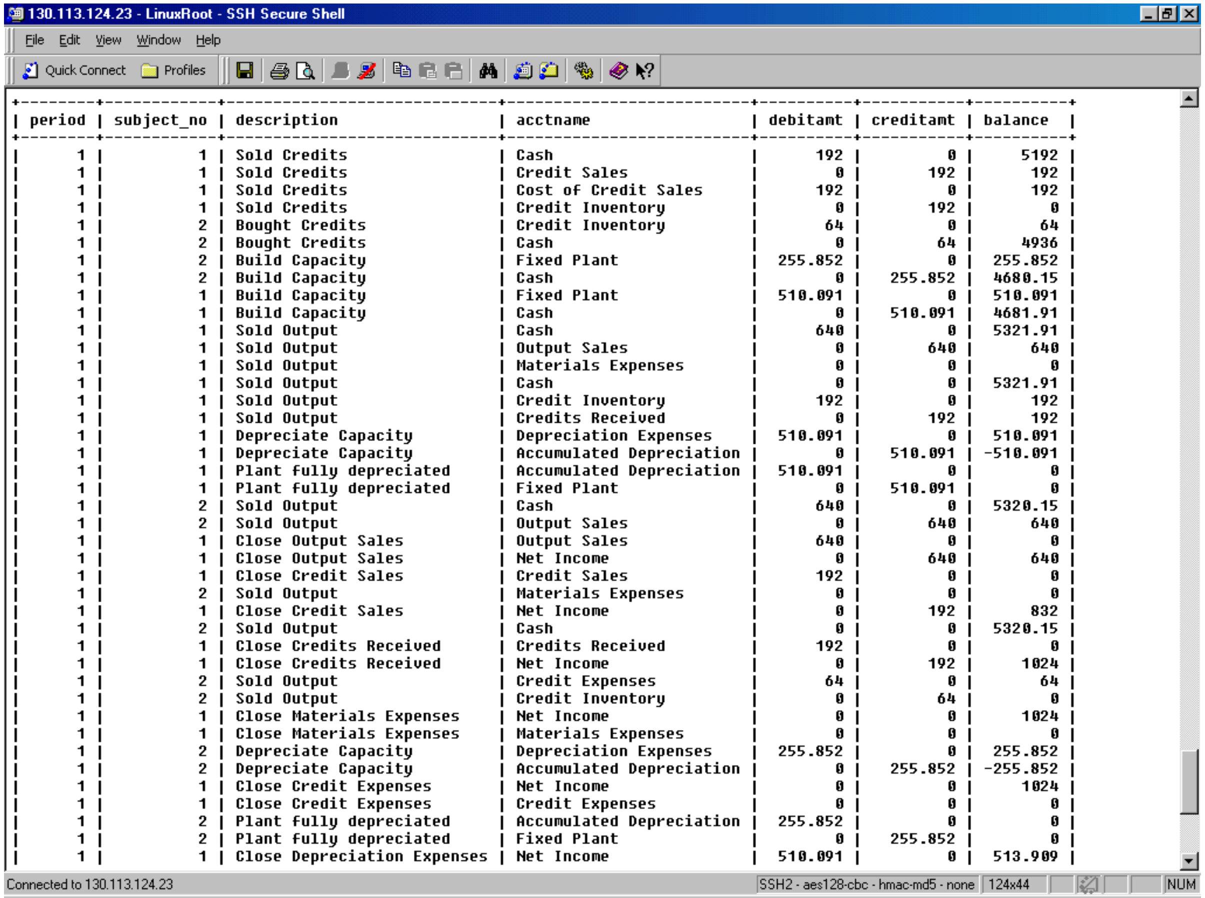


Figure 3.4: Income Statement Window



period	subject_no	description	acctname	debitamt	creditamt	balance
1	1	Sold Credits	Cash	192	0	5192
1	1	Sold Credits	Credit Sales	0	192	192
1	1	Sold Credits	Cost of Credit Sales	192	0	192
1	1	Sold Credits	Credit Inventory	0	192	0
1	2	Bought Credits	Credit Inventory	64	0	64
1	2	Bought Credits	Cash	0	64	4936
1	2	Build Capacity	Fixed Plant	255.852	0	255.852
1	2	Build Capacity	Cash	0	255.852	4680.15
1	1	Build Capacity	Fixed Plant	510.091	0	510.091
1	1	Build Capacity	Cash	0	510.091	4681.91
1	1	Sold Output	Cash	640	0	5321.91
1	1	Sold Output	Output Sales	0	640	640
1	1	Sold Output	Materials Expenses	0	0	0
1	1	Sold Output	Cash	0	0	5321.91
1	1	Sold Output	Credit Inventory	192	0	192
1	1	Sold Output	Credits Received	0	192	192
1	1	Depreciate Capacity	Depreciation Expenses	510.091	0	510.091
1	1	Depreciate Capacity	Accumulated Depreciation	0	510.091	-510.091
1	1	Plant fully depreciated	Accumulated Depreciation	510.091	0	0
1	1	Plant fully depreciated	Fixed Plant	0	510.091	0
1	2	Sold Output	Cash	640	0	5320.15
1	2	Sold Output	Output Sales	0	640	640
1	1	Close Output Sales	Output Sales	640	0	0
1	1	Close Output Sales	Net Income	0	640	640
1	1	Close Credit Sales	Credit Sales	192	0	0
1	2	Sold Output	Materials Expenses	0	0	0
1	1	Close Credit Sales	Net Income	0	192	832
1	2	Sold Output	Cash	0	0	5320.15
1	1	Close Credits Received	Credits Received	192	0	0
1	1	Close Credits Received	Net Income	0	192	1024
1	2	Sold Output	Credit Expenses	64	0	64
1	2	Sold Output	Credit Inventory	0	64	0
1	1	Close Materials Expenses	Net Income	0	0	1024
1	1	Close Materials Expenses	Materials Expenses	0	0	0
1	2	Depreciate Capacity	Depreciation Expenses	255.852	0	255.852
1	2	Depreciate Capacity	Accumulated Depreciation	0	255.852	-255.852
1	1	Close Credit Expenses	Net Income	0	0	1024
1	1	Close Credit Expenses	Credit Expenses	0	0	0
1	2	Plant fully depreciated	Accumulated Depreciation	255.852	0	0
1	2	Plant fully depreciated	Fixed Plant	0	255.852	0
1	1	Close Depreciation Expenses	Net Income	510.091	0	513.909

Figure 3.5: Example Accounting Entries

Depreciation on fixed capital and net income for the period is also reported. Figure 3.5 shows the types of accounting ledger entries that the experimental software generates from subject choices.

Full documentation of the final version of the software created for this project is contained in Appendix E.

Chapter 4

Long-run Implications of Alternative Emission Trading Plans: An Experiment with Robot Traders

4.1 Introduction

Theoretical considerations discussed in Chapter 2 suggest the long-run equilibria of cap-and-trade and baseline-and-credit regulation will differ because the performance standard in a baseline-and-credit plan embodies a variable emissions baseline linked to output, which is equivalent to an output subsidy. Compared to a cap-and-trade plan with the same average emission rate, the baseline-and-credit plan will exhibit higher output and emissions. Thus, baseline-and-credit plans entail an inherent efficiency loss.

Although the theoretical prediction is reasonably straightforward, it relies on competitive equilibria being realized in two interrelated markets: the market for output and the market for emission permits. Laboratory methods are ideal to test emission trading theory in real markets. Laboratory markets can be created 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.

Testing the two competing trading mechanisms requires a relatively complex, fully specified experimental environment.[1] Chapter 3 provides details of the laboratory implementation based on the theoretical environment from Chapter 2, and how it is different from that used in previous emission trading studies cited in Chapter 1.

This chapter reports on the progress of a major research program designed to testbed basic forms of the cap-and-trade and the baseline-and-credit methods of emissions trading, particularly to test whether the predicted difference in emissions levels will actually be realized. We use robot traders programmed with myopic profit maximization principles to simulate a long-run experiment to test whether the predicted long-run equilibria are realized. We begin by summarizing the predicted outcomes. Secondly, we discuss the parameters used and their associated equilibrium predictions. Fourth, we describe the strategies programmed into the robot traders. Fifth, we report the results of simulations run under a long-run setting. Lastly, we conclude with discussion and speculation.

4.2 Theoretical Analysis

Previous theoretical literature investigating alternative emission regulations were primarily focused on the cost minimizing, profit maximizing and generally efficient nature of cap-and-trade style institutions over rate-based baseline-and-credit institutions (Thomas 1980; Helfand 1991; Dewees 2001). The theoretical studies of Fischer (2001, 2003) are rather different in that they focus on comparing cap-and-trade with baseline-and-credit regulation in a partial equilibrium framework. This framework, involving simultaneously

[1] A fully specified experimental environment is required because differences between the alternative emission trading plans involve interaction between permit and output markets.

determined emission rate and output, provides a good starting point for an experimental environment.

Chapter 2 presented a multi-firm partial equilibrium model based on work by Fischer (2001, 2003). We summarize the long-run theoretical predictions spelled out in Chapter 2 in the following propositions.

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

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

Section 4.3 provides details of the parameters used in the simulations and provides specific equilibrium predictions associated with them that are consistent with Propositions 1 and 2.

4.3 Parameters and Implementation

The experimental environment depends on various parameters: the slope and intercept of the linear demand curve for output, the shape of the unit capacity cost curve, allowance endowments, performance standards, initial holdings of cash and emission rights and, of course, the number of firms in the market. This section details the functional forms and environmental parameters involved in our laboratory implementation of the basic environment discussed in Chapter 3.

For the simulated sessions reported in this chapter, we chose an exogenous inverse demand curve with equation $P = 100 - Q$. To keep things simple, the unit variable cost is assumed to be zero, $w_i = 0 \; \forall i$. As stated in Chapter 3, the laboratory environment is based on a population of eight firms, two of each of four cost types. A spectrum of firm types rated on a scale from A, using the cleanest technology, to D, using the dirtiest technology, is used. Type D firms have the highest marginal abatement costs. The general form used for the unit capacity cost function, as stated in Chapter 3, is

$$c_i(r_i) = u_0 + (u_1 - u_0)[(r_{max} - r_i)/r_{max}]^{\alpha_i}. \tag{4.1}$$

Parameters u_1 and u_0 specify maximum and minimum unit costs, respectively, and α_i determines the curvature of the unit MAC curve. Emission rates are restricted to *integer* values in the range $[0, ..., r_{max}]$, where r_{max} is the maximum emission rate. Due to the relatively complex nature of the experimental environment, r_{max} is set equal to 3 for the simulations. This implies that the relevant marginal abatement cost curves will be step functions based on the discrete difference in the $c_i(r_i)$ function above for values of r_i equal to 0, 1, 2 and 3. This allows enough variation that each of the four firm types can have a separate equilibrium emission rate and provides more choices than the three technology level possibilities in the Ben-David et al. (1999,2000) environment. Table 4.1 shows the parameter values for each of the four firm types.

For cap-and-trade treatments, allowances equal to the optimal emissions are distributed between the firms, while for baseline-and-credit treatments the emission rate standard is chosen to be the average emission rate implied by the optimal amount of emissions and optimal quantity of output. Table 4.2 shows the theoretical predictions of the model using these parameters. Since a total of 24 units of output and 24 units of emissions result from the optimal

Table 4.1: Long-run Cost Parameters

Firm Type	u1	u0	α	w_i	Optimal Emission Rate	C&T Endowment	B&C Performance Standard
A - Lowest MAC	76	65	3	0	0	2	1
B - Lower MAC	89	59	3	0	1	4	1
C - Higher MAC	90	59	3	0	2	4	1
D - Highest MAC	269	52	3	0	3	2	1

Table 4.2: Long-run Predictions

Trading Institution	Price of Allowances or Credits	Output Price	Aggregate Output	Aggregate Emissions	Active Firm Types
Uncontrolled	-	52	48	144	D
B&C	8	68	32	32	A,B,C,D
C&T (Optimal)	8	76	24	24	A,B,C,D

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

cap-and-trade equilibrium, these values correspond to the optimal average emission rate of one, and are reflected by the performance standard of one imposed in the baseline-and-credit case. While firms can produce optimal levels of output by choosing an emission rate of one without trading, this will not be cost minimizing. Trading permits and choosing the optimal emission rates displayed in Table 4.1 will be efficient under both plans.

Notice from Table 4.2 that aggregate output and emissions are higher in the baseline-and-credit equilibrium than under the cap-and-trade equilibrium. The predictions presented in the table highlight the fact that only type D firms will survive in the uncontrolled equilibrium. It is the minimum uncontrolled unit capacity costs of type D firms that allow them to out-compete the other firm types by driving output levels so high, and corresponding output prices so low, that the other firms cannot cover their costs. While output and emissions are both predicted to be equal to 24 under cap-and-trade and 32 under baseline-and-credit, uncontrolled output and emissions are predicted to be 48 and 144, respectively. Uncontrolled equilibrium aggregate emissions are 144 since output is predicted to be 48 and emission rates are predicted to be 3; there are no cost savings if firms choose emission rates above 3.[2]

4.4 Robot Traders

As a first step to test our software, we created robot strategies to make the decisions required of human subjects. Although the primary focus of these experiments is not to create artificial intelligence traders that operate exactly the way humans would, we do want to incorporate decision rules that are both simple and reasonable. The purpose of the robots is to test the logic of the software, to illustrate the interactions between the markets, and, lastly, to primitively simulate results of experiments. We assume our robots to be price-takers that use profit maximization principles when making decisions and to have myopic expectations that future values will be equal to past values. Details are reported in the following paragraphs.

4.4.1 Permit Market Strategy

The first event in a typical period is the call market for allowances or credits. This takes place under a fixed capacity for producing output, but before an emission rate has been chosen for the period. Since the emission rate is unknown, a bid and ask strategy that reveals the robot's entire demand

[2]In fact, the experimental software ensures that emission rates are not able to exceed r_{max}.

and supply schedule for emission rights is constructed, allowing for an optimal subsequent choice of emission rate. The exact bids and asks depend on the firm's established capacity and on its inventory of allowances or credits. The robot assumes that output will be at capacity because it takes output price as given and it has constant marginal cost. The firm will make a bid or an ask for each possible selection of emission rate, r. The robot considers each emission rate, from 0 to $r_{max} = 3$ in succession, deciding whether it will need to buy emission rights to reach this goal or whether it will have excess to sell off. If allowances or credits need to be bought, the robot submits a bid for the required amount, net of any previous amounts needed to achieve previously considered emission rates, at a price equal to the unit cost increase of lowering its emission rate by one unit. If the robot has allowances or credits to sell at the considered emission rate, the extra permits beyond what would be needed at the previous emission rate are priced at the cost savings of raising the emission rate by one unit. That is, the robot prices bids and asks at the firm's marginal abatement cost. The bids and asks generated from this algorithm are profit maximizing in that any price outcome in the market results in the robot buying or selling the proper quantity of permits in order to be able to produce and sell the maximum capacity of output at an optimal emission rate. This results in the robots bidding and asking along their marginal abatement cost curve.

Before considering the next phase, we shall investigate how these decisions differ between our two emission trading institutions. Under a cap-and-trade scheme, the above robot rationality implies that allowances are priced at their *use* value. This signifies that allowances are priced using their cost savings during the current period since allowances can be used to choose higher emission rates with lower associated capacity costs. Under a baseline-and-credit regime there is a unique problem. Using the above stated rule, a firm's first credits are priced at their cost which is the cost increase of reducing its emission rate one unit *below* the emission rate standard. However, these credits were produced at the end of last period. One might argue that the cost of creating the credits during the preceding period is sunk and that, in this period they have a value equal to the cost decrease of being able to increase the emission rate one unit *above* the standard. In a continuous time simultaneous decision making model like the one presented in Chapter 2, the issue of sunk costs does not arise. In our own environment, we program robots with the original rationality. This assumption seems to be a good fit with our implementation, as credits would not be created in the first place unless subjects intended to sell them with a specific reservation price in mind.

The issue discussed in the previous paragraph is similar to the general distinction between production in advance and production to demand. When comparing these two models of production, do we expect agents to price inventory at marginal cost under advance production assumptions, or do we expect agents to treat the production as a sunk cost and price their inventory at zero? 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.[3] However, the authors conclude that the two production models generate similar price distributions and prices under advanced production are significantly higher than the price of zero suggested by the sunk cost theory.

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

4.4.2 Emission Rate Choice Strategy

In the next phase of the experiment, each subject must choose an emission rate. Since our robot is a profit maximizer, it simply chooses the discrete value of r between 0 and r_{max} which yields the highest expected profit. Since the robot is assumed to have myopic static expectations, this strategy amounts to the robot simply choosing r so that its $MAC_i(r_i)$ equals the price of allowances or credits from the current period.

The robot does face a few restrictions. First, total capacity cost at the chosen emission rate must be affordable. If it is not, the robot is programmed to choose the lowest emission rate that is affordable. Secondly, if the robot did not sell its entire capacity last period, the robot will definitely not choose to increase its emission rate from last period, due to the possibility that the shortfall in output was caused by the inability of the robot to procure enough permits.

4.4.3 Output Market Strategy

Next in the sequence of events, the output market uses a call market mechanism to elicit a supply curve from subjects. Since capacity and emission rate have already been chosen for the period, the unit capacity cost is sunk at this point, therefore, robot traders are programmed to price their output at total marginal variable cost. Therefore, in our simulations, the output is priced at the variable cost $w_i = 0$ plus the value of the required allowances or credits evaluated at their *cost-basis*.

The firm's cost-basis is the average value of allowances or credits that has been entered in inventory. Each time an allowance or credit is bought, its price augments the cost-basis. When emission rights are used, or sold, they are removed from inventory at the current cost-basis value. This rationality is similar to that detailed in Section 4.4.1. At this price, the robot sells the maximum quantity of output possible, constrained by capacity and permit holdings. If the robot is facing a baseline-and-credit plan and if the robot's emission rate is lower than the emission rate standard, credits are being created. These created credits are evaluated at the current period's market price and act as a subsidy entering as a negative term in the price of the output offer.

4.4.4 Capacity Choice Strategy

The last decision a subject is required to make in a period is to choose a capacity. To allow for a simple design which does not require robots to consider whether other robots are changing capacity at the same time, it was decided that each of the eight firms would choose capacity in separate periods. When testing our decision sequence algorithm, we found that various simultaneous capacity decision setups produced instability and cycling which disturbed the convergent properties of the basic theoretical equilibrium. To solve this incompatibility with the underlying model, a staggered capacity choice was decided upon. This implied a longer but stable convergence process.

To allow for a slow and clean convergence to an equilibrium, we also restrain the robots from raising or lowering their capacities by more that one unit at a time. Robots earning positive marginal profit and currently selling at capacity this period will raise their capacity by one unit because they are profit maximizing price takers with constant marginal costs.

If robots are earning negative profits, or if they do not sell their entire capacity during the current period, they will lower their capacity by one unit.

If robots are earning positive profits they will raise their capacity by one unit. If none of these conditions are met, the robot will not modify its capacity.

To allow for rounding errors, positive profit is defined to be greater than \$1 and negative profit is defined to be less that -\$1. In a baseline-and-credit equilibrium, total and marginal profits are zero due to constant price and constant marginal cost assumptions. However, firms in a cap-and-trade equilibrium could earn positive total profits and zero marginal profits because of the fixed endowment of allowances given to the firm each period. This difference is explained by the relative nature of the credit scheme compared to the absolute nature of the allowance scheme. It is worthy to reiterate that firms under baseline-and-credit regulation that start in a cap-and-trade equilibrium earn positive profit due to the output subsidy effect and have an incentive to expand output capacity, eventually driving those profits to zero. Cap-and-trade firms that start in a baseline-and-credit equilibrium earn negative marginal profits because of the low output price and have an incentive to contract output until marginal profits are zero and total profits are equal to the equilibrium value of the allowance endowment.

4.5 Simulated Session Results

In this section we present results of a simulated experiment designed primarily to test the operation of the software. In addition to demonstrating the feasibility of the computerized environment, we wish to investigate whether a change in regulation from cap-and-trade to baseline-and-credit trading leads to the higher levels of output and emissions predicted by Proposition 2, and whether the stability of the system would be affected by random decision making errors by the subjects. We compare two institutional conditions: a switch to cap-and-trade rules starting from the predicted equilibrium under baseline-

Table 4.3: Number of Simulated Sessions by Treatment

		Error Condition		
Trading Institution	Initial Equilibrium	No Errors	Low Errors COV= 5%	High Errors COV= 15%
B&C	C&T	1	1	1
C&T	B&C	1	1	1

and-credit trading and vice versa. We consider three levels of decision error: none, low and high.

In the no decision error treatment, all robots follow deterministic strategies described in Section 4.4. In the remaining two treatments, robots submit bids and asks chosen from a normal distribution around the profit maximizing price. The small decision error treatment chooses price from a normal distribution with a standard deviation set equal to 5% of the profit maximizing price, therefore with a coefficient of variation of 5%. The large decision error treatment is constructed assuming a 15% coefficient of variation. Table 4.3 illustrates this 2x3 factorial design. In each cell, we report results from only one simulation as it makes the presentation of the results much clearer. Replications produce similar results to those disclosed in this section. The observations below are based on the simulation results illustrated in Figures 4.1 through 4.6.

Figure 4.1 illustrates the cap-and-trade simulation using robots making no decision errors and starting parameters at the higher output levels consistent with a baseline-and-credit equilibrium. The upper-left panel shows how capacity and output quickly and smoothly converge to their equilibrium level. Once they have done so, however, rearrangements toward an equilibrium distribution of output between firms causes minor perturbations in the allowance market in the lower-left panel. This is caused by firms changing capacities

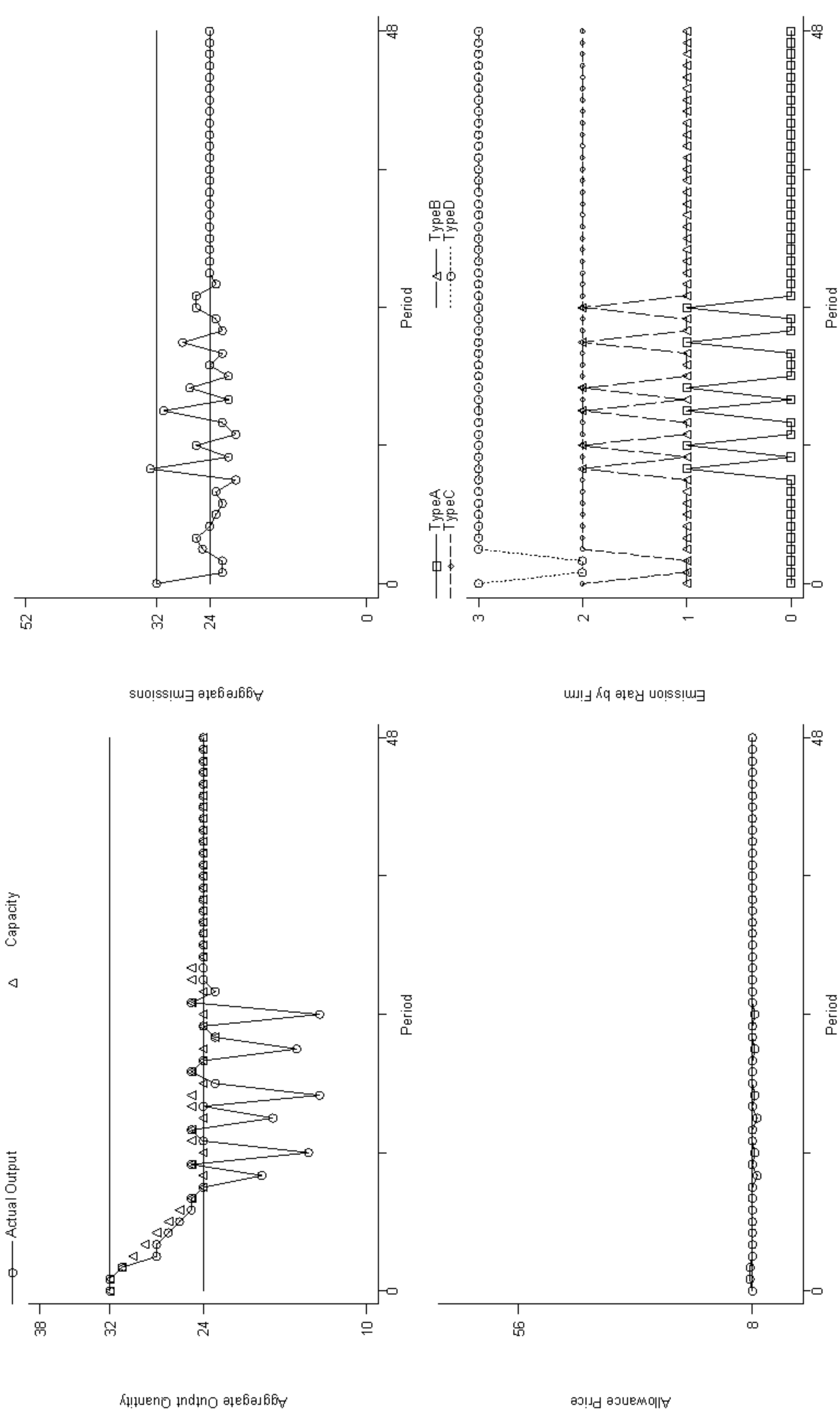


Figure 4.1: Cap-and-Trade - No Error Treatment

and hence switching between the role of buyer and seller, because allowance distribution between the firms is constant. These very minor deviations in the allowance market result in subsequent discrete emission rate changes in the lower-right panel. These emission rate fluctuations cause aggregate emissions to follow an oscillating convergence pattern toward equilibrium. As predicted by theory, all four panels show that the cap-and-trade equilibrium is convergent. Proposition 1 is supported by the result that, when profit maximizing decisions are made, the cap-and-trade outcome is optimal.

Figure 4.2 illustrates a simulated baseline-and-credit plan, with no decision error, starting from cap-and-trade equilibrium values. Note that, at the start of the period, credit price in the lower-left panel is high because firms are not initially provided with any credits to sell or use. Subsequent emission rate choices are all low because no firm can procure the credits needed to emit above the emission standard. As credits become available in the subsequent periods, they feed output expansion since the emission rate standard acts as an output subsidy. Consequently, emission rates return to their equilibrium and capacity, output and aggregate emissions climb smoothly to their new, higher equilibrium levels. Notice that capacity overshoots its equilibrium value as the sequence of capacity expansion leads to an unstable distribution of output between firms that must unravel itself appropriately until aggregate capacity drops down to the equilibrium output level. Thus, Figure 4.2 supports Proposition 2 as it illustrates that long-run equilibrium output and emissions are greater under baseline-and-credit than they are under a cap-and-trade plan with an identical average emission rate.

Figures 4.3 through 4.6 illustrate that results are rather different when robots make errors in their pricing decisions. Generally speaking, while under the no decision error assumption, robot simulations reveal more volatility on the convergence path under a cap-and-trade plan than under a baseline-and-

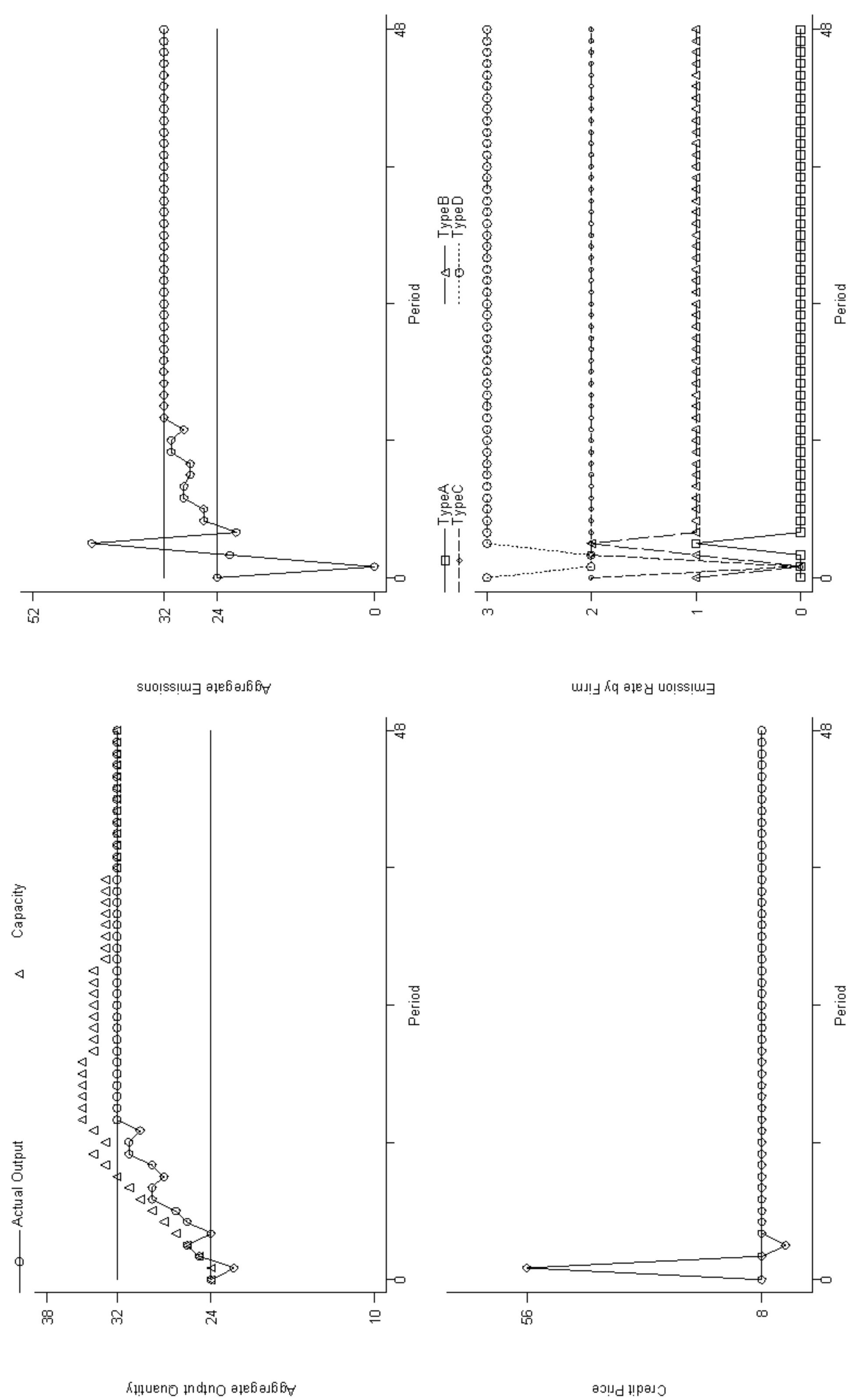


Figure 4.2: Baseline-and-Credit - No Error Treatment

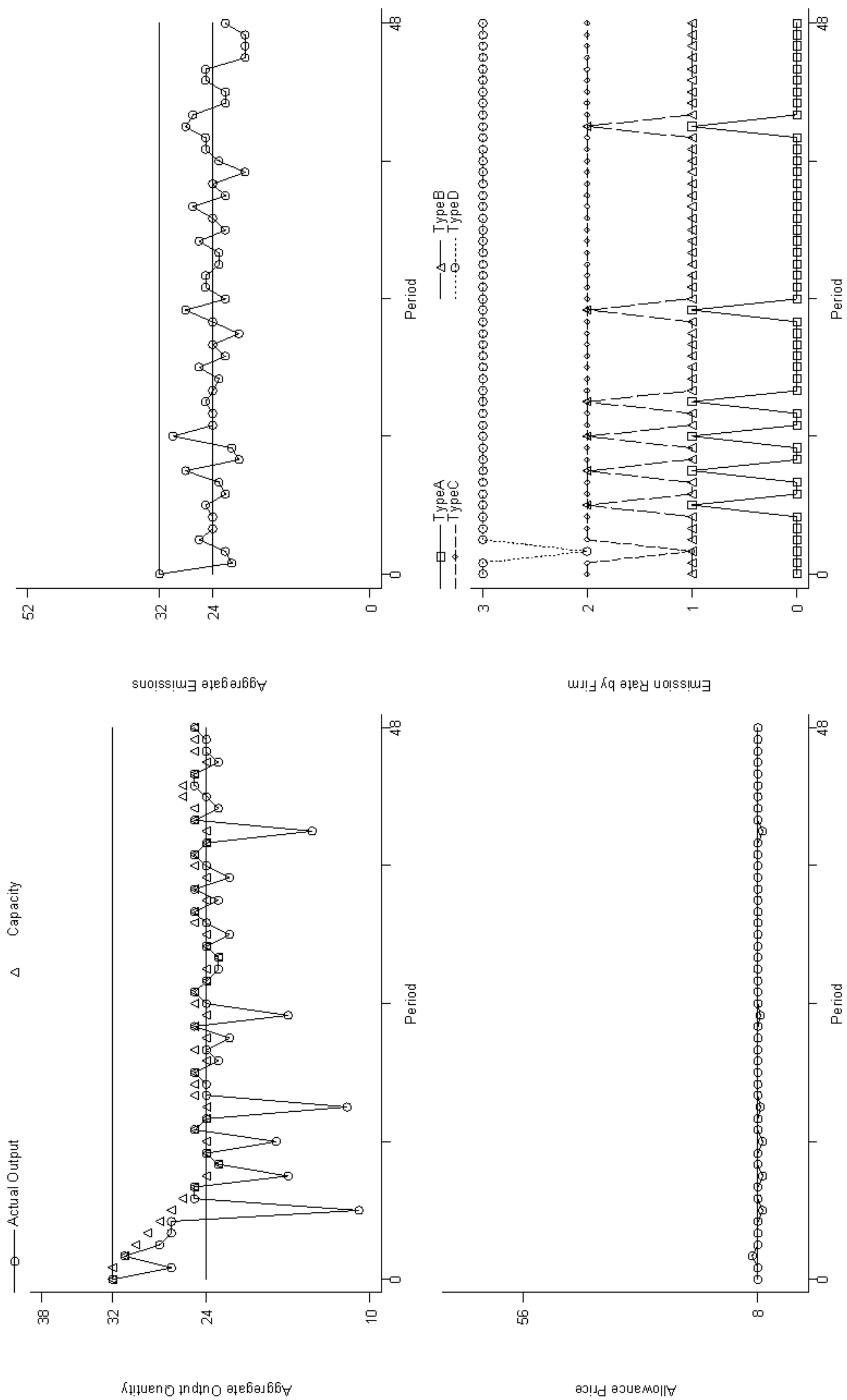


Figure 4.3: Cap-and-Trade - Low Error Treatment

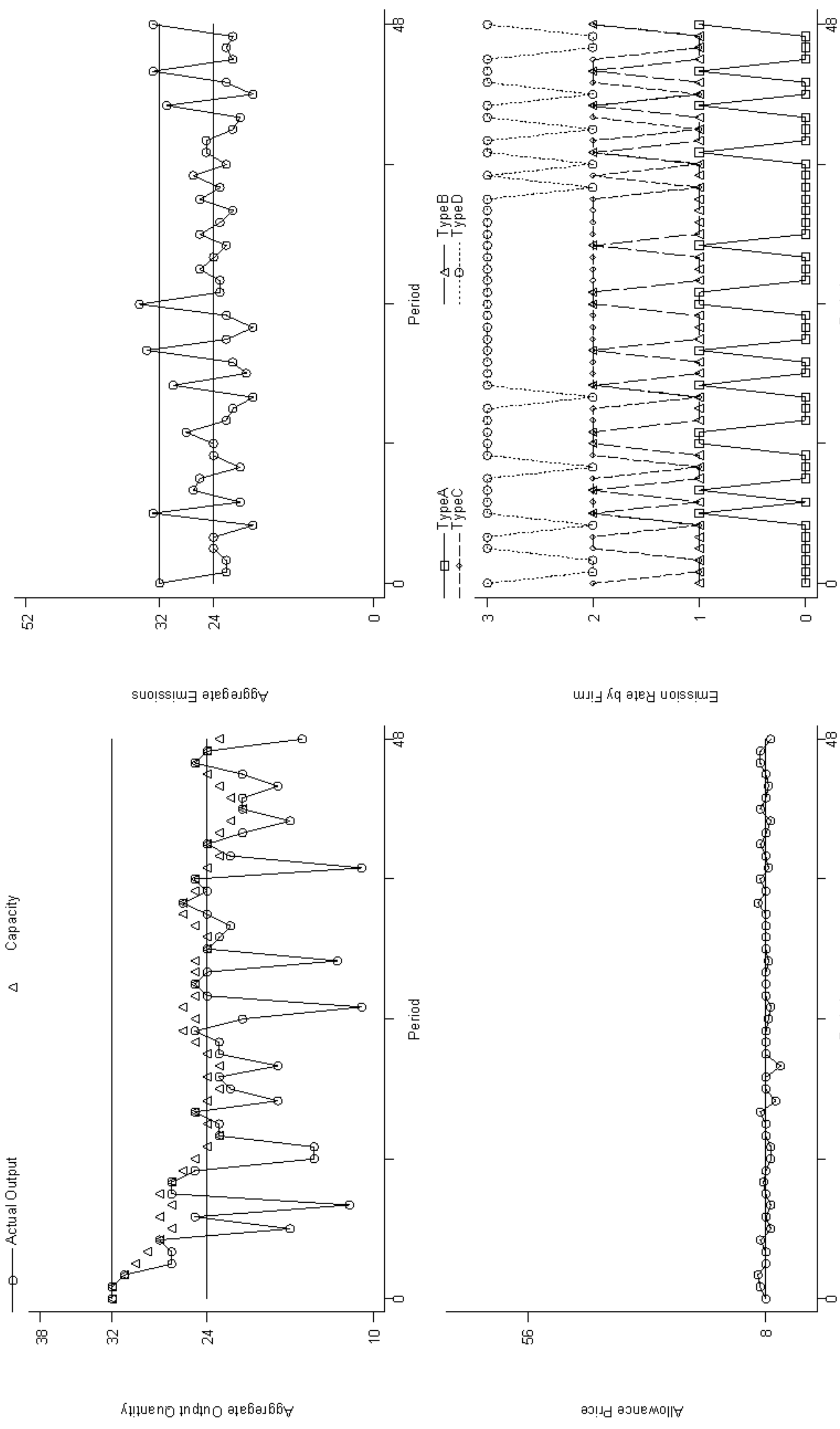


Figure 4.4: Cap-and-Trade - High Error Treatment

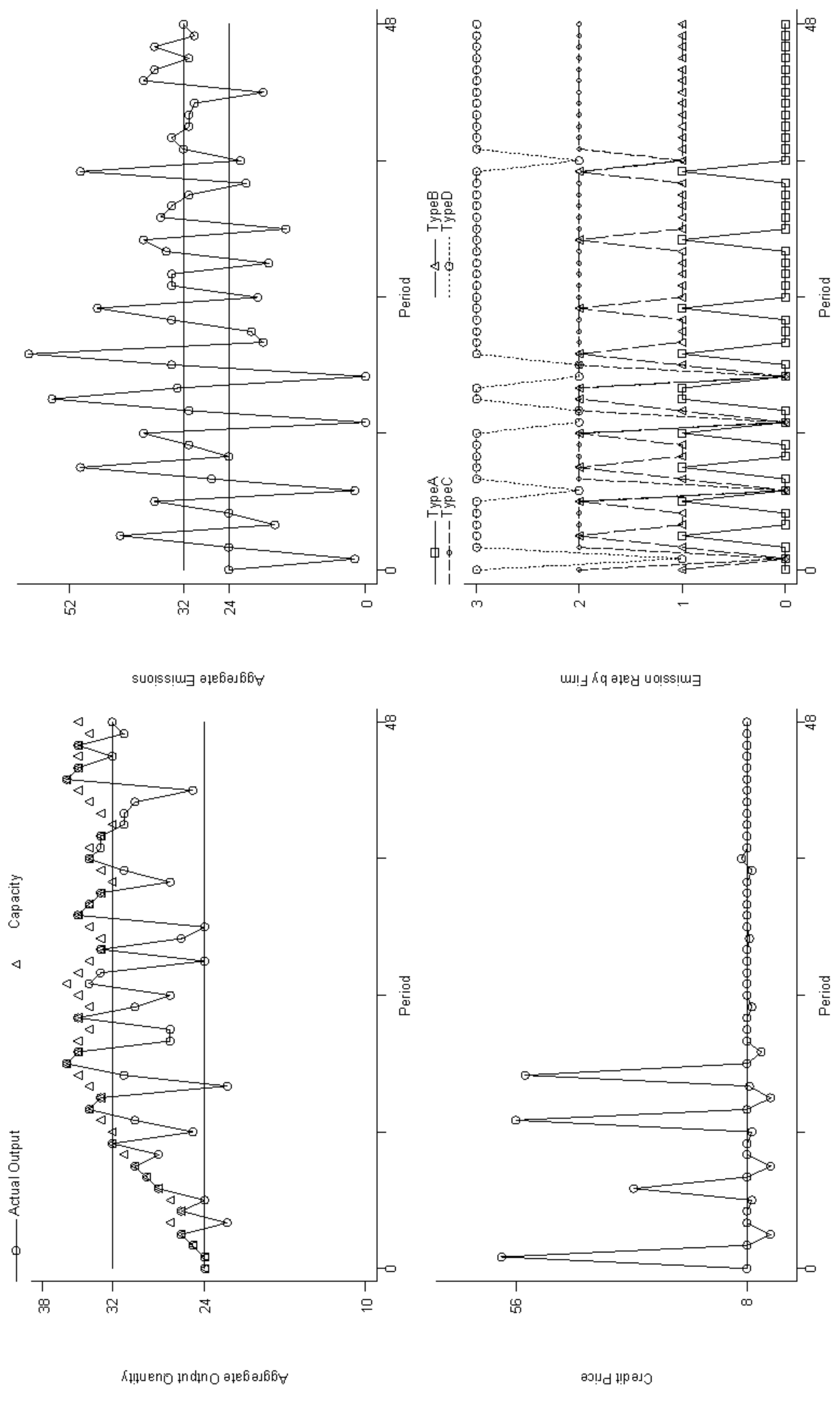


Figure 4.5: Baseline-and-Credit - Low Error Treatment

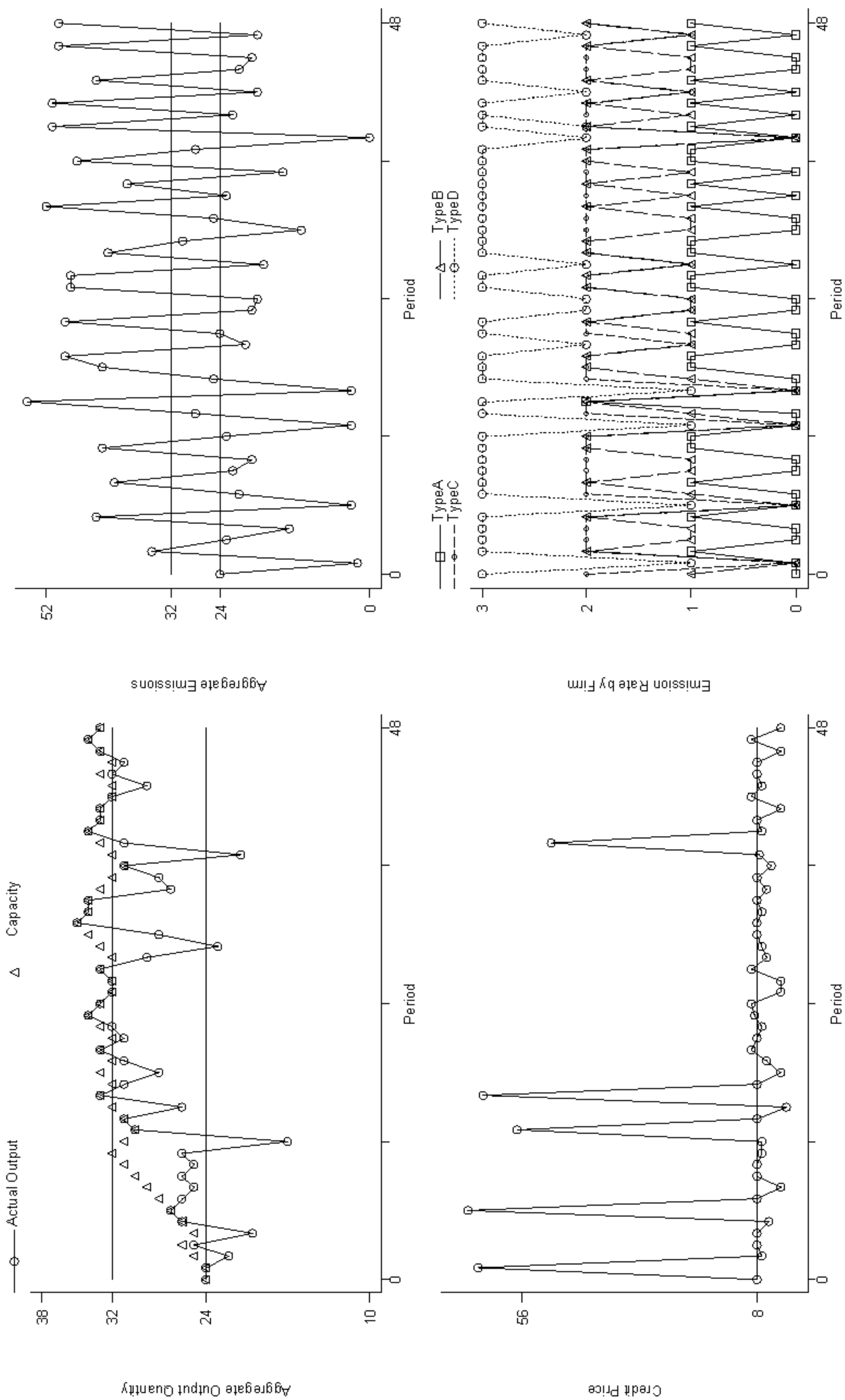


Figure 4.6: Baseline-and-Credit - High Error Treatment

credit plan; this does not hold true when robots make decision errors. The cap-and-trade sessions in Figures 4.3 and 4.4 show less volatility in the output market, the emission rights market, emission rate choice and aggregate emissions than the corresponding baseline-and-credit simulations in Figures 4.5 and 4.6. The discrepancy is most pronounced when comparing the upper-right emissions panel and lower-left permit price panel of Figures 4.4 and 4.6 involving large decision errors.

The period 1 spike in credit prices found in the lower-left panel of Figure 4.2, explained by the lag in credit creation, appears to have created even more volatility in the ERC decision error treatments, evidenced in the lower-left panels of Figures 4.5 and 4.6. If firms are endowed with a sufficient initial holding of credits, this irregularity will not occur.

The wild oscillations in aggregate emissions under the baseline-and-credit plan is the most unexpected result and could have very significant welfare repercussions due to the weakly convex environmental damage function. Baseline-and-credit institutions can provoke more volatility than cap-and-trade institutions when firms make errors because firms can fuel their own mistakes, emission-wise, due to their variable emission baseline. Remember that a firm with an emission rate equal to or less than the performance standard need not redeem any credits to the regulator. Under a cap-and-trade system, random decision error is not as much of a problem, on account of the fixed allocation of allowances every period.

The allowance and credit permit markets exhibit only minor volatility compared to aggregate emissions. This is most likely due to the susceptibility of emissions to volatilities from multiple sources such as instability of emission rates, capacity levels and permit holdings. There seems to be evidence, however, that fluctuations in emission rates might be driving the volatility in emissions more than other factors. The lower-right panels of Figures 4.4 and 4.6 provide evidence of frequent oscillations in emission rate choice. The theory presented in Chapter 2 suggests that profit maximizing agents set emission rates so that their marginal abatement cost equals permit price. However, the volatility found in the permit market displayed in the lower-left panel of the two figures does not match the scale found in the emission rate volatilities. An explanation of this mismatch could be due to the fact that we have implemented firms with marginal abatement cost curves with only three steps (remember emission rates can be any integer value between 0 and 3). Instead of a smooth MAC curve which will result in small changes in emission rates due to small permit price fluctuations, our simulations may lead to drastic changes in emission rates, effectively caused by our discontinuous MAC step function. While a continuous function may be too complicated for experimental subjects, increasing the number of steps in the function (i.e. increasing r_{max} greater than 3) may mitigate this problem.

Nonetheless, there is evidence in the high and low error treatment results that permit market volatility is greater under baseline-and-credit than under cap-and-trade. The higher volatility in the credit market is partly caused by current period demand being influenced by current period expectations and outcomes, while current period credit supply is determined in the previous period according to the previous period's expectations and outcomes. It appears as if the lag in credit creation, which has no corollary in the cap-and-trade environment, causes the credit market to be more volatile than the market for allowances.

These findings may be summarized by the following observations.

Observation 1 *With the assumption of no decision error, robot traders under both cap-and-trade and baseline-and-credit emission trading schemes converge to their respective predicted equilibria, supporting Propositions 1 and 2.*

Observation 2 *Each emission trading institution's output market convergence pattern seems to frequently under-supply output when decision errors are made, but both treatments' capacities converge to their equilibrium levels from above, whether there are small, large, or no decision errors at all.*

Observation 3 *While the call auction trading mechanism seems robust in the face of robots making decision errors, the performance standard and credit creation lag inherent in the baseline-and-credit emission trading scheme makes the credit market more volatile than the allowance market. This volatility may be mitigated by a credit for early action period or simply endowing firms with an initial supply of credits.*

Observation 4 *Decision errors greatly increase the volatility of aggregate emissions under a baseline-and-credit plan while only mildly raising the volatility of emissions under a cap-and-trade plan. There is evidence that emission volatilities could be due to the implementation of a discontinuous MAC function.*

4.6 Discussion and Conclusions

This chapter is the first report on the construction of a new emission trading experimental environment. Focus is placed on designing and implementing a computerized laboratory environment suitable for testing long-run predictions about cap-and-trade and baseline-and-credit emission trading plans. While a working program was created in which permits, emission rates and output are determined in interrelated markets, much work remains before the experiment can produce credible results from human subjects. The robot simulations reported in this chapter support our two propositions that cap-and-trade outcomes are optimal and that baseline-and-credit outcomes exhibit higher output and emissions. While the theory presented in Chapter 2 simply states the existence of these separate long-run equilibria, the results from the simulations presented in this chapter prove that simple myopic profit maximizing robots exhibit behaviour leading them to the theorized equilibria.

At the technical level, we have discovered that robot strategies achieve equilibrium only when parameters and the order of the decision making sequence are carefully chosen. We have also found greater than expected volatility in various aspects of the environment, under both types of trading plans. We believe this instability may be due to the small number of discrete steps permitted in emission rate choices and we plan to expand the number of steps by increasing the range of discrete emission rate choices to mitigate this problem in future human experimental sessions.

With this first look at a laboratory baseline-and-credit emission trading plan, we discovered various consequences of the performance standard and the lag in credit creation. Firstly, it is evident that the above two discerning factors of baseline-and-credit trading are causing the higher volatilities found in the credit plan compared to those found under cap-and-trade. The performance standard creates the possibility of pricing errors leading to greater emission volatility because emissions are not capped. Since firms with emission rates equal to or below the standard are not required to redeem any permits, pricing errors could drive them to create higher levels of emissions than are possible under a capped plan. The lag in credit creation, on the other hand, causes volatility by separating effects on demand and supply into consecutive periods. The lag in credit creation also implies that, if some baseline-and-credit firms are not explicitly endowed with credits in the first decision period, there will be no credits to buy and sell until the second period. This lack of "starting" credits provokes some early permit price volatility under baseline-and-credit. A reasonable solution to this problem might be to endow firms with their equilibrium level of credits at the beginning of the first period. Firms with equilibrium emission rates below the standard should begin the experiment with the number of credits they would create in equilibrium; all others should start without credits.

In running the robot simulations, it was apparent that robot strategies must also be constrained to adjust capacity by one unit at a time on a rotating basis in order to avoid unstable cycling behaviour. This implementation led to slow convergence to equilibrium and artificially long capital lives. We plan to investigate whether this constraint could be relaxed if capacity decisions were explicitly related to profit levels. It remains to be seen whether human subjects making simultaneous capacity decisions will demonstrate cyclical behaviour constantly over- and under-shooting the equilibrium level of output.

The next logical step is to test the laboratory environment with human subjects. The decision making environment is complex and we must investigate whether it can be effectively communicated to human subjects. Pilot sessions using the current interface will be crucial in this attempt. The difficulty experienced when programming profit maximizing myopic robots, along with the volatility found throughout the experimental environment using simulations, suggests that a less complicated environment is required before testing initial laboratory experiments with human subjects.

Chapter 5

Short-run Implications of Alternative Emission Trading Plans: Experimental Evidence

5.1 Introduction

This chapter presents results from the first laboratory experiment to compare baseline-and-credit emission permit trading with cap-and-trade emission permit trading. Because of 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, leaving the testing of a more complicated long-run setting for future research.

While the long-run baseline-and-credit equilibrium is inefficient, the short-run baseline-and-credit equilibrium is identical to the corresponding optimal cap-and-trade equilibrium. The short-run (and long-run) theoretical predictions discussed in Chapter 2 rely on competitive equilibria being realized in two interrelated markets: the market for output and the market for emission permits. The complexity of the environment increases with the addition of an emission rate choice along with a fixed output capacity in the short-run. If the theoretical predictions are not to be considered a mere curiosity, it would be useful to demonstrate whether the potential gains from trade will actually be achieved under the two schemes, as conjectured, in real markets. Robot simulations reported in Chapter 4 provide evidence that myopic profit maximizing firms exhibit behaviour consistent with the long-run equilibrium predicted by theory. However, decision sequence effects and market volatilities in the simulations, suggest that a long-run experiment involving human subjects is premature.

This chapter reports progress on a laboratory experiment designed to testbed basic forms of cap-and-trade and baseline-and-credit methods of emission trading to discover whether (1) the predicted short-run identical emission levels will actually be realized, (2) the prices of permits and output will reflect the equilibrium predictions and (3) the quantity of output will reach capacity. 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 experiment reported here comprises of 6 sessions: 3 sessions facing cap-and-trade regulation and 3 sessions facing baseline-and-credit regulation. The chapter is organized as follows. First, we summarize the relevant theoretical framework from Chapter 2. Second, we introduce three pilot experiments involving a different accounting treatment. Third, we describe the computerized trading environment that we implemented for the experiments with human subjects, which differs slightly from that reported in Chapters 3 and 4. Fourth, the predictions of the model are discussed. Subsequently, we report the experimental results and, lastly, we discuss and conclude the study.

5.2 Theoretical Framework

Chapter 2 discussed the theoretical equilibrium predictions relative to our long-run and short-run environments. As assumed in Chapter 2, the short-run environment implemented in the experiment and presented in this chapter fixes output at its optimal level, $Q = Q^*$, which also happens to be the long-run cap-and-trade equilibrium level. Chapter 2 discusses in detail how the short-run equilibrium predictions are identical for both cap-and-trade and baseline-and-credit trading plans. This section lays out specific testable propositions based on the theory presented earlier.

In the short-run, where 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.*

Proposition 3 *aggregate profits are identical in the cap-and-trade and baseline-and-credit competitive equilibria.*

5.3 Pilot Sessions

The experiments reported in this chapter are based on a double-entry accounting framework and use emission right accounting procedures akin to those set out by the IFRIC as documented in Chapter 3. Before running the short-run sessions reported in this chapter, three pilot sessions were conducted to test the feasibility of the experiment. Results from these pilots provided evidence of unexpectedly high permit inventories which might be attributable to a misrepresentation in the accounting of emission permits. This potential accounting inconsistency was raised in Section 3.5.2 where it was discussed how buying permits and not using them in the current period does not affect a subject's income statement. Reliance on the income statement as a profitability indicator may lead some subjects to build inventories and suffer large losses later in the experiment. For the six regular short-run sessions, it was decided that we would warn subjects of this misrepresentation in the experiment's instructions and on the income statement screen in the experimental software. A comparison between the pilots and the six regular sessions provides an interesting accounting treatment effect which is presented along with the regular results in Section 5.6.

5.3.1 Details of Pilot Sessions

The first pilot session was run in September of 2003. It implemented a baseline-and-credit environment similar to that reported in the simulations of Chapter 3 except that output capacity was fixed and emission rates between zero and nine were allowed to be chosen.[1] Debriefing subjects following the first pilot revealed that the environment and software were still too complicated. While results from the pilot looked promising, subjects were carrying large quantities of permit inventories. This was a concern, as it is irrational for myopic profit maximizing agents to carry any inventory from period to period. Even though there may be legitimate reasons why human subjects might carry inventories, such as risk aversion (this will be discussed in detail in Section 5.6), we could not eliminate a general misunderstanding of the baseline-and-credit environment as a major cause of the inventory carryover since we had not yet run any pilot sessions in a cap-and-trade environment to provide a comparison.

[1] This choice of emission rate range will be discussed in Section 5.4

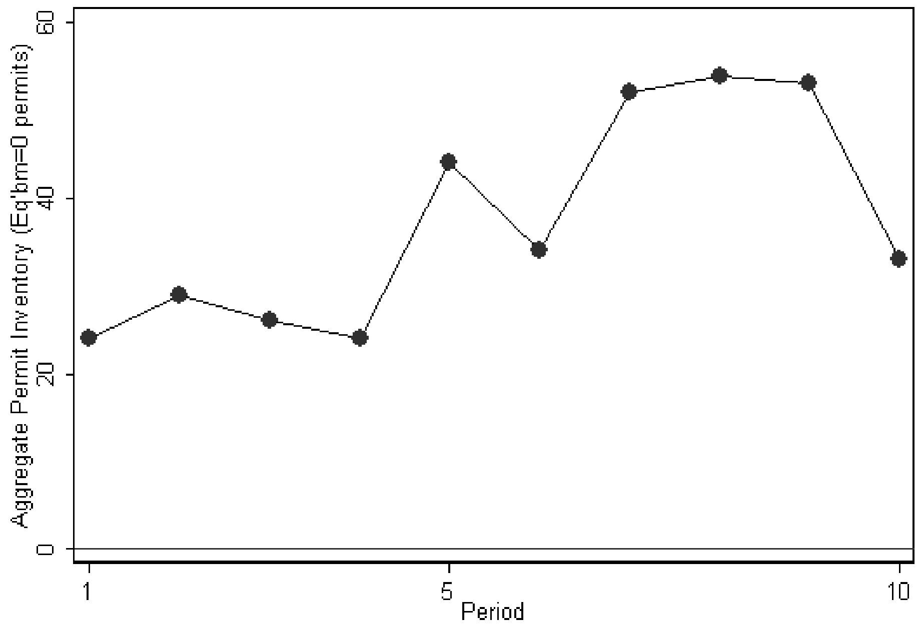


Figure 5.1: Inventory Carryover under Baseline-and-Credit Regulation in Pilot 1

Figure 5.1 illustrates aggregate inventory holdings at the end of each period during the first pilot. End of period holdings are defined to be the total inventory held by all subjects at the end of each period not including the credits created at the end of that period. With this definition, risk neutral agents should have no motivation to carry an inventory in any period, under both emission trading schemes. However, if agents are risk averse, the only prediction we can make is that they will not carry an inventory in the last period. As will be explained in Section 5.4.1, subject earnings in the experiment are based only on cash holdings at the end of period 10; any permits kept in inventory at the end of period 10 are worthless. This provides an incentive to use or sell all permits before the end of the last period. So, while risk averse agents may carry inventories between periods, there is no rational reason for them to do so in period 10. Risk aversion can be eliminated as the sole motivation for inventory carryover as excess inventory holdings still dominate in period 10 of the first pilot. There is some evidence of risk aversion however, as inventories built up over the first nine periods are almost cut in half in period 10.

After the first pilot, part of the instructions were revised and the software interface was modified using feedback from previous subjects.[2] The parameters of the environment were also changed; the new values were eventually used for the second and third pilot and also for all six regular sessions reported in this chapter. The second pilot was conducted in October of 2003 and used the short-run baseline-and-credit treatment. The third pilot was held in November of 2003 and replicated the second pilot under a cap-and-trade framework. Their identical parameterization implies that the results from the last two pilots are directly comparable to the six regular sessions, while the results from the first pilot are not.

We decided to make only two changes between the last two short-run pilots and the six regular short-run sessions. First, we decided not to change the software implementation that accounted for emission rights as an intangible asset. This accounting interpretation is expected to be finalized by the International Accounting Standards Board before the end of 2004. Instead, we decided to warn subjects of the misrepresentation of permit inventory by adding a note in the laboratory instructions and in the income statement. This warning provides laboratory subjects with the kind of specialized knowledge that industry decision makers will be armed with when the IASB standards are adopted. Whether these warnings will be sufficient to eliminate the seemingly irrational

[2]Bidding and asking behaviour from the first pilot demonstrated a significant number of subjects entering orders at the previous period's market price without using the ability to enter multiple bids and/or asks so that they could buy or sell appropriately no matter what the price turned out to be this period. Based on subject debriefings, we concluded that this behaviour was caused by our initial instructions for the call auction; therefore the relative section of the instructions was rewritten to clarify how the market clearing price and quantity are determined in the uniform price call auction being used.

inventory behaviour from the first pilot remained to be seen, but will be addressed in the results (Section 5.6). The added notice warned subjects how changes in permit inventory would not be reflected on the income statement until the period in which the permits were used or sold. An example was given explaining how buying permits and holding them in inventory would not influence the income statement, but that it would affect cash holdings, which is the sole factor in determining subject payoffs at the end of the experiment.

The second change implemented between the last two pilots and the six regular sessions was that the output market decision became automated for subjects. During pilot session debriefings, it was discovered that the output market was adding length and confusion to the experiment. Subjects remarked how the profit maximizing strategy in pricing output, when output capacity and the demand for output was fixed, was relatively easy compared to formulating a permit market strategy. Subjects felt that the extra time spent on formulating a strategy in this uninteresting market was causing them to lose focus on the permit market and their emission rate choice, which contributed to longer decision times and, overall, a lengthy experiment. For these reasons, it was decided that subjects in the six official short-run sessions would be forced to sell the maximum amount of output possible, constrained by capacity and permit holdings, at the market clearing price. The debriefing of subjects participating in the six official short-run sessions gave evidence that this simplification was successful. This addition of a forced output market strategy is, however, a nuisance variable if one is interested in investigating the effects of warning the subjects regarding the misrepresentation inherent to the IFRIC/IASB accounting methods, because both were implemented at the same time.

5.3.2 Accounting Treatment Predictions

Since only two changes were made, any difference in results between the last two pilots and the later six sessions can be attributed to the accounting misrepresentation and the forced output market decision. Care must be taken in trying to separate the effects, however, given that the consequences of the accounting warning and output market change are interrelated. For example, the accounting rule is theorized to affect permit inventories directly while the output market rule could impact permit inventories indirectly since it may affect the quantity of output sold which in turn affects the number of permits required to be redeemed. These two modifications may influence permit market, emission rate and output market outcomes in a confounding manner throughout all ten periods of the experiment due to the interrelated nature of the components in our model.

However, there are a few distinctions to be made between the effects. The forced output decision implemented after the pilots produces only one direct effect, the possibility of greater output production and sales. It cannot lead to lower output sales since an ask is automatically submitted on behalf of the subject to sell the maximum amount of output at a price of zero. While output sales are predicted to be at capacity before the forced decision, strategic error on behalf of a pilot subject could cause a shortfall in output.[3] On the other hand, the profit and loss misrepresentation warning is predicted to generate lower permit inventories as a direct effect. Fortuitously, we can use our alternative emission trading schemes to identify each effect separately.

Under cap-and-trade, potentially greater output caused by the new output rule could *decrease permit inventories* due to the fixed supply of permits and the higher redemption obligations of increased output, ceteris paribus.

[3] Under the pilot rules, a subject may price his/her output above the market clearing price and not sell output at his/her capacity.

This conjecture is confounded by the prediction of *lower permit purchases and inventories* directly caused by subjects buying and holding less permits in inventory due to the income statement warning. If one finds significantly lower permit inventories after the cap-and-trade pilots, the theorized treatment effect can be supported, but cause cannot be attributed to either change specifically; theory predicts both modifications will lead to lower permit inventories under cap-and-trade regulation.

The baseline-and-credit scenario, however, allows for identification of the problem. Under ERC trading, a potential increase in output caused by the new output rule should not affect permit inventory in any way, because there is no fixed permit supply as there is in the cap-and-trade case. Under baseline-and-credit trading, the supply of credits is proportional to output because of the relative target imposed by the performance standard.[4] Thus, when output increases under an ERC plan, this induces a proportional increase in the supply of permits which allows for the extra redemptions required without affecting permit inventories. The effect of the accounting warning is fully identified under baseline-and-credit, as the accounting warning is predicted to lower permit inventories directly and the forced output decision is predicted to possibly raise output, but this higher output will not cause a drain on ERC permit inventories (due to the performance standard, demand and supply of permits increase when industry output increases).[5]

To see why the forced output decision is predicted to have no impact on baseline-and-credit permit inventories, consider the simple example below. If the forced output market decision caused each cap-and-trade firm to sell one

[4] See Chapter 2 for more details.

[5] This prediction assumes that the increase in output is allocated symmetrically across both firms above and below the performance standard, implying that firms that create credits (with emission rates below the standard) increase their output in an identical fashion to firms that redeem credits (with emission rates above the standard).

more unit of output per period, this would require each firm to redeem one additional permit from inventory per period. The forced output rule is predicted to potentially lower permit inventories under cap-and-trade regulation. On the other hand, if the forced output market decision caused each baseline-and-credit firm to sell one more unit of output per period, this would require each firm with an emission rate above the performance standard to redeem one more permit from inventory per period; however, the increased output would cause each firm with an emission rate below the performance standard to create one more permit in inventory. The average emission rate in a baseline-and-credit equilibrium must always equal the performance standard (otherwise demand for credits will not equal supply), so the amount of permits created and added to inventory in this baseline-and-credit example must equal the number of permits taken from inventory. The forced output rule is predicted to have no effect on permit inventories under baseline-and-credit regulation.

The aforementioned conjectures are consolidated in the following propositions which will be addressed when the laboratory results are analyzed in Section 5.6.

Proposition 4 *Under cap-and-trade, the treatment effect of the output and accounting changes implemented after the pilot sessions is predicted to yield lower permit inventories. The separate implications of the two modifications cannot be identified.*

Proposition 5 *Under baseline-and-credit, the treatment effect of the output decision modification has no effect, but the accounting modification implemented after the pilot sessions is predicted to yield lower permit inventories.*

5.4 Experimental Design

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 for each emission trading scheme.[6] Each of these sessions involves 8 subjects and were run in March and April 2004. All 48 recruited subjects were McMaster University undergraduates who had passed a standard 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. Table 5.1 presents a summary of the experimental design, including the two pilot sessions pertinent to the current study.

Unlike many emission trading experiments that re-use subjects for different treatments due to the high cost of training (e.g. Ben-David et al. 1999; Murphy and Stranlund 2004), we used different subjects for all sessions. Once a subject participated in a session, they were not allowed to participate in

[6] This is in addition to a pilot session for each trading scheme, run in preparation of this short-run experiment.

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

Table 5.1: Experimental Design: Number of Sessions

Trading Institution	Pilots with Theorized Accounting Problem	Regular Sessions with Accounting Warning
Cap-and-trade	1	3
Baseline-and-credit	1	3

any others. This allows us to consider the 3 sessions for each emission trading scheme as being truly independent of each other.

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. Please see Chapter 3 for an overview of the environment and Appendix E for programming details of the computer software. It is a fully specified environment with 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 chapter.

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 us more control over subjects' interpretation across treatments, but allows us to create an environment in which the operation of alternative emissions trading plans could be demonstrated to students and policy-makers. Experimental instructions for the cap-and-trade and baseline-and-credit treatments reported in this chapter are provided in Appendix C and Appendix D, respectively.

During the experiment, we presented a short-run frame in which subjects are told that they represent firms producing an output at a constant cost up to a fixed capacity level, k. The variable cost of production, w_i, mentioned in Chapter 2, is set to zero. Since heterogeneity of abatement costs is necessary for potential gains in emission trading, output capacity is imposed to be uniform across all firms for simplicity; k is set at 4 for all firms.

We employed a design using eight firms per session. Two firms had one of four different marginal abatement cost schedules. 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 were broken down into nine steps corresponding to emission rate possibilities ranging from integer values between 0 and 9. While Ben-David et al. (1999,2000) implement an explicit emission rate choice with three possible levels, we have learned from the robot simulations reported in Chapter 4 that MAC functions with a limited number of steps may contribute to the volatility of permit price, emission rates and aggregate emissions. MAC functions for this experiment were 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 identical to that used in the robot simulations, detailed in Chapter 3,

$$c_i(r_i) = u_0 + (u_1 - u_0)[(r_{max} - r_i)/r_{max}]^{\alpha_i}, \tag{5.1}$$

only now 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

Table 5.2: Short-run Cost Parameters

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

Note: B&C is Baseline-and-Credit and C&T is Cap-and-Trade. $\alpha = 3$ and $w_i = 0$ under both trading plans.

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 5.2 presents firm-specific parameters used in the short-run sessions reported in this chapter. Table 5.3 summarizes the associated short-run equilibrium predictions under the alternative emission trading mechanisms.

[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 then sell them to other firms with emission rates above the performance standard.

Table 5.3: 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.

5.4.1 Decision Making Sequence During the Experiment

The first action to be taken in a period involves allowances and credits to be traded in a call 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, each firm, once the permit market is cleared, can choose their own emission rate ranging from zero to nine. The ten possible choices give an acceptable approximation to a continuous variable. Figure 5.2 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.

Assuming a production-to-demand model, output units trade in a similar call market, except that the buyers are represented by a simulated demand curve. At the end of each period, allowances are redeemed and credits are created/redeemed by the governing authority. Any permits held over at the

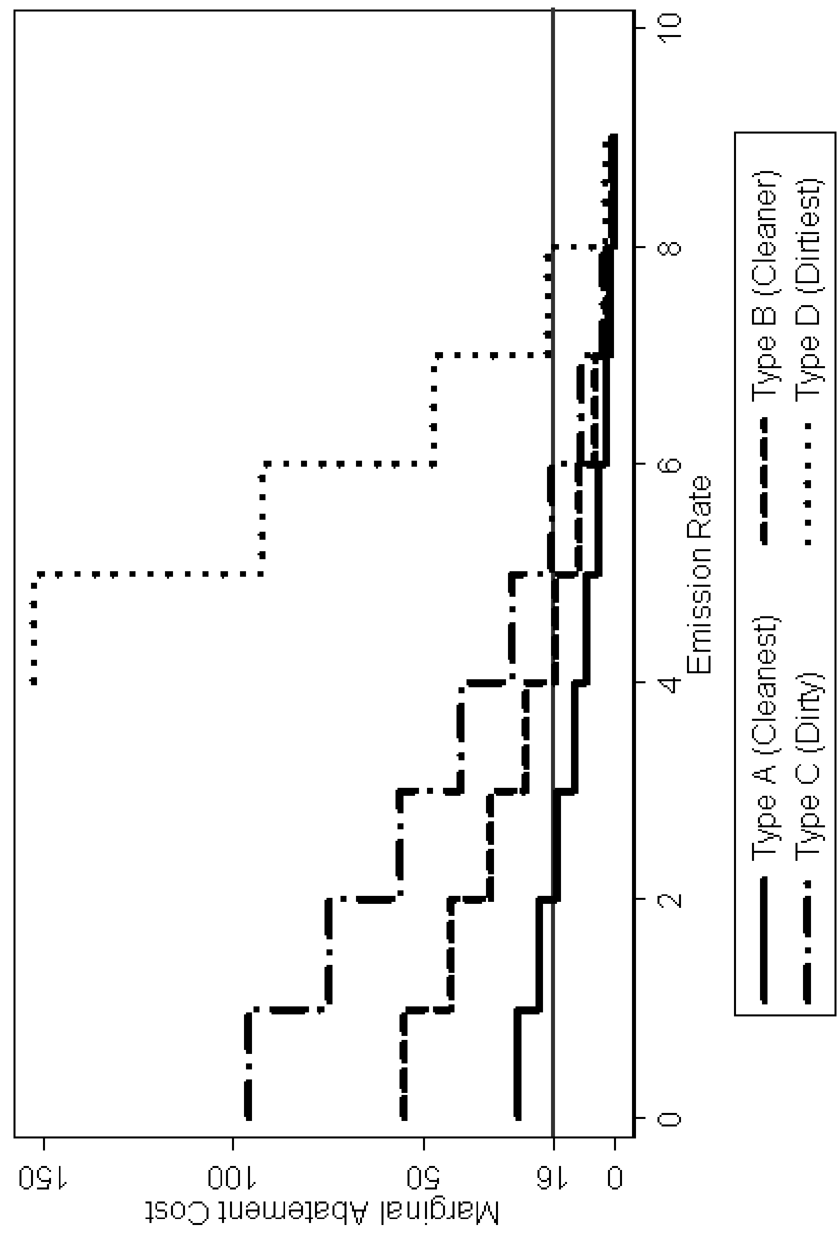


Figure 5.2: Marginal Abatement Cost Curves

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 amount of output produced/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 5.3. See Chapter 3 for additional detail on this environment.

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 stated in Chapter 3, since only marginal traders affect the market clearing price, this institution provides transparent incentives for most traders to reveal their true abatement cost. As discussed by Smith et al. (1982), while traders have incentives to bid below values and ask above costs, traders of infra-marginal units near the margin that determines 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.

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. Simulation and pilot experiment results

[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.

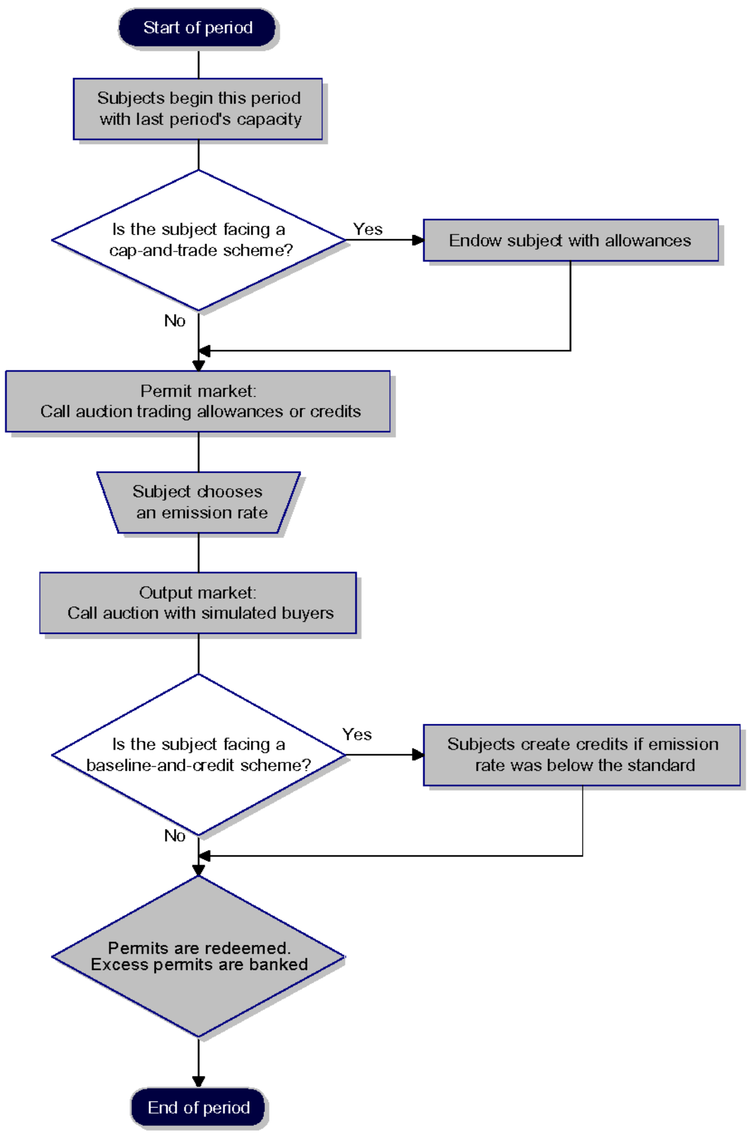


Figure 5.3: Sequence of Events in a Typical Period

lead us to 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.[10]

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 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. As discussed in Chapter 3, this lag will create permit market volatility at the beginning of each experiment if firms are not initially given credits in inventory so that they can be sold in the first period. To eliminate this fabricated disturbance, it was decided that baseline-and-credit firms with equilibrium

[10]This strategy is optimal if it is assumed that permits have no intrinsic value. While this notion is debatable, it does not significantly affect our implementation, as aggregate output in the short-run has been fixed such that output price will always be above equilibrium permit value. A few pilots we ran without this imposed market action did not show any significant difference in output market behaviour or outcomes.

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 above in Table 5.2.

5.5 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. Below is a discussion of four reasons why cap-and-trade and baseline-and-credit outcomes may differ in the short-run. Although the paragraphs below describe why short-run firm behaviour under the schemes may diverge, there are often conflicting forces which render predicting the effects of these differences problematic. One must keep in mind that inefficiency in this environment is a dynamic phenomenon. A mistake 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 emission 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, that were not suggested by theory alone (Buckley, Mestelman, and Shehata 2003). On the other hand, the relative framing of baseline-and-credit regulation might inadvertently lend more stability, than cap-and-trade regulation, 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 its emission rate is zero.

Secondly, this 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 schemes may be affected differently. In addition, the smaller 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 make up for it due to the regulating authority distributing a fixed number of permits each period. Permits endowed and not used in one period can easily be banked for future use. 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 or in bidding and asking for permits (which constrains how much pollution, and hence output, one can produce), 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 permit supply under the comparable baseline-and-credit mechanism will result in inefficiency. While this is the only possible associated short-run inefficiency, in the long-run output deviations could raise output above the optimal level and emissions could be inefficiently high.[11]

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 schemes. For instance, if a cap-and-trade firm intends on choosing 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, as previously explained, it mirrors characteristics of many real-world credit systems and is a requirement in our simple sequential decision making environment (that does not contain any "forward" permit markets).[12] 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.

5.6 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

[11] Dewees (2001) focuses on the long-run theoretical properties of alternative emission trading institutions, stating that the crucial difference is that with cap-and-trade the total allowed pollution for the industry does not vary with current economic activity, while with ERC trading emissions may increase in proportion to industrial activity.

[12] As discussed in Chapter 3, many real world ERC plans are project-based in which emission reductions must be realized and proven to exist on a project-by-project basis before credits are actually granted.

under either system falls within acceptable bounds of the predicted equilibrium is also of importance. Accordingly, the following analysis of the experimental results 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. The results section will conclude with a look at the distribution of firm payoffs under the alternative trading mechanisms.

5.6.1 A First Look

A natural question to ask when running an experiment involving an environment as complicated as this one 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 awareness. An obvious benchmark to compare the bid-ask behaviour found in this experiment is the results from a similar uniform price auction presented by Cason and Plott (1996).

One must keep in mind that the uniform price auctions investigated by Cason and Plott (1996) occur in a solitary auction setting and not in a much more complicated fully specified environment, as are the permit auctions 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 are in fixed roles as either buyers or sellers, while the environment presented in this chapter involves traders that will have incentives to buy and sell, at different prices, in the current period, depending on permit inventory (which is affected by permit market and emission rate decisions made by all subjects in past periods). The Cason and Plott auctions are applicable, however, since they involve 4 buyers and 4 sellers, identical to the equilibrium in our model involving 8 subjects. While the buyers and sellers in Cason and Plott implicitly had a fixed output equal to 1 and an implicitly defined emission rate with 5 possible values, the environment presented in this chapter implements a fixed output equal to 4 with 10 possible emission rate choices.

In their static uniform price auction sessions, Cason and Plott (1996) conclude that, over time, subjects tend to reveal their true costs and values, especially for units near the margin that decides price. Figures 5.4 to 5.6 present results similar to those presented by Cason and Plott, showing actual bids and asks against the underlying incentives, for periods 2 and 9, for each of the 6 short-run sessions. In each graph contained in Figures 5.4 to 5.6, 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 prices for units around the margin that determines price are expected to fully reveal underlying values. Looking at the six session graphs presented in Figures 5.4 to 5.6, one can ascertain that subject behaviour appears very rational: bids and asks tend to reveal the true underlying values, especially those close to the price margin, and this revelation gets more accurate over time. It appears as if subjects facing baseline-and-credit make more evident bid-ask pricing errors at the beginning of the experiment than subjects facing cap-and-trade. This difference disappears over time, comparing the period 2 to 9 results for both plans. It is remarkable how similar the results illustrated in Figures 5.4 to 5.6 are to those found in the simpler Cason and Plott environment. We acknowl-

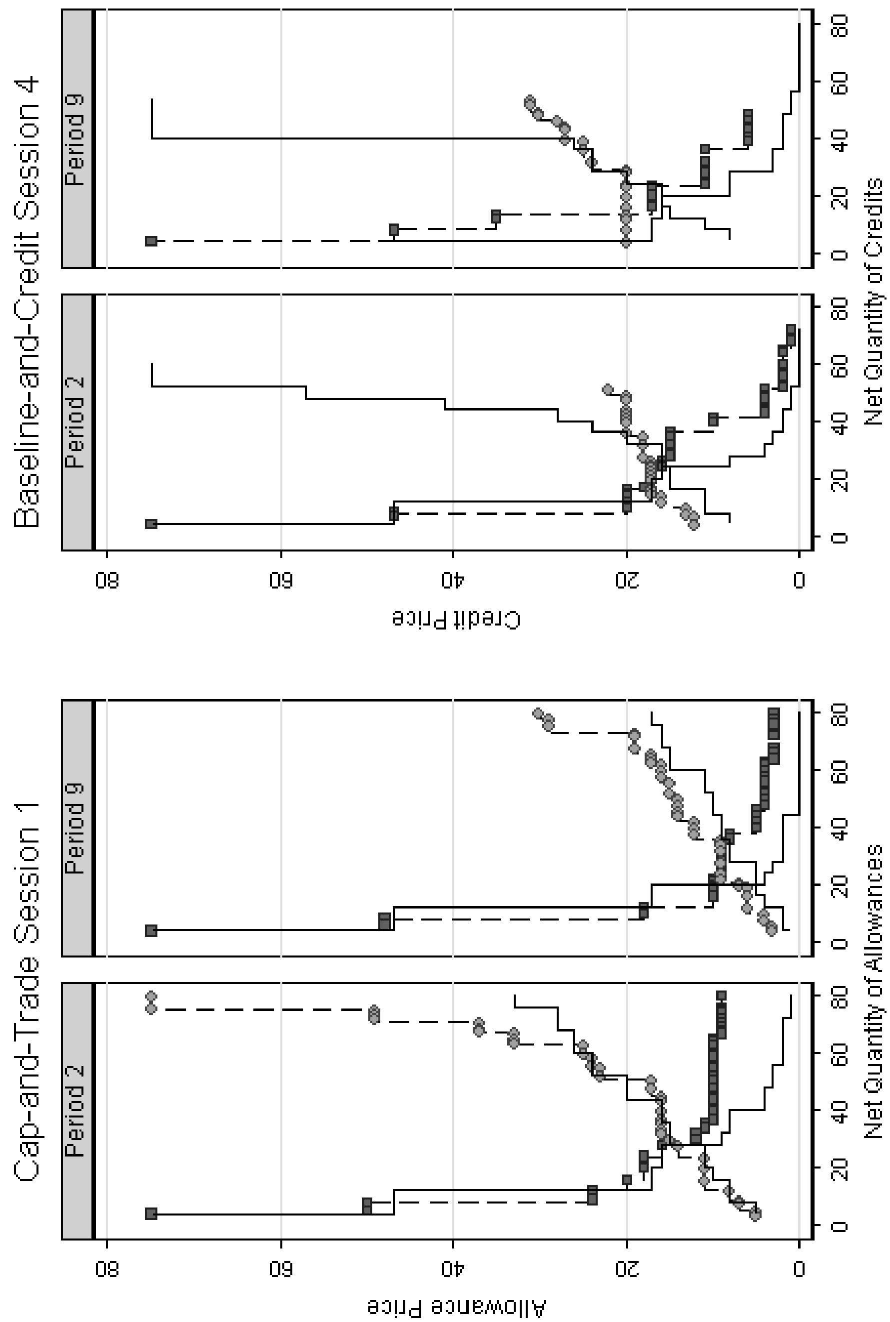


Figure 5.4: Actual Bids and Asks for Permits in Sessions 1 and 4

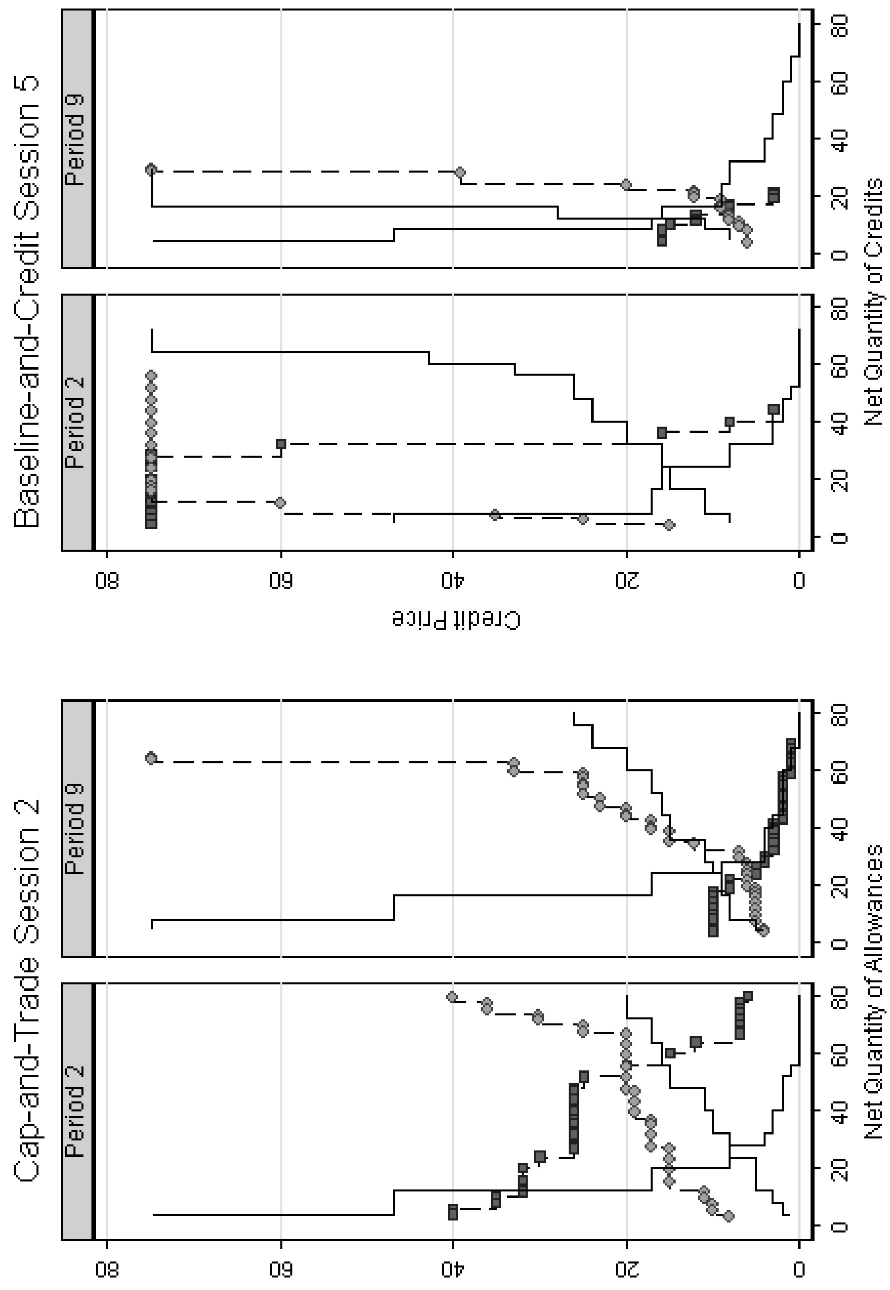


Figure 5.5: Actual Bids and Asks for Permits in Sessions 2 and 5

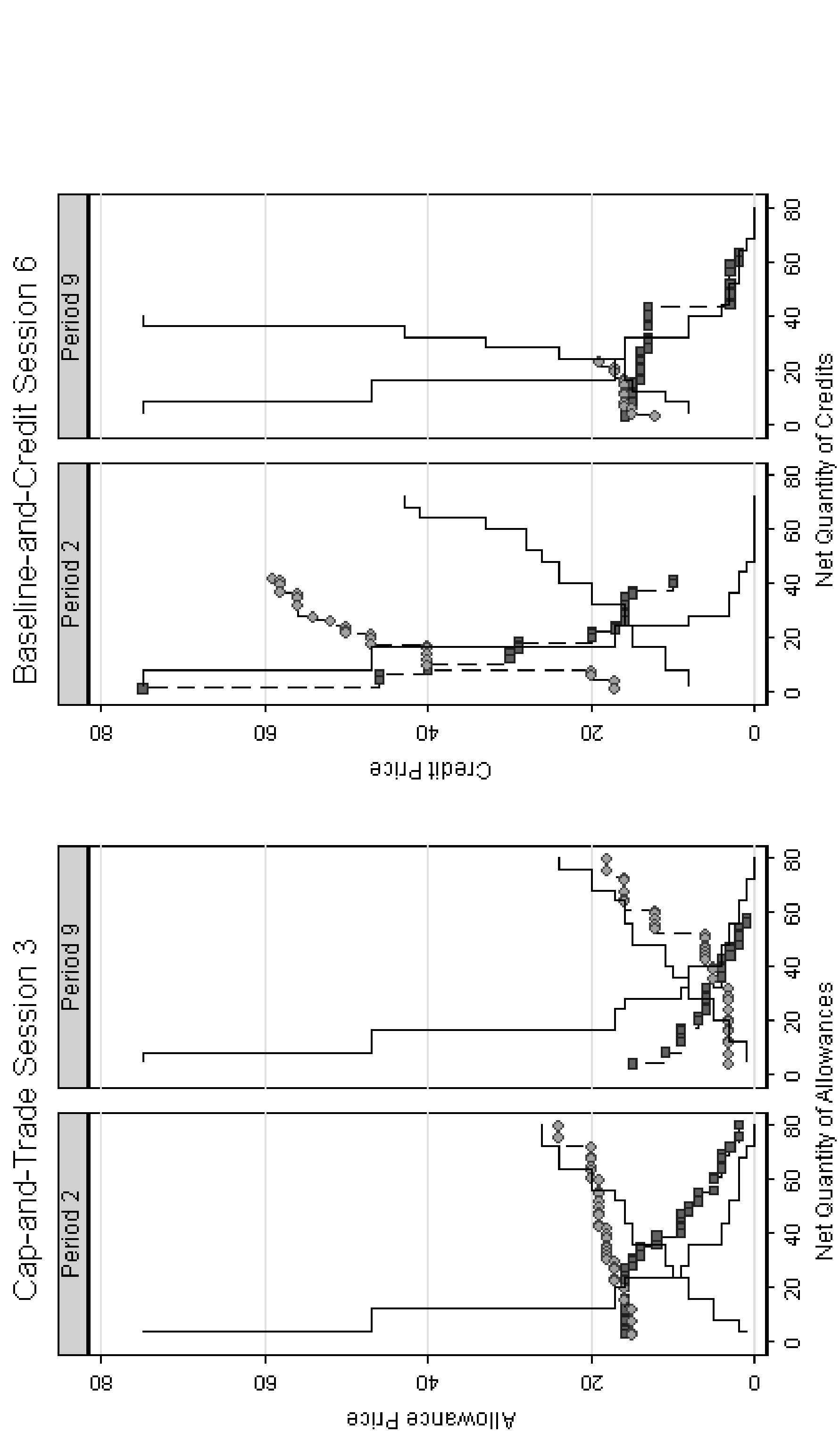


Figure 5.6: Actual Bids and Asks for Permits in Sessions 3 and 6

edge 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. We will not present a quantitative analysis of the bid-ask behaviour from this experiment, as there is no reason to expect the extra-marginal units to reveal the underlying values.

5.6.2 Permit Market, Output Market and Aggregate Emissions

The overall data analysis strategy employed in this section was decided before running any sessions. Because of the dynamic nature of the experiment whereby subjects' decisions 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 would be provided illustrating summary results from periods 1 to 10, all statistical tests would be based on the mean market indicators over periods 1 to 9 and 6 to 9 separately.[13] Emphasis will be placed on the results from analyses focusing on the period 6 to period 9 time frame, to negate any learning effects or decision errors made in the initial periods of the experiment.

Predicted equilibrium values of the main market indicators, based on the theoretical model presented in Chapter 2, are provided with the experimentally observed values in Table 5.4 and Table 5.5. Table 5.4 provides mean per

[13] 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.

Table 5.4: Mean Values over Periods 1 to 9 by Treatment

	Permit Market		Output	Aggregate	Permit
	Price*	Volume*	Volume*	Emissions	Inventories
Cap-and-Trade:					
Session 1	12.83	25.00	29.11	153.11	44.56
Session 2	12.78	28.77	30.56	155.33	74.78
Session 3	10.56	20.89	28.67	156.89	73.11
Treatment Mean	12.06	24.89	29.45	155.11	64.15
Baseline-and-Credit:					
Session 4	19.05	20.67	30.67	151.33	30.67
Session 5	45.94	19.56	31.11	157.22	71.11
Session 6	30.11	17.78	32.00	159.11	56.44
Treatment Mean	31.70	19.34	31.26	155.89	52.74
Prediction:	16.00b	32.00cb	32.00c	160.00	0.00cb

* Treatment effect is significant using an ANOVA 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.

period values by session evaluated over periods 1 through 9. Table 5.5 presents these values based on periods 6 through 9 only, in an effort to account for market convergence over time. The results from analysis of variance (ANOVA) testing is also summarized in Tables 5.4 and 5.5. Since this chapter computes tests by simply comparing summary statistics from the six cap-and-trade and baseline-and-credit sessions, the ANOVA test is identical to a basic t-test on the 6 observations. A non-parametric Mann-Whitney U-test was conducted in parallel with each parametric ANOVA 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.

Table 5.5: 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 an ANOVA 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 5.7 illustrates the minimum, maximum and mean session permit price under each emission trading mechanism. This indicates that the observation at the top edge of 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 Tables 5.4 and 5.5 and Figure 5.7, the observed trading price for permits appears to be higher under baseline-and-credit than with cap-and-trade. An ANOVA analysis 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. Tables 5.4 and 5.5 highlight that this significant result is consistent over the length of the experiment.

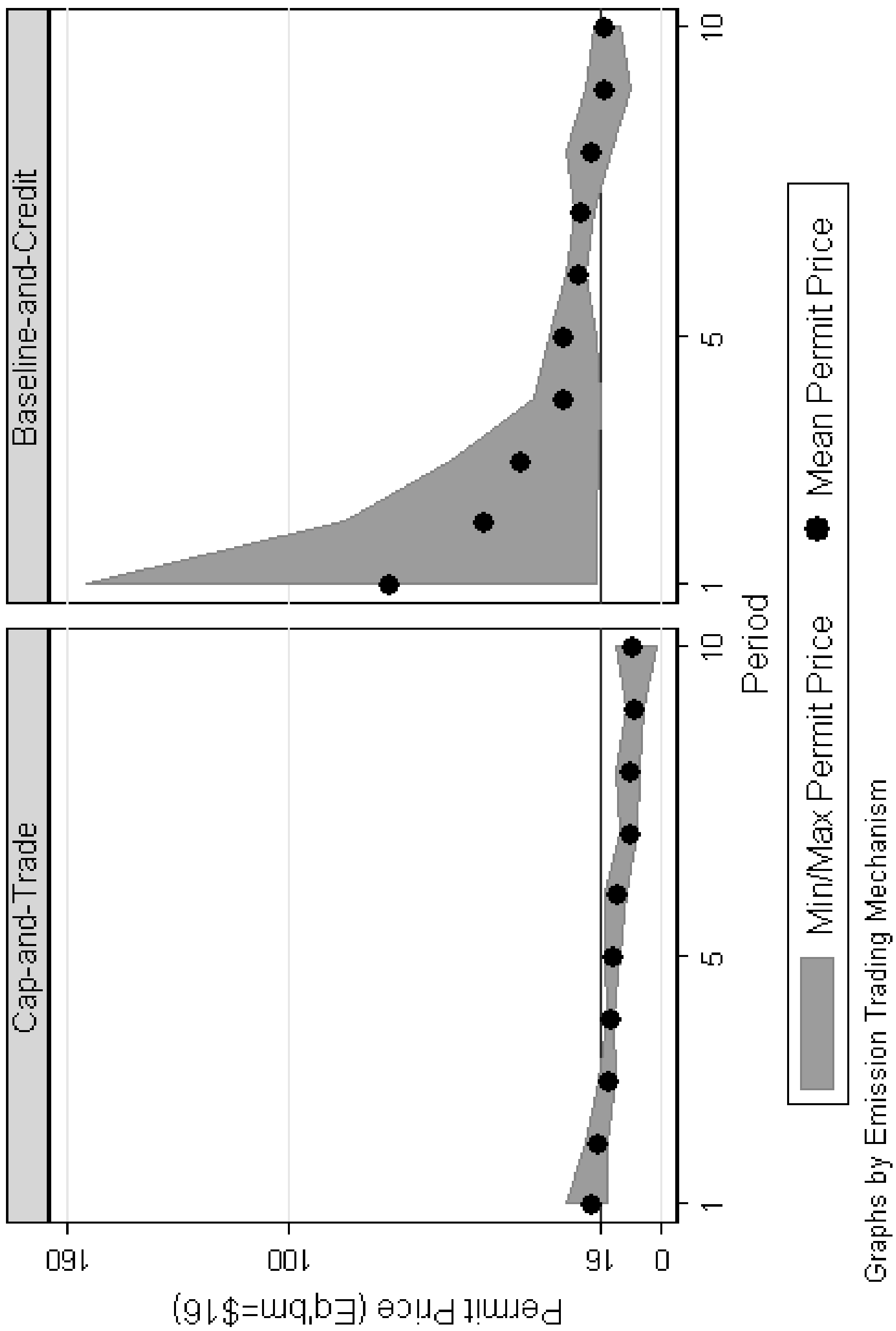


Figure 5.7: Permit Trading Prices

In summary, the mean cap-and-trade permit price was \$12.06 and the mean baseline-and-credit permit price was \$31.70 over the first 9 periods. Table 5.5 provides evidence of price convergence as mean price levels were \$8.42 and \$18.92, respectively, over periods 6 to 9. Overall, the permit price observations under the baseline-and-credit treatment are significantly different from the equilibrium prediction of \$16 at the 5% level using a t-test. However, when considering the last 4 relevant periods alone, only the cap-and-trade prices are found to be significantly different from equilibrium. 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 5.8 illustrates frequent shortfalls in permit trading volumes from equilibrium predictions. Evidence from Tables 5.4 and 5.5 supports the notion that both permit trading programs result in permit trading volumes that are significantly below the predicted equilibrium rate. The per period graphical analysis demonstrates 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 ANOVA test on all mean session trading volumes proves that the deviation from the equilibrium is, using a t-test, significant at the 5% level for both schemes. The evidence regarding a possible treatment effect is less clear. Although the volumes in Figure 5.8 appear to be similar across treatments, Tables 5.4 and 5.5 show the three mean session volumes to be significantly higher under cap-and-trade

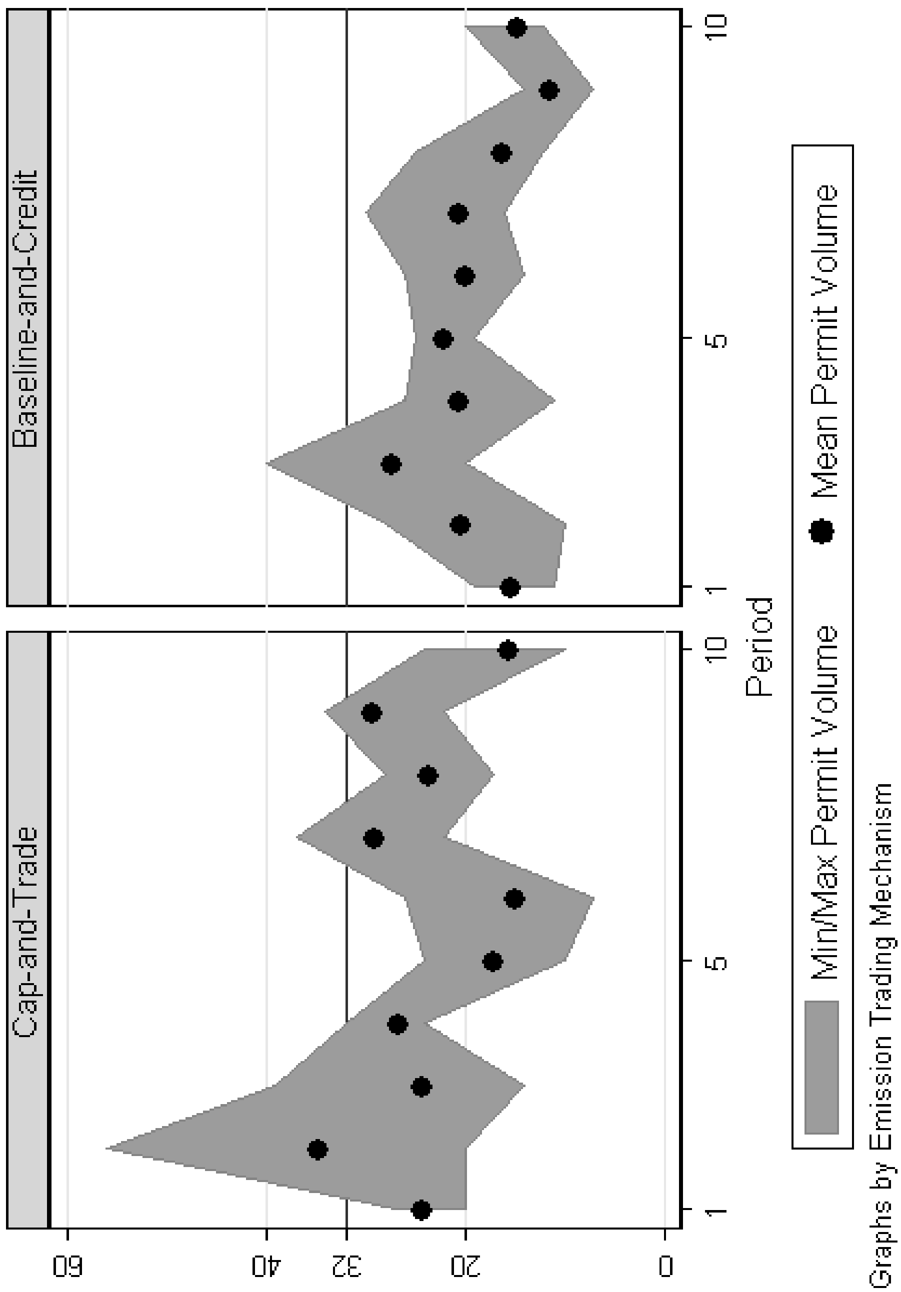


Figure 5.8: Permit Trading Volumes

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 market for credits created by the nature of the relative framing of the baseline-and-credit trading institution, as discussed in Section 5.5.

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 5.9 confirms the results from the ANOVA statistical tests reported in Tables 5.4 and 5.5. Whether one focuses on periods 1 to 9 or only on periods 6 to 9, only the cap-and-trade treatment displays significantly different (lower) output volumes from the equilibrium prediction (according to t-tests at the 5% level), and there is a significant treatment effect over period 1 to 9 (ANOVA and Mann-Whitney U-test is significant at the 10% level). 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; remember firms can ensure that they will not be required to deliver any permits to the regulator by choosing emission rates 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 difference in regulation allows firms that made permit trading errors to produce output at

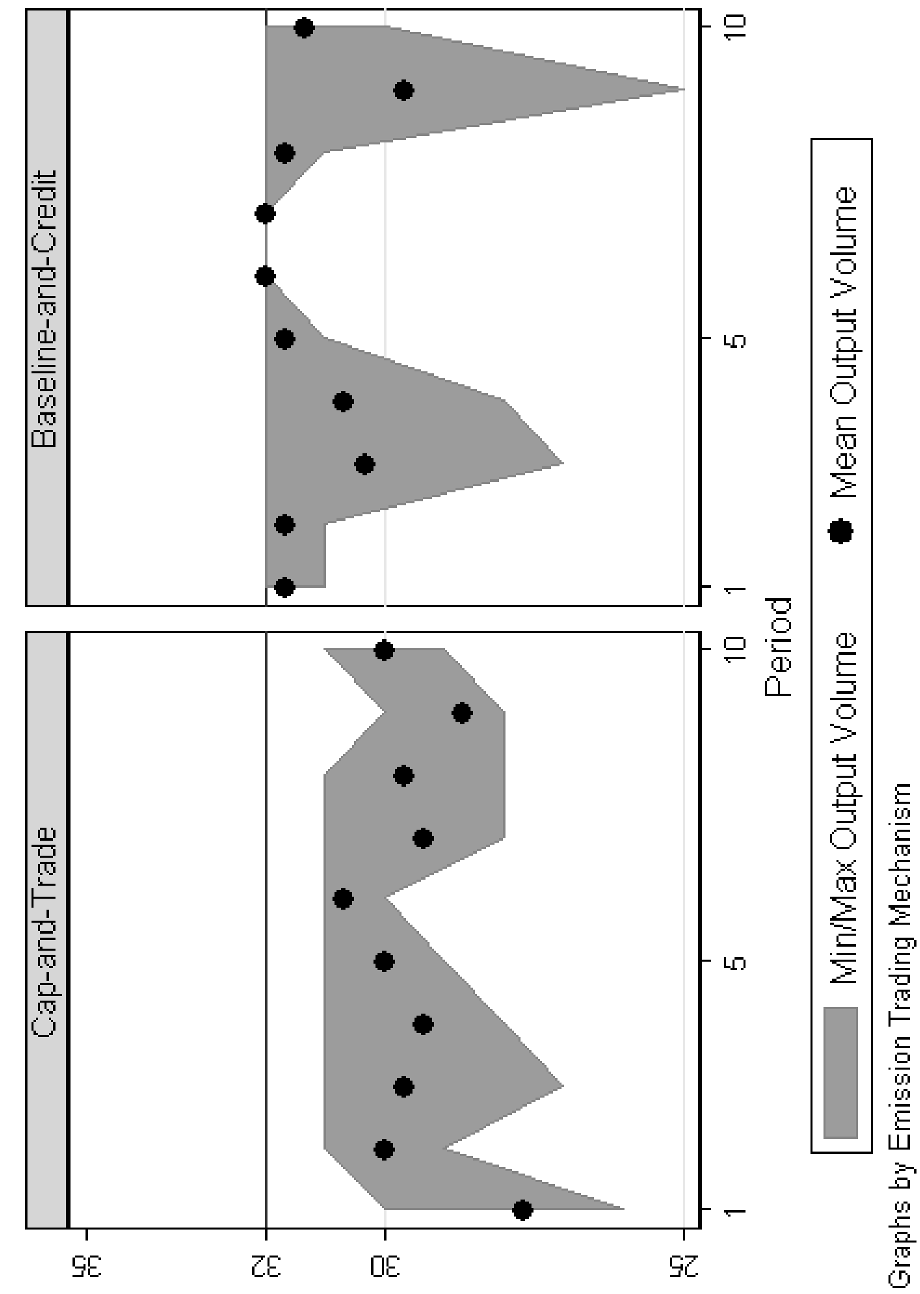


Figure 5.9: Output Volume

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. Of course, 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 first few 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 5.10 highlights an almost identical upward trend of aggregate emissions under cap-and-trade and baseline-and-credit trading. Tables 5.4 and 5.5 cite mean cap-and-trade emission levels at 155 and 171 over periods 1 to 9 and 6 to 9, respectively, and comparable baseline-and-credit emission levels at 156 and 172, respectively. The mean aggregate per period emission levels under cap-and-trade and baseline-and-credit are not significantly different from each other, or from the equilibrium prediction of 160, at a 10% 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 these levels different from the optimal levels.

One might note that, although not statistically different from 160, average emissions are lower than 160 under both plans. Figure 5.10 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 redeemed later to contribute towards producing emissions and output. Is the initial under-polluting and inventory build-up due to in-

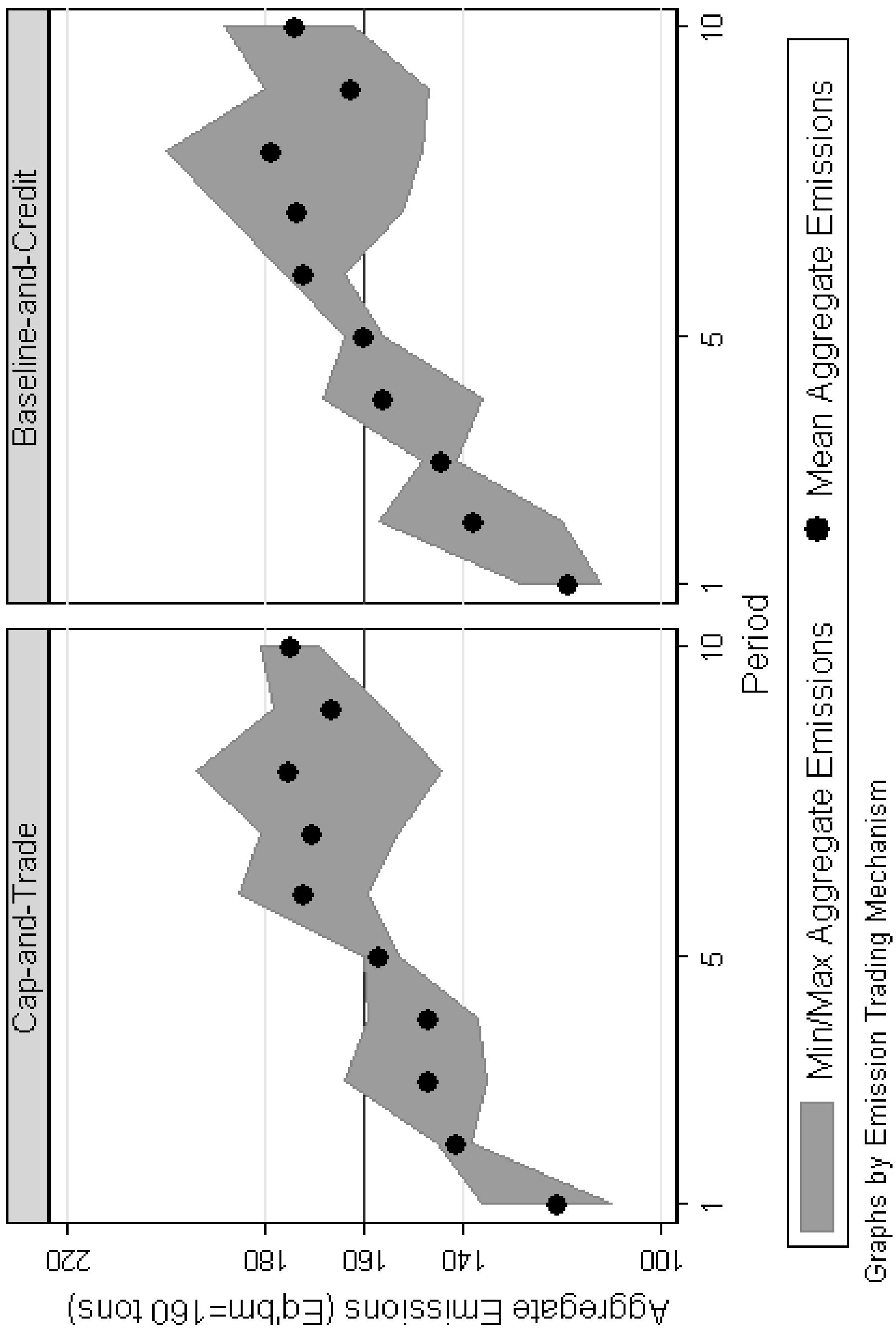


Figure 5.10: Aggregate Emissions

experience or strategy (e.g. risk aversion)? To help shed light on the issue, we shall examine permit inventories period by period. Figure 5.11 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. Tables 5.4 and 5.5 provide 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-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 5.11 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

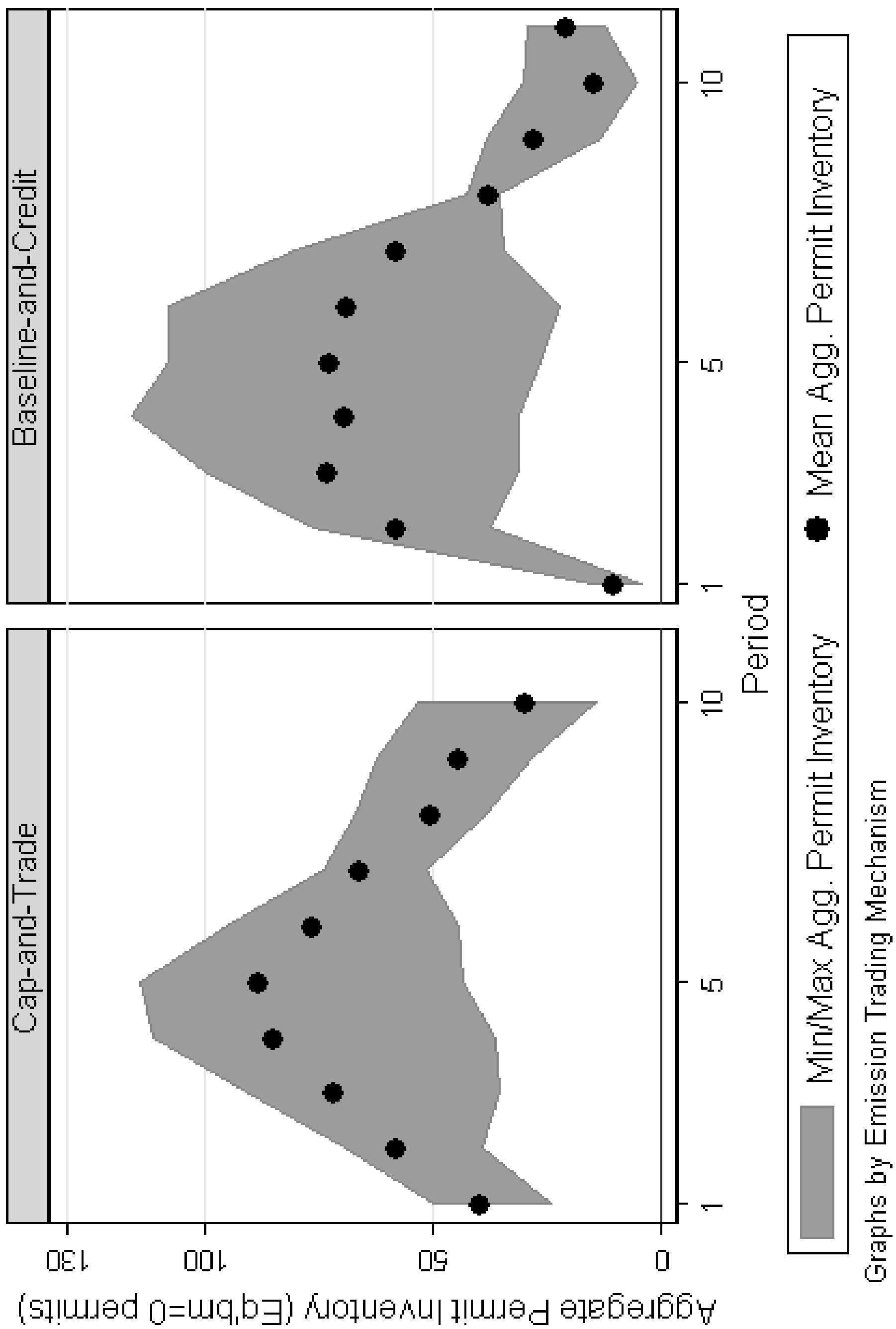


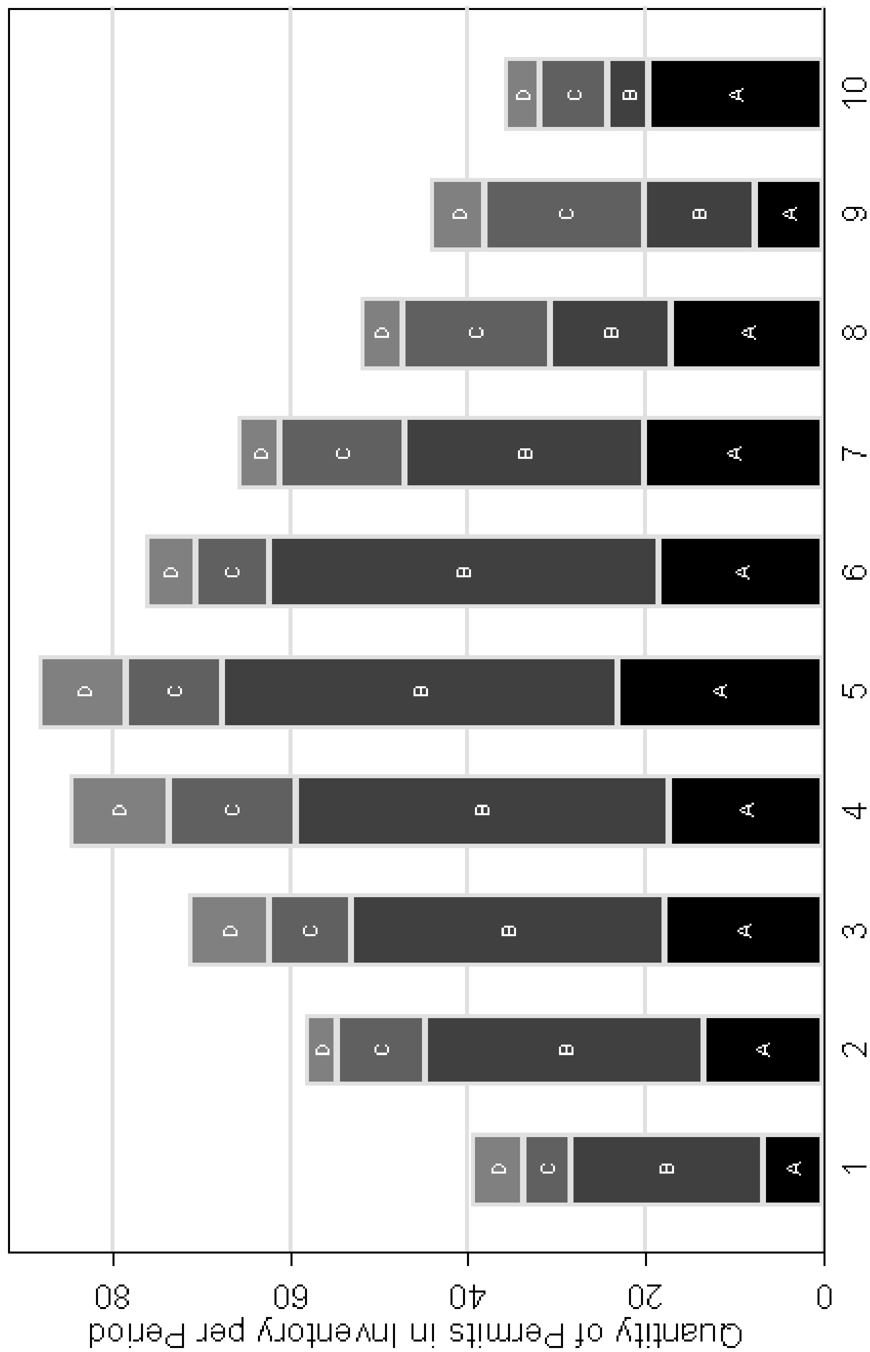
Figure 5.11: Aggregate Inventory

it actually does not (as evidenced by Figure 5.11) 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 (as described in Section 5.5). These potentially lower permit supplies, evidenced by the low credit trading volumes in Figure 5.8, would influence permit inventories to be lower under baseline-and-credit regulation compared to a cap-and-trade scheme.[14]

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 a 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 5.12 and 5.13 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 results averaged over the three sessions per treatment 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. When looking at the two inventory breakdown figures, it is natural to question whether some firm types dominate the inventory holdings. To answer this, 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

[14]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.



Note: Darker colours represent inventories by firm types with lower marginal abatement costs.

Figure 5.12: Cap-and-Trade Mean Inventories at End of Each Period

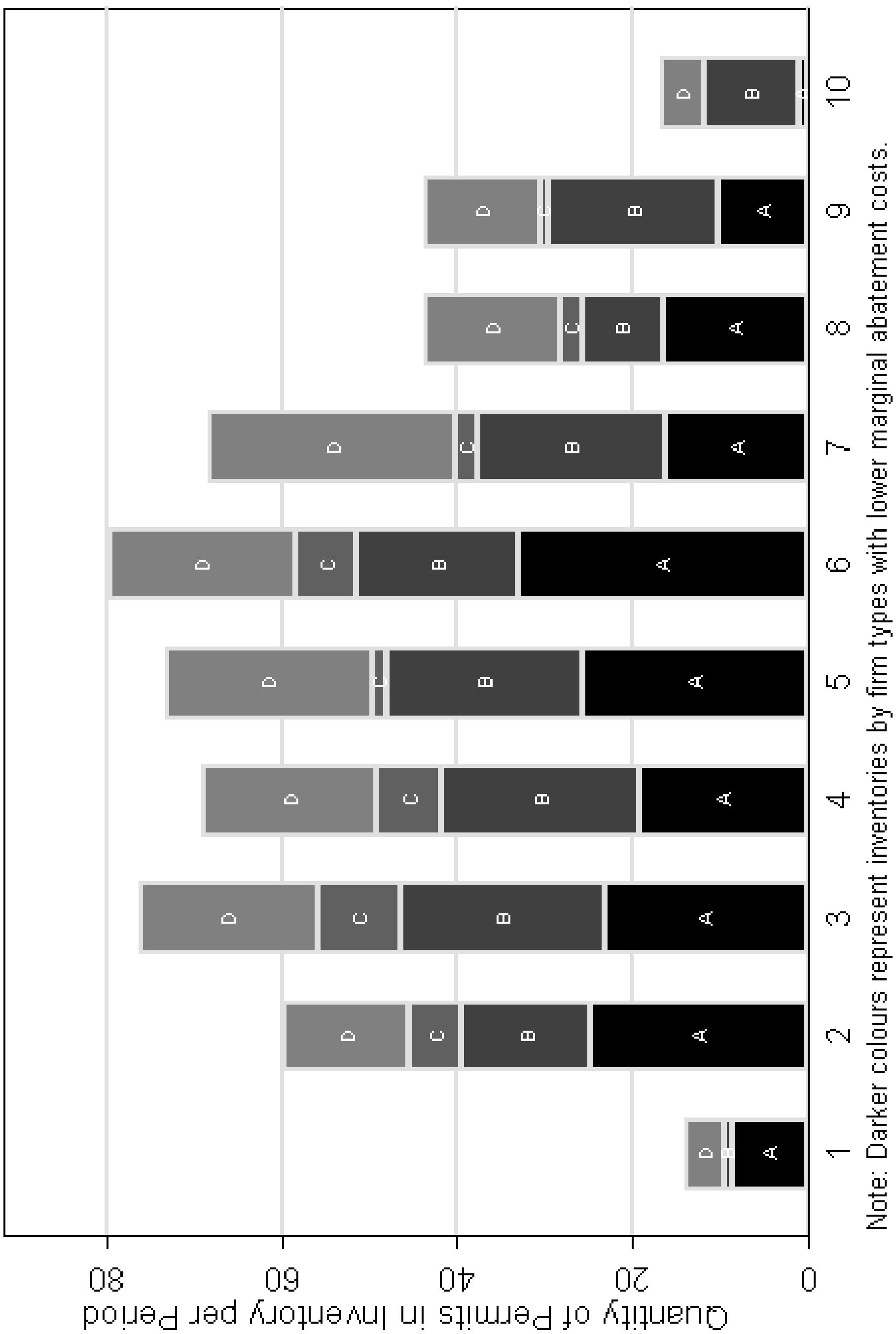


Figure 5.13: Baseline-and-Credit Mean Inventories at End of Each Period

firms are predicted to be the sellers of permits in the short-run equilibrium and are represented by the darkest segments in Figures 5.12 and 5.13. 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 (ANOVA, 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, while all six observations pooled over both plans are significantly different from 50%, using a two-tailed t-test at a 5% 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, keeping their inventories high.

5.6.3 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

$$S = Total\,Social\,Surplus = Consumer\,Surplus + Producer\,Surplus \\ +Environmental\,Surplus \tag{5.2}$$

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, it is natural to frame a mechanism's efficiency 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, but 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

$$\text{Efficiency} = \frac{S^{actual} - S^{command/control}}{S^{optimal} - S^{command/control}} \tag{5.3}$$

where S is defined in equation 5.2. The environmental damage function is assumed to be weakly convex in our assumptions stated in Chapter 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

Table 5.6: Decomposition of Mean Efficiency over Periods 1 to 9

		Components of Efficiency		
	Efficiency =	Consumer Surplus* +	Producer Surplus** +	Environmental Surplus +
Cap-and-Trade:				
Session 1	73.38%	-43.32%	105.80%	10.91%
Session 2	63.18%	-22.13%	77.92%	7.39%
Session 3	61.14%	-49.48%	105.69%	4.93%
Treatment Mean	65.90%	-38.31%	96.47%	7.74%
Baseline-and-Credit:				
Session 4	62.89%	-19.90%	69.06%	13.72%
Session 5	46.95%	-12.70%	55.26%	4.40%
Session 6	45.39%	0.00%	43.99%	1.41%
Treatment Mean	51.74%	-10.87%	56.10%	6.51%

* Treatment effect is significant using an ANOVA test at a 10% critical level and a Mann-Whitney U-test at a 5% level.
** Treatment effect is significant using an ANOVA test and a Mann-Whitney U-test at a 5% critical level.

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 5.14 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 simply calculated by actual surplus divided by optimal surplus.

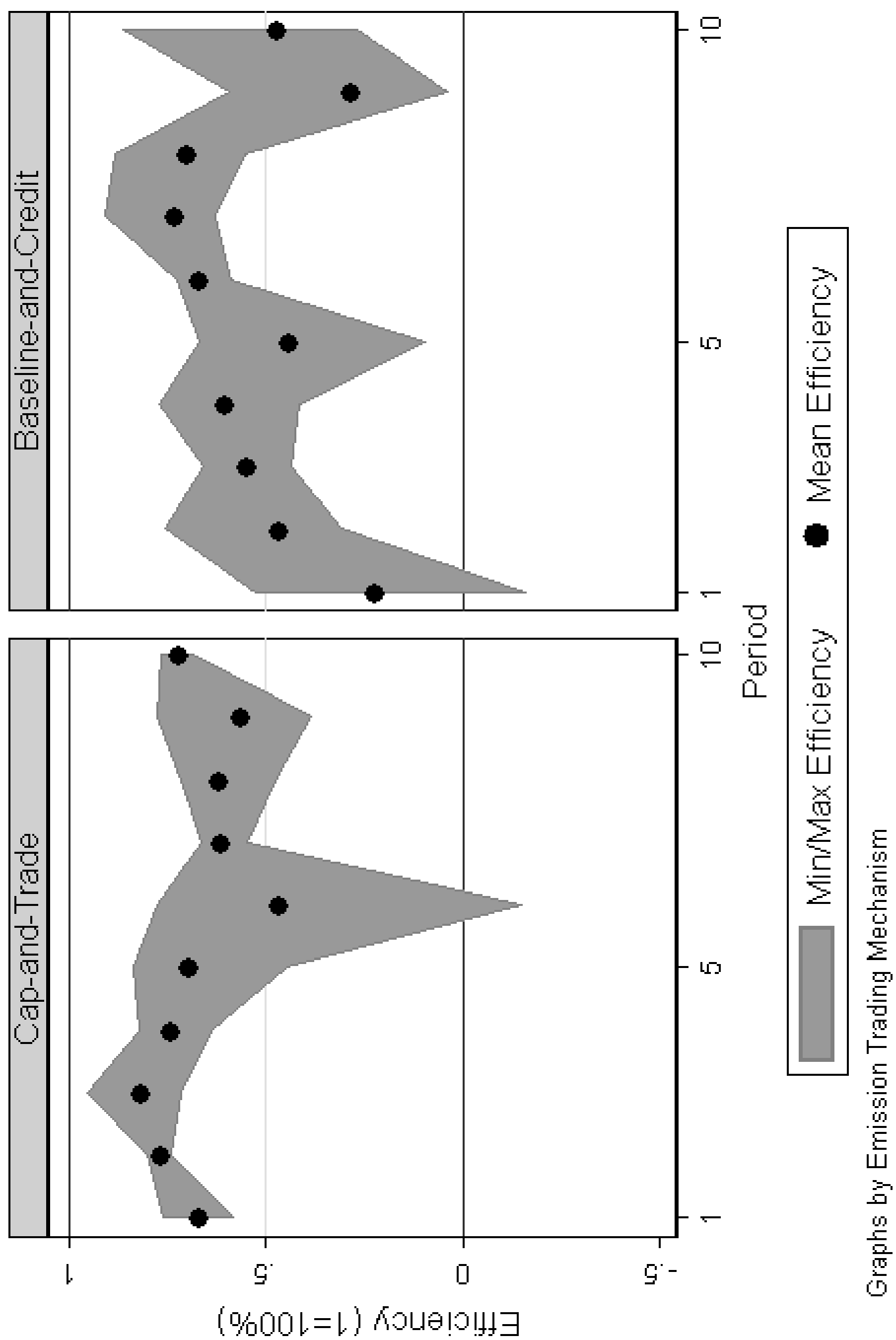


Figure 5.14: Efficiency (Gains from Trade)

Table 5.7: Decomposition of Mean Efficiency over Periods 6 to 9

		Components of Efficiency		
	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 an ANOVA test at a 10% critical level.

Tables 5.6 and 5.7 present the quantitative results behind Figure 5.14, averaged over periods 1 to 9 and 6 to 9, respectively. 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 percentages sum to the overall efficiency of each session. For example, the consumer surplus component is defined as

$$Consumer\,Surplus\,Component = \frac{CS^{actual} - CS^{command/control}}{S^{optimal} - S^{command/control}} \tag{5.4}$$

where CS denotes the level of consumer surplus. Again, the environmental surplus will be negative if environmental damages are positive. For instance, Table 5.6 contains positive environmental surplus components for all sessions. This is indicative of emission levels below those in the command and control outcome, rendering actual environmental damages lower than under command and control. This result is supported by the evidence from Figures 5.10 and 5.11 which illustrate inventories being carried forcing aggregate emission to be below the equilibrium prediction.

Also, notice that the consumer surplus components are never positive values because output, and hence consumer surplus, can never exceed the fixed output capacity in this short-run environment. To provide an example of how to interpret values in Tables 5.6 and 5.7, an explanation of the first line in Table 5.6 will be provided. The first line states that the mean efficiency in periods 1 to 9 in cap-and-trade session 1 was 73.38%, meaning 73.38% of the potential gains from trading emission permits was actually realized. 43.32 percentage points of this efficiency were lost due to actual consumer surplus falling below the benchmark, while 105.8 and 10.91 percentage points were due to gains in actual producer and environmental surplus above the command and control benchmark values, respectively.

Statistical testing implies 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 ANOVA or Mann-Whitney tests. 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 5.7 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 an ANOVA test at the 10% level only (the corresponding nonparametric Mann-Whitney test p-value is above 10%). Over periods 6 to 9, 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.

5.6.4 Payoff Distribution

Proposition 3 predicts that aggregate, and hence mean, profits will be identical under both emission trading mechanisms in the short-run. While we are interested in testing this proposition using the laboratory results, we are also interested in investigating any distributional effects in payoffs. Although the distribution of payoffs was not a focus of the theory presented in Chapter 2, since output is fixed to be equal across all firms and firms receive equal shares of the aggregate permit endowment under cap-and-trade, the short-run equilibrium profits per firm discussed in Chapter 2 will be identical in the two treatments under the current environmental parameters. According to the short-run equilibrium parameters and predictions summarized in Section 5.4, each cap-and-trade firm is predicted to earn $P_c A_i = D'(E^*)E^*/N = 16 \cdot 160/8 = 320$ and each baseline-and-credit firm is predicted to earn $q_i P_b r^s = {q_i}^* D'(E^*)E^*/Q^* = 4 \cdot 16 \cdot 160/32 = 320$, per period.

Figure 5.15 presents the payoff distribution amongst all subject firms by treatment, aggregating all eight firms in each of all three sessions within each treatment.[15] The left hand side panel of Figure 5.15 displays evidence that payoffs over the entire 10 periods are distributed very differently under the two treatments, while the right hand side panel shows that payoffs over periods 4 to 10 have a similar distribution in both treatments. Although in the first three

[15] A fitted kernel density is displayed with each corresponding histogram to give the reader an idea of the underlying continuous distribution. The kernel density was estimated using the default settings of the *kdensity* command in STATA release 8.0 (StataCorp 2003).

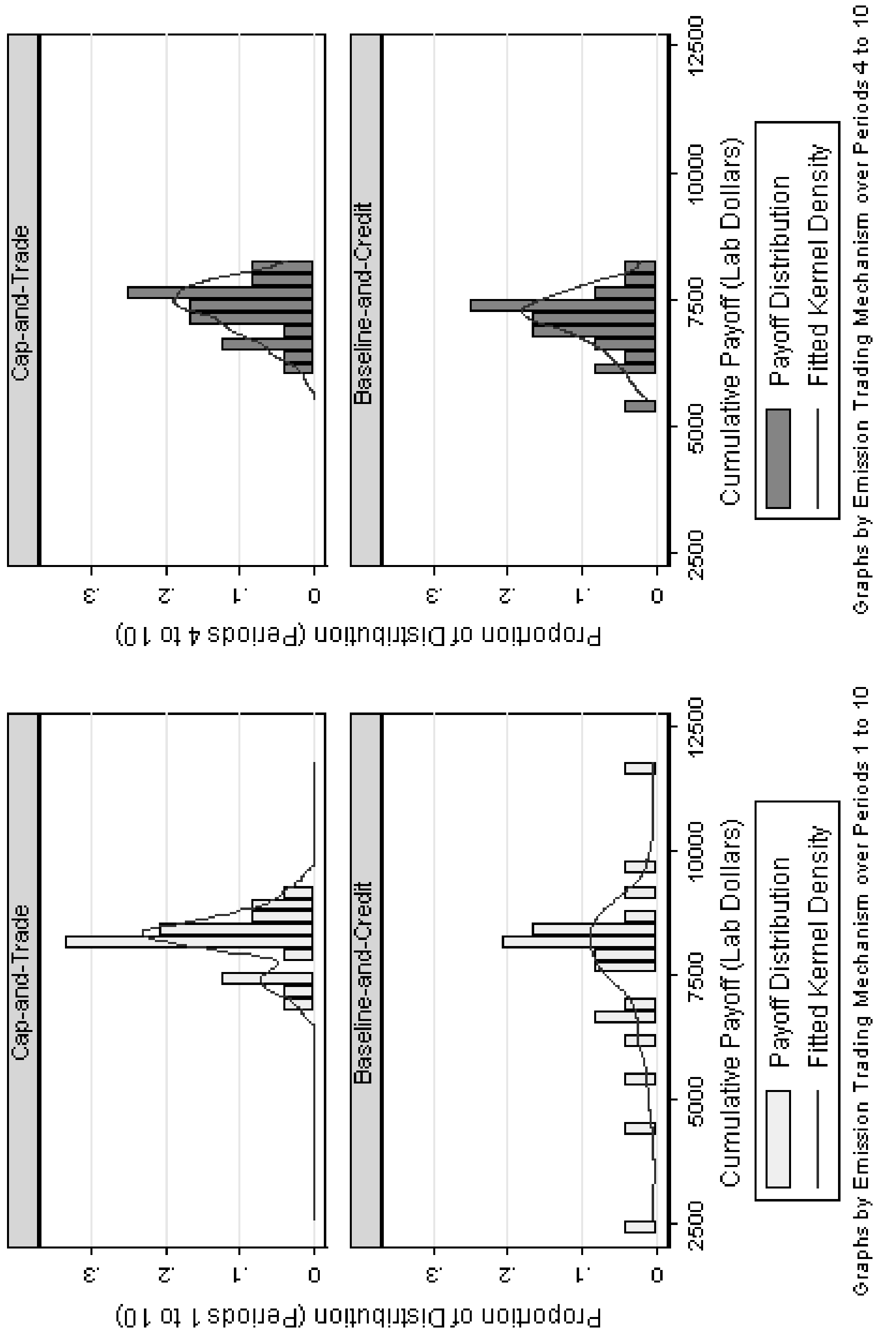


Figure 5.15: Distribution of Payoffs

Table 5.8: Mean and Coefficient of Variation (C.O.V.) of Subject Payoffs by Session

	Payoffs over:					
	Periods 1 to 3		Periods 4 to 10		Periods 1 to 10	
	Mean	C.O.V.**	Mean*	C.O.V.	Mean*	C.O.V.**
Cap-and-Trade:						
Session 1	970.78	15.78	2327.12	21.91	3297.89	18.79
Session 2	782.98	33.39	2210.90	28.58	2993.87	18.54
Session 3	912.10	28.58	2410.85	16.32	3322.95	16.82
Treatment Mean	888.62	25.92	2316.29	22.27	3204.91	18.05
Baseline-and-Credit:						
Session 4	840.29	40.74	2027.41	21.24	2867.70	25.03
Session 5	458.36	527.99	2199.27	26.29	2657.64	109.93
Session 6	580.07	80.02	1959.23	41.51	2539.30	41.89
Treatment Mean	626.24	216.25	2061.97	29.68	2688.21	58.95

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

periods payoff variance is certainly higher under baseline-and-credit regulation, and this causes it to dominate the entire 10 period session, the treatment means of the payoff distributions do not seem to be different from each other.

Table 5.8 provides details on the distribution of payoffs from a different perspective: the mean and coefficient of variation of payoffs by session and treatment.[16] This provides one truly independent observation per session so that formal statistical significance tests can be conducted. Mean session payoffs are found to be significantly higher under cap-and-trade than under baseline-and-credit at a 5% level over periods 1 to 10 and 4 to 10 using ANOVA and Mann-Whitney tests. This difference is important to document, as it provides evidence that mean payoff levels are converging to higher values under cap-

[16]The coefficient of variation is the standard deviation of payoffs to individuals in a session divided by the mean payoff to these individuals multiplied by 100. This provides a normalized measure of the distribution of payoffs in each treatment as it expresses the magnitude of variance relative to the payoffs themselves and therefore allows comparison of the income distribution across the different treatments.

and-trade compared to baseline-and-credit, contradicting Proposition 3 based on the theory in Chapter 2. Over periods 4 to 10, cap-and-trade mean payoffs are 12% higher than those under baseline-and-credit.

When observing the coefficient of variation of payoffs by session, only the non-parametric Mann-Whitney U-test supports the contention that the distribution of payoffs is less equitable under a baseline-and-credit regime (and it is significant at a 5% level). This is true over periods 1 to 3 and 1 to 10 but not for the end of the experiment alone. This confirms the evidence in Figure 5.15, suggesting that differences in the variance of payoffs between the two trading mechanisms will disappear over time. Although firm type breakdowns are not shown in Figure 5.15 or Table 5.8, statistical tests found no significant difference in payoffs according to firm types within each trading plan or across trading plans.[17]

5.6.5 Pilot Results

We conclude our short-run analysis by comparing the inventory results from Figure 5.11, discussed above, to the inventory results from the second and third pilot sessions, in hopes to find evidence supporting or refuting Propositions 4 and 5 put forth in Section 5.3. The two changes instituted between the pilot and regular short-run sessions have confounding effects, due to the interrelated nature of the permit and output markets. Our propositions, however, outline

[17]Even if mean payoffs were not found to be significantly higher under cap-and-trade than baseline-and-credit, it would still be possible that the payoff distribution by firm type could be significantly different between the two schemes. To formally test this hypothesis, the percentage of total payoff accrued to each firm type was calculated by session. Since each firm, regardless of firm type, is predicted to earn an identical payoff under both trading schemes in the short-run equilibrium, theory predicts the percentage of total payoff accrued to each firm type within a session to be 25% regardless of which of the two emission trading mechanisms is used. This resulted in six independent observations for each firm type. These firm type total payoff percentages were not found to be significantly different from 25% within each trading mechanism, nor were they significantly different from each other across trading mechanism (t-tests, 6 observations each, all p-values>0.10)

specific predictions concerning permit inventory carryover under cap-and-trade and baseline-and-credit emission trading. Testing these propositions requires that inventories from the pilot session from each trading scheme be compared to those from the three sessions conducted under the corresponding scheme. Since relevant significance tests would only involve 4 independent observations each, no meaningful significance testing can be conducted. Figure 5.16 illustrates the aggregate inventory holdings at the end of each period. The figure plots the cap-and-trade and baseline-and-credit inventory from each pilot session before the treatment changes were made along with the minimum, maximum and mean permit inventory of the three sessions under each emission trading plan after the treatment changes were made. While Figure 5.16 presents permit inventories for each period, Table 5.9 provides mean per period aggregate inventory by session.

The left hand panel of Figure 5.16 illustrates how cap-and-trade permit inventories possess a "hill" shape over the duration of the experiment. The pilot inventories seem to follow a pattern similar to, but well above, the three regular session inventories after period 4. While the effects of the accounting warning and output decision change cannot be disentangled in the cap-and-trade case, the diagrammatic results do support the predicted treatment effect of lower permit inventories as stated in Proposition 4. Table 5.9 also provides evidence substantiating Proposition 4 if one focuses on the values the mean inventories are converging to: the mean inventory values over periods 6 to 10. When comparing the three cap-and-trade session inventory values of 55.4, 52.4 and 51.4 to the matching pilot inventory value of 80.6, one can acknowledge that all three session inventories are converging to values well below the value of the pilot with a difference in means of 27.5 permits in inventory.

The right hand panel of Figure 5.16 presents results on permit inventories held under baseline-and-credit regulation. While permit inventories possess a

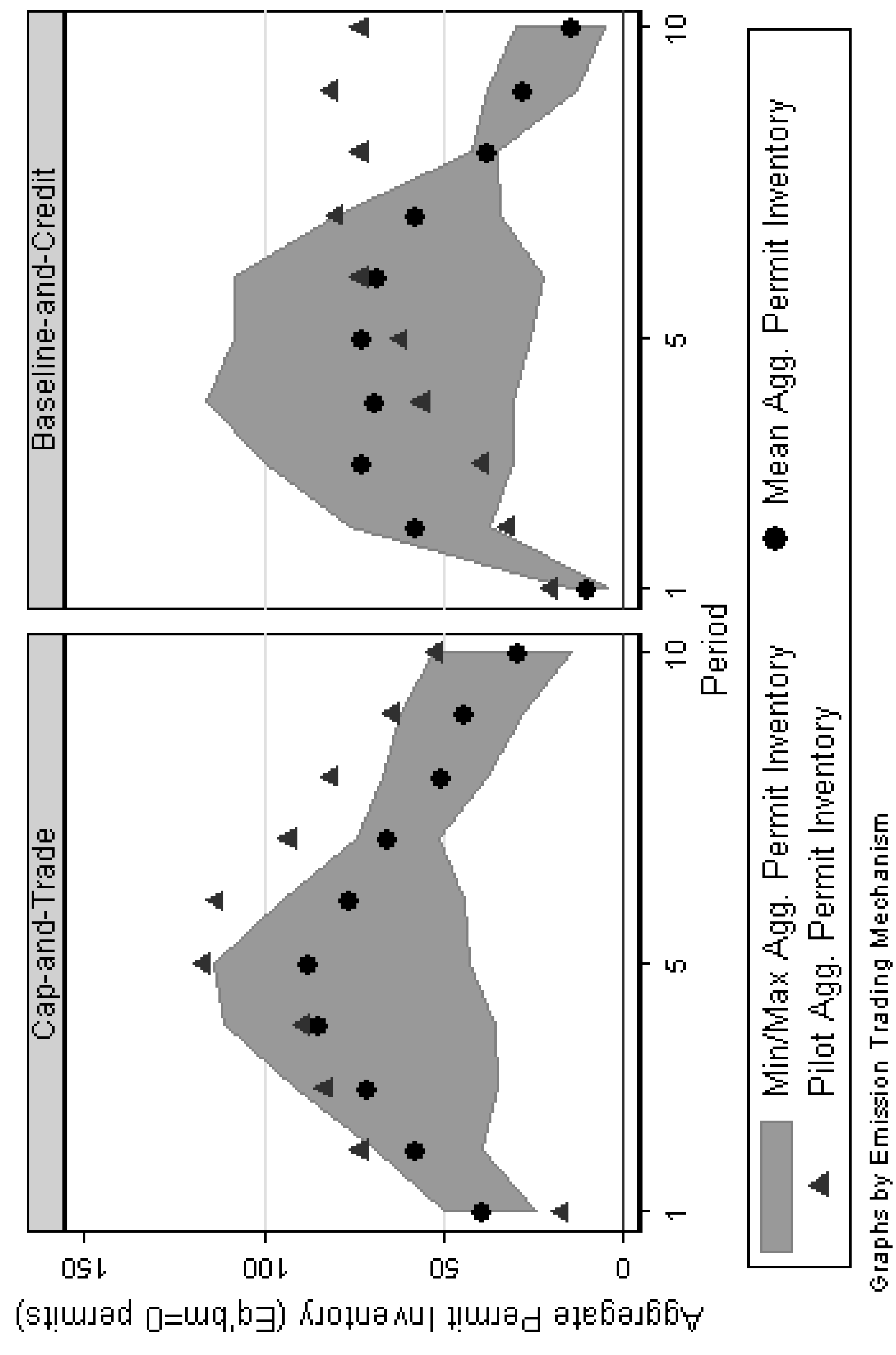


Figure 5.16: Aggregate Inventory Carryover

Table 5.9: Mean per Period Aggregate Permit Inventories by Session

	Mean per Period Aggregate Permit Inventory over Periods...	
	1 to 5	6 to 10
Cap-and-Trade:		
Session 1	35.4	55.4
Session 2	86.4	52.4
Session 3	83.0	51.4
C&T Mean	68.3	53.1
C&T Pilot	75.8	80.6
Baseline-and-Credit:		
Session 4	28.0	33.2
Session 5	80.8	48.2
Session 6	60.8	42.4
B&C Mean	56.5	41.3
B&C Pilot	41.8	76.0

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

familiar "hill" shape in the three treatment sessions with the accounting warning and the forced output decision, the pilot session without these changes displays quite a different pattern. Unlike the cap-and-trade pilot, which displayed a build-up of inventory which was worked off, to some extent, over the second half of the experiment, the baseline-and-credit pilot provides evidence of increased permit inventories over the entire duration of the experiment. This difference in the baseline-and-credit pilot inventories is consistent with a treatment effect dominated by the accounting misrepresentation as stated in Proposition 5. Figure 5.16 highlights how the last four periods of baseline-and-credit pilot inventories are higher than the corresponding inventories of the three non-pilot sessions. This trend is consistent with the hypothesis that the emission right accounting is misleading in that permits added to inventory are not reflected by the income statement even though cash holdings decrease.

Table 5.9 confirms these results as it indicates how mean inventories under baseline-and-credit sessions converge to values of 33.2, 48.2 and 42.4 over periods 6 to 10. All three session mean inventory levels are well below the corresponding mean inventory level of 76 under the pilot. The difference in means is 34.7 permits in inventory. Despite the limited observations we have, the misleading accounting appears to be a potential problem. As mentioned, formal statistical analysis of the two propositions is difficult due to small sample sizes. As one can note from Table 5.9, mean session inventories from the three non-pilot sessions under each trading scheme are all lower than their associated pilot inventories, over periods 6 to 10. An ANOVA regression based on the eight observations in this column, aggregating over both trading plans, provides evidence of a significant difference between the pilot and non-pilot inventories over periods 6 to 10 (p-value$<$0.01).

5.7 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 chapter reports results on controlled laboratory sessions in a short-run environment.

Despite the host of reasons cited in Section 5.5 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 hypothesis that aggregate emission levels under cap-and-trade and baseline-and-credit are identical and we cannot reject the hypothesis that either scheme is 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 the short-run. This supports the two propositions we first introduced in Section 5.2.

One caveat, however, is that it appears that mean payoffs may be higher under cap-and-trade regulation. Proposition 3 encapsulates the theory presented in Chapter 2 predicting that mean and aggregate profit levels under the two schemes should be identical in the short-run. We found that this significant difference strengthened over time and resulted in cap-and-trade payoffs levels 12% above those under baseline-and-credit. The coefficient of variation of payoffs were found to be significantly greater under baseline-and-credit trading over the first three periods. Since this inequity was found to disappear over the length of an experimental session, most likely caused by decision errors while learning the more complex mechanism, it seems reasonable to expect this to be a problem only for a short period of time once a baseline-and-credit plan is implemented. It is possible, however, that frequent shifts in the market environment (such as variations in the performance standard or in the demand for output) may lead to payoff inequities over a longer period of time under a baseline-and-credit plan. We leave for future experiments the task of disentangling the confounding factors in order to truly test whether baseline-and-credit inequities can be a long-run phenomenon in a constantly changing marketplace.

Permit inventories were an essential focus of our short-run analysis. Our initial interest was simply investigating whether subjects carried inventories at all, and if they did, whether they worked them off over the length of the experiment as predicted. Results show that while a great deal of inventories were being carried under both trading plans, these inventories were generally worked off 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 result not surprising considering that permits are not as directly valuable to these types of firms.

Our analysis of permit inventories also allowed us to test for differences in an accounting treatment based on how specific emission permit accounting rules misrepresent profits and losses and thus may affect inventory behaviour. Early short-run pilot sessions using an accounting method similar to the one being implemented by the IFRIC of the International Accounting Standards Board suggested that mismatching entries between income statement and balance sheet accounts could potentially cause irrational behaviour leading to accumulated permit inventories. Compared to the six regular sessions which warned subjects of the accounting misrepresentation and implemented a forced output market decision, inventories under the pilots were noticeably higher. In the baseline-and-credit treatment, the forced output decision was not predicted to affect permit inventories and so higher pilot inventory outcomes under this trading scheme can be attributed to the lack of the accounting-related warning. This leads us to conclude that the mismatching of accounting entries inherent to the IASB/IFRIC method could lead to irrational inventory accumulation and potential losses faced by real-world firms using the method. While our results suggest that inventories and associated losses may be lowered by warning firms of the potential problem, we do not find that warning them eliminates irrational inventory holdings entirely.

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. Knowledge on the short-run outcome of the two alternative trading mechanisms can provide a basis for analyzing long-run behaviour under cap-and-trade and baseline-and-credit trading programs.

Chapter 6

Conclusion

Primarily, this dissertation presents results from the first ever experimental economic analysis comparing the two most commonly proposed emission trading policy instruments: cap-and-trade and rate-based baseline-and-credit emission permit trading. This study speaks not only to the interests of economists, but also to those of policy makers due to the implications of the theoretical and laboratory results.

Although countries around the world are using cap-and-trade and baseline-and-credit emission trading instruments in an effort to reach greenhouse gas targets in a cost-effective manner, most research has focused only on cap-and-trade emission permit trading. Cap-and-trade systems are based on a fixed pollution cap, while baseline-and-credit systems operate on a more complicated relative framework employing a regulated emission technology performance standard. While economic theory predicts that long-run output and emissions will be higher under baseline-and-credit trading when the performance standard is set equal to the optimal average emission rate, no economic laboratory work has been conducted on baseline-and-credit style regulation. This dissertation presents the first economic experiments comparing baseline-and-credit to cap-and-trade regulation. First, a summary of the lessons learned through this research will be provided and a discussion of future work will follow.

6.1 Summary and Conclusions

The first chapter of this dissertation provides historical background and a literature review on the two alternative emission trading programs. Relevant details of previous cap-and-trade laboratory work are provided as a basis of comparison for the development of a new laboratory environment presented in Chapters 2 and 3. The influence of emission permit accounting standards, a topic often overlooked by laboratory studies, is also introduced.

Chapter 2 presents a formal theoretical model with long- and short-run theoretical predictions. While baseline-and-credit is shown to be inefficient in the long-run, its short-run equivalence to the optimal cap-and-trade outcome is also discussed. In addition to deriving the short- and long-run predictions, the chapter also derives the prediction that aggregate profits under both plans are identical in the short-run equilibrium when output is fixed at the optimal level.

Chapter 3 describes the creation of an experimental environment rich enough to test the theoretical predictions stated in Chapter 2. Previously published cap-and-trade experiments assume constant output or implicitly determined emission rates. The environment created for this project lets us consider an explicitly chosen emission rate and output capacity for each firm. Details are provided on how the simultaneous decision model of Chapter 2 has been implemented as a sequential decision, multi-period, laboratory environment. The chapter discusses many of the problems we experienced with different sequential choice algorithms, many of which produced results conflicting with those from the simultaneous choice model. The created environment incorporates both a final output market and a permit market which are linked by a detailed double-entry accounting system. The software created for this project is robust in that it can be quickly adapted to study many facets of emission permit trading above and beyond those studied in this dissertation. The underlying accounting framework invented for our emission trading software not only allows for a host of accounting treatments to be tested, but also provides the means to easily implement potential modifications to the emission trading schemes for further study. Lastly, the emission trading user interface has been programmed using language and terminology from the emission trading context. This allows it to not only be used for research, but also as a teaching tool for students and policy makers interested in the operation and dynamics of alternative emission trading plans.

Chapter 4 presents results from robot simulations that are used to test the experimental software and to provide insight into myopic profit maximizing firm behaviour in a long-run setting. Simulations involving robots making various degrees of pricing errors are also presented. Results from the simulations support the long-run prediction of higher output and emissions under baseline-and-credit regulation. Results also suggest that the small range of emission technology choices might be the cause of permit and output market volatility in the decision error treatments, implying that the range of choices should be expanded before conducting experiments with human subjects. It is also clear from the simulations that the lag inherent to credit creation implies that baseline-and-credit firms would have no permits to sell in the first period unless they were explicitly endowed with them. Since our baseline-and-credit simulations do not involve such endowments, credit market price volatilities are experienced over the first few periods. Based on the simulations presented in Chapter 4, it was decided that the emission rate scale would be enlarged to 10 possible values, and that baseline-and-credit firms would begin the experiment with their equilibrium quantity of credit inventory.

Chapter 5 describes and presents results from the first baseline-and-credit experiment run with human subjects. Due to the complex nature of the laboratory environment, it was decided to first investigate the alternative emission trading plans under a short-run setting, where the predicted outcomes are identical between the two plans. Gaining evidence on the short-run outcomes of the two mechanisms provides a basis for future long-run analysis, as any basic mechanical differences between the two institutions can be determined. Results from the short-run experiment provide evidence of higher mean payoffs under cap-and-trade. Also, permit prices are found to be above the predicted price under baseline-and-credit over the first half of the experiment, and below the predicted price under cap-and-trade over the second half of the experiment. However, important characteristics, such as emissions and overall efficiency, are identical under the plans and are not significantly different from the predicted equilibrium values. The fact that short-run emissions under the two trading schemes are produced as predicted, indirectly lends confidence to the long-run theoretical prediction of higher output and emissions under baseline-and-credit. The results from the short-run investigation will be important to keep in mind when analyzing the two schemes in a long-run setting, in order to attribute any differences between the two schemes to the long-run setting and short-run setting appropriately.

Chapter 5 also provides an analysis focusing on the accounting of emission rights within the context of the short-run laboratory experiment. The short-run experimental environment treats emission permits as intangible assets, a treatment being supported by The International Accounting Standards Board's IFRIC. After running three pilot short-run sessions in preparation for the six regular short-run sessions, we noticed that subjects were holding irrational levels of permit inventories, possibly due to a misrepresentation between the income statement and balance sheet. According to the IFRIC method implemented in our environment, buying permits and keeping them in inventory affects the balance sheet but does not affect the income statement. Based on subject debriefings after the pilots, we realized that subjects depending on the income statement as an indicator of profits and losses may accumulate permit inventories unknowingly. Before running the six regular short-run sessions, a warning was introduced in the laboratory instructions explaining the accounting misrepresentation. The output decision was also modified between the pilots and regular sessions. The effect of the accounting warning can only be identified under baseline-and-credit trading. A careful analysis of the pilot and non-pilot sessions shows evidence that accounting for emission permits as intangible assets, without warning subjects of the accounting misrepresentation, results in significantly higher and irrational permit inventories being held. Permit inventories are especially high during the last few periods. This evidence highlights a problem inherent to the IFRIC accounting method which will be finalized in the next few months in anticipation of initial trading under the European Union's official emission trading scheme in January 2005. The most disturbing conclusion of this accounting analysis is that the irrational inventories are not eliminated by warning subjects of the inherent problem.

The many results and lessons learned from this dissertation have been summarized above, but one must not forget the major contribution of this work. Although Chapter 5 has presented evidence that baseline-and-credit outcomes are similar to cap-and-trade outcomes in the short-run, the laboratory simulations discussed in Chapter 4 prove that profit maximizing behaviour in our environment supports the theoretical prediction of higher output and emissions under baseline-and-credit trading. Now that the inherent inefficiency of baseline-and-credit trading has been demonstrated in real laboratory markets, the economic prediction of baseline-and-credit inferiority is no longer just a theory.

6.2 Future Research

Now that the necessary computer software has been developed and tested, various comparisons of baseline-and-credit and cap-and-trade emission trading programs can be conducted. While this dissertation has conducted long-run simulations and short-run experiments comparing the main outcomes of the alternative emission programs, it has also made it possible to investigate other emission trading issues. This dissertation concludes with a discussion of ideas for further research.

To reiterate, we investigated a laboratory setting in which firms in a fully specified environment can choose an emission rate but output capacity is fixed. The most obvious next step in the line of research initiated by this dissertation is testing the long-run theoretical predictions of cap-and-trade versus baseline-and-credit emission permit trading when firms can choose both emission rates and output capacities.

Also, future research may investigate the laboratory setting in which, opposite to our assumptions, firms choose output capacity but emission rates are fixed. This experiment would be interesting in that the expected outcome of higher output and emissions under baseline-and-credit could be tested. This environment would provide subjects with a less complicated alternative to the long-run model proposed above. Such a setting would also be crucial in understanding behaviour in the long-run environment in which both emission rate and output capacity are chosen.

There is a host of issues which have already been investigated in laboratory studies of cap-and-trade emission trading. Considering that baseline-and-credit schemes are prevalent around the world, conducting these studies in a baseline-and-credit environment is also important. Such studies could investigate the effect of emissions uncertainty, market power and compliance in baseline-and-credit trading markets. As mentioned in Chapter 1, theoretical studies on baseline-and-credit trading predict that uncertainty in future demand, GDP and emissions can affect the alternative plans differently (Ellerman and Wing 2003). Market power is also a very interesting topic for future research. As Chapter 5 discusses, the relative framing of the baseline-and-credit mechanism creates a thin permit market which could potentially be manipulated more easily than a corresponding cap-and-trade permit market. Additionally, the endogenous permit supply inherent to baseline-and-credit regulation is a nonexistent issue for market power studies under cap-and-trade regulation (Muller, Mestelman, Spraggon, and Godby 2002; Elliott, Godby, and Kruse 2003). Lastly, the software created for this work allows one to conduct a study on compliance behaviour under both schemes unlike any that have been conducted to date: in a fully specified trading environment in which firms can affect compliance with their emission rate choice, their output capacity choice, their behaviour in the permit market and their behaviour in the output market.

In addition to the common topics of laboratory research mentioned above, a few new areas for possible study will be highlighted. The first is *credit for early action*. The lag in credit creation that exists in most real world baseline-and-credit implementations may cause initial credit price volatility, as evidenced in the Chapter 4 simulation results. A credit for early action plan may alleviate this volatility. A credit for early action plan involves the imposition of a "voluntary" period before the regulation is imposed and during which firms are allowed to create credits but are not required to redeem credits. While this type of plan is hypothesized to, amongst other things, acclimatize firms to the regulation, evidence on the effect of credit for early action on firm payoffs and on credit prices in real markets is needed before policy makers can make an informed opinion.

Lastly, we will discuss a need for laboratory research pertinent to the emission permit trading mechanism currently implemented in the province of Ontario. As mentioned in Chapter 1, in 2002 the Ontario Ministry of the Environment implemented a hybrid emission trading scheme drawing elements from both cap-and-trade and baseline-and-credit mechanisms (OMOE 2003). Mandatory cap-and-trade regulation is coupled with a voluntary ERC-based system. Fischer (2003) analyzes a combined cap-and-trade and rate-based regulation similar to the Ontario trading system. Fischer's theoretical study concludes that unrestricted trade between these two types of programs always raises combined emissions. The emission trading environment created for this dissertation could be easily adapted to the Ontario case to investigate outcomes and behaviour under a combined cap, credit and trade system in real laboratory markets. This would provide local policy makers with evidence on the incentive characteristics inherent to their chosen emission trading mechanism.

Bibliography

Ben-David, S., D. S. Brookshire, S. Burness, M. McKee, and C. Schmidt (1999). Heterogeneity, irreversible production choices, and efficiency in emission permit markets. *Journal of Environmental Economics and Management 38*(2), 176–194.

Ben-David, S., D. S. Brookshire, S. Burness, M. McKee, and C. Schmidt (2000). Attitudes toward risk and compliance in emission permit markets. *Land Economics 76*(4), 590–600.

Buckley, N. J., S. Mestelman, and M. Shehata (2003). Subsidizing public inputs. *Journal of Public Economics 87*(3-4), 819–846.

Cason, T. N. (1995). An experimental investigation of the seller incentives in the EPA's emission trading auction. *American Economic Review 85*(4), 905–922.

Cason, T. N. (1997, Summer). Market masked regulation. *Regulation 1997*, 177–195.

Cason, T. N. and L. Gangadharan (2004, Apr). Emissions variability in tradable permit markets with imperfect enforcement and banking. manuscript, Purdue University.

Cason, T. N. and C. Plott (1996). EPA's new emission trading mechanism: A laboratory evaluation. *Journal of Environmental Economics and Management 30*(2), 133–160.

Cramton, P. and S. Kerr (2002). Tradeable carbon permit auctions: How and why to auction and not grandfather. *Energy Policy 30*, 333–345.

Crocker, T. (1966). The structuring of atmospheric pollution control systems. In *The Economics of Air Pollution*. New York: W. W. Norton.

Dales, J. H. (1968). *Pollution, Property and Prices*. Toronto: University of Toronto Press.

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

Dewees, D. (2001). Emissions trading: ERCs or allowances? *Land Economics 77*(4), 513–526.

Ellerman, A. D., R. Schmalensee, P. L. Joskow, J. P. Montero, and E. M. Bailey (1997). *Emissions Trading under the US Acid Rain Program: Evaluation of Compliance Costs and Allowance Market Performance*. Cambridge, Mass.: MIT Center for Energy and Environmental Policy Research.

Ellerman, A. D. and I. S. Wing (2003). Absolute versus intensity-based emission caps. *Climate Policy 3S2*, S21–S28.

Elliott, S. R., R. Godby, and J. B. Kruse (2003). An experimental examination of vertical control and cost predation. *International Journal of Industrial Organization 21*(2), 253–281.

Fischer, C. (2001). Rebating environmental policy revenues: Output-based allocations and tradable performance standards. Discussion Paper 01-22, Resources for the Future.

Fischer, C. (2003). Combining rate-based and cap-and-trade emissions policies. *Climate Policy 3S2*, S89–S109.

Fischer, C., I. W. H. Parry, and W. A. Pizer (2003). Instrument choice for environmental protection when technological innovation is endogenous. *Journal of Environmental Economics and Management 45*(3), 523–545.

Franciosi, R., R. M. Isaac, D. Pingry, and S. S. Reynolds (1993). An experimental investigation of the Hahn-Noll revenue neutral auction for emissions licences. *Journal of Environmental Economics and Management 24*, 1–24.

Godby, R. (1999). Market power in emission permit double auctions. In R. M. Issac and C. Holt (Eds.), *Emission Permit Experiments*, Volume 7 of *Research in Experimental Economics*, pp. 121–162. Stanford, Conn.: JAI Press.

Godby, R. W., S. Mestelman, R. A. Muller, and J. D. Welland (1997). Emissions trading with shares and coupons when control over discharges is uncertain. *Journal of Environmental Economics and Management 32*, 359–389.

Hahn, R. W. and G. L. Hester (1989). Marketable permits: Lessons for theory and practice. *Ecology Law Quarterly 16*, 361–406.

Hasselknippe, H. (2003). Systems for carbon trading: an overview. *Climate Policy 3S2*, S43–S57.

Helfand, G. E. (1991). Standards versus standards: The effects of different pollution restrictions. *American Economic Review 81*(3), 622–634.

Kagel, J. H. and A. E. Roth (Eds.) (1995). *Handbook of Experimental Economics*. Princeton, NJ.: Princeton University Press.

Ledyard, J. O. and K. Szakaly-Moored (1994). Designing organizations for trading pollution rights. *Journal of Economic Behavior and Organization 25*, 167–196.

Mendenhall, W., J. E. Reinmuth, and R. J. Beaver (1993). *Statistics for Management and Economics*. Duxbury Press.

Mestelman, S., R. Moir, and R. A. Muller (1999). A laboratory test of a Canadian proposal for an emissions trading program. In R. M. Issac and

C. Holt (Eds.), *Emission Permit Experiments*, Volume 7 of *Research in Experimental Economics*, pp. 45–92. Stanford, Conn.: JAI Press.

Mestelman, S. and J. D. Welland (1991). Inventory carryover and the performance of alternative market institutions. *Southern Economic Journal 57*(4), 1024–1042.

Montgomery, D. (1972). Markets in licenses and efficient pollution control programs. *Journal of Economic Theory 5*, 395–418.

Muller, R. A. and S. Mestelman (1994). Emission trading with shares and coupons: A laboratory experiment. *Energy Journal 15*(2), 185–211.

Muller, R. A., S. Mestelman, J. Spraggon, and R. Godby (2002). Can double auctions control monopoly and monopsony power in emissions trading markets? *Journal of Environmental Economics and Management 44*(1), 70–92.

Murphy, J. J. and J. Stranlund (2004). Direct and market effects of enforcing emissions trading programs: An experimental analysis. Amherst Resource Economics Working Paper 2004-5, University of Massachusetts.

OMOE (2003, January). Ontario emissions trading code. Technical report, Ontario Ministry of the Environment (OMOE). http://www.ene.gov.on.ca/envision/env_reg/er/documents/2003/XA03E0001.pdf.

PERT (1997, May). Pilot emission reduction trading 1996 project report. Technical report, PERT Project.

Plott, C. R. (1983). Externalities and corrective policies in experimental markets. *Economic Journal 93*, 106–127.

Smith, V. L., A. W. Williams, W. K. Bratton, and M. G. Vannoni (1982). Competitive market institutions: Double auction versus sealed bid-offer auctions. *American Economic Review 72*, 58–77.

StataCorp (2003). *Stata Reference Manual Release 8 G-M*, Volume 2. College Station, TX: Stata Corporation.

Thomas, V. (1980). Welfare cost of pollution control. *Journal of Environmental Economics and Management 7*(2), 90–102.

Tietenberg, T. H. (2000). *Environmental and Natural Resource Economics 5th edition*. Addison Wesley Longman.

Weitzman, M. (1974). Prices vs. quantities. *Review of Economic Studies 41*(4), 477–491.

Appendix A

Mathematical Appendix

A.1 Proof that Social Planner's Solution is Optimal

The solutions to all of the optimization problems in Chapter 2 are all relative maxima. Since proof of this is similar across all regulation models, only the proof for the socially optimal case will be provided below. This mathematical proof will use a representative agent model slightly different from the multi-agent model presented in Chapter 2, as the proof is more straightforward when presented under this assumption. One can always envision the representative agent as the average firm.

To recap, the social planner's maximization problem is

$$\max_{\{r,q\}} S = \int_0^Q P(z) - c_i(r)Q - wQ - D(rQ). \tag{A.1}$$

The first order conditions for an interior maximum are

$$S_r = Q^*[-c'(r^*) - D'(r^*Q^*)] = 0 \tag{A.2}$$

and

$$S_Q = P(Q^*) - c(r^*) - w - r^* D'(r^* Q^*) = 0. \tag{A.3}$$

The S_r condition can be satisfied if Q^* equals zero or if the bracketed term equals zero. Considering that we are only interested in confirming whether the positive output equilibrium is a relative maximum, we assume that condition (A.2) implies that $-c'(r^*) = D'(r^* Q^*)$. The necessary and sufficient second order conditions for a relative maximum at this critical point are that $S_{rr} < 0$, $S_{QQ} < 0$ and $S_{rr} S_{QQ} - {S_{rQ}}^2 > 0$. In our surplus maximization context based on our assumptions around the cost and environmental damage functions stated in Table 2.1 of Chapter 2, these bivariate conditions are met.

We can demonstrate that

$$S_{rr} = Q^*[-c''(r^*) - Q^* D''(r^* Q^*)] < 0 \tag{A.4}$$

because $c'' > 0$ implies that the first term is negative and $Q^* > 0$ along with $D'' > 0$ yield a negative second term. This ensures that, under our assumptions, S_{rr} will be lower than zero. We can also prove that

$$S_{QQ} = P'(Q^*) - r^{*2} D''(r^* Q^*) < 0. \tag{A.5}$$

With $P' < 0$, $r^* > 0$ and $D'' > 0$, S_{QQ} will also be lower than zero.

The last second order condition that must be met is that $S_{rr} S_{QQ} - {S_{rQ}}^2 > 0$. S_{rr} and S_{QQ} are calculated above and S_{rQ} is given by

$$S_{rQ} = -c'(r^*) - D'(r^* Q^*) - r^* Q^* D''(r^* Q^*) = -r^* Q^* D''(r^* Q^*). \tag{A.6}$$

Note how the cross derivative simplifies to one term when evaluated at the critical point, specifically when S_r is substituted in the formula. At this point, it is possible to demonstrate that the last second order condition for maximization is met, given our parametric assumptions from Table 2.1 in Chapter 2. We substitute conditions (A.4), (A.5) and (A.6) into $S_{rr}S_{QQ} - {S_{rQ}}^2$ to obtain

$$S_{rr}S_{QQ} - {S_{rQ}}^2 = Q^*[-c''(r^*) - Q^*D''(r^*Q^*)][P'(Q^*) - r^{*2}D''(r^*Q^*)] - [r^*Q^*D''(r^*Q^*)]^2$$

$$= [-Q^*c''(r^*)P'(Q^*) - Q^{*2}D''(r^*Q^*) + r^{*2}Q^*c''(r^*)D''(r^*Q^*) + r^{*2}Q^{*2}[D''(r^*Q^*)]^2 - r^{*2}Q^{*2}[D''(r^*Q^*)]^2$$

$$= -Q^*c''(r^*)P'(Q^*) - Q^{*2}D''(r^*Q^*)P'(Q^*) + r^{*2}Q^*c''(r^*)D''(r^*Q^*)$$

$$> 0$$

By definition, the final second order condition is met because every term in the second to last line above must be positive because $Q^* > 0$, $r^* > 0$, $c'' > 0$, $P' < 0$ and $D'' > 0$. Therefore, the critical r^* and Q^* values defined by the first order conditions are indeed consistent with a surplus maximum.

Appendix B

IASB Emission Rights Draft Interpretation

B.1 International Accounting Standards Board Emission Rights Notice

IFRIC Activities

Emission Rights

18th Aug 2004. Last discussed by IFRIC: September 2004 Latest revision: 2004/9/13

Several governments either have, or are in the process of developing, schemes to encourage reduced emissions of pollutants, in particular of greenhouse gases. Some schemes are based on a ‘cap and trade’ model whereby participants are allocated emission rights or ‘allowances’ equal to a ‘cap’ (ie target level of emissions) and are permitted to trade those allowances.

Because there is presently no guidance on the accounting for such schemes and because no consensus has emerged among market participants on what the accounting treatment should be, the IFRIC concluded that it should issue an Interpretation to explain how International Financial Reporting Standards (IFRSs) should be applied to such scheme.

The IFRIC issued a draft Interpretation (D1 Emission Rights) for public comment in May 2003. In summary, the draft Interpretation proposed that:

- allowances, whether allocated by government or purchased in the market, are intangible assets and are accounted for in accordance with IAS 38 Intangible Assets. Allowances that are allocated for less than fair value are measured on initial recognition at fair value. Allowances are not amortised but are tested for impairment.
- when allowances are allocated by government for less than fair value, the difference between their fair value and the amount paid is a government grant that is accounted for in accordance with IAS 20 Government Grants and Disclosure of Government Assistance.
- as emissions are made, a provision is recognised for the obligation to deliver allowances to cover those emissions (or to pay a penalty). The provision is accounted for under IAS 37 Provisions, Contingent Liabilities and Contingent Assets and therefore is normally measured at the market value of the required number of allowances.

(A copy of the draft Interpretation may be downloaded here).

The IFRIC received 40 comment letters on its proposals and it discussed the main points raised in those letters at its meetings in September and December 2003. The comment letters, other than where respondents requested confidentiality, may be downloaded here.

After considering the comments received (including suggested alternative interpretations of IFRSs), the IFRIC confirmed its view that the proposals set out in the draft Interpretation are the most appropriate interpretation of IFRSs.

The IFRIC, however, noted that many respondents to the draft Interpretation had expressed concern about the lack of symmetry (or mismatch) in the accounting, which resulted in what was viewed as 'artificial' volatility of reported profit or loss. This arises because IFRSs contain both a mixed measurement model (whereby some items are measured at cost and others at fair value) and a mixed presentation model (whereby some gains and losses on items measured at fair value are recognised in profit or loss and others in equity). In particular, when allowances are carried under the allowed alternative treatment in IAS 38 at fair value, changes in the value of the allowances above cost are recognised in equity while changes in value of the liability for the obligation to surrender allowances are recognised in profit or loss.

The IFRIC's initial response to these comments was to seek to address this mismatch by amending IAS 38 to carve out a subset of intangible assets (to include allowances) that should be measured at fair value with all changes in value recognised in profit or loss. Accordingly, in December 2003 the IFRIC secured the tentative approval of the Board to re-expose the draft Interpretation together with a limited amendment to IAS 38 so that any intangible asset

- that is like a currency, in that it has value only because it is used to settle an obligation; and
- whose fair value is determinable by reference to an active market (as defined in IAS 38)

is measured at fair value with changes in value recognised in profit or loss.

In addition, because of its own project to amend IAS 20, the Board requested that the IFRIC delay issuing the revised draft Interpretation until the proposals for the amended IAS 20 were completed. In other words, the Board envisaged the IFRIC issuing a revised draft Interpretation that reflected the proposed amendments to IASs 20 and 38.

The Board discussed its approach to amending IAS 20 at its meetings February and July 2004. An exposure draft is now in preparation. (Details of the Board's project can be found here.)

At its September 2004 meeting, the IFRIC noted that it was unlikely that the Board would be able to issue a final amended IAS 20 for at least another year and therefore that D1 could not be finalised until that time. Given that the EU Emissions Trading Scheme starts at the beginning of 2005, and given the potential for diversity of accounting for that scheme, the IFRIC reconsidered whether it should finalise its original proposals in D1 rather than waiting for IASs 20 and 38 to be amended.

The IFRIC acknowledged that finalising the original proposals in D1 would mean that if allowances were subsequently measured at fair value, changes in value above cost would be recognised in equity rather than in profit or loss. Nonetheless, most of the members present noted that the disadvantage of this treatment specified by the current IAS 38 would be outweighed by the benefits of providing timely accounting guidance that would promote consistent application of current IFRSs.

The IFRIC also noted that if the Board amended IAS 20, any required modifications to the Interpretation would be dealt with as a consequential amendment arising from the amended Standard.

Therefore, the view of the majority of IFRIC members present at the September meeting was that D1 should be finalised in substantially its present form and issued in the fourth quarter. The IFRIC will vote on the final Interpretation at its next meeting.

Appendix C

Cap-and-Trade Instructions for Emissions Trading Experiment[1]

C.1 Introduction

Thank you for agreeing to participate in this experiment. During this experiment you will represent a firm. You and 7 other people will each have to make decisions on how to operate your firms. You will participate in 14 decision rounds, called periods. Each period your firm will produce and sell output and buy or sell a special kind of input called a discharge allowance. The profits of your firm will depend on the decisions you make and the decisions made by other participants in the session. At the end of the session the cash held by your firm will be converted into Canadian dollars and paid to you privately in cash. Accordingly, the more profits you earn for your firm, the more money you will take home.

[1]Appendix C is found on the CD-ROM enclosed in the pouch on the inside cover at the back of this thesis.

C.2 Production and Costs

You represent a firm which produces a product (for example, electricity) and emits a pollutant (for example, nitrogen oxides - NO_x). There is an upper limit on the amount of output your firm can produce. This is your capacity. In today's session your capacity is fixed. You cannot change it.

You will be able to decide how much output to produce and how much pollution is emitted for each unit of output you produce (this is called your emission rate).

$$\textit{Emission Rate} = \frac{\textit{Pollution Emitted}}{\textit{Output}}$$

Your total pollution emitted is equal to your output multiplied by your emission rate.

$$\textit{Pollution Emitted} = \textit{Output} \times \textit{Emission Rate}$$

In today's session you will have a fixed cost, which is determined solely by your emission rate. The fixed cost is inversely related to the emission rate. When emission rates are low, fixed cost is high, and vice versa. The basic understanding behind this is that you can produce things cheaply but you will pollute a lot, or you can use more expensive technology and only pollute a little. Table 1 shows an example of how your costs might change as your emission rate changes. This example is for illustration only. The numbers in the experiment will be different.

Column [a] shows 10 possible emission rates. Column [b] shows the total fixed cost for each rate. Notice total fixed cost falls as emission rate rises.

Table C.1: Example of Emission Rates and Fixed Costs when Capacity is 10

[a] Emission Rate (tons per unit output)	[b] Total Fixed Cost	[c] Unit Fixed Cost	[d] Change in Unit Fixed Cost
0	1990	199	
			93
1	1060	106	
			32
2	740	74	
			17
3	570	57	
			10
4	470	470	
			7
5	400	40	
			6
6	340	34	
			4
7	300	30	
			3
8	270	27	
			2
9	250	25	

Column [c] shows unit fixed cost, which equals total fixed cost divided by the capacity of 10. Column [d] shows the change in unit fixed cost between values of the emission rate. For example, if the emission rate is 1 rather than 0, then unit fixed cost will decrease by 93 (from 199 to 106). Figure 1 illustrates the relationship between emission rate and the change in unit fixed cost.

Your average fixed cost is your total fixed cost divided by your output produced. Table 2 shows how average fixed cost might change as output changes for the case when emission rate equals 0.

$$AverageFixedCost = \frac{TotalFixedCost}{Output}$$

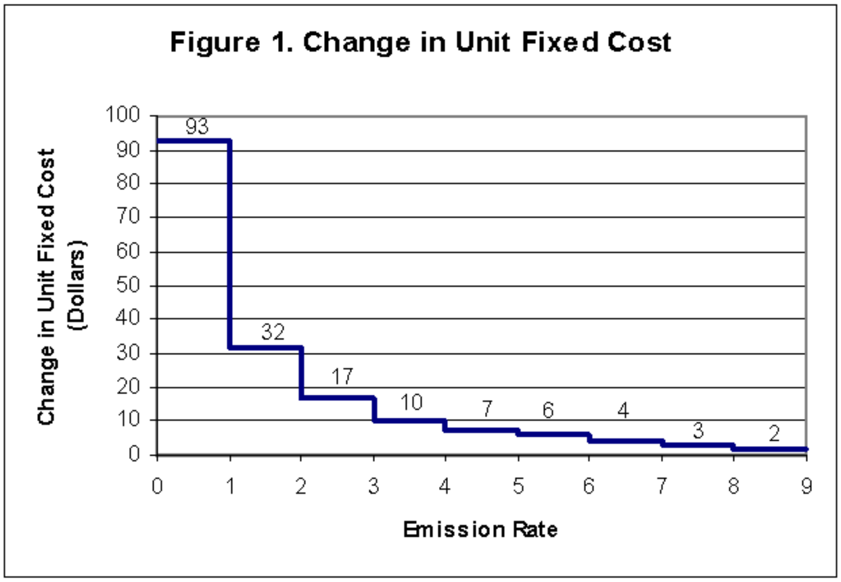


Table C.2: Example of Average Fixed Cost for an Emission Rate of Zero

Emission Rate [a]	Total Fixed Cost [b]	Unit Fixed Cost [c]	Average Fixed Cost when output is ... [d] 1	[e] 5	[f] 10
0	1990	190	1990	398	199

If your output equals your capacity of 10 then your average fixed cost will equal your unit fixed cost of 199. If your output is less than your capacity, say 5, your average fixed cost will rise to 398. Although Table 2 only shows a limited number of output values (1, 5 and 10), output may actually take on any integer value between 1 and your maximum capacity. The computer will provide you with a cost calculator which will calculate the average and total fixed cost of any quantity of output and emissions rate you choose.

Please answer the following questions, referring to the equations on page 1 and Table 1 and 2 when necessary. When you are done, raise your hand and we will check your work.

a. You produce 5 units of output and 15 tons of pollution. What is your emission rate?

_______ tons of pollution per unit of output.

b. How many tons of pollution are produced when output is 10 and emission rate is 2?

_______ tons of pollution.

c. What is the total fixed cost of producing 10 units of output when the emissions rate is 2?

_______ dollars.

d. How much do you save, per unit of capacity, by choosing an emission rate of 3 rather than 2?

_______ dollars.

e. By how much do your unit fixed costs increase when you choose an emission rate of 1 rather than 2?

_______ dollars.

f. What is the average fixed cost of producing 5 units of output when the emissions rate is 0?

_______ dollars per unit of output.

C.3 Discharge Allowances

In this session the discharge of pollution is controlled by discharge allowances. At the end of each period you must redeem one allowance for each ton of pollution you discharge. The computer will not let you sell output if you do not have enough allowances to cover the pollution discharged.

At the start of each period, you will be given a certain number of allowances, called an endowment. You may use these to cover your discharge of pollution, keep them to use in following periods or sell them to other participants. You may also buy allowances from the other participants.

For example, suppose you are given an endowment of 30 allowances at the start of the period and your capacity is 10. Also suppose that you neither buy nor sell any allowances this period. If your emission rate is 7 then you will only be allowed to produce a maximum of 4 units of output, because 4 units of output would require you to redeem 28 of your 30 allowances. If your emission rate was 1 (instead of 7) you could produce at a full capacity of 10 requiring you to redeem only 10 allowances, leaving 20 to be used or sold next period. If your emission rate was 3, you could produce 10 units of output and redeem all of your 30 allowances. Remember next period you will receive another endowment of allowances.

Please answer the following questions. When you are done, please raise your hand and we will check your answer.

`g.    Suppose you produce and sell 5 units of output with an emissions rate of 3.`

`i.    How much pollution will you produce?`

________ tons of pollution.

ii. How many allowances would you need to redeem?

________ allowances.

iii. Suppose you had 13 allowances in inventory, how many discharge allowances must you buy?

________ allowances.

iv. Given the amount bought in part iii, if the price of allowances is $8 each, how much will you have to pay for allowances in total?

________ dollars.

h. Suppose you have 35 allowances in inventory and you produce and sell 7 units of output at an emissions rate of 2

i. How many allowances can you sell, at most?

________ allowances.

ii. How much will you earn from selling the allowances created in part i, if the price is $2 per allowance?

________ dollars.

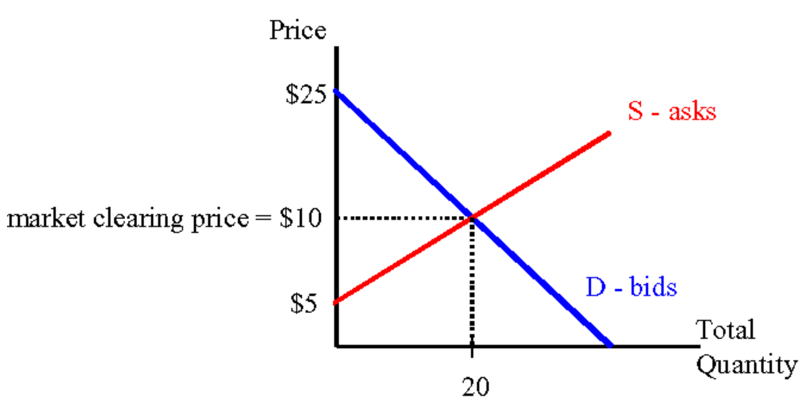
Each period you will buy and sell allowances before you choose your emission rate and before you sell your output.

C.4 Buying and Selling Discharge Allowances

In this session, allowances will be bought and sold in a call market. Participants in a call market submit offers to buy (called "bids") or sell (called "asks"). Each bid and ask specifies a price and a maximum quantity. Participants may offer multiple bids and asks. For example, a participant may offer to buy 5 allowances at $10 and 3 more allowances at $8, and offer to sell 2 allowances at $12 and sell 4 more allowances at $15. When all offers have been submitted, a market clearing price is computed and all transactions are made at this price.

All bids are ranked from highest to lowest. This gives us a curve like 'D' in Figure 2. All asks are ranked from lowest to highest. This gives us a curve like 'S' in Figure 2. The total number of allowances bought and sold (20 units in Figure 2) is determined by the intersection of S and D. This means that the 20 allowances with the lowest ask prices are sold to the buyers with the 20 highest bid prices. The market clearing price ($10 in Figure 2) is also determined by the intersection of S and D. All allowances bought and sold exchange at this price regardless of the price bid or asked. For example, the first allowance in Figure 2 has an ask price of $5 and a bid price of $25. The buyer will pay $15 less than he bid, and the seller will receive $5 more than he asked.

Figure 2: Market price determination



It may turn out that the market clearing price just happens to be exactly equal a subject's bid or ask price. In this case sellers who asked a price exactly equal to what turns out to be the market clearing price may find they have not sold all the allowances they offered. Similarly, buyers who bid exactly what turns out to be the market clearing price may find they have not purchased all the allowances they bid for. In this case the available allowances are shared among these buyers or sellers as evenly as possible.

To reiterate, if you submit a bid at a particular price, and if your bid is successful, you may have to pay what you bid but you may pay less. Conversely, if you submit an ask to sell some allowances and your units are sold, you may receive the price you asked but you may receive more.

C.5 Emission Rate Decision

When the allowance market is over, you must choose your emission rate for the period. In this session you will be able to choose emission rates between 0 and 9. High emission rates reduce your fixed cost. However, higher emission rates require you to redeem more allowances. You may need to have purchased additional allowances to produce at full capacity. Low emission rates increase your fixed cost. However, lower emission rates require fewer allowances. You may be able to increase your profits by selling unneeded allowances.

C.6 Selling Output

In this session the amount of output you produce and sell is determined automatically. Your output does not affect your fixed cost, it only affects how much pollution you will discharge, which will equal your quantity of output sold times your emission rate. This, in turn, affects the number of allowances you will need to redeem. In this session you must have sufficient allowances to cover your discharge of pollution implied by your output sold. You will not be allowed to sell output if you do not have enough allowances to redeem against the amount of pollution discharged implied by that output.

You will be a seller in the output market. The buyers in this market are simulated by a computer program. Your computer will automatically sell the maximum amount of output possible, constrained by your capacity and the number of allowances you have (as explained in the paragraph above), at the highest price the computer buyers will pay. The price of output can be calculated with the following function:

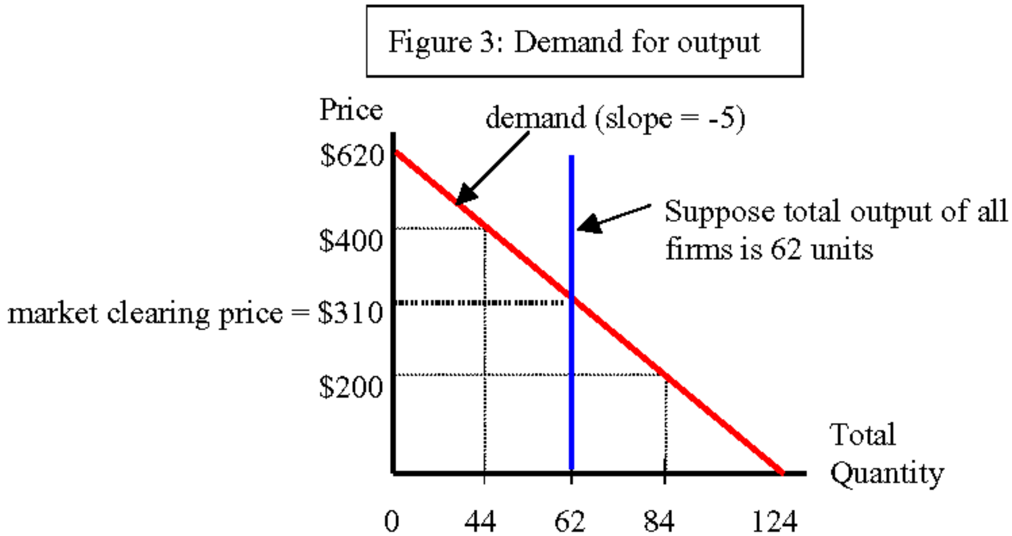
$$Output\ Price = 620 - 5 \times Total\ Output\ of\ All\ Firms$$

When the output market is finished you will be told how many units you have sold. Your output and emissions will be determined automatically and your inventory of allowances will be adjusted accordingly.

Figure 3 shows a diagram of how the computer buyers in this session will operate as detailed by the formula above. If the total output of all 8 firms is equal to 62 then the price will be \$310 ($= 620 - 5 \times 62$). If the total output was 44 units then each unit of output would be sold at \$400.

C.7 Practice Periods

To let you learn more about the experiment we are going to run 4 practice periods. Please follow these instructions as they are read aloud and enter the decisions that are discussed below. The results from this period will not



contribute to your final earnings. If you have any questions during this period, please raise your hand and we will answer them. After the practice periods are over, we will begin the 10 periods which contribute to your earnings. We will all walk through the first practice period together. The cost values and decisions we make in the first practice period bear no relation to decisions you should make on your own when the experiment starts, they are for demonstration only. All numbers on your screen will be rounded to two decimal places.

[Monitor starts the session]

The dollar values and numbers we will discuss below will differ depending on whether your subject number is even or odd. Your subject number can be found in the bottom left hand corner of your computer screen. Would everyone with an even subject number please raise your hand now? Thank you, you may put down your hands. Would everyone with an odd subject number please raise your hand? Thank you. Numbers and values in the text below will apply to even numbered subjects, and those in parentheses (like this) will apply to odd numbered subjects. If there are no parentheses then the plain text number applies to everyone.

At the end of these instructions you will find Table 3 and Figure 4 on page 20 (19), please find this now. This sheet of paper shows the costs you will have in these 4 practice periods and is comparable to Table 1 and Figure 1 that were described earlier.

Now please examine your computer screens. Please ***click*** on the words "Dataview Window" in the upper right-hand part of your screen now, the title bar will turn blue. Below the title bar are three tabs, please ***click*** on the *cost table tab* now.

The cost table provides a software version of Table 3 and includes information on your average fixed cost. Clicking on a row of the cost table temporarily selects the emission rate in the left most column of that row. The software will fill out the unit fixed cost difference information of decreasing the emission rate by 1 and of increasing the emission rate by 1 and display the results below the cost table. These exact numbers can be found on your hard copy of Table 3 if you find that easier.

Now let us explore some of the other tabs on the Dataview window. Beside the cost table tab is the *planner tab*. Please ***click*** on the planner tab now. This planner tab contains a *cost calculator panel* on the left-hand side that will calculate total fixed cost given assumptions on capacity and emission rate. It will also calculate average cost based on assumptions of output and the value of allowances.

Please follow along on your screen as I read the text in the cost calculator aloud. "Capacity is 10. Emission rate is 7 (3). Total fixed cost will be 1633.91 (1956.67). If I sell 10 units of output and if each allowance is worth $8 then I will emit 70 (30) tons of pollution, and I must redeem 70 (30) allowances. Each unit of output will cost 56 (24) dollars for 7 (3) allowances redeemed and 163.39 (195.67) dollars in average fixed costs. My overall average cost per unit of output is 219.39 (219.67) dollars." The overall average cost just adds together the average fixed cost and the assumed value of allowances redeemed stated above. Are there any questions about these numbers? Please use the arrow buttons to ***change*** your emission rate to 9. Notice that you now emit 90 tons of pollution. Notice how your total fixed cost falls to $1600 ($1770), the cost of required allowances rises to $72, your average fixed cost falls to $160 ($177) and your overall average cost rises to $232 ($249). Now use the arrow buttons to ***change*** your units of output from 10 to 5. What has changed? Notice that you now only emit 45 tons of pollution. Notice how average fixed cost has risen to $320 ($354) and overall average cost has risen to $392 ($426). Lastly, use the arrow buttons to ***change*** the value of allowances from 8 to 16 dollars per allowance, and note how the cost of allowances doubles to $144 and your overall average cost becomes $464 ($498). The value of allowances spinner can be used to find your costs under various possible value conditions.

Below the calculator is the *capacity and emission rate panel* containing information on this and last period's capacity, emission rate and cost information. Notice that last period's capacity is assumed to be 10 and last period's emission rate is assumed to be 7 (3), for this practice period. Notice that your capacity in this practice period is 10 units. This period's emission rate and cost information will remain blank until you choose it later on in the period.

To the right of the capacity and emission rate panel is the *output market panel*. This and last period's output price and amount sold appear in it. Last period's market price was $220 and last period's market volume was 80. The market volume is the total amount of output sold amongst all subjects. The amount of output you sold last period is given as 10, since it is assumed that you sold the maximum amount of output last period. This period's market price and volume is left blank because it has not been determined yet.

Your cash balance is displayed in the *cash panel* which is in the top right of the Dataview window. You start this practice period with $5,000 in laboratory cash.

Below the cash panel is the *allowance market panel*. This panel shows detailed information regarding the allowance market last period and this period. Notice that the market price of allowances was $8 last period and market volume was 80. Notice how this period's market price and volume is blank since the market has not been conducted yet. At the bottom of the panel you are notified that you will receive an endowment of 50 allowances at the beginning of every period and that you currently have 50 allowances in inventory.

Lastly, notice that the status bar at the bottom of the screen provides quick reference to important statistics such as cash, inventory of allowances, capacity and emission rate.

We are now ready to start the first practice period. We will all walk through the first period together and then you can make your own decisions during the remaining 3 practice periods. All of your firm's decisions will be entered in the left-most window on the screen and the Dataview window will always remain on screen to provide you with information. The first decision to be made every period is to submit an allowance order. This is the only point in the period that you are able to buy and sell allowances. You are able to enter up to three bid and three ask orders. The *allowance order window* is visible in the upper-left portion of your screen. Please ***click*** on its title bar now.

Because the price of allowances is calculated using all submitted bids and asks we do not yet know what the market clearing price will be for this period, even if the market price has been stable for the last few periods. You may be tempted just to enter a bid or ask at last period's market price but if you use the ability to enter bids and asks at multiple prices you can ensure that you buy and sell appropriately whatever the price may be. You may decide to be buyer at some prices and seller at other prices.

When deciding on what bids and asks to make you might wish to consult your cost calculator or cost table, even though your emission rate and cost implications have not yet been chosen for the period. Below we will enter a practice order.

First let us look at the allowance order window. Notice that your capacity is equal to 10. Since you have 50 allowances in inventory you could choose a maximum emission rate of 5, without needing to buy or sell any allowances.

Everyone please look at Table 3, odd and even subjects will have different values in their table. First focus on the line in the table associated with an emission rate of 5 since this would require you to redeem all 50 of the allowances in your inventory.

Allowances let you to choose higher emission rates which are associated with lower fixed costs. You might wish to sell allowances if you can sell them for a price greater than their cost savings. Looking upward along column [d] shows how unit fixed cost increases as lower emission rates are chosen. Since you do not have to redeem as many allowances when choosing lower emission rates, you might want to use these costs in column [d] when pricing your allowances for sale. For instance if you produce output at your capacity of 10, and choose an emission rate of 4 instead of 5 (which is the maximum given your current inventory of allowances), then you could sell your extra 10 allowances. Column [d] shows that unit fixed cost increases by 25.86 (5.27) going from an emission rate of 5 to 4, and so not using each of these allowances cost you 25.86 (5.27). In order to sell 10 more allowances (20 total) you would have to choose an emission rate of 3, raising your unit fixed cost by an additional 38.57 (7.87). Likewise, lowering your emission rate from 3 to 2 would allow you to sell 10 more allowances (30 total) and your costs would increase by 53.83 (10.97) each. Since an ask price is the lowest integer price you would be willing to sell at, you might want to ask $26 ($6) to sell your first 10 allowances, $39 ($8) each for another 10 allowances (20 total) and $54 ($11) each for another 10 allowances. Please ***enter*** these three asks in the bottom part of the allowance order window. The ask order in the top most line must be at the lowest price.

Using your change in unit fixed cost to set the ask price for allowances effectively sets the minimum price at which you would sell equal to the cost of not using the allowances. By submitting this minimum price you increase the chance of actually selling the units, since the lowest asks get sold first. It also insures that you will not sell the allowances at a loss and, it does not directly affect the price you will actually sell them at, which could be higher than the minimum price entered.

Now think about buying allowances. Buying allowances allows you to choose higher emission rates, which are associated with lower fixed costs. Looking downward along column [d] in Table 3 shows the most you would probably want to pay for allowances. For instance, if you produce 10 units of output and choose an emission rate of 6 instead of 5 (remember given your 50 allowances in inventory this is the maximum emission rate you can choose) you would be required to redeem 10 more allowances. Redeeming each of these 10 allowances would save you 15.68 (3.20) in unit fixed costs. If you currently have 50 allowances in inventory you might be willing to bid \$15 (\$3) each for 10 more allowances since this is the maximum integer price that allows you to make a profit. Remember, bidding your true value sets the maximum price you will pay, effectively increasing your chances that you will buy the units, and will not directly effect the market clearing price that you will pay. Buying 10 more allowances (20 in total) would allow someone currently with 50 allowances and a capacity of 10 to choose an emission rate of 7 instead of 6, and save a further 8.05 (1.64) in unit fixed costs, hence giving an incentive to bid \$8 (\$1) for 10 more allowances. Using the change in unit fixed cost in a similar fashion we can see how choosing an emission rate of 8 rather than 7 would save 2.97 (0.60) in unit fixed costs. Even numbered subjects with 50 allowances might bid \$2 each for 10 more allowances (30 in total). Since the cost savings for odd subjects when increasing their emission rate from 7 to 8 is 0.60, any integer price above zero would mean a loss and so odd subjects will only bid for 20 allowances maximum under these circumstances. Please

enter a bid of $15 ($3) for 10 units in the first bid line and a bid of $8 ($1) for 10 more units on the second bid line. Would even numbered subjects enter a third bid of $2 for 10 more units on the third bid line.

Notice that since your capacity is equal to 10, it makes sense to bid and ask for allowances in quantities of 10. You are not allowed to sell allowances that you do not possess in inventory, nor bid for allowances if you do not have enough cash to cover the transaction. When you have finished entering your bid and ask orders a monitor will check your work. Normally you will click on the submit button to submit your order when you are ready, but during this practice period the monitor will submit all your decisions for you.

[All allowance orders are submitted]

Once the bid and ask orders are submitted the market will be called and a market clearing price and quantity will be determined. The results window in the top left of your screen identifies if you bought or sold any allowances this period. The even numbered subjects have bought 20 allowances each and the odd numbered subjects have sold 20 allowances each. The results window also tells you that the market clearing price was $8 and a total volume of 80 allowances were bought and sold. Please ***click*** on the planner tab in the Dataview window. Notice how your current cash in the cash panel is now $4,840 ($5,160) and your allowances inventory in the allowances panel is now 70 (30), to reflect your transaction this period. During the experiment the software will keep the allowance market results window on screen for 10 seconds before automatically continuing on with the rest of the period. You do not need to write these results down, as they are immediately stored in the allowance market panel of your planner. Also, the results from past period's get stored in your income statement which we will discuss at the end of the first practice period.

The second decision to be made each period is choosing an emission rate. Your *emission rate choice window* provides a spinner that you can use to choose an emission rate. Remember your capacity is 10, and that you have 70 (30) allowances in inventory. The emission rate spinner starts off at the emission rate you chose last period, but you may use the arrow button to choose a new emission rate this period. One way to choose an emission rate might be to use your cost calculator to find which emission rate minimizes your overall average cost. This is equivalent to maximizing profit as long as everything other than your emission rate stays constant. If you spin the emission rate in your cost calculator panel from 0 to 9 you will notice that an emission rate of 7 (3) will minimize your overall average cost.

Before selecting your emission rate you must not forget that if your emission rate is greater than your inventory of allowances divided by your capacity, 70/10 (30/10), then you will not have enough allowances to produce and sell output at full capacity. For this practice period, ***click*** on the emission rate arrow buttons in the emission rate choice window and choose an emission rate of 7 (3), since this will minimize your overall average cost and you will have enough allowances in inventory to produce at full capacity. After a monitor has checked your work he will click the submit button for you. Confirm the results shown on the next window. Again, the software will store this information in your planner and income statement for later reference and the rest of the period will continue in about 10 seconds.

After you have been notified of your emission rate choice, the output market occurs automatically. The computer automatically sells the maximum amount of output possible, which according to your capacity and holding of allowances is 10 units. The output market clearing price of \$220 and volume of 80 units is displayed in the results window ($220 = 620 - 5 \times 80$). The 10 units of output sold and produced by your firm is also displayed. Lastly, a message is provided identifying that you redeemed 70 (30) allowances this period. Again, during the experiment, the output market results window will stay on screen for about 20 seconds and all the information on it will be stored in your planner and income statement.

It is now the end of period 1. Notice the income statement tab beside the planner and cost table tabs in the Dataview window. The income statement gives a breakdown of your profits earned at the end of each period. Please ***click*** on the income statement tab now

Your income statement shows that you earned \$2200 revenue from selling output. Odd numbered subjects will find that they earned \$160 revenue from the 20 allowances they sold during the period. The 50 allowances you were endowed with at the start of the period are valued at the market price of \$8 each for a total of \$400. The cost of goods sold section of the income statement details how the value of the allowances you redeemed is subtracted from your revenue. The 70 (30) allowances were redeemed at a market value of \$8 each for a total of \$560 (\$240). Odd numbered subjects will have an entry for the cost to them of the 20 allowances sold during the period totalling \$160, as we are assuming they were purchased the period earlier at the market price of \$8. The last subtraction from your revenue is your total fixed cost of

$1633.91 ($1956.67). Your profit, or net income, for this practice period should be $406.09 ($403.33). Take special note that this net income value can be misleading if you are buying allowances and keeping them in inventory. When you buy allowances your cash decreases but your value of inventory increases by the same amount and this does not show on your income statement. The profits or losses you make on the allowances you buy and keep in inventory will not appear until the period you either sell them or redeem them. Therefore, beware that buying up allowances and holding them in inventory looks like a good thing according to the income statement but if you do not use or sell those allowances by the end of the experiment, they will be worthless to you (and so you could experience a large loss in the last period). As will be discussed in the paid periods section of the instructions, only your firm's cash balance at the end of the experiment will be converted to Canadian dollars as your payout, you net income will not.

At the bottom of the income statement you will find a restatement of your capacity, emission rate, output and allowance inventory for the period. In addition you will find the allowance and output market price and volume information, which can easily be referenced later. After this practice period, you will play through 3 more practice periods by yourselves. The 10 paid periods of this session will follow.

We are now finished the first practice period. The rest of the experiment is automated. When you are done entering a decision make sure to click the appropriate submit or continue button. Your cost and capacity values will be the same for the next 3 practice periods but will change for the paid periods.

When the fourth practice period is over, the monitor will read aloud the last section of the instructions.

[Period 2 starts]

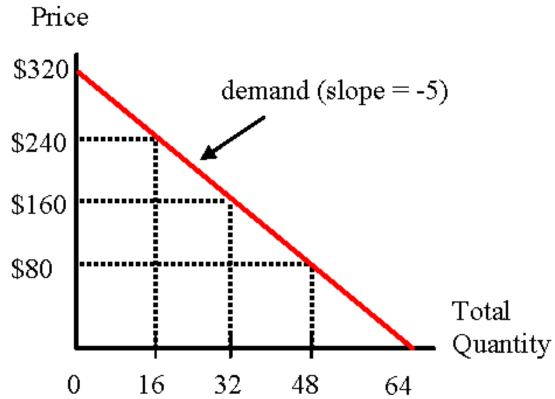
We are now starting practice period 2. The allowance order window is now displayed on everyone's screens. If you are wondering what bids and asks to enter you might wish to start by referring back to what we entered in the first practice period, detailed on page 12. To help keep people's focus the allowance order phase will be limited to 3 minutes in length and the emission rate choice will be limited to 2 minutes in length. You will be given roughly double as much time to get acquainted with the software in the fist few periods.

C.8 Paid Periods

We will now start the 10 paid periods. We now restart at period 1 and will end after period 10. The experiment will operate exactly as during the practice periods only now subjects will experience different parameters. Your costs will be different from the practice period values but will remain constant over the 10 periods. Your capacity and starting allowance inventory will also be different. You will receive an endowment of 20 allowances at the start of each period and everyone will have a capacity of 4. Since capacity has changed from 10 to 4, you will most likely wish to bid and ask for allowances in quantities of 4 instead of quantities of 10 (as we did in the practice periods). Lastly, the demand for output will operate as in the Figure 3 below, according to the formula:

$$Output\ Price = 320 - 5 \times Total\ Output\ of\ All\ Firms$$

Figure 4: New demand for output



Everyone will start the first paid period with 5000 lab dollars in cash. At the end of period 10 we will convert your final cash balance in excess of 5000 lab dollars into Canadian dollars. This cash profit will be converted at the rate of 1 Canadian dollar for every 92 lab dollars and will be paid to you privately in cash. Accordingly, the more profits you earn for your firm, the more money you will take home. Take note, payoffs will be based on your firm's CASH holdings only. Allowances not sold or redeemed by the end of the last period will be worthless and not converted to Canadian dollars.

Please standby while the monitor restarts the software for the first paid period. Make sure to familiarize yourself with all the new numbers in the planner, and your new cost table, before proceeding on to making decisions in the first period. . Again, if you are wondering what bids and asks to enter you might wish to start by referring back to the method we used in the first practice period, detailed on page 10, only now you have a different cost table.

C.9 Tables and Figures for Experiment

1. Practice periods for odd subjects: Table 3 and Figure 5
2. Practice periods for even subjects: Table 3 and Figure 5
3. Paid periods for subjects 1 and 5 (ER=2): Table 4 and Figure 6
4. Paid periods for subjects 3 and 7 (ER=4): Table 4 and Figure 6
5. Paid periods for subjects 2 and 6 (ER=6): Table 4 and Figure 6
6. Paid periods for subjects 4 and 8 (ER=8): Table 4 and Figure 6

Table C.3: Odd Numbered Subjects' Fixed Costs for Practice Periods (ER=3, Capacity=10)

[a] Emission Rate (tons per unit output)	[b] Total Fixed Cost	[c] Unit Fixed Cost	[d] Change in Unit Fixed Cost
0	2400.00	240.00	
			18.75
1	2212.47	221.25	
			14.61
2	2066.42	206.64	
			10.97
3	1956.67	195.67	
			7.87
4	1878.02	187.80	
			5.27
5	1825.31	182.53	
			3.20
6	1793.33	179.33	
			1.64
7	1776.91	177.69	
			0.60
8	1770.86	177.09	
			0.09
9	1770.00	177.00	

Figure 5. Change in Unit Fixed Cost (Practice Periods)

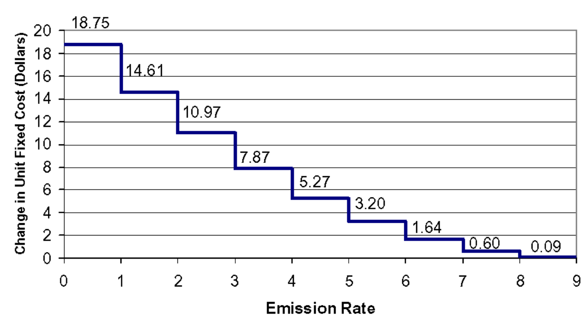


Table C.3: Even Numbered Subjects' Fixed Costs for Practice Periods (ER=7, Capacity=10)

[a] Emission Rate (tons per unit output)	[b] Total Fixed Cost	[c] Unit Fixed Cost	[d] Change in Unit Fixed Cost
0	4690.00	469.00	
			91.98
1	3770.21	377.02	
			71.63
2	3053.87	305.39	
			53.83
3	2515.56	251.56	
			38.57
4	2129.84	212.98	
			25.86
5	1871.28	187.13	
			15.68
6	1714.44	171.44	
			8.05
7	1633.91	163.39	
			2.97
8	1604.24	160.42	
			0.42
9	1600.00	160.00	

Figure 5. Change in Unit Fixed Cost (Practice Periods)

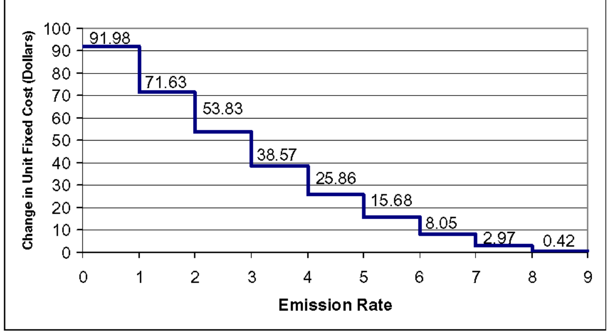


Table C.4: Fixed Costs for Paid Periods (ER=2, Capacity=4)

[a] Emission Rate (tons per unit output)	[b] Total Fixed Cost	[c] Unit Fixed Cost	[d] Change in Unit Fixed Cost
0	688.00	172.00	
			25.00
1	587.98	147.00	
			19.48
2	510.09	127.52	
			14.63
3	451.56	112.89	
			10.59
4	409.61	102.40	
			7.02
5	381.50	95.37	
			4.27
6	364.44	91.11	
			2.19
7	355.69	88.92	
			0.80
8	352.46	88.12	
			0.12
9	352.00	88.00	

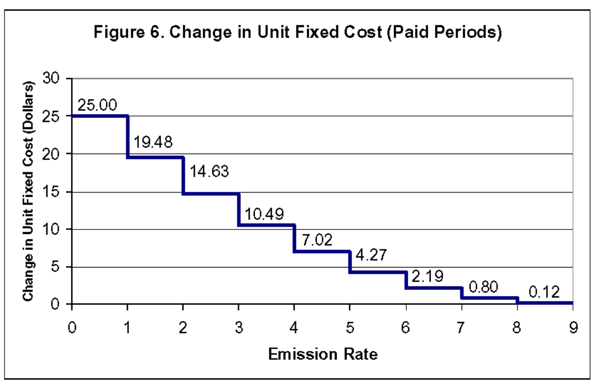


Table C.4: Fixed Costs for Paid Periods (ER=4, Capacity=4)

[a] Emission Rate (tons per unit output)	[b] Total Fixed Cost	[c] Unit Fixed Cost	[d] Change in Unit Fixed Cost
0	996.00	249.00	
			55.07
1	775.73	193.93	
			42.88
2	604.18	151.05	
			32.23
3	475.26	118.82	
			23.09
4	382.89	95.72	
			15.48
5	320.97	80.24	
			9.39
6	283.41	70.85	
			4.82
7	264.12	66.03	
			1.77
8	257.02	64.26	
			0.26
9	256.00	64.00	

Figure 6. Change in Unit Fixed Cost (Paid Periods)

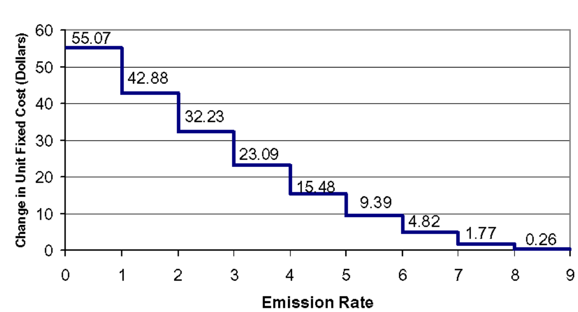


Table C.4: Fixed Costs for Paid Periods (ER=6, Capacity=4)

[a] Emission Rate (tons per unit output)	[b] Total Fixed Cost	[c] Unit Fixed Cost	[d] Change in Unit Fixed Cost
0	1500.00	375.00	
			96.15
1	1115.41	278.85	
			74.87
2	815.90	203.98	
			56.28
3	590.81	147.70	
			40.31
4	429.54	107.39	
			27.03
5	321.43	80.36	
			16.40
6	255.85	63.96	
			8.41
7	222.18	55.55	
			3.11
8	209.77	52.44	
			0.44
9	208.00	52.00	

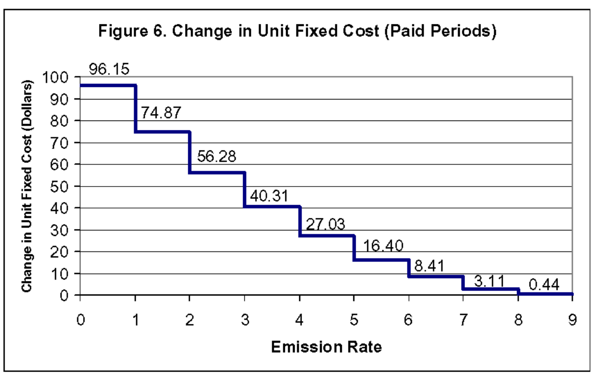
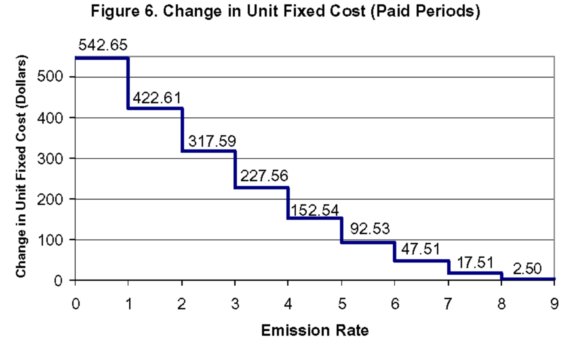


Table C.4: Fixed Costs for Paid Periods (ER=8, Capacity=4)

[a] Emission Rate (tons per unit output)	[b] Total Fixed Cost	[c] Unit Fixed Cost	[d] Change in Unit Fixed Cost
0	7408.00	1852.00	
			542.65
1	5237.40	1309.35	
			422.61
2	3546.94	886.74	
			317.59
3	2276.59	569.15	
			227.56
4	1366.34	341.59	
			152.54
5	756.18	189.05	
			92.53
6	386.07	96.52	
			47.51
7	196.02	49.01	
			17.51
8	126.00	31.50	
			2.50
9	116.00	29.00	

Figure 6. Change in Unit Fixed Cost (Paid Periods)



Appendix D

Baseline-and-Credit Instructions for Emissions Trading Experiment[2]

D.1 Introduction

Thank you for agreeing to participate in this experiment. During this experiment you will represent a firm. You and 7 other people will each have to make decisions on how to operate your firms. You will participate in 14 decision rounds, called periods. Each period your firm will produce and sell output and buy or sell a special kind of input called an emission reduction credit. The profits of your firm will depend on the decisions you make and the decisions made by other participants in the session. At the end of the session the cash held by your firm will be converted into Canadian dollars and paid to you privately in cash. Accordingly, the more profits you earn for your firm, the more money you will take home.

[2] Appendix D is found on the CD-ROM enclosed in the pouch on the inside cover at the back of this thesis.

D.2 Production and Costs

You represent a firm which produces a product (for example, electricity) and emits a pollutant (for example, nitrogen oxides - NO_x). There is an upper limit on the amount of output your firm can produce. This is your capacity. In today's session your capacity is fixed. You cannot change it.

You will be able to decide how much output to produce and how much pollution is emitted for each unit of output you produce (this is called your emission rate).

$$Emission\ Rate = \frac{Pollution\ Emitted}{Output}$$

Your total pollution emitted is equal to your output multiplied by your emission rate.

$$Pollution\ Emitted = Output \times Emission\ Rate$$

In today's session you will have a fixed cost, which is determined solely by your emission rate. The fixed cost is inversely related to the emission rate. When emission rates are low, fixed cost is high, and vice versa. The basic understanding behind this is that you can produce things cheaply but you will pollute a lot, or you can use more expensive technology and only pollute a little. Table 1 shows an example of how your costs might change as your emission rate changes. This example is for illustration only. The numbers in the experiment will be different.

Column [a] shows 10 possible emission rates. Column [b] shows the total fixed cost for each rate. Notice total fixed cost falls as emission rate rises.

Table D.1: Example of Emission Rates and Fixed Costs when Capacity is 10

[a] Emission Rate (tons per unit output)	[b] Total Fixed Cost	[c] Unit Fixed Cost	[d] Change in Unit Fixed Cost
0	1990	199	
			93
1	1060	106	
			32
2	740	74	
			17
3	570	57	
			10
4	470	470	
			7
5	400	40	
			6
6	340	34	
			4
7	300	30	
			3
8	270	27	
			2
9	250	25	

Column [c] shows unit fixed cost, which equals total fixed cost divided by the capacity of 10. Column [d] shows the change in unit fixed cost between values of the emission rate. For example, if the emission rate is 1 rather than 0, then unit fixed cost will decrease by 93 (from 199 to 106). Figure 1 illustrates the relationship between emission rate and the change in unit fixed cost.

Your average fixed cost is your total fixed cost divided by your output produced. Table 2 shows how average fixed cost might change as output changes for the case when emission rate equals 0.

$$AverageFixedCost = \frac{TotalFixedCost}{Output}$$

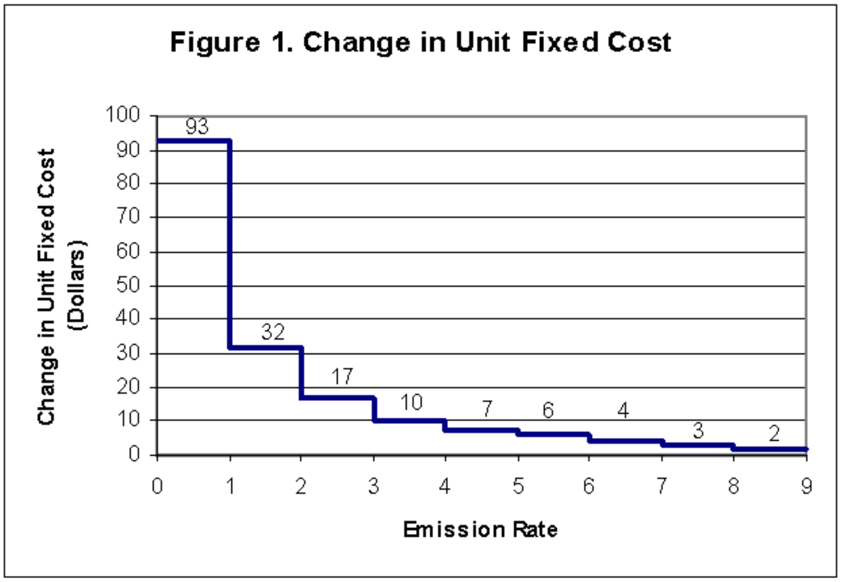


Table D.2: Example of Average Fixed Cost for an Emission Rate of Zero

Emission Rate [a]	Total Fixed Cost [b]	Unit Fixed Cost [c]	Average Fixed Cost when output is . . . [d] 1	[e] 5	[f] 10
0	1990	190	1990	398	199

If your output equals your capacity of 10 then your average fixed cost will equal your unit fixed cost of 199. If your output is less than your capacity, say 5, your average fixed cost will rise to 398. Although Table 2 only shows a limited number of output values (1, 5 and 10), output may actually take on any integer value between 1 and your maximum capacity. The computer will provide you with a cost calculator which will calculate the average and total fixed cost of any quantity of output and emissions rate you choose.

Please answer the following questions, referring to the equations on page 1 and Table 1 and 2 when necessary. When you are done, raise your hand and we will check your work.

a. You produce 5 units of output and 15 tons of pollution. What is your emission rate?

_______ tons of pollution per unit of output.

b. How many tons of pollution are produced when output is 10 and emission rate is 2?

_______ tons of pollution.

c. What is the total fixed cost of producing 10 units of output when the emissions rate is 2?

_______ dollars.

d. How much do you save, per unit of capacity, by choosing an emission rate of 3 rather than 2?

_______ dollars.

e. By how much do your unit fixed costs increase when you choose an emission rate of 1 rather than 2?

_______ dollars.

f. What is the average fixed cost of producing 5 units of output when the emissions rate is 0?

_______ dollars per unit of output.

D.3 Emission Reduction Credits

In this session the pollution is controlled by emission reduction credits. Each firm will be subject to an emission rate performance standard. If your chosen emission rate is less than the standard, you will create emission reduction credits. If your chosen emission rate is greater than the standard, you will need to redeem emission reduction credits. Credits are created according to the formula,

$$CreditsCreated = Output \times (PerformanceStandard - ChosenEmissionRate)$$

Credits are redeemed according to the formula

$$CreditsRedeemed = Output \times (ChosenEmissionRate - PerformanceStandard)$$

For example, suppose the performance standard is 3. If your emission rate is 7 and you produce 10 units of output then you must redeem (7-3) $\times$ 10 = 40 credits. If your emission rate was 1 (instead of 7) you would create (3-1) $\times$ 10 = 20 credits. If your emission rate was 3, you would neither create nor redeem credits ((3-3) $\times$ 10 = 0).

When your emission rate exceeds the performance standard, your output is limited by your holding of credits, the computer will not let you sell output if you do not have enough credits to redeem. For example, if your emission rate is 7, the performance standard is 3 and you hold 20 credits, then you cannot exceed an output of 5 (20/(7-3) = 5) since doing so would require more than 20 credits to be redeemed. Hence, if you wanted to sell 10 units of output, your maximum emission rate would be 5 under these circumstances of a performance standard of 3 and 20 credits in inventory. Credits are redeemed and created at the very end of each period. Created credits cannot be used until the following period. In that period they may be sold to other participants, redeemed, or held for use in still later periods. Please answer the following questions. When you are done, please raise your hand.

```
g.    Suppose the performance standard is 1. Suppose you produce and
      sell 5 units of output with an emissions rate of 3.

 i.   How much pollution will you produce?
   ________ tons of pollution.
 ii.  How many credits would you need to redeem?
   ________ credits.
 iii. Suppose you had 8 credits in inventory, how many more credits
      must you buy?
   ________ credits.
 iv.  Given the amount bought in part iii, if the price of credits
      is $8 each, how much will you have to pay for credits in total?
   ________ dollars.

h.    Suppose the performance standard is 5 and you produce and sell
      7 units of output at an emissions rate of  2.

 i.   How many credits will you create at the end of the period?
   ________ credits.
```

ii. How much will you earn from selling the above credits if the price is $2 per credit?

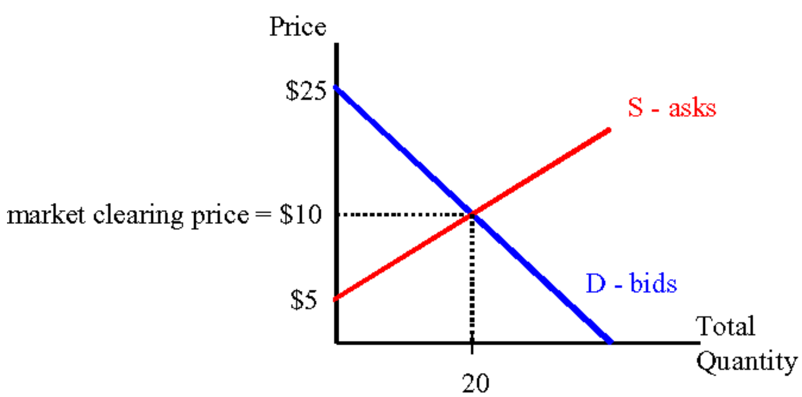
________ dollars.

Each period you will buy and sell credits before you choose your emission rate and before you produce and sell your output.

D.4 Buying and Selling Emission Reduction Credits

In this session, credits will be bought and sold in a call market. Participants in a call market submit offers to buy (called "bids") or sell (called "asks"). Each bid and ask specifies a price and a maximum quantity. Participants may offer multiple bids and asks. For example, a participant may offer to buy 5 credits at $10 and 3 more credits at $8, and offer to sell 2 credits at $12 and sell 4 more credits at $15. When all offers have been submitted, a market clearing price is computed and all transactions are made at this price.

Figure 2: Market price determination



All bids are ranked from highest to lowest. This gives us a curve like 'D' in Figure 2. All asks are ranked from lowest to highest. This gives us a curve like 'S' in Figure 2. The total number of credits bought and sold (20 units in Figure 2) is determined by the intersection of S and D. This means that the 20 credits with the lowest ask prices are sold to the buyers with the 20 highest bid prices. The market clearing price ($10 in Figure 2) is also determined by the intersection of S and D. All credits bought and sold exchange at this price regardless of the price bid or asked. For example, the first credit in Figure 2 has an ask price of $5 and a bid price of $25. The buyer will pay $15 less than he bid, and the seller will receive $5 more than he asked.

It may turn out that the market clearing price just happens to be exactly equal a subject's bid or ask price. In this case sellers who asked a price exactly equal to what turns out to be the market clearing price may find they have not sold all the credits they offered. Similarly, buyers who bid exactly what turns out to be the market clearing price may find they have not purchased all the credits they bid for. In this case the available credits are shared among these buyers or sellers as evenly as possible.

To reiterate, if you submit a bid at a particular price, and if your bid is successful, you may have to pay what you bid but you may pay less. Conversely, if you submit an ask to sell some credits and your units are sold, you may receive the price you asked but you may receive more.

D.5 Emission Rate Decision

When the credit market is over, you must choose your emission rate for the period. In this session you will be able to choose emission rates between 0 and 9. High emission rates reduce your fixed cost. However, higher emission rates require you to redeem more credits, or create fewer credits. You may need to purchase additional credits. Low emission rates increase your fixed cost. However, lower emission rates require fewer credits, or create more credits. You may be able to increase your profits by selling unneeded or created credits.

D.6 Selling Output

In this session the amount of output you produce and sell is determined automatically. Your output does not affect your fixed cost, it only affects how much pollution you will emit, which will equal your quantity of output sold times your emission rate. This, in turn, affects the number of credits you will need to redeem or create based on the performance standard (see formulas on page 4). In this session you must have sufficient credits to redeem as implied by your output if your emission rate is higher than the performance standard. Hence, in this case, you will not be allowed to sell output if you do not have

$$CreditsRedeemed = Output \times (ChosenEmissionRate - PerformanceStandard)$$

credits in inventory. Of course, if your emission rate is lower than the performance standard you do not need to redeem any credits, and in fact you will create credits.

You will be a seller in the output market. The buyers in this market are simulated by a computer program. Your computer will automatically sell the maximum amount of output possible, constrained by your capacity and the number of credits you have (as explained in the paragraph above), at the highest price the computer buyers will pay. The price of output can be calculated with the following function:

$$Output\ Price = 620 - 5 \times Total\ Output\ of\ All\ Firms.$$

When the output market is finished you will be told how many units you have sold. Your output and emissions will be determined automatically and your inventory of credits will be adjusted accordingly.

Figure 3: Demand for output

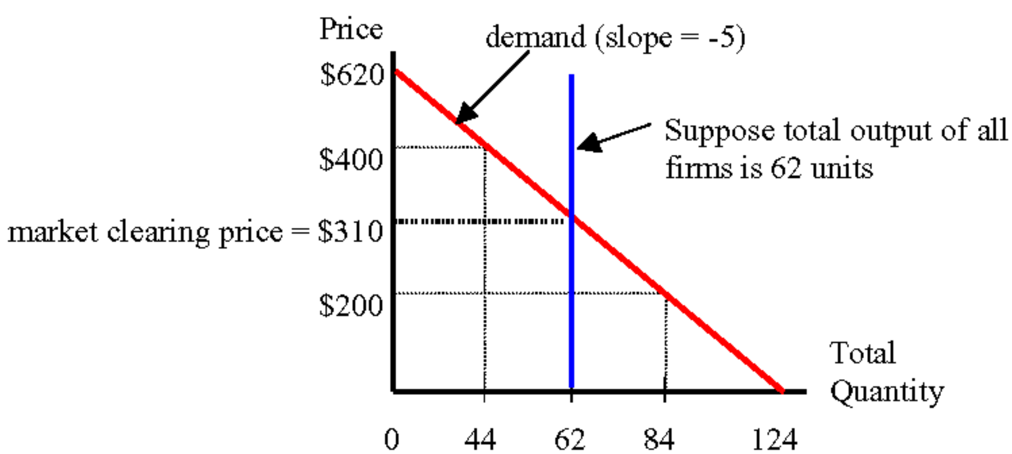


Figure 3 shows a diagram of how the computer buyers in this session will operate as detailed by the formula above. If the total output of all 8 firms is equal to 62 then the price will be \$310 (=620-5×62). If the total output was 44 units then each unit of output would be sold at \$400.

D.7 Practice Periods

To let you learn more about the experiment we are going to run 4 practice periods. Please follow these instructions as they are read aloud and enter the decisions that are discussed below. The results from this period will not contribute to your final earnings. If you have any questions during this period, please raise your hand and we will answer them. After the practice periods are over, we will begin the 10 periods which contribute to your earnings. We will all walk through the first practice period together. The cost values and decisions we make in the first practice period bear no relation to decisions you should make on your own when the experiment starts, they are for demonstration only. All numbers on your screen will be rounded to two decimal places.

[Monitor starts the session]

The dollar values and numbers we will discuss below will differ depending on whether your subject number is even or odd. Your subject number can be found in the bottom left hand corner of your computer screen. Would everyone with an even subject number please raise your hand now? Thank you, you may put down your hands. Would everyone with an odd subject number please raise your hand? Thank you. Numbers and values in the text below will apply to even numbered subjects, and those in parentheses (like this) will apply to odd numbered subjects. If there are no parentheses then the plain text number applies to everyone.

At the end of these instructions you will find Table 3 and Figure 4 on page 21 (20), please find this now. This sheet of paper shows the costs you will have in these 4 practice periods and is comparable to Table 1 and Figure 1 that were described earlier.

Now please examine your computer screens. Please ***click*** on the words "Dataview Window" in the upper right-hand part of your screen now, the title bar will turn blue. Below the title bar are three tabs, please ***click*** on the *cost table tab* now.

The cost table provides a software version of Table 3 and includes information on your average fixed cost. Clicking on a row of the cost table temporarily selects the emission rate in the left most column of that row. The software will fill out the unit fixed cost difference information of decreasing the emission rate by 1 and of increasing the emission rate by 1 and display the results below the cost table. These exact numbers can be found on your hard copy of Table 3 if you find that easier.

Now let us explore some of the other tabs on the Dataview window. Beside the cost table tab is the *planner tab*. Please ***click*** on the planner tab now. This planner tab contains a *cost calculator panel* on the left-hand side that will calculate total fixed cost given assumptions on capacity and emission rate. It will also calculate average cost based on assumptions of output and the value of credits.

Please follow along on your screen as I read the text in the cost calculator aloud. "Capacity is 10. Emission rate is 7 (3). Total fixed cost will be 1633.91 (1956.67). If I sell 10 units of output and if each credit is worth $8 then I will emit 70 (30) tons of pollution, and I must redeem 20 (will create 20) credits. Each unit of output will cost 16 (-16) dollars for 2 credits redeemed (created) and 163.39 (195.67) dollars in average fixed costs. My overall average cost per unit of output is 179.39 (179.67) dollars." The overall average cost just adds together the average fixed cost and the assumed value of credits redeemed stated above. Are there any questions about these numbers? Please use the arrow buttons to ***change*** your emission rate to 9. Notice that you now emit 90 tons of pollution. Notice how your total fixed cost falls to $1600 ($1770), the cost of required credits rises to $32, your average fixed cost falls to $160 ($177) and your overall average cost rises to $192 ($209). Now use the arrow buttons to ***change*** your units of output from 10 to 5. What has changed? Notice that you now only emit 45 tons of pollution. Notice how average fixed cost has risen to $320 ($354) and overall average cost has risen to $352 ($386). Lastly, use the arrow buttons to ***change*** the value of credits from 8 to 16 dollars per credit, and note how the cost of credits doubles to $64 and your overall average cost becomes $384 ($418). The value of credits spinner can be used to find your costs under various possible value conditions.

Below the calculator is the *capacity and emission rate panel* containing information on this and last period's capacity, emission rate and cost information. Notice that last period's capacity is assumed to be 10 and last period's emission rate is assumed to be 7 (3), for this practice period. Notice that your capacity in this practice period is 10 units. This period's emission rate and cost information will remain blank until you choose it later on in the period.

To the right of the capacity and emission rate panel is the *output market panel.* This and last period's output price and amount sold appear in it. Last period's market price was $220 and last period's market volume was 80. The market volume is the total amount of output sold amongst all subjects. The amount of output you sold last period is given as 10, since it is assumed that you sold the maximum amount of output last period. This period's market price and volume is left blank because it has not been determined yet.

Your cash balance is displayed in the *cash panel* which is in the top right of the Dataview window. You start this practice period with $5,000 in laboratory cash.

Below the cash panel is the *credit market panel*. This panel shows detailed information regarding the credit market last period and this period. Notice that the market price of credits was $8 last period and market volume was 80. Notice how this period's market price and volume is blank since the market has not been conducted yet. Also included here is notification that in this practice period the performance standard is an emission rate of 5. Your current inventory of credits is displayed at the bottom of the panel telling you that you currently have 0 (20) credits carried over from last period. For now we will assume that the 20 credits in inventory possessed by the odd numbered subjects was created by choosing an emission rate last period below the performance standard.

Lastly, notice that the status bar at the bottom of the screen provides quick reference to important statistics such as cash, inventory of credits, capacity and emission rate.

We are now ready to start the first practice period. We will all walk through the first period together and then you can make your own decisions during the remaining 3 practice periods. All of your firm's decisions will be entered in the left-most window on the screen and the Dataview window will always remain on screen to provide you with information. The first decision to be made every period is to submit a credit order. This is the only point in the period that you are able to buy and sell credits. You are able to enter up to three bid and three ask orders. The *credit order window* is visible in the upper-left portion of your screen. Please ***click*** on its title bar now.

Because the price of credits is calculated using all submitted bids and asks we do not yet know what the market clearing price will be for this period, even if the market price has been stable for the last few periods. You may be tempted just to enter a bid or ask at last period's market price but if you use the ability to enter bids and asks at multiple prices you can ensure that you buy and sell appropriately whatever the price may be. You may decide to be buyer at some prices and seller at other prices.

When deciding on what bids and asks to make you might wish to consult your cost calculator or cost table, even though your emission rate and cost implications have not yet been chosen for the period. Below we will enter a practice order.

First let us look at the credit order window. Notice that your capacity is equal to 10. If you choose an emission rate equal to the performance standard of 5 then you do not need to use any credits. Since you have 0 (20) credits in inventory you could choose a maximum emission rate of 5 (7), without needing to buy or sell any credits.

Everyone please look at Table 3, odd and even subjects will have different values in their table. First, let us focus on inputting asks to sell credits. Focus on the line in the table associated with an emission rate of 5 since this is the performance standard.

Looking upward along column [d] shows how unit fixed cost increases as lower emission rates are chosen. Since credits are created by choosing emission rates lower than the performance standard and incurring these costs, you might want to use the costs in column [d] when pricing your credits for sale. For instance if you produce output at your capacity of 10, in order to create 10 credits you would have to choose an emission rate of 4 (compared to the performance standard of 5). Column [d] shows that unit fixed cost increases by 25.86 (5.27), and so each of these credits cost you 25.86 (5.27) to produce. In order to create 10 more credits (20 total) you would have to choose an emission rate of 3, raising your unit fixed cost by an additional 38.57 (7.86). Since an ask price is the lowest integer price you would be willing to sell at, you might want to ask $26 ($6) to sell your first 10 credits and $39 ($8) each for another 10 credits. Since only odd subjects currently have credits in inventory, please ***enter*** an ask of $6 for 10 credits in the top most line and an ask of $8 for 10 more credits in the second line if your subject number is odd.

Using your change in unit fixed cost to set the ask price for credits effectively sets the minimum price at which you would sell equal to the cost of creating the credits. By submitting this minimum price you increase the chance of actually selling the units, since the lowest asks get sold first. It also insures that you will not sell the credits at a loss and, it does not directly affect the price you will actually sell them at, which could be higher than the minimum price entered.

Now think about buying credits. Buying credits allows you to choose higher emission rates, which are associated with lower fixed costs. Looking downward along column [d] in Table 3 shows the most you would probably want to pay for credits. For instance, if you produce 10 units of output and choose an emission rate of 6 instead of the performance standard of 5 you would be required to redeem 10 credits. Redeeming each of these 10 credits would save you 15.68 (3.20) in unit fixed costs. If you currently have zero credits in inventory you might be willing to bid $15 ($3) each for 10 credits since this is the maximum integer price that allows you to make a profit. Remember, bidding your true value sets the maximum price you will pay, effectively increasing your chances that you will buy the units, and will not directly effect the market clearing price that you will pay. Buying 10 more credits (20 in total) would allow someone currently with zero credits to choose an emission rate of 7 instead of 6, and save a further 8.05 (1.64) in unit fixed costs, hence giving an incentive to bid $8 ($1) for 10 more credits. Using the change in unit fixed cost in a similar fashion we can see how choosing an emission rate of 8 rather than 7 would save 2.97 (0.60) in unit fixed costs. Even numbered subjects with no credits might bid $2 each for 10 more credits (30 in total). Since even numbered subjects currently have zero credits in inventory, would even subjects please ***enter*** a bid of $15 for 10 units in the first bid line, another bid of $8 for 10 more units on the second bid line, and a third bid of $2 for 10 more units on the third bid line.

If your subject number is odd, you currently have 20 credits in inventory. You might realize that your first 10 credits bought would give you a total of 30 credits, allowing you to choose an emission rate of 8 (if output is 10 and performance standard is 5) instead of your maximum of 7 implied by the performance standard and your current inventory of credits. Since the cost savings for odd subjects when increasing their emission rate from 7 to 8 is 0.60, any integer price above zero would mean a loss. Even if bought at $1 each, the credits would only save odd subjects $0.60 each, implying a loss per credit of $0.40. Odd subjects will not enter any bids this period.

Notice that since your capacity is equal to 10, it makes sense to bid and ask for credits in quantities of 10. You are not allowed to sell credits that you do not possess in inventory, nor bid for credits if you do not have enough cash to cover the transaction. When you have finished entering your bid and ask orders a monitor will check your work. Normally you will click on the submit button to submit your order when you are ready, but during this practice period the monitor will submit all your decisions for you.

[All credit orders are submitted]

Once the bid and ask orders are submitted the market will be called and a market clearing price and quantity will be determined. The results window in the top left of your screen identifies if you bought or sold any credits this period. The even numbered subjects have bought 20 credits each and the odd numbered subjects have sold 20 credits each. The results window also tells you that the market clearing price was $8 and a total volume of 80 credits were bought and sold. Please ***click*** on the planner tab in the Dataview window. Notice how your current cash in the cash panel is now $4,840 ($5,160) and your credits inventory in the credits panel is now 20 (0), to reflect your transaction this period. During the experiment the software will keep the credit market results window on screen for 10 seconds before automatically continuing on with the rest of the period. You do not need to write these results down, as they are immediately stored in the credit market panel of your planner. Also, the results from past period's get stored in your income statement which we will discuss at the end of the first practice period.

The second decision to be made each period is choosing an emission rate. Your *emission* rate choice window provides a spinner that you can use to choose an emission rate. Remember that the performance standard is 5, your capacity is 10, and that you have 20 (0) credits in inventory. The emission rate spinner starts off at the emission rate you chose last period, but you may use the arrow button to choose a new emission rate this period. One way to choose an emission rate might be to use your cost calculator to find which emission rate minimizes your overall average cost. This is equivalent to maximizing profit as long as everything other than your emission rate stays constant. If you spin the emission rate in your cost calculator panel from 0 to 9 you will notice that an emission rate of 7 (3) will minimize your overall average cost. Before selecting your emission rate you must not forget that if your emission rate is above the standard that you will not be allowed to produce output unless you have the proper number of credits to redeem. If you have no credits in inventory and you choose an emission rate above the performance standard then you will not be allowed to sell any output, since even producing one unit of output would require you to redeem at least one credit. For this practice period, ***click*** on the emission rate arrow buttons in the emission rate choice window and choose an emission rate of 7 (3), since this will minimize your overall average cost and you will have enough credits in inventory to produce at full capacity. After a monitor has checked your work he will click the submit button for you. Confirm the results shown on the next window. Again, the software will store this information in your planner and income statement for later reference and the rest of the period will continue in about 10 seconds.

After you have been notified of your emission rate choice, the output market occurs automatically. The computer automatically sells the maximum amount of output possible, which according to your capacity, the performance standard, and your holding of credits, is 10 units. The output market clearing price of \$220 and volume of 80 units is displayed in the results window ($220 = 620 - 5 \times 80$). The 10 units of output sold and produced by your firm is also displayed. Lastly, a message is provided identifying that you redeemed 20 (created 20) credits this period. Again, during the experiment, the output market results window will stay on screen for about 20 seconds and all the information on it will be stored in your planner and income statement.

It is now the end of period 1. Notice the income statement tab beside the planner and cost table tabs in the Dataview window. The income statement gives a breakdown of your profits earned at the end of each period. Please ***click*** on the income statement tab now.

Your income statement shows that you earned \$2200 revenue from selling output. Odd numbered subjects will find that they earned \$160 revenue from the 20 credits they sold during the period. Odd subjects also created 20 credits worth \$160 at the current market price. The cost of goods sold section of the income statement details how the value of the credits you redeemed is subtracted from your revenue. Only even numbered subjects needed to redeem credits because odd numbered subjects chose an emission rate less than the standard. Even numbered subjects were required to redeem 20 credits since their emission rate was 2 units above the standard and they produced 10 units of output. The 20 credits redeemed were valued at the market price of \$8 each, totalling \$160. Odd numbered subjects will have an entry for the cost to them of the 20 credits sold during the period totalling \$160, as we are assuming they were purchased the period earlier at the market price of \$8. The last subtraction from your revenue is your total fixed cost of \$1633.91 (\$1956.67). Your profit, or net income, for this practice period should be \$406.09 (\$403.33). Take special note that this net income value can be misleading if you are buying credits and keeping them in inventory. When you buy credits your cash decreases but your value of inventory increases by the same amount and this does not show on your income statement. The profits or losses you make on the credits you buy and keep in inventory will not appear until the period you either sell them or redeem them. Therefore, beware that buying up credits and holding them in inventory looks like a good thing according to the income statement but if you do not use or sell those credits by the end of the experiment, they will be worthless to you (and so you could experience a large loss in the last period). As will be discussed in the paid periods section of the instructions, only your firm's cash balance at the end of the experiment will be converted to Canadian dollars as your payout, you net income will not.

At the bottom of the income statement you will find a restatement of your capacity, emission rate, output and credit inventory for the period. In addition you will find the credit and output market price and volume information, which can easily be referenced later. After this practice period, you will play through 3 more practice periods by yourselves. The 10 paid periods of this session will follow.

We are now finished the first practice period. The rest of the experiment is automated. When you are done entering a decision make sure to click the appropriate submit or continue button. Your cost and capacity values will be the same for the next 3 practice periods but will change for the paid periods. When the fourth practice period is over, the monitor will read aloud the last section of the instructions.

[Period 2 starts]

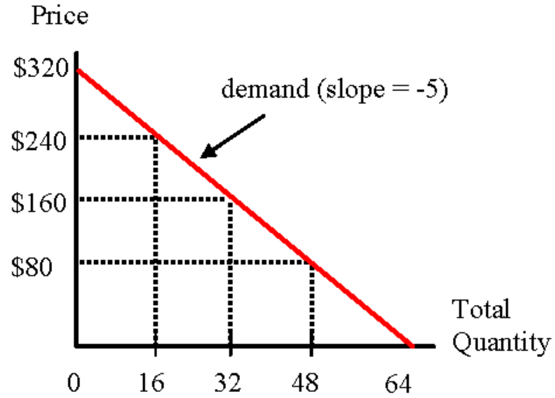
We are now starting practice period 2. The credit order window is now displayed on everyone's screens. If you are wondering what bids and asks to enter you might wish to start by referring back to what we entered in the first practice period, detailed on page 10. . To help keep people's focus the credit order phase will be limited to 3 minutes in length and the emission rate choice will be limited to 2 minutes in length. You will be given roughly double as much time to get acquainted with the software in the first few periods.

D.8 Paid Periods

We will now start the 10 paid periods. We now restart at period 1 and will end after period 10. The experiment will operate exactly as during the practice periods only now subjects will experience different parameters. Your costs will be different from the practice period values but will remain constant over the 10 periods. Everyone will now have a capacity of 4 but the performance standard will still be 5 for all 10 paid periods. Since capacity has changed from 10 to 4, you will most likely wish to bid and ask for credits in quantities of 4 instead of quantities of 10 (as we did in the practice periods). Lastly, the demand for output will operate as in the Figure 3 below, according to the formula:

$$Output\ Price = 320 - 5 \times Total\ Output\ of\ All\ Firms$$

Figure 4: New demand for output



Everyone will start the first paid period with 5000 lab dollars in cash. At the end of period 10 we will convert your final cash balance in excess of 5000 lab dollars into Canadian dollars. This cash profit will be converted at the rate of 1 Canadian dollar for every 92 lab dollars and will be paid to you privately in cash. Accordingly, the more profits you earn for your firm, the more money you will take home. Take note, payoffs will be based on your firm's CASH holdings only. Credits not sold or redeemed by the end of the last period will be worthless and not converted to Canadian dollars.

Please standby while the monitor restarts the software for the first paid period. Make sure to familiarize yourself with all the new numbers in the planner, and your new cost table, before proceeding on to making decisions in the first period. Again, if you are wondering what bids and asks to enter you might wish to start by referring back to the method we used in the first practice period, detailed on page 10, only now you have a different cost table.

D.9 Tables and Figures for Experiment

Note: The tables and figures for the baseline-and-credit instructions are identical to those provided for cap-and-trade in Appendix C.

Appendix E

“ERC” Emission Permit Trading Software Documentation[3]

E.1 ERC Software Overview

The McEEL ERC software is a Borland Delphi client/server application that uses a MySQL database to facilitate an experimental economics emission trading experiment. The software can be used to test various environments and was written to explore cap-and-trade and baseline-and-credit emission trading systems.

The software has been successfully tested running a server executable and various client executables from within Microsoft Windows 98 and Windows 2000 and serving a MySQL database from a Windows or Linux machine. The software requires a MySQL database server and the Borland Database Engine (the BDE can be installed with any Corel Office product, Delphi itself, or a redistributable package) with a MySQL ODBC driver installed on the monitor/server machine as well as all client machines. Installing the files found in the ERCSoftwareNov2004 directory of the accompanying CD-ROM will pro-

[3]Appendix E is found on the CD-ROM enclosed in the pouch on the inside cover at the back of this thesis.

vide the server and client executables, as well as the BDE and the ODBC MySQL installation files, for a Windows system.

As illustrated in Table E.1, the server and client programs are made up of some unique and some common Delphi program units. A description of these units, the MySQL database and various useful procedures, will be documented in the pages that follow. A flow chart of the decision sequences that take place in a typical ERC period is provided in Figure E.1.

E.2 ERC Delphi Program File Descriptions

E.2.1 Server Files

The server executable provides a connecting point for all client machines. The server coordinates the experiment by controlling flow and by conducting procedures such as initializing database tables, calculating market clearing prices and volumes and calculating payoffs. Figure E.2 displays the server program's unit structure.

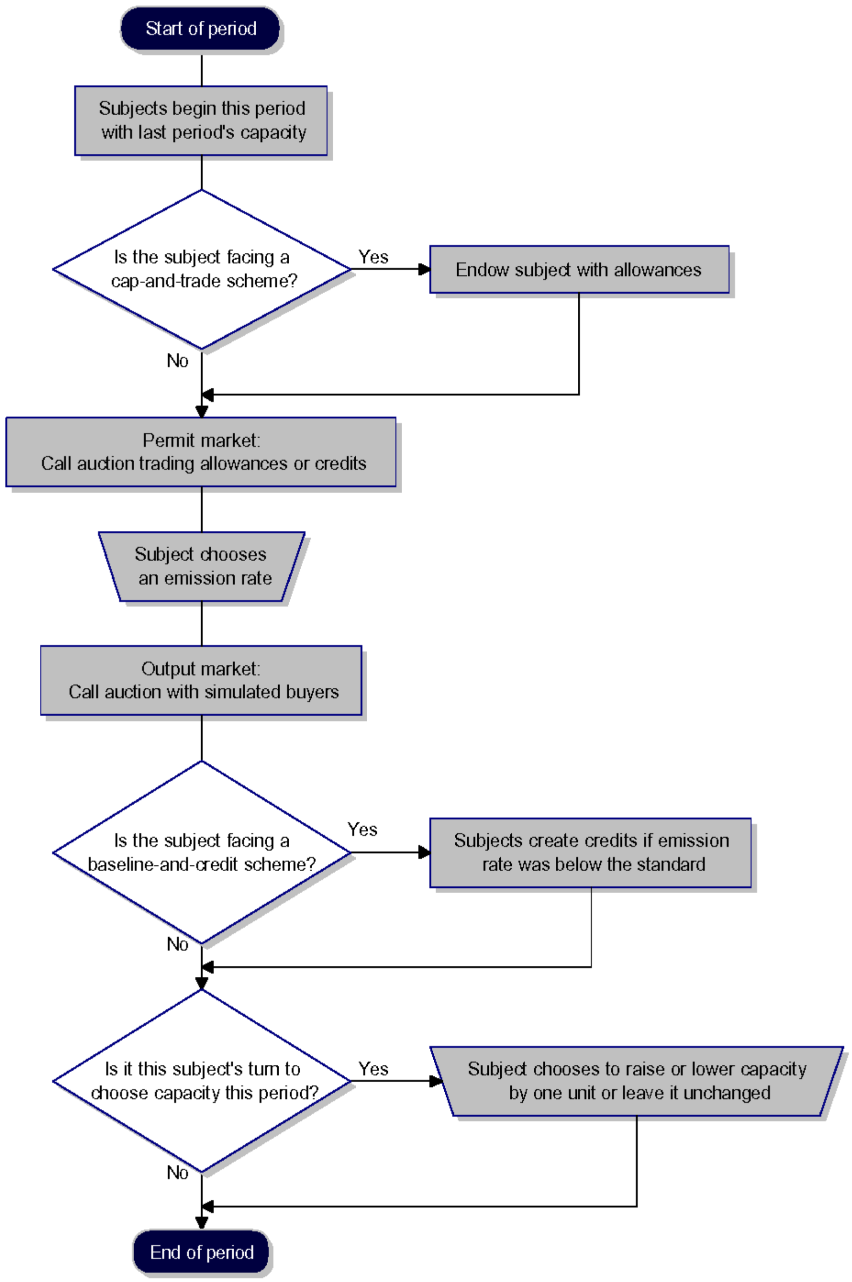


Figure E.1: Sequence of Events

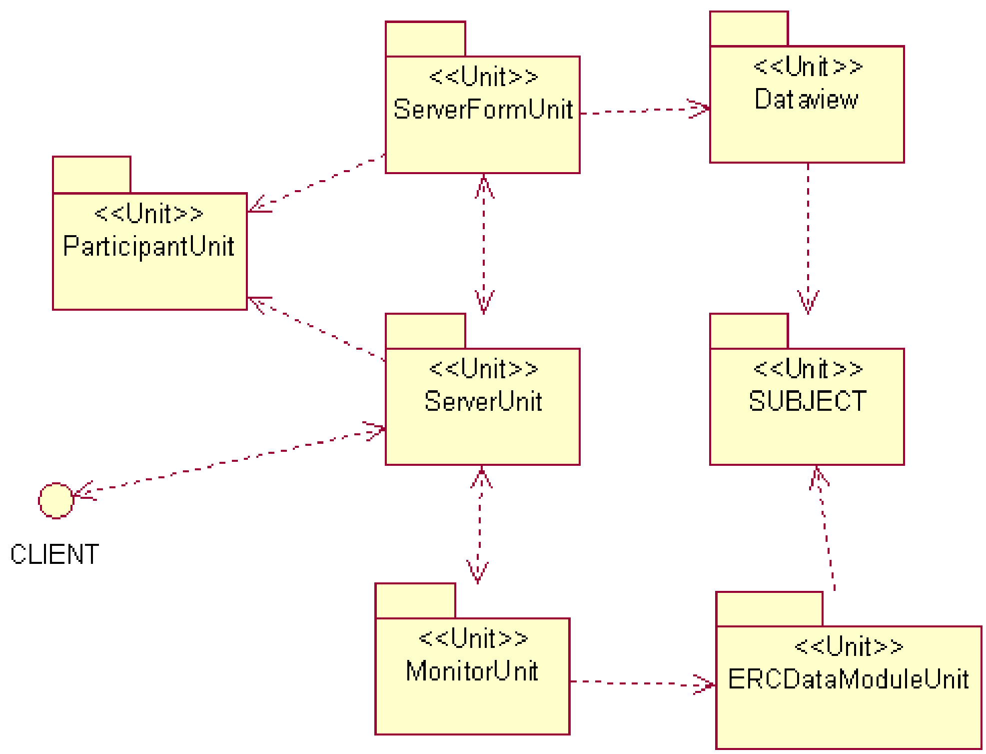


Figure E.2: Server Program Unit Structure

Table E.1: ERC Program Units

Client	Common	Server
ClientUnit	SubjectUnit	ServerUnit
ClientFormUnit	ERCDataModuleUnit	ServerFormUnit
ClientDemographicsFormUnit	DataviewUnit	MonitorUnit
SubjectFormUnit	ParticipantUnit	
RobotUnit		
PermitOrderUnit		
PermitOrderResultsUnit		
PlantOrderUnit		
PlantOrderResultsUnit		
OutputOrderUnit		
OutputOrderResultsUnit		
CapacityOrderUnit		
EndofPeriodResultsUnit		
EndofSessionResultsUnit		
WaitUnit		

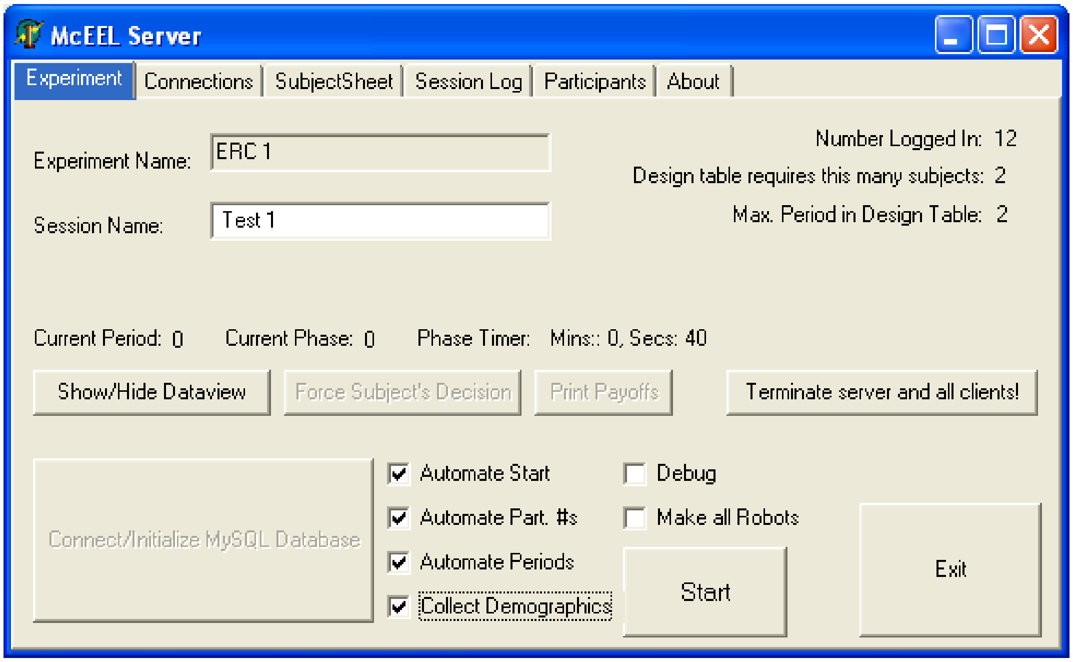


Figure E.3: ServerFormUnit Screen

ServerUnit Implements server side of communication (internet TCP/IP) with clients through the use of a “serversocket”component. It handles the sending of all messages as well as the parsing and handling of all incoming messages.

ServerFormUnit This is the graphical user interface (GUI) that the experimenter uses to startup the experimental software server. It is mainly used to connect to the MySQL database and to select options such as automatic period progression, auto subject numbering and robot subjects, etc. The “Participants” tab can be used to check the current phase of each participant and the “Session Log” tab can be used to view debug messages if the debug option is selected. It is this form that is initially displayed to the experimenter when the server program is executed.

MonitorUnit The code in this unit controls the server's flow of the experiment and handles calculations (e.g. calling the permit and output markets and calculating cumulative payoffs for subjects) and what procedures are followed during different phases (or SubjectStatus) of the experiment.

E.2.2 Common Files

These programming units contain code that are used by both the client and server executables.

ParticipantUnit This common unit for client and server should be used for all experimental designs in that it handles the PARTICIPANT messages and info, not the experiment-specific subject messages. It handles the loading and saving of participant messages so that they can move between the program and the internet socket efficiently.

SubjectUnit This is a common unit for client and server and some content is common to all experimental designs. This unit sets up a class of programming objects called "TSubject". Each instance of this class has fields describing the parameters affecting the experimental subject and the decisions the subject makes (these properties, such TSubStatus and U0 and U1, are generally experiment-specific). Each instance contains methods for accessing and setting this data (these methods, such as "CalcPayoff" and "SetPhase", are mostly common across all experimental designs). Load and Save methods are used to upload and download the subject's info to and from a StringList so that it can be sent as a message across an internet socket.

ERCDataModuleUnit This unit houses all database components and code to interact with the database. All units that need to load/save database information do so by calling functions and procedures stored here. Borland Delphi components are used to access an external MySQL database server through the use of the Borland Database Engine (BDE) and an OBDC MySQL Windows driver (therefore the BDE and this ODBC driver must be installed on all machines).

DataviewUnit This form/unit displays experiment information to the subject (and experimenter on the server) such as market prices and volumes. It also provides a cost wizard, a cost table, and access to an income statement (and a raw table query grid for the experimenter). The data is derived straight from the MySQL database tables themselves (through the ERCDataModuleUnit).

SymbolicConstantsUnit This unit contains constant parameters and variables common to the server and clients but that are particular to the current design.

E.2.3 Client Files

The client executable provides a connection to the server and displays the subject's graphical user interface. Figure E.8 displays the client program's unit structure.

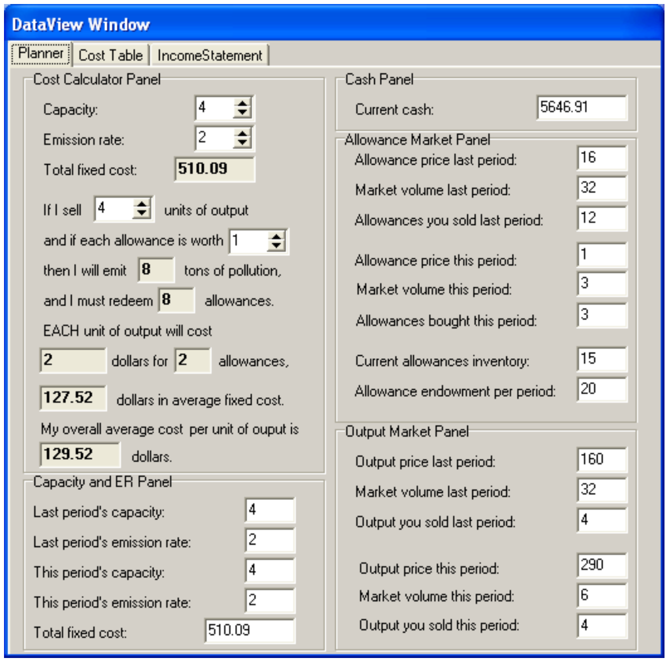


Figure E.4: Dataview Planner Screen

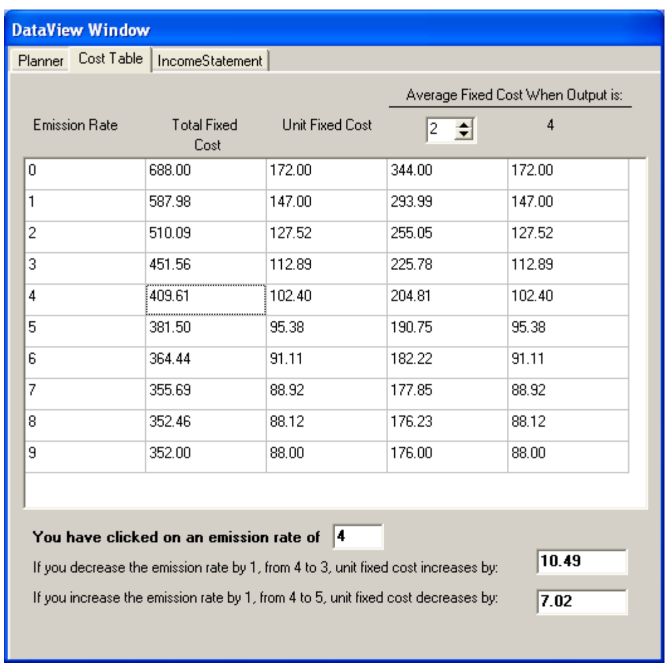


Figure E.5: Dataview Cost Table Screen

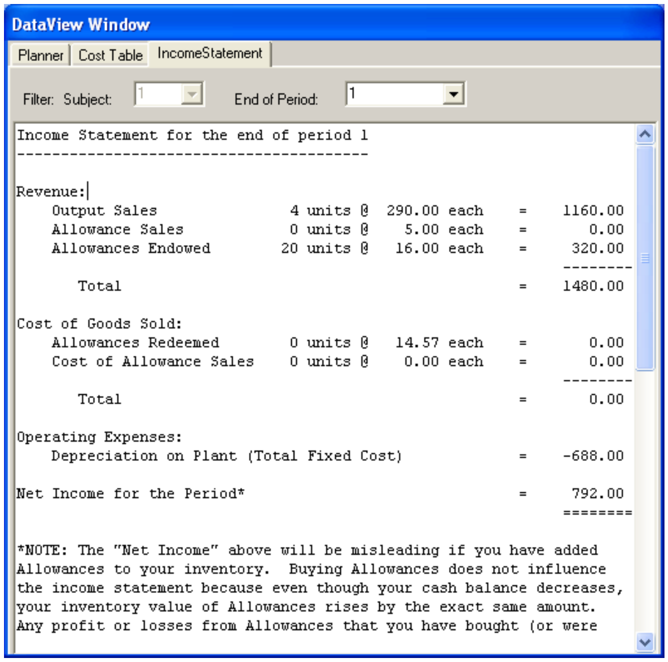


Figure E.6: Dataview Top of Income Statement Screen

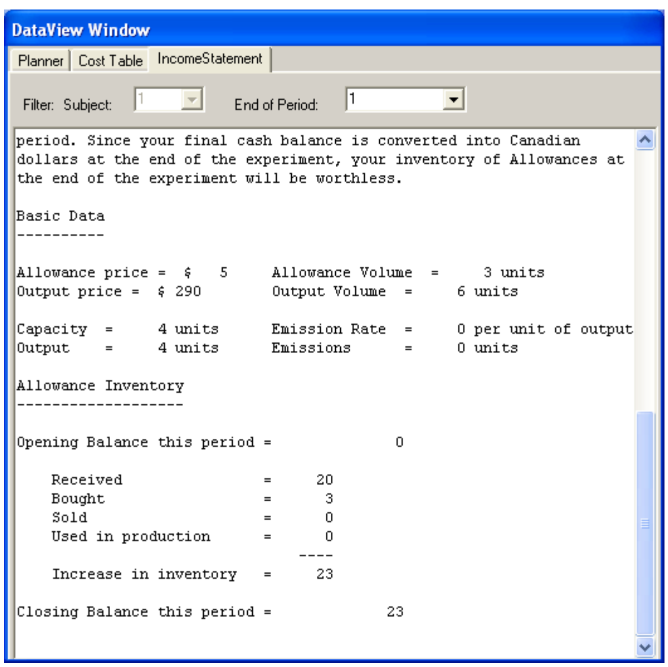


Figure E.7: Dataview Bottom of Income Statement Screen

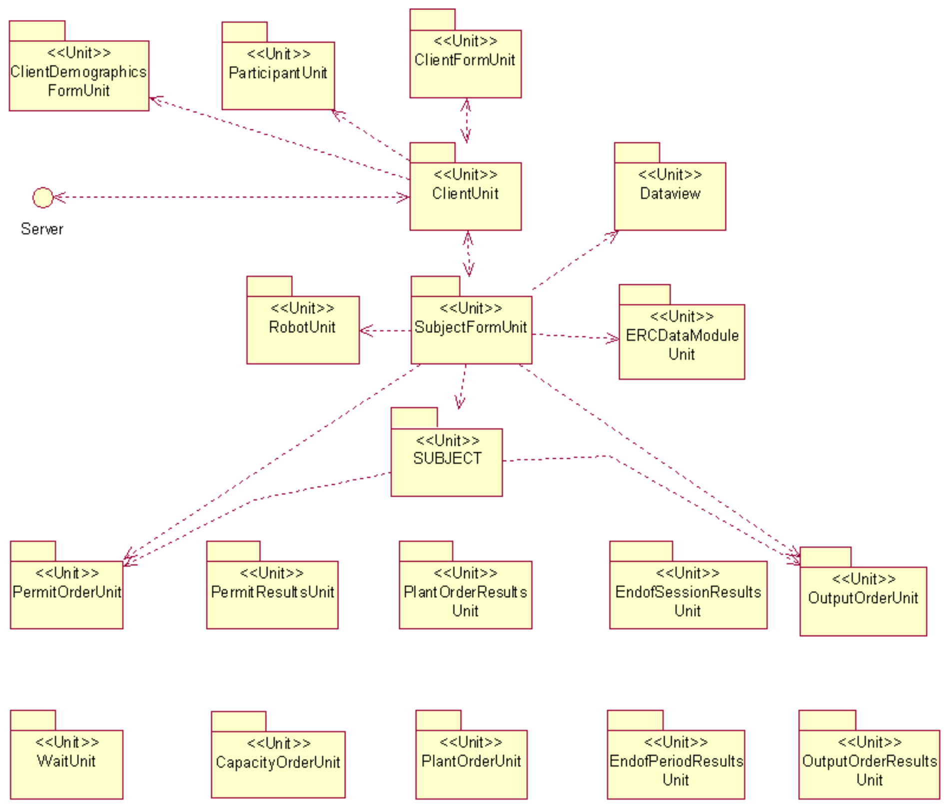


Figure E.8: Client Program Unit Structure

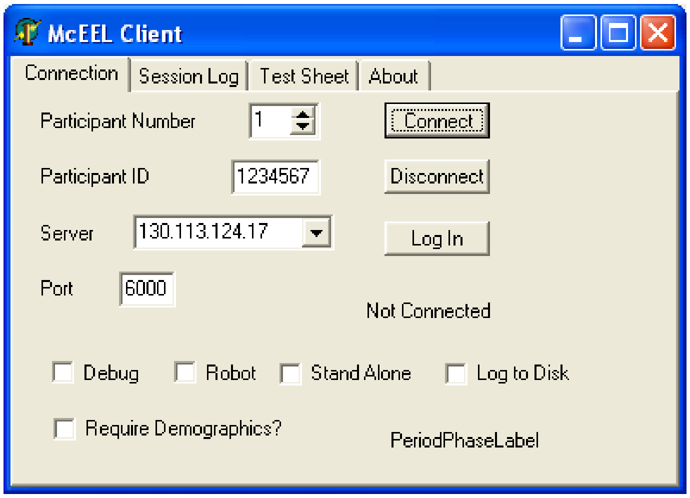


Figure E.9: ClientFormUnit Screen

ClientUnit Handles all of the client's internet TCP/IP message passing, distributing and parsing through the use of a ClientSocket component. Messages sent out are done so with the use of a timer that is used to add slight random wait intervals to aid in avoiding socket collisions during robotic simulations.

ClientFormUnit This form controls the client side functions outside the actual experiment such as making the internet TCP/IP socket connection and logging on to the server. It is the form that is initially displayed to the user when the client program is executed. Participant #, ID, Robot, and Require Demographics do not need to be set if the "automatic" features of the server form/executable are turned on.

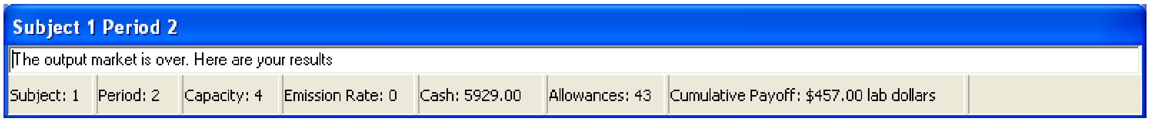


Figure E.10: SubjectFormUnit Screen

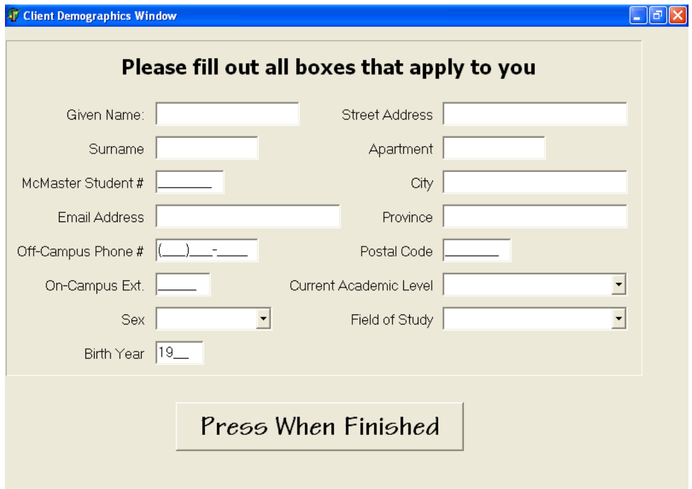


Figure E.11: ClientDemographicsFormUnit Screen

SubjectFormUnit This unit is particular to this ERC experiment only and is the main visual form that subjects interact with during the experiment. Although the form itself is just a status bar, it is this unit that calls up the appropriate decision or information screens depending on what phase (SubStatus) the subject is in.

DemographicsFormUnit This form accepts participant demographic information and saves it to a stringlist so that it may be saved in the demographicstable by the ERCDataModule.

RobotUnit This unit contains artificial intelligence code that is used to make decisions in the experiment when the IsRobot property for the client is true (used to test the program or to run controlled simulations). Currently the Robot is setup to make perfect profit maximizing decisions by myopic agents. White noise can be added using he ErrorPercentageDeviation variable.

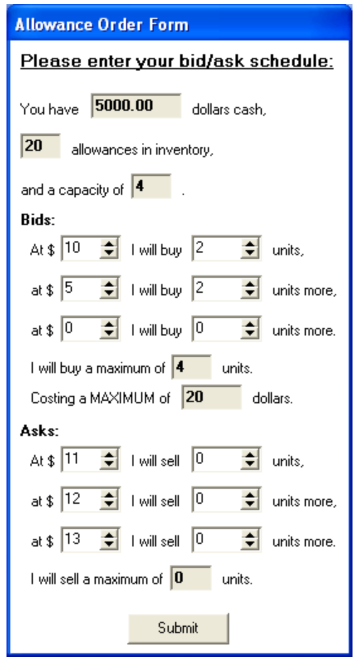


Figure E.12: PermitOrderUnit Screen

PermitOrderUnit This screen displays an interface for the subject to enter three permit bid and three ask orders while providing the subject with needed information.

PermitResultsUnit This screen displays results of the current permit market, including how many units a subject bought or sold and at what price.

PlantOrderUnit This form facilitates subject input for choosing an emission rate level. It is called 'PlantOrderUnit' because, after choosing an emission rate, the cost of building a plant with the chosen emission rate and the period's current capacity is written into the capacity and ledger tables like a factory/plant was just built.

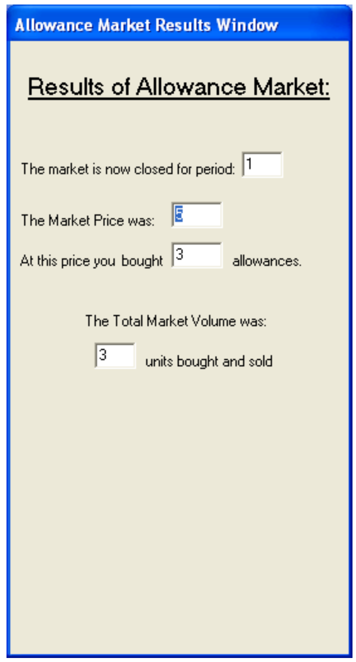


Figure E.13: PermitResultsUnit Screen

PlantOrderResultsUnit This screen displays results of the current plant choice, including your chosen capacity and emission rate and cost information for the period.

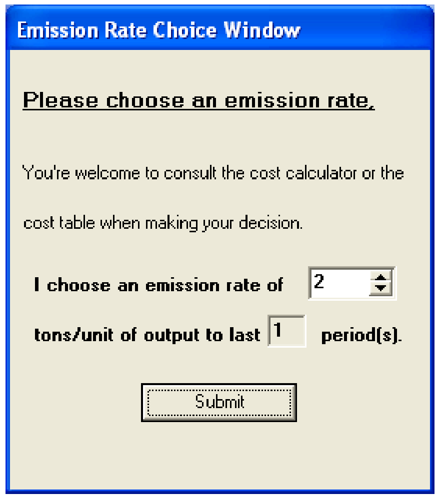


Figure E.14: PlantOrderUnit Screen

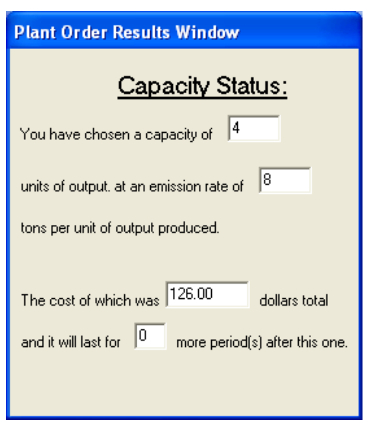


Figure E.15: PlantOrderResultsUnit Screen

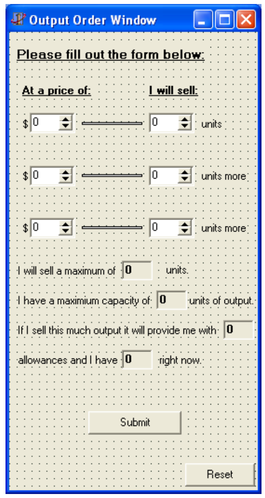


Figure E.16: OutputOrderUnit Screen

OutputOrderUnit This screen displays an interface for the subject to enter three output ask orders while providing the subject with needed information.

OutputOrderResultsUnit This screen displays results of the current output market, including how many units the subject (and market aggregate) sold and at what price.

CapacityOrderUnit This form facilitates subject input for choosing capacity levels. Currently shown at the end of each period where a change is allowed.

EndofPeriodResultsUnit This screen displays the result that the current period is over.

EndofSessionResultsUnit This screen displays results of the current session including subject payoff in lab dollars and Canadian dollars. It is the very last screen the participant will see.

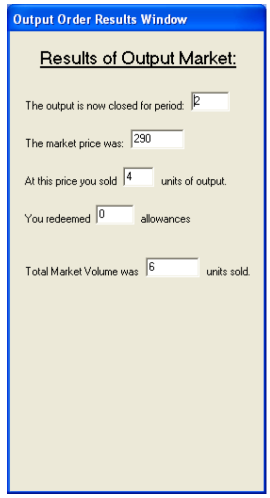


Figure E.17: OutputOrderResultsUnit Screen

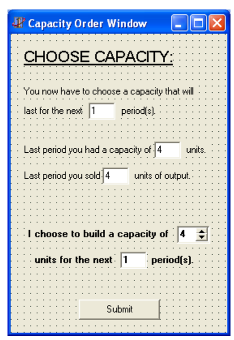


Figure E.18: CapacityOrderUnit Screen

WaitUnit This screen displays a "WAIT" message that informs the subject to hold until other subjects have made their decisions.

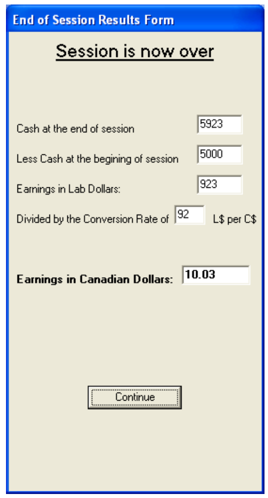


Figure E.19: EndofSessionResultsUnit Screen

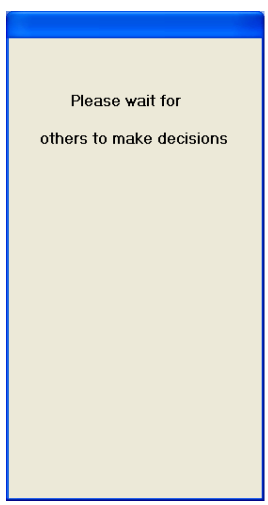


Figure E.20: WaitUnit Screen

E.3 ERC Program Phases and Messages

What makes the whole ERC client/server software work is, of course, a complex structure of phases and communication messages. Figures E.21 to E.24 give an excellent visual representation of the messaging and flow of the ERC client/server software. Figure E.21 displays the process flow that the server program undertakes when an ERC message is received from a client machine. Figure E.22 displays the process flow that the client program undertakes when an ERC message is received from the server machine. Figures E.23 and E.24 illustrate the phase and procedure flow of a typical ERC session between the server and a typical client machine.

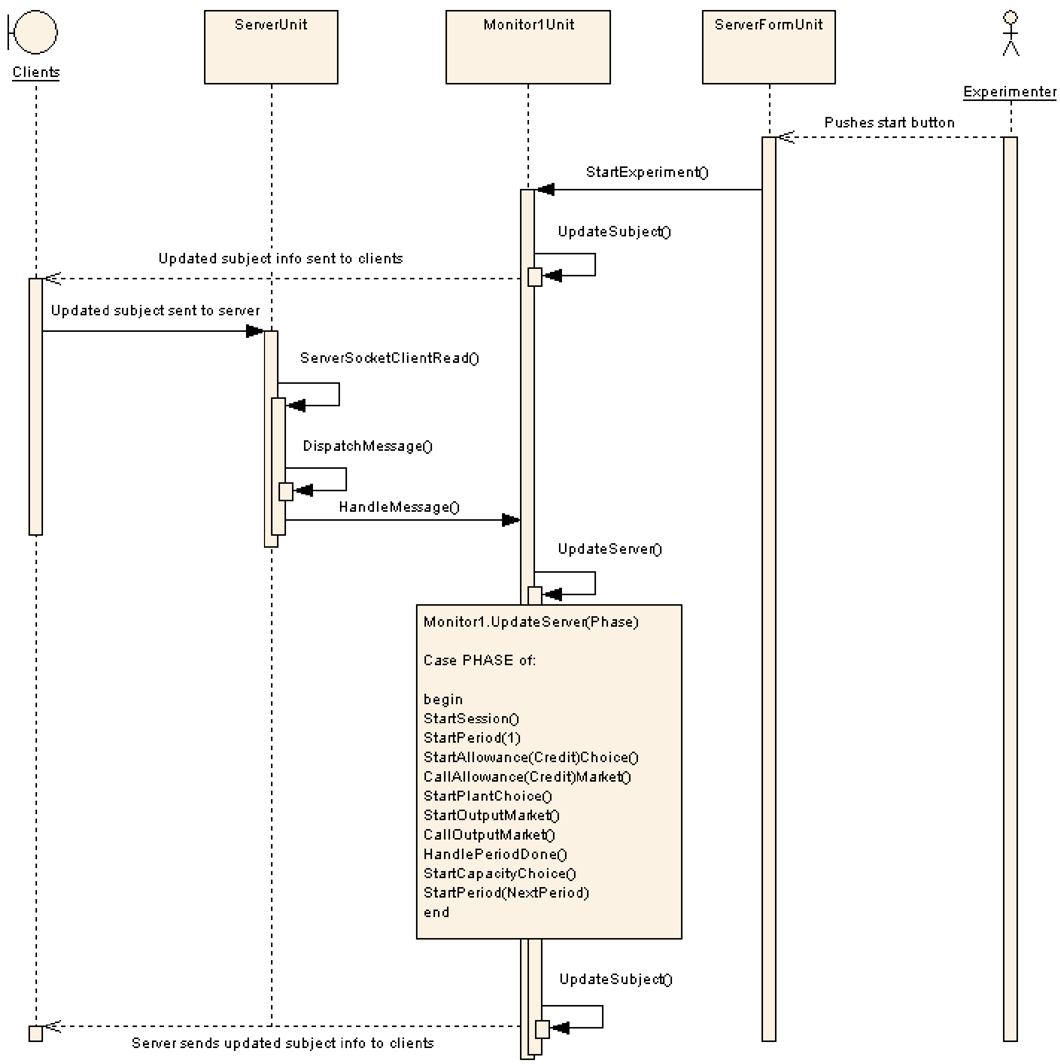


Figure E.21: Server Message Sequence

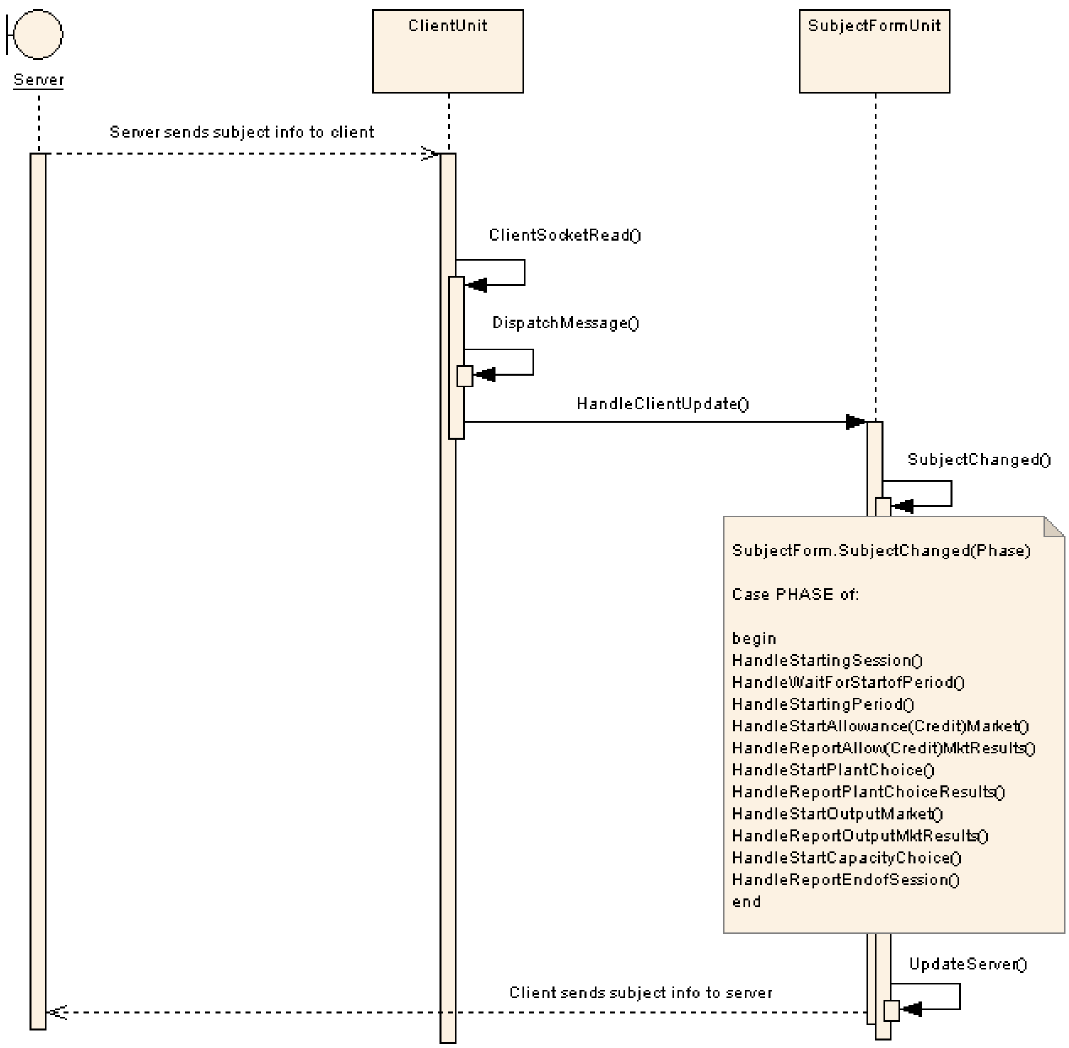


Figure E.22: Client Message Sequence

Server: MonitorUnit **Procedures** and code		**Client: SubjectFormUnit** **Procedures** and code
StartExperiment: StartSession		
StartSession: CurrentPhase = sstStartSession WaitforPhase = sstDisplayingStartofSession UpdateSubjects	→	SubjectChanged: if phase = sstStartSession then HandleStartingSession
HandleUpdateServer: if all subjects in sstDisplayingStartofSession then StartPeriod(1)	←	**HandleStartingSession:** Collect Demographics phase = sstDisplayingStartofSession UpdateServer
StartPeriod: CurrentPhase = sstStartPeriod WaitforPhase = sstDisplayingStartofPeriod UpdateSubjects	→	SubjectChanged: if phase:=sstStartPeriod then HandleStartingPeriod
HandleUpdateServer: if all subjects in sstDisplayingStartofPeriod then StartAllowance(Credit)Choice	←	**HandleStartingPeriod:** Initialize tables and dataview/planner phase = sstDisplayingStartofPeriod UpdateServer
StartAllowance(Credit)Choice: CurrentPhase= sstStartAllow(Credit)Mkt WaitforPhase = sstReportingAllow(Credit)MktOrders UpdateSubjects	→	SubjectChanged: if phase = sstStartAllow(Credit)Mkt then HandleStartAllowance(Credit)Market
HandleUpdateServer: if all subjects in sstReportingAllow(Credit)MktOrders then CallAllowance(Credit)Market	←	**HandleStartAllowance(Credit)Market:** Display Permit Order Form phase = sstReportingAllow(Credit)MktOrders UpdateServer
CallAllowance(Credit)Market: Call Permit Market CurrentPhase = sstReportAllow(Credit)MktResults WaitforPhase = sstFinishedDisplayingAllow(Credit)Mkt UpdateSubjects	→	SubjectChanged: if phase = sstReportAllow(Credit)MktResults then HandleReportAllow(Credit)MktResults
HandleUpdateServer: if all subjects in sstFinishedDisplayingAllow(Credit)Mkt then StartPlantChoice	←	**HandleReportAllow(Credit)MktResults:** Handle Permit Market Accounting Display Permit Market Results phase = sstFinishedDisplayingAllow(Credit)Mkt UpdateServer
StartPlantChoice: CurrentPhase = sstStartPlantChoice WaitforPhase = sstReportingPlantChoice UpdateSubjects	→	SubjectChanged: if phase = sstStartPlantChoice then HandleStartPlantChoice
HandleUpdateServer: if all subjects in sstReportingPlantChoice then StartOutputMarket	←	**HandleStartPlantChoice:** Display Emission Rate Choice Form HandleReportPlantChoiceResults phase = sstReportingPlantChoice UpdateServer

Figure E.23: ERC Communication and Phase Structure, Part 1 of 2

Server: MonitorUnit **Procedures** and code		**Client: SubjectFormUnit** **Procedures** and code
StartOutputMarket: CurrentPhase = sstStartOutputMkt WaitforPhase = sstReportingOutputMktOrders UpdateSubjects	→	SubjectChanged: if phase = sstStartOutputMkt then HandleStartOutputMarket
HandleUpdateServer: if all subjects in sstReportingOutputMktOrders then CallOutputMarket	←	**HandleStartOutputMarket:** Display Output Order Form phase = sstReportingOutputMktOrders UpdateServer
CallOutputMarket: Call Output Market CurrentPhase = sstReportOutputMktResults WaitforPhase = sstFinishedDisplayingOutputMkt UpdateSubjects	→	SubjectChanged: if phase = sstReportOutputMktResults then HandleReportOutputMktResults
HandleUpdateServer: if all subjects in sstFinishedDisplayingOutputMkt then HandlePeriodDone	←	**HandleReportOutputMktResults:** Handle Output Market Accounting Handle End of Period Accounting Display Output Market Results phase = sstFinishedDisplayingOutputMkt UpdateServer
HandlePeriodDone: Update Payoffs and save in SubjectsTable CurrentPhase = sstStartEndofPeriod WaitforPhase = sstFinishedReportingEndofPeriod UpdateSubjects	→	SubjectChanged: if phase = sstStartEndofPeriod then HandleDisplayEndOfPeriodResults
HandleUpdateServer: if all subjects in sstFinishedReportingEndofPeriod then StartCapacityChoice	←	**HandleDisplayEndOfPeriodResults:** Create Income Statement phase = sstFinishedReportingEndofPeriod UpdateServer
StartCapacityChoice: CurrentPhase = sstStartCapacityChoice WaitforPhase = sstFinishedDisplayingCapacityChoice UpdateSubjects	→	SubjectChanged: if phase = sstStartCapacityChoice then HandleStartCapacityChoice
HandleUpdateServer: if all subjects in sstDisplayingStartofPeriod then if period=last then HandleExperimentFinished else StartPeriod(next)	←	**HandleStartCapacityChoice:** Display Capacity Choice Form phase = sstFinishedDisplayingCapacityChoice UpdateServer
HandleExperimentFinished: Print Cumulative Subject Payoffs CurrentPhase = sstReportEndofSession WaitforPhase = sstFinishedReportingEndofSession UpdateSubjects	→	SubjectChanged: if phase = sstReportEndofSession then HandleReportEndofSession
		HandleReportEndofSession: Display End of Session Payoff Form phase = sstFinishedReportingEndofSession Terminate Client

Figure E.24: ERC Communication and Phase Structure, Part 2 of 2

E.4 ERC MySQL Database Tables Description

Figure E.25 displays a data diagram of the ERC MySQL database. This figure provides a great overview of how tables can be categorized as being design tables or results tables. The figure also details table field types and which fields are primary keys. Primary key fields are identified with the "*PK*" abbreviation signifying that these fields must be unique to each record in the table. It is imperative that the entire database and all its tables be backed up (or "dumped") as soon as a session is finished to secure the experiment's results. This is needed because the server executable clears out and initializes the database tables every time the server software is started.

E.4.1 Design Tables

Design tables contain information regarding how the experimental session is to be run. They must be completed before the session is started. If you want to set up a specific treatment you will need to modify these tables.

E.4.1.1 SessionTable

This table contains information that varies across periods but not across subjects.

Period(*PK*) The decision making period number pertaining to the current record.

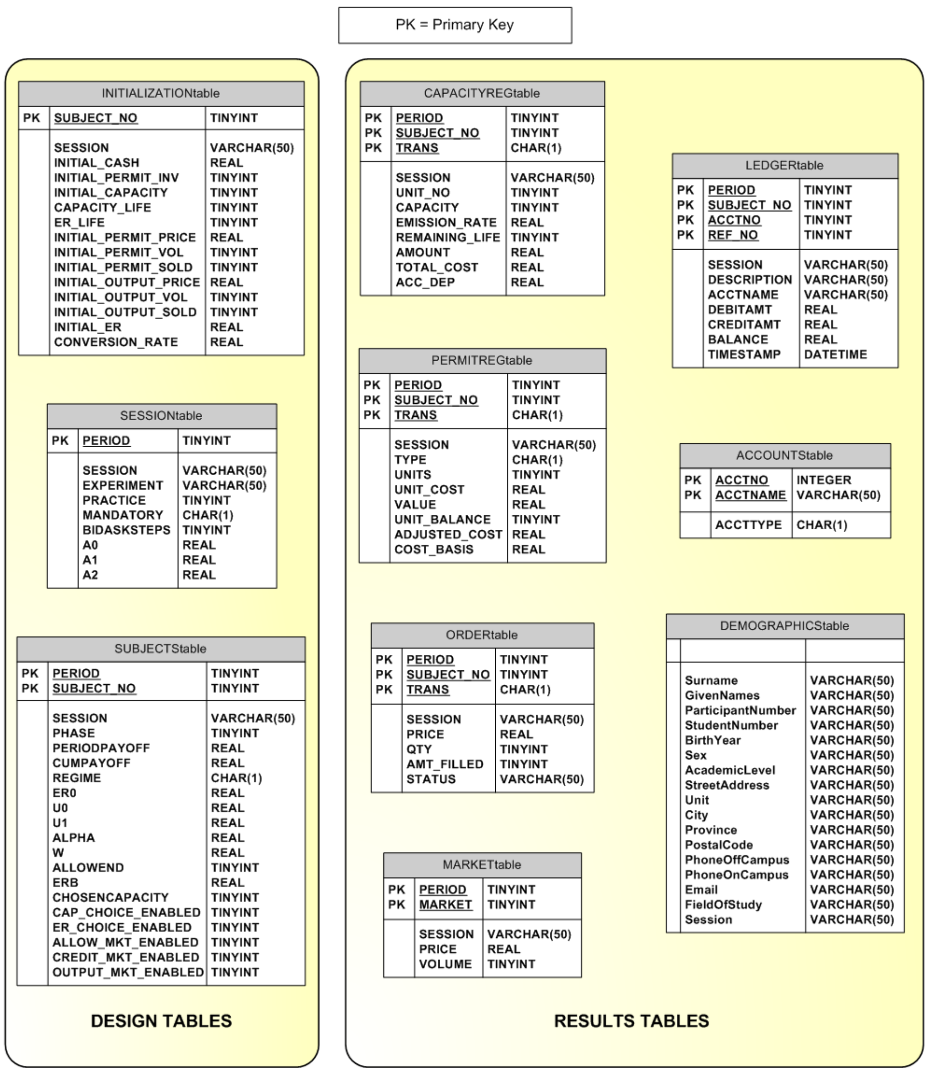


Figure E.25: ERC MySQL Database Diagram

Session This field houses the name/label of the session to be run. This should be unique to the session, for example, "erccredit-fixedcapacity-21june04'. The "session" field in this table is unique in that it is the master field for all other tables in the database; once the experiment starts, the label in SessionTable.Session will over-write the session label in all other tables.

Experiment This is the label for the experimental project. For example, "ERC" or "ERCearlyaction" etc.

Practice Set to 1 for a scripted practice period, 0 otherwise. When set to 1 (zero) the subject submit/continue buttons are disabled so that subjects cannot enter their own decisions for a scripted practice period. The experimenter must press the "force decision" button on the server to force subjects' decisions as implemented in the "Force ..." procedures in the SubjectFormUnit in the client.

Mandatory Set to 1 to require redemption of permits as per regulation, set to 0 to allow endowment/creation of permits but does not require subjects to redeem permits at end of period. This might be used for early action periods where permits can be created but do not have to be redeemed.

BidAskSteps This number can range from 1 to 3 and informs the PermitOrderForm and OutputOrderForm on how many price-quantity steps to display in their interfaces.

A0 This is the price intercept of the exogenous inverse demand function for output.

A1 This is the absolute value of the slope term of the exogenous inverse demand function for output. Since it is assumed that the demand function is downward sloping, enter this value without a negative sign.

A2 This is the variance parameter for the exogenous demand function, it is not currently being used by the program.

E.4.1.2 InitializationTable

This table contains information that varies across subjects but not across periods.

Subject_No(*PK*) The subject number. Ranges from 1 to maximum number of subjects.

Session This field houses the name of the session.

Initial_Cash Subject's cash balance at the start of period 1.

Initial_Permit_Inv Subject's permit balance at the start of period 1.

Initial_Capacity Subject's hypothetical capacity in period 0 which will also hold for period 1.

Capacity_Life When a subject chooses a new capacity, this is how many periods it will last before a new one needs to be chosen. It is displayed on the capacity order form.

ER_Life When a subject chooses a new emission rate, this is how many periods it will last before a new one needs to be chosen. It is displayed on the plant (emission rate) order form.

Initial_Permit_Price Permit price subject faced in period 0. This is usually set at the equilibrium level.

Initial_Permit_Vol Permit volume subject faced in period 0. This is usually set at the equilibrium level.

Initial_Permit_Sold Assumed number of permits sold (negative values imply permits bought) by subject in period 0. This is usually set at the equilibrium level.

Initial_Output_Price Output price subject faced in period 0. This is usually set at the equilibrium level.

Initial_Output_Vol Output volume subject faced in period 0. This is usually set at the equilibrium level.

Initial_Output_Sold Assumed number of units of output sold by subject in period 0. This is usually set at the equilibrium level.

Initial_ER Subject's hypothetical emission rate in period 0. This is usually set at the equilibrium level.

Conversion_Rate This is used to convert lab dollar earnings into Canadian dollars. Canadian dollar payoff = lab dollar payoff divided by conversion rate. This should be set to zero when a session is comprised entirely of practice periods (the software deals with the divided by zero problem).

E.4.1.3 SubjectsTable

This table contains information that varies across subjects and periods.

Period(*PK*) The decision making period number pertaining to the current record.

Subject_No(*PK*) The subject number. Ranges from 1 to maximum number of subjects.

Session This field houses the name of the session.

Phase This contains the number which identifies where a subject is located in time during the current period. This is an integer associated with the enumerated SubStatus type defined in the SubjectUnit. It is this field that tells the client and server programs what screens to show and what procedures to follow.

PeriodPayoff This field does not need to be provided at design time. When an experiment starts, the field is wiped clean and at the end of each period the lab dollar payoff is entered.

CumPayoff This field does not need to be provided at design time. When an experiment starts, the field is wiped clean and at the end of each period the lab dollar cumulative payoff is entered.

Regime This important field tells the software to use a cap-and-trade emission trading system with allowances (regime='A') or a baseline-and-credit emission trading system with credits (regime='C').

ER0 The uncontrolled emission rate, that is, the minimum emission rate with the lowest possible cost. It is used in the firm's total cost formula: $Capacity \times [U0 + (U1 - U0) \times (\frac{ER0 - ER}{ER0})^{alpha}]$.

U0 The uncontrolled (ER=ER0) unit capacity cost, used in the firm's total cost formula: $Capacity \times [U0 + (U1 - U0) \times (\frac{ER0 - ER}{ER0})^{alpha}]$.

U1 The totally controlled (ER=0) unit capacity cost, used in the firm's total cost formula: $Capacity \times [U0 + (U1 - U0) \times (\frac{ER0 - ER}{ER0})^{alpha}]$.

Alpha The exponent parameter from the firm's total cost formula: $Capacity \times [U0 + (U1 - U0) \times (\frac{ER0 - ER}{ER0})^{alpha}]$.

W The variable materials cost of producing output. Set to '0' (zero) for our current experiment.

AllowEnd The number of allowance permits, under a cap-and-trade plan, that the subject receives at the start of the period. Set equal to zero under a baseline-and-credit plan.

ERB The emission rate performance standard under a baseline-and-credit plan. This is usually constant across all subjects. Set equal to zero under a cap-and-trade allowance plan.

ChosenCapacity This field does not need to be provided at design time. At the end of each period, the capacity chosen by the subject (or last period's capacity if capacity is fixed) is stored into this field.

Cap_Choice_Enabled This binary variable indicates whether the subject is allowed to choose a new capacity at the end of the period, 1 for YES, 0 for NO. If '0', the default capacity of last period's value will be enforced. Set this to zero for all periods to set up a session with fixed capacity.

ER_Choice_Enabled This binary variable indicates whether the subject is allowed to choose a new emission rate during the current period, 1 for YES, 0 for NO. If '0', the default emission rate of last period's value will be enforced. Set this to zero for all periods to set up a session with a fixed emission rate.

Allow_Mkt_Enabled This binary variable indicates whether the subject is allowed to operate in the allowance market this period, 1 for YES, 0 for NO. Set this to zero for all periods to set up a session of baseline-and-credit trading (i.e. if regime='C').

Credit_Mkt_Enabled This binary variable indicates whether the subject is allowed to operate in the credit market this period, 1 for YES, 0 for

NO. Set this to zero for all periods to set up a session of cap-and-trade allowance trading (i.e. if regime=‘A’).

Output_Mkt_Enabled This binary variable indicates whether the subjects are allowed to enter their own output market order period, 1 for YES, 0 for NO. Set this to zero for all periods to set up a session where output orders are made automatically to sell the maximum amount of output possible (constrained by capacity and holdings of permits) at a price of zero.

E.4.2 Results Tables

Results tables contain information regarding what happened during an experimental session. They are automatically cleared before an experiment starts and are automatically completed by the server and client software. The results of an ERC session are stored in the following tables:

E.4.2.1 DemographicsTable

This table contains demographic information provided by the participant before the session starts. This can be used to call back experienced subjects to participate in more sessions etc.

Surname The last/family name of the participant.

GivenName The first name of the participant.

ParticipantNumber The subject number in the current session. Ranges from 1 to maximum number of subjects.

StudentNumber The McMaster student number.

BirthYear The year the participant was born.

Sex Male or Female.

AcademicLevel The highest level of schooling completed (i.e. the level completed last year).

StreetAddress Off campus or on campus address.

Unit Room, apartment, or unit number.

City City of residence.

Province Province of residence.

Postal Code Postal code of residence.

PhoneOffCampus Phone number if participant lives off campus.

PhoneOnCampus Phone extension if participant lives on campus.

Email Particpant's email address.

FieldofStudy Field or discipline.

Session This field houses the name of the session.

E.4.2.2 LedgerTable

Every action that the subject undertakes or is subject to generates a double entry accounting record. These entries are posted to the ledger table. Many entries to this table are also reflected in other tables, for instance when a participant buys permits, the entry of debiting permit inventory and crediting cash is posted here and the permitregtable is updated with the newly purchased permits. Each double entry accounting post generates at least two records/rows in the ledger table (one debit and one credit).

Period(*PK*) The decision making period number pertaining to the current record.

Subject_no(*PK*) The subject number. Ranges from 1 to maximum number of subjects.

AcctNo(*PK*) The numerical code of the account being posted to. This can be referenced in the accountstable.

RefNo(*PK*) This is an automatically incremented counter to keep track of each participant's ledger entry ordering. Each double entry has a new integer reference number.

Session This field houses the name of the session.

Description This field briefly describes the action generating the double entry accounting posting.

AcctName This field contains the name corresponding to the account number (AcctNo) being posted to (looked up from the accountstable).

DebitAmt This is the amount being debited to the given account for the current entry.

CreditAmt This is the amount being credited to the given account for the current entry.

Balance This is the resulting balance after debiting or crediting to the given account.

TimeStamp This is a date/time stamp generated at the time of posting.

E.4.2.3 OrderTable

The order table keeps track of all bids and asks for the allowance, credit, and output market. The subjects put their market orders into the table and the server uses these orders to call the respective markets. It is possible that there is one record in this table for each bid or ask step provided to a subject when making his/her order decision.

Period(*PK*) The decision making period number pertaining to the current record.

Subject_No(*PK*) The subject number. Ranges from 1 to maximum number of subjects.

Trans(*PK*) The transaction field can be either "B"(id) or "A"(sk) as specified by the subject.

Price(*PK*) This field contains the bid or ask price specified by the subject.

Session This field houses the name of the session.

Qty This field contains the bid or ask quantity specified by the subject.

Amt_Filled After the appropriate market is called, the server uses this field to identify how many of the units bid or asked for were actually bought or sold.

Status This order status field is used by the server to identify whether orders are: (1) O(pen) in that the market has not been called yet, (2) F(ull) when all units have transacted successfully, (3) P(artial) if some, but not all, units bid or asked for were transacted, or (4) E(xpired) in that, after the market was called, no units for the current order were transacted.

E.4.2.4 MarketTable

This table contains allowance, credit and output market prices and quantities of the periods through the experiment. This table is updated by the server immediately after calling a market.

Period(*PK*) The decision making period number pertaining to the current record.

Market(*PK*) This is the enumerated market number: 1 for allowance market, 2 for credit market and 3 for output market.

Session This field houses the name of the session.

Price The market clearing price.

Volume The overall quantity bought and sold in the market that period.

E.4.2.5 PermitRegTable

The permit registry table contains a registry of all transactions involving allowances and credits. Permits enter the registry at current market price but leave the registry at cost basis. Cost basis is the average value of permits in inventory.

Period(*PK*) The decision making period number pertaining to the current record.

Subject_no(*PK*) The subject number. Ranges from 1 to maximum number of subjects.

Trans(*PK*) The type of transaction being recorded: (1) I(nitialize), used for starting values at the beginning of the session, (2) E(ndowment), for goverment/regulator appointed allowances at the beginning of a period, (3) B(uy), for permits bought, (4) S(ell), for permits sold, (4) C(reate), for credits created due to emission rates below the standard and (5) R(edeem), for when permits must be surrendered to the regulator to cover emissions.

Session This field houses the name of the session.

Type Specifies the permit type, either "A" for allowances under a cap-and-trade regime or "C" for credits under a baseline-and-credit regime.

Units The number of permits transacted.

Unit_Cost The average value of each permit transacted. Either the market price or cost basis.

Value This is just "units" multiplied by "unit cost".

Unit_Balance The total inventory of permits held after the current transaction takes place.

Adjusted_Cost The total value of all permits in inventory. Permits enter adjust cost at their current market value and leave at current average inventory value (cost basis).

Cost_Basis This is the average value of a permit held in inventory.

E.4.2.6 CapacityRegTable

The capacity registry table contains a registry of all transactions involving changing emission rate or capacity. Whenever a new plant is built (whenever the lifespan of the last plant is over) the accounting entries are written into this registry. For each period in the lifespan of the plant, the total cost depreciates and corresponding entries are tracked in the capacityregtable.

Period(*PK*) The decision making period number pertaining to the current record.

Subject_no(*PK*) The subject number. Ranges from 1 to maximum number of subjects.

Trans(*PK*) "B" for a build entry and "D" for a plant depreciation entry. If the plant life is only 1 period (that is, a new emission rate or capacity is chosen every period), the full plant cost will depreciate each period.

Session This field houses the name of the session.

Unit_no This is a counter equal to the number of times a new plant (i.e. emission rate or capacity) decision has been made.

Capacity The capacity for producing output built into the plant.

Emission_Rate The amount of pollution emitted per unit of output built into the plant. Low emission rates signify clean and expensive technology.

Remaining_Life The number of periods remaining until the subject must choose a new emission rate and/or capacity.

Amount The current dollar amount currently being Built or Depreciated. The amount built should be the total cost and the amount depreciated each period should be Total_Cost/Plant_Life.

Total_Cost The total cost of the plant choice corresponding with the chosen emission rate and capacity.

Acc_Dep The accumulated depreciation on the current plant unit. Since straight line depreciation is used at the end of plant life the Acc_Dep must equal the Total_Cost.

E.4.2.7 AccountsTable

This table is not a true results or design table, it should not be changed for any session and it is never updated during an experiment. This table contains a listing of account names, numbers and types.

AcctNo(*PK*) The two-digit account number of each account. Asset accounts start with '1', liabilities start with '2', net worth starts with '3', income accounts start with '4', expense accounts start with '5' and summary accounts start with '6'.

AcctName(*PK*) The label attached to each account.

AcctType One character identifies the account type, asset (A), liability (L), net worth (Q), income (I), expense (E), and summary (S).

E.5 MySQL Basics

MySQL open source database software groups information into tables and groups related tables into databases. For instance, "erc" is the name of the database that contains all tables of information for the ERC experimental software. "Subjectstable", "initializationtable" and "markettable" are a few of the tables in the "erc" database that the ERC software stores information in. MySQL requires that a semi-colon follow all commands. The MySQL directory on the lab linux box is /var/lib/mysql. The following commands are the basic MySQL commands that are used the most often. They must be typed at the MySQL prompt and must be terminated by a semi-colon.

Instead of using an SSH Telnet Client to log into the MySQL Linux server and run MySQL commands from there, one can also use the freeware Database Manager software (the install file, mysql-dbmanager-freeware.exe, is in the "c:\dev\erc\documentation\" folder) to dump/backup/export/import to and from the erc database. However, it is a good idea to try and learn the commands yourself first.

use *databasename*; "use erc;" lets MySQL know that all proceeding commands are to operate on the ERC database.

show tables; This command will list all tables in the currently selected database.

describe *tablename*; "describe subjectstable;" will list all of the fields and their respective properties in subjectstable.

select * from *tablename*; "select * from subjectstable;" will list all fields (hence the asterisk) and all records from subjectstable.

update *table* set *var*=*val*; "update subjectstable set u1=150 where subject_no=1;" will set subject number 1's u1 cost parameter to 150 for all periods (record lines) in the subjectstable.

source *filename*; "source ercallowmarch04.sql;" loads the database information from the SQL text file into the current database in MySQL. You can also type "mysql erc ¡ ercallowmarch04.sql" at the Linux prompt while in the /var/lib/mysql directory to perform the same function.

mysqldump *options* When typing "mysqldump −−opt erc > erc21june2004.sql" or "mysqldump -umceel -phello −−opt erc > erc21june2004.sql" at the general Linux prompt while in the MySQL directory it will take all of the information in all of the tables in the "erc" database and output them to a text file named erc21june2004.sql. This text file is not simply the data from the tables, but also contains MySQL database structure information to input the data back into a formal MySQL database at a later time (by using the *source* command). The option -u*username* is used to specify your MySQL login username if it is different from your Linux username. The -p*password* option is used to specify the password for your MySQL account.

system *linux command* The "system" command in MySQL is used to carry out Linux shell commands (e.g. mysqldump) within MySQL. "system mysqldump −−opt erc > erc21june2004.sql" dumps the current database to an SQL file from within MySQL.

E.6 How to Install the ERC Software

The ERC experiment requires that the Borland Database Engine and ODBC MySQL Database Drivers be installed on the server machine and all client machines. It also requires that you have a functional MySQL server with the ERC database that is accessible by a user named 'mceel' with password as specified in the database component in the ERCDatamoduleUnit. These can be set up as documented below. Lastly, one requires the server/client executables. One can find all needed executables and install files in the ERC-SoftwareNov2004 directory on the accompanying CD-ROM.

E.7 How to Install the Borland Database Engine (BDE)

To install the BDE on a computer you can install Corel Office on it or you can install the ERC installation package found in the ERCSoftwareNov2004 directory on the accompanying CD-ROM.

E.8 How to Install the ODBC MySQL Driver

1. The install/setup file (MyODBC-3.51.06.exe) for the driver can be found in "c:\dev\erc\server\" or "d:\experiments\erc\server\". They can also be downloaded from the internet. The version tested with the program is the MyODBC version 3.51.06 driver.

2. Make sure you have the Borland Database Engine already installed on this machine. It is provided with Corel Office and in the ERCSoftwareNov2004 directory on the accompanying CD-ROM. Once the BDE is installed, install the MyODBC-3.51.06.exe file (double click it and follow instructions) to provide a computer with an ODBC driver for MySQL.

3. Go to the Control Panel in Windows and double click on the BDE administrator.

4. Under the 'Databases' tab, right click the "myodbc3-test" entry and select ODBC Administrator. (This may also be found by going to the 'Control Panel', then click on 'Administrative Tools', then clicking on 'Data Sources ODBC').

5. Under the 'User DSN' tab, click on the MySQL ODBC 3.51 driver and then click on the Configure button to the right.

6. Enter the following information:

   Data Source name: ERCMySQL Host/Server Name: 130.113.124.23 Database name: erc User: mceel Password: mceel

7. Click "Test Connection", if it says that it connected successfully then you know that it works!

8. Click OK button, and then click on the next OK button.

9. With the myodbc3-test (or ERCMySQL if it has already been updated) driver still selected in the BDE Administrator, set SQLPAssthrumode to "Not Shared" and SQLQRYMODE to "Server". Now exit. Done!

E.9 How to Run a Session of the ERC Experiment

This section details the steps required in running a session of the ERC experiment as illustrated in Figure E.26. It is assumed that the Linux MySQL database server is up and running and that the BDE and ODBC MySQL drivers are installed on all machines. These instructions start with details on preparing the client and subject software (ERCCLient.exe and ERCServer.exe respectively), and walk through the events of a typical session. The session itself usually takes about 3 hours to complete, not including the preparations detailed below.

E.9.1 At Least 2 Hours Before the Experiment Start Time

Make sure to print out enough copies (usually 8 for subjects, 1 for the experimenter and 1 extra) of the instructions that are applicable to the treatment

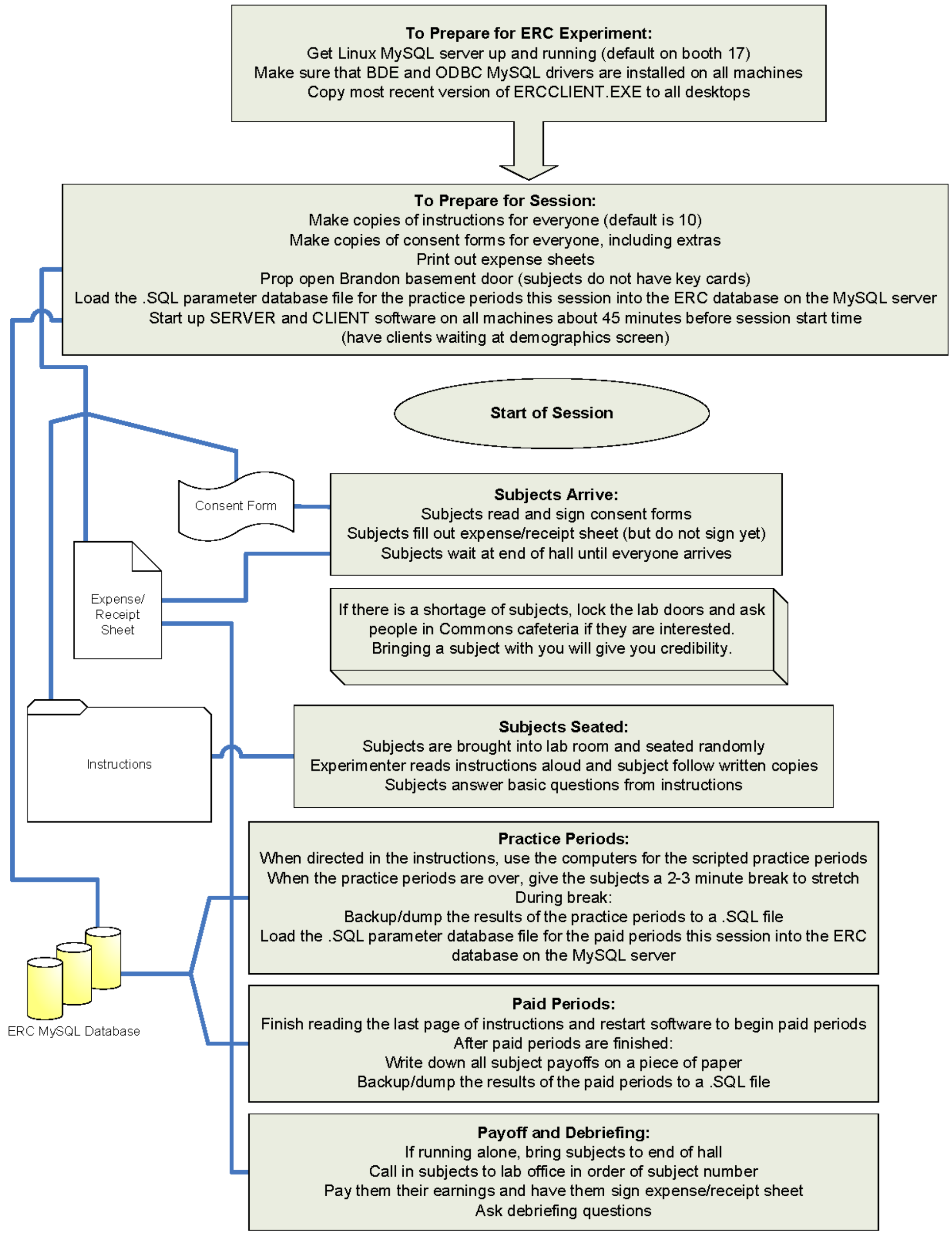


Figure E.26: Steps in running a session of ERC you are running (e.g. allowance fixed capacity, credit fixed emission rate etc.). Also print out enough copies of the consent form for all subjects and extras (usually around 12). Do not forget to print out a copy of the McEEL expense sheet to record subject contact and payment information. It is also a good idea to bring the list of people that signed up for the experiment so that on campus people may be called if they do not show up on time and that extras may easily be identified. Electronic copies of the instructions, consent form and expense sheet can can be found in the folder "c:\dev\erc\documentation\"and "d:\experiments\erc\documentation\" on the monitor machine.

Turn on 8 client machines and the monitor machine. The machines should login using their booth numbers as a username with a blank password. The booth numbers are stencilled on the ethernet sockets on the power bar behind each computer. (Note: The booth number of the monitor machine is 11 and its host name on the network is PC-MULLER-11. Since a machine's IP address is always 6 plus its booth number, the IP address for the server is 130.113.124.17)

It is assumed that all machines have the BDE and MySQL database drivers installed. If you are unsure whether the client machines have the most up to date ERCClient.exe executable, recopy it from the server onto each machine's desktop. On each client machine: Click on "My Network Places", then on "Computers Near Me" and then on "PC-MULLER-11"(If you cannot find PC-MULLER-11, try using the START -> "Search" -> "For Files or Folders"command from the taskbar. Make sure to select "Computers"and not "Files or Folders" and search for PC-MULLER-11). Click on "DEV", then on "ERC", then on "CLIENT" folders. Find ERCClient.exe and copy it to the current machine's desktop (make sure not to make a shortcut). Alternatively, you can log into the monitor machine as “administrator” to connect to the client machines to copy the ERCClient.exe, since the administrator has rights to log into all machines.

On the monitor machine’s desktop, use/click “SSH Secure Shell Client”(if needed, you can install it from c:\dev\erc\documentation\, it may be downloaded from the McMaster Software Depot, or you can find other SSH clients from www.downloads.com). Use the SSH Client to telnet to the Linux database server by “Quick Connecting” to host “pc-muller-17.mcmaster.ca” with user name “mceeluser” using the proper password (see Andy Muller for the password). Once logged in, type “cd /var/lib/mysql” then hit enter. Now log in to MySQL by typing “mysql” (This will log you into MySQL using the same username and password used to log in to the LINUX machine itself. If this does not work then see Andy Muller for a separate login account for MySQL that has access rights to the ERC database and use “mysql -u‘username’ -p‘password” to log in). Now type “use erc;” at the MySQL prompt (see section on “MySQL commands” for more information). Type “source ercallowmarch04-practice.sql;” or reference some other relevant practice database creation file (e.g. erccreditmarch04-practice.sql). If, for some reason, you are not running practice periods before your session, use the appropriate file and adjust instructions below accordingly. You can minimize the SSH Client window so that you can use it later without needing to log back in.

E.9.2 At Least 45 Minutes Before Experiment

Since the experiment is fairly long, it is a good idea to start up the experimental software well before people arrive in order to save time. Before preparing the software, it is a good idea to go out to the grey door leading into Brandon Hall basement and prop a stone or a twig in the door to keep it open. The swipe card needed to get in will prevent subjects from entering and leaving by themselves so the door must be propped open for subject arrival and departure times.

First, start the server software by running ERCServer.exe in "c:\dev\erc\server\" or "d:\experiments\erc\server\" on the monitor machine. Once this is loaded check any boxes that are appropriate for the current session. You will most likely use the default setup but make sure to put a check mark next to "Require Demographics" to make sure that you collect participant information. Now click the "Connect/Initialize" button, this connects to the MySQL database on the Linux machine running on booth 17 and clears any previous database entries from relevant tables. (Note: this deletes all experimental data so care should be taken not to press "Connect/Initialize" unless you are sure any useful experimental data has been backed up by "dumping the database to an SQL file). If you incur an error at this stage, make sure that the Linux machine on booth 17 has power and reboot it if necessary. Before moving on ensure that you type in a session label name into the now white "session name" edit box on the server form. Make a session name that is in some way unique for this particular session. A good idea is to include the word 'allow' or 'credit', the word 'fixedcap' or 'varcap', the date and lastly a session number. An example session name might be "ercsession4-allow-fixedcap-11july04-3pm".

After the server software is started and the "Connect/Initialize" button has been pushed, the clients can log in. Log in the clients yourself in order of subject number. Simply go to the first computer booth near the door and double click on the ERCClient.exe on the desktop. A small application will pop up. Simply click the connect button and the client will automatically log in to the server with the first subject number. Repeat for each machine, one at a time, and it will automatically log them in in ascending subject number order.

Once all 8 client machines are logged, in the software will automatically start the first practice period and the participant demographics screen will appear (if you did not checkmark the "require demographics" then the permit order phase will begin). At this point, your preparation of the software is finished. You can turn off the monitors and return to the main lab office. You will tell subjects to turn on their monitors at the appropriate time during the instructions (detailed below). Since the main submission buttons are deactivated for the first practice period, this early preparation saves time and the software will be fine even if subjects bump the keyboard while reading instructions.

E.9.3 30 Minutes Before Experiment

Subjects usually arrive about 5-10 minutes early as requested, but sometimes a few people show up 30 minutes early. For this reason it is a good idea to to be in the main office 30 minutes before start time to be ready to sign people in.

As people show up, make sure they read and fill out a consent form and that they fill out a line on the expense sheet (make sure they do not use the "payment" and "signature" columns of the expense sheet yet, they will be asked to sign beside their earnings at the end of the experiment). Once people have completed their paperwork, ask them to stand and wait at the end of the hall (near the water fountain and washrooms) until everyone has arrived. Make sure all subjects, even extras, fill out this paperwork.

E.9.4 At Experiment Start Time

If everyone on the sign-up list shows up before the experiment time, feel free to pay any "extras" $5 (have them sign for it on the expense sheet) and start the experiment early. If there are some "no-shows" at experiment time, but you have enough extras to fill in, start the experiment with them. If you are short some people, there are a few options. First, you could check the sign-up list for any no-shows that live on campus and call them. You could ask the subjects that have arrived whether they know anyone who lives on campus and might be interested in participating (and who hasn't been a subject before). Lastly, you ask subjects to wait at the end of the hall, lock the two lab rooms and proceed to go up to Commons Cafeteria to find participants. Sometimes, it helps to bring a volunteer subject with you to Commons to give you credibility. Obviously, it would be preferable to not reach this stage because if you cannot find the required participants in Commons (it has only happened once in about 6 years) you will have to pay attending participant a $5 show up fee and ask them whether they would be interested in signing up for another session.

Once you have enough subjects, the client/server software has been started and the MySQL database has been initialized, you can start the experiment. Ask subjects to enter the lab room and try to assign seating randomly. By sitting friends apart from each other, you will not have to worry as much about subjects conversing. You can now ask subjects not to touch their computers just yet, and hand out the instructions.

Read the experimental instructions aloud and ask subjects to follow along. When prompted, have the subjects answer the questions in the instructions and provide help anyone who requires it. (I like to go out and close the outside basement door at this point. I then re-prop it open 5 minutes before the experiment is finished) When prompted in the instructions, have subjects turn on their computer monitors in order to study the experimental software screen.

As stated in the instructions, the first practice period needs to be advanced by the experimenter. When prompted in the instructions, click on the "Force Decision" button on the ERCServer.exe software on the monitor machine (this submits all subject decisions for them as stated in the instructions). This is only required for the first practice period.

E.9.5 Approximately 1 Hour and 50 Minutes into Experiment

When the practice periods are over, inform the subjects that they should get up, stretch and walk to the end of the hall (where they can use the water fountain or go to the washroom) for a 3 minute break while you reboot all the machines. At this point, click the "terminate server and all client machines" button on the server window in order to close down the software on all machines.

The machines need to be rebooted between the practice and regular periods of the experiment to make sure things run smoothly. First, shut down each client computer using ALT-F4 or selecting START -> Shut Down. (Now that the lab is running on Windows 2000 instead of 98 I do not think you need to reboot the machines.)

While the client machines are rebooting, use the monitor machine to backup the practice data and re-initialize the MySQL database for the rest of the experiment.

Bring up the SSH Client window that was left sitting at the MySQL interface. [If you have problems, just log back in. Like last time, use/click "SSH Secure Shell Client" on the monitor's desktop. Telnet to the linux database server by "Quick Connecting" to host "pc-muller-17.mcmaster.ca" with user name "mceeluser". See Andy Muller for the password to this account. Once logged in, type "cd /var/lib/mysql" then hit enter. Then log into MySQL by typing "mysql" or 'mysql -u'username' -p'password'. Finally, type 'use erc;'.] To backup the practice periods data type "system mysqldump -u'mysqlusername' -p'mysqlpassword' −−opt erc > erc21march2004credit -practice.sql"(with current date and treatment information, of course). This puts the contents of the ERC database into a MySQL text file.

Now you must clean and re-initialize the database for the paid periods. At the MySQL prompt, type "source ercallowmarch04.sql;" or reference some other relevant database creation file for the paid periods (e.g. erccredit-march04.sql). You can now minimize the SSH Client window to use it later.

[If you think a reboot is necessary, type "exit;" and "exit" to log out. Now you can shutdown and reboot the monitor machine.]

Now start up the server on the monitor machine and click "Connect" (you probably don't need to "require demographics again"). Now load up ERC-Client.exe on the subject machines and log in each machine at a time in the same order you did before. To keep roles and payoffs organized, make sure that the subjects do not touch the machines at all and you personally log in the clients. Make sure the subjects sit back at the same booth after the break.

Now you may read the "Paid Periods" section of the instructions aloud and then ask subjects to start the experiment. Make sure that you time phases as stated in the instructions. If a phase lasts the limit stated in the instructions, make a quick announcement for subjects to enter their decisions or they will not be allowed to make one. Technically, the "Force Submission" button forces them to enter zeros for their decision but it is preferable to approach the student and ask them to submit their decision immediately.

At the end of the experiment, immediately at the end of the last period, the subject earnings will appear on the monitor/server machine. Make sure to write down each subject number and its corresponding payoff. [If anything goes wrong, you can get the lab dollar payoffs from logging into the MySQL server and type 'use erc;' and then 'select cumpayoff from subjectstable where period=10;']. This amount does not include the $5 show up fee. Hit "OK" after writing down each payoff. When all payoffs have been written down, the payments will appear on each subject's screen. Make sure to remind them that a $5 show up fee will be added. Ask subjects to gather their things and wait at the end of the hall and that you will pay each person privately in order of subject number. Lock the lab room and prop open the outside basement door with a large rock. Then, in turn, call each subject into the office. When they arrive, write their earnings, rounded up to the nearest quarter including the $5 show up fee, on the expense sheet next to their name and ask them to sign beside it. Pay the subject and ask him/her to send in the next subject number on their way out. Try and use the cardboard screen to hide other participants' payoffs while each participant signs.

After paying everyone, return to the lab room to backup the experimental data. Bring up the minimized SSH Client window you left at the MySQL prompt. [If you need to log back in then use/click "SSH Secure Shell Client" on the monitor machine's desktop. Telnet to the Linux database server by "Quick Connecting' 'to host "pc-muller-17.mcmaster.ca" with user name "mceeluser" and password as before. Once logged in type "cd /var/lib /mysql" then hit enter]. To backup the paid periods data type "system mysqldump −−opt erc > erc21march2004credit.sql" or "system mysqldump -u 'username' -p 'password' −−opt erc > erc21march2004credit.sql"(with current date and treatment information, of course). This puts the contents of the ERC paid database tables into a MySQL text file. Then type "exit;" and "exit" to log out. Now you can shutdown the monitor and client machines.

The experiment is finished!

E.10 How to Download Tables from MySQL

The best way to get the information from the ERC database tables to your computer so that you can analyze them is to use StatTransfer for Stata from a computer that has the ODBC MySQL 3.51 drivers already installed on it. First make sure that the database tables you want to download are currently loaded into the MySQL “ERC” database. If you have dumped the database to a .SQL text file, you will need to reload the database back into MySQL before you can download the tables (use the ‘source’ command as documented below).

1. Load the data into MySQL on the Linux machine (see below) then load up StatTransfer (this works on Version 6 and later) on the machine on which you want the tables.

2. Set ‘Input File Type’ to ‘ODBC Data Source’.

3. Set ‘ODBC Data Sources’ to the ‘MySQL ODBC 3.51 Driver’ or ‘ERCMySQL’.

4. Set ‘Table’ to the table you would like to convert to a known table format and download on your computer.

5. Set ‘Output File Type’ to desired data format (e.g. Stata Version 7).

6. Click on the BROWSE button next to ‘File specification’ to choose a local folder and file name to save the file as.

7. Click on the TRANSFER button to complete download and conversion.

8. Click the RESET button and choose another table if necessary.

9. Click EXIT when finished.

E.11 How to Backup/dump a MySQL Database to a .SQL Text File

This process backs up the data in the current ERC database by dumping the data and table structure information to .SQL text file that can easily be loaded back into the MySQL database later.

To dump the ’erc’ database to a file called 8personcredit21may2004.sql you would type, “mysqldump −−opt erc > 8personcredit21may2004.sql” or “mysqldump -‘mysqlusername’ -p‘password’ −−opt erc > 8personcredit21may2004.sql” at the Linux main prompt while in the /var/lib/mysql folder. To use these commands within MySQL, prefix them with the word “system”.

E.12 How to Load a SQL Text File into a MySQL Database

To load the 8personcredit21may2004.sql file back into MySQL you would:

1. Log in to the Linux server.
2. Type: cd /var/lib/mysql/
3. At the Linux prompt type: mysql erc < 8personcredit21may2004.sql
4. Instead, you could have logged into mysql by typing “mysql”, then typed “use erc;”, and then type “source 8personcredit21may2004.sql;”.

E.13 How to Create/modify ERC Session Treatment Parameters

1. First, load a basic design into the "erc" MySQL database as detailed above and "use erc;".

2. To make a change to the design, for example, to change the table from an allowance treatment to a credit treatment, one might change field values in one or more tables. Let us use this treatment change as an example.

3. First, change the treatment regime. "update subjectstable set regime='C';".

4. Next, make sure to enable credit market and disable the allowance market: "update subjectstable set allow_mkt_enalbed=0;" and "update subjectstable set credit_mkt_enalbed=0;".

5. Next, replace endowment with appropriate performance standard: "update subjectstable set allowend=0;" and "update subjectstable set erb=5;".

6. To backup this new design, just type "mysqldump −−opt erc > newcredit21may2004.sql" or "mysqldump -'mysqlusername' -p'password' −−opt erc > newcredit21may2004.sql".

E.14 How to Backup Session Information into a Merged Experiment MySQL Database

Once many sessions have been run, you will have dumped the results of these sessions to many .SQL text files. This section details how one should merge these databases into a single uber-database so that data analysis can easily compare sessions. This process uses ideas found in the sample .SQL text files in the erc documentation directory (e.g. createerctablestructure.sql and ercaddpilotstomultisessiondatabase.sql).

To create an uber-database, we simply create database tables with the structure of our current database tables, only with different names. We then backup this uber-database by dumping it to a .SQL file.

1. First, make sure the current erc database has been backed up and dumped to a .SQL file.
2. Type ‘use erc;’ at the MySQL prompt.
3. We start assuming that you have many individual session .SQL files and no merged database yet. To create a merged uber-database, use the createerctablestructure.sql sample file by typing “source createerctablestructure.sql” at the MySQL prompt. This will create empty tables with the same name as all the current ‘erc’ database tables but with the prefix ‘erc’. The tables that have names that start with ‘erc…’ will contain information from all sessions.
4. Now we can drop all of the regular tables by issuing commands such as ‘DROP TABLE IF EXISTS accountstable;’ for all regular erc tables so that only the tables prefixed by ‘erc’ remain.
5. Now we can backup the uber-database files by typing “mysqldump −−opt erc > ercallsessions.sql”.

This creates the uber-database but what about adding session information to it?

1. First enter MySQL and type: “use erc;”.
2. We then load in our multi-session uber-database by typing “source ercallsessions.sql;”

3. Now we load in one of our recently run session .SQL files by typing "source ercsession1.sql;". This loads the session data into the regular tables though, not the new ones prefixed by 'erc'.

4. We must then copy the data from the regular tables to the new 'erc' prefixed tables by typing commands like "insert into erccapacityregtable select * from capacityregtable;" for each of the 10 tables.

5. We now can drop all the regular tables by issuing commands such as 'DROP TABLE IF EXISTS accountstable;' for all regular erc tables so that only the tables prefixed by 'erc' remain.

6. We can now backup the multi-session uber-database files by typing "mysqldump −−opt erc > ercallsessions.sql".

7. We can follow these same steps each time a new session is run and needs to be copied to the multi-session database.

E.15 Glossary of Terms

BDE - The Borland Database Engine (BDE) is used by the ERC program so that the Delphi components used in accessing the database can connect to the ODBC MySQL drivers. The BDE is automatically installed with Corel Office and is also installed with the ERC software package.

Booth - This term simultaneously refers to a computer and its location. The computers in the BB111 lab represent booths 5 to 17. The monitor machine is booth 11 and the Linux MySQL server is booth 17. Booth numbers can be found stenciled on the ethernet socket attached to the power bar near each machine. The last coordinate of each machine's IP address is simply the booth number plus 6.

Client - The client is the program which interacts with human subjects and handles communication with the monitor.

Client Machine - These are the machines in the lab that subjects use to interact with the experimental software. Each machine has an IP address of "130.113.124.#", where # is the booth number plus 6.

Experimenter - The experimenter is the person running the experimental session on behalf of the lab. Sometimes this person is referred to as the "monitor" of the experiment (not to be confused with the monitor machine).

Linux/MySQL Server - This is the machine sitting in the last booth which is running Linux and serves our lab MySQL. All of the data generated by subjects in an experiment is stored, and later backed up, on this machine. Its host name is "PC-MULLER-17" and its IP address is "130.113.124.23".

Monitor Machine - The experimental software server machine. This machine facilitates the experiment by guiding the client machines appropriately. It's the one sitting by itself in the Brandon Lab. Its host name is "PC-MULLER-11" in the workgroup "MCEEL" and it has an IP address of "130.113.124.17".

MySQL - The MySQL database server is the world's most popular open source database. A manual with comments from regular users can be found at: http://dev.mysql.com/doc/mysql/en/index.html. This manual contains detailed instructions on how to install and use MySQL. The

ERC software uses a MySQL ODBC driver to interface with a MySQL database in order to store and retrieve experimental data.

Participant - Those aspects of the human being participating in the session which are independent of the experiment being run, including name, id, and label (e.g. participant1). Also refers to the computerized representation of the human participant.

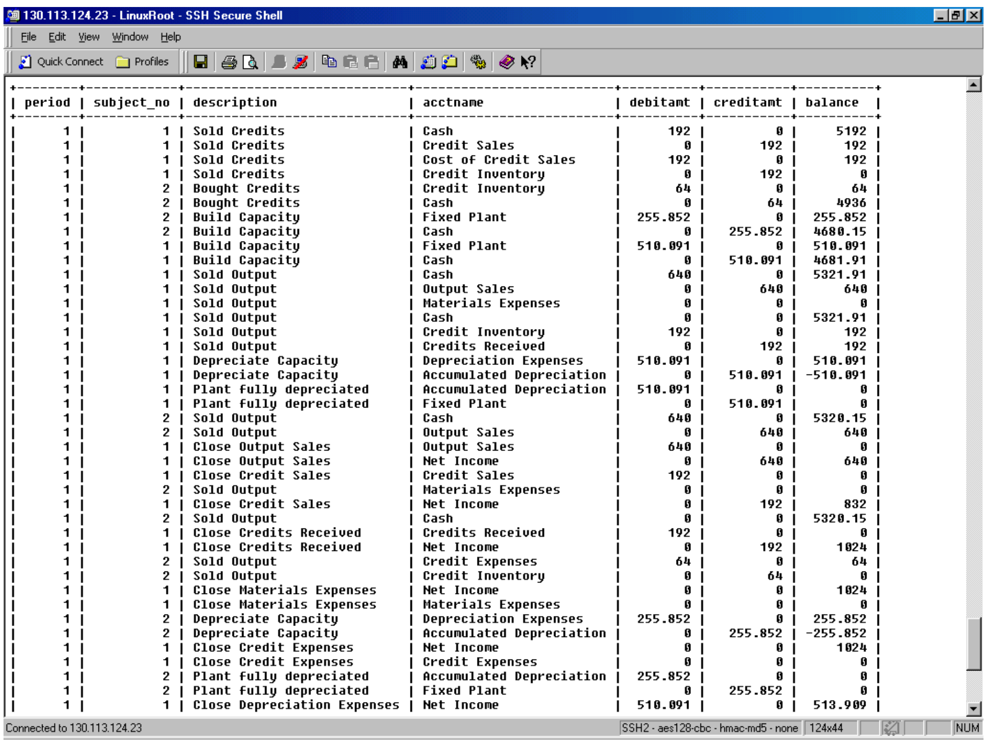
Phase - The term “phase” refers to an interval in the sequence of actions that takes place each period in an experimental session. The phase structure is declared by the Subject Unit in the form of a “SubStatus” enumerated variable. The server and client software use the phase property of each subject to keep track of which stage each subject is currently at during an experiment.

Subject - The student participant in an experimental session.

Server - The term ‘server’ is used in two way (1) the program which interacts with the human experimenter and handles communication between the participants (2) that part of the server program which maintains information about individual participants and handles the details of sending messages over the network.

E.16 ERC Screenshots

Figures E.27 to E.31 illustrate various subject screens from the ERC software.



period	subject_no	description	acctname	debitamt	creditamt	balance
1	1	Sold Credits	Cash	192	0	5192
1	1	Sold Credits	Credit Sales	0	192	192
1	1	Sold Credits	Cost of Credit Sales	192	0	192
1	1	Sold Credits	Credit Inventory	0	192	0
1	2	Bought Credits	Credit Inventory	64	0	64
1	2	Bought Credits	Cash	0	64	4936
1	2	Build Capacity	Fixed Plant	255.852	0	255.852
1	2	Build Capacity	Cash	0	255.852	4680.15
1	1	Build Capacity	Fixed Plant	510.091	0	510.091
1	1	Build Capacity	Cash	0	510.091	4681.91
1	1	Sold Output	Cash	640	0	5321.91
1	1	Sold Output	Output Sales	0	640	640
1	1	Sold Output	Materials Expenses	0	0	0
1	1	Sold Output	Cash	0	0	5321.91
1	1	Sold Output	Credit Inventory	192	0	192
1	1	Sold Output	Credits Received	0	192	192
1	1	Depreciate Capacity	Depreciation Expenses	510.091	0	510.091
1	1	Depreciate Capacity	Accumulated Depreciation	0	510.091	-510.091
1	1	Plant fully depreciated	Accumulated Depreciation	510.091	0	0
1	1	Plant fully depreciated	Fixed Plant	0	510.091	0
1	2	Sold Output	Cash	640	0	5320.15
1	2	Sold Output	Output Sales	0	640	640
1	1	Close Output Sales	Output Sales	640	0	0
1	1	Close Output Sales	Net Income	0	640	640
1	1	Close Credit Sales	Credit Sales	192	0	0
1	2	Sold Output	Materials Expenses	0	0	0
1	1	Close Credit Sales	Net Income	0	192	832
1	2	Sold Output	Cash	0	0	5320.15
1	1	Close Credits Received	Credits Received	192	0	0
1	1	Close Credits Received	Net Income	0	192	1024
1	2	Sold Output	Credit Expenses	64	0	64
1	2	Sold Output	Credit Inventory	0	64	0
1	1	Close Materials Expenses	Net Income	0	0	1024
1	1	Close Materials Expenses	Materials Expenses	0	0	0
1	2	Depreciate Capacity	Depreciation Expenses	255.852	0	255.852
1	2	Depreciate Capacity	Accumulated Depreciation	0	255.852	-255.852
1	1	Close Credit Expenses	Net Income	0	0	1024
1	1	Close Credit Expenses	Credit Expenses	0	0	0
1	2	Plant fully depreciated	Accumulated Depreciation	255.852	0	0
1	2	Plant fully depreciated	Fixed Plant	0	255.852	0
1	1	Close Depreciation Expenses	Net Income	510.091	0	513.909

Figure E.27: ERC Double-Entry Accounting

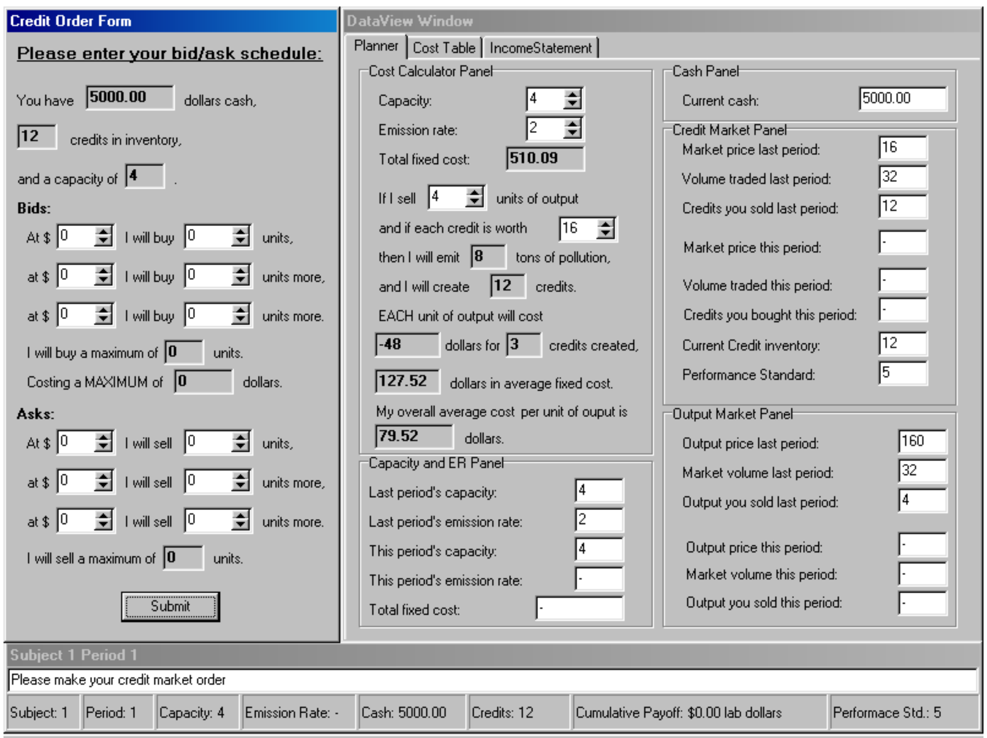


Figure E.28: Baseline-and-Credit Market Form

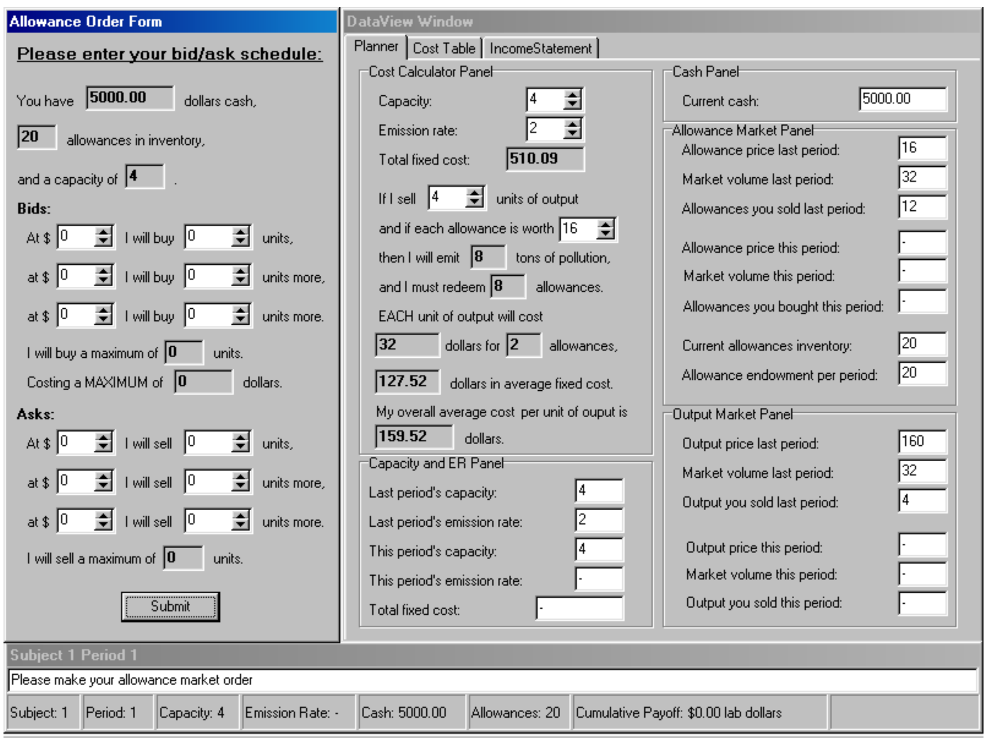


Figure E.29: Cap-and-Trade Market Form

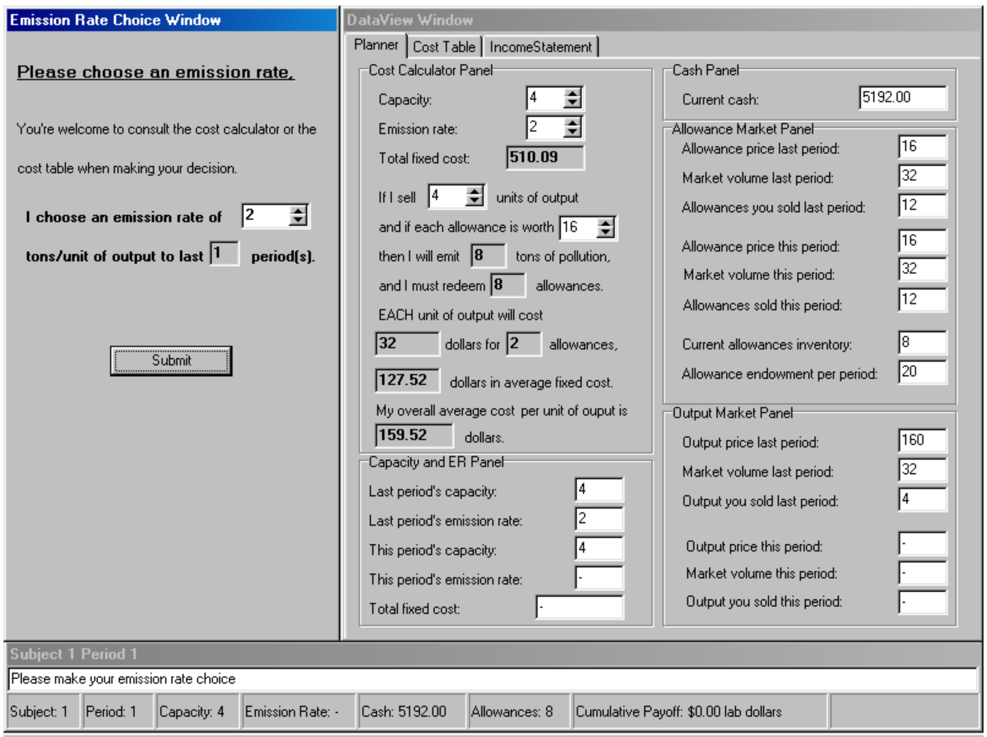


Figure E.30: Emission Rate Choice Form

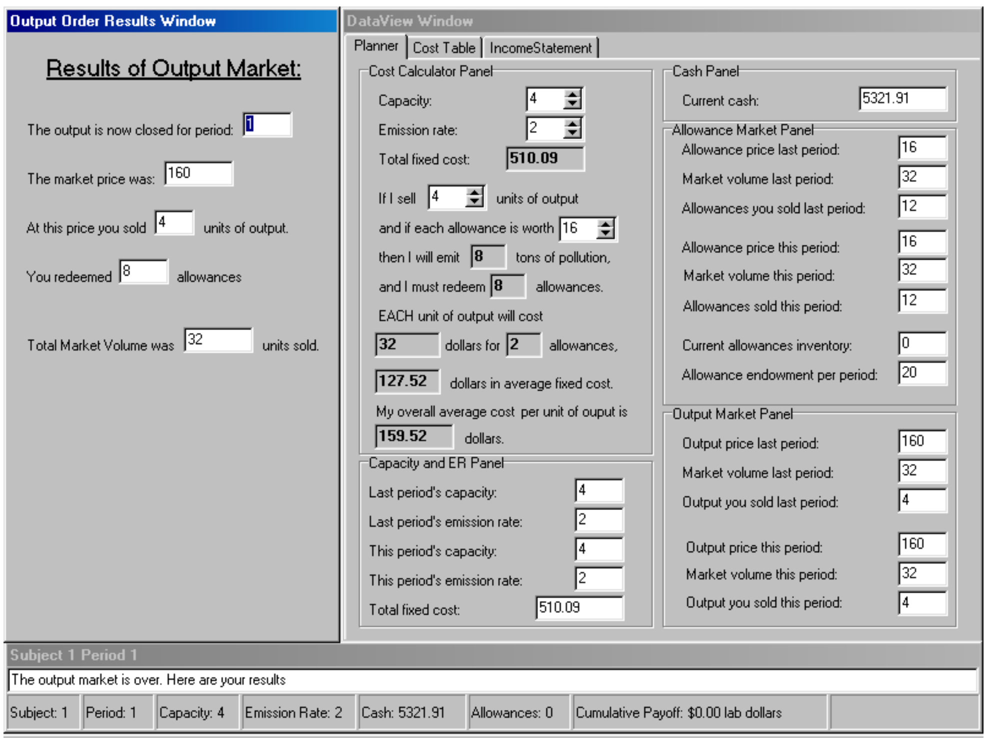


Figure E.31: Output Market Results

E.17 ERC Program Unit Class Structure

Figures E.32 to E.51 illustrate the ERC program unit class structures. The diagrams highlight variables, properties, procedures and functions, as well as identifying private and public access.

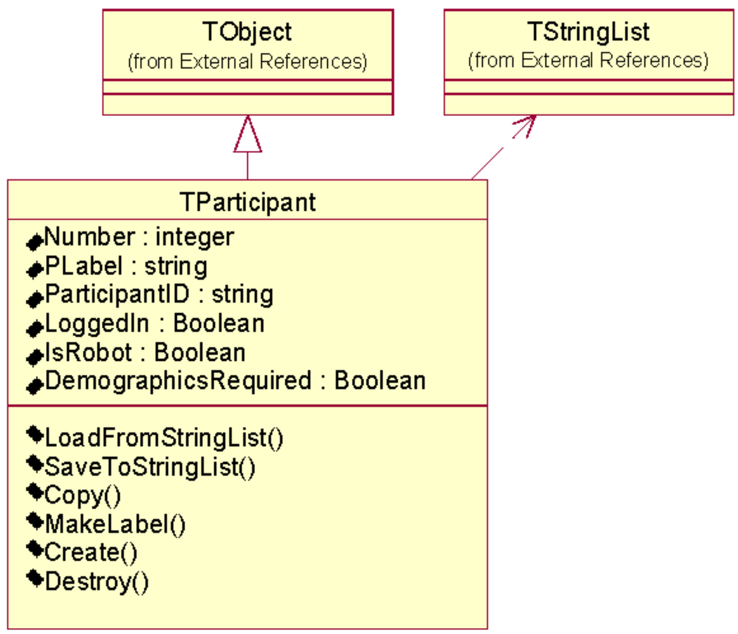


Figure E.32: ParticipantUnit

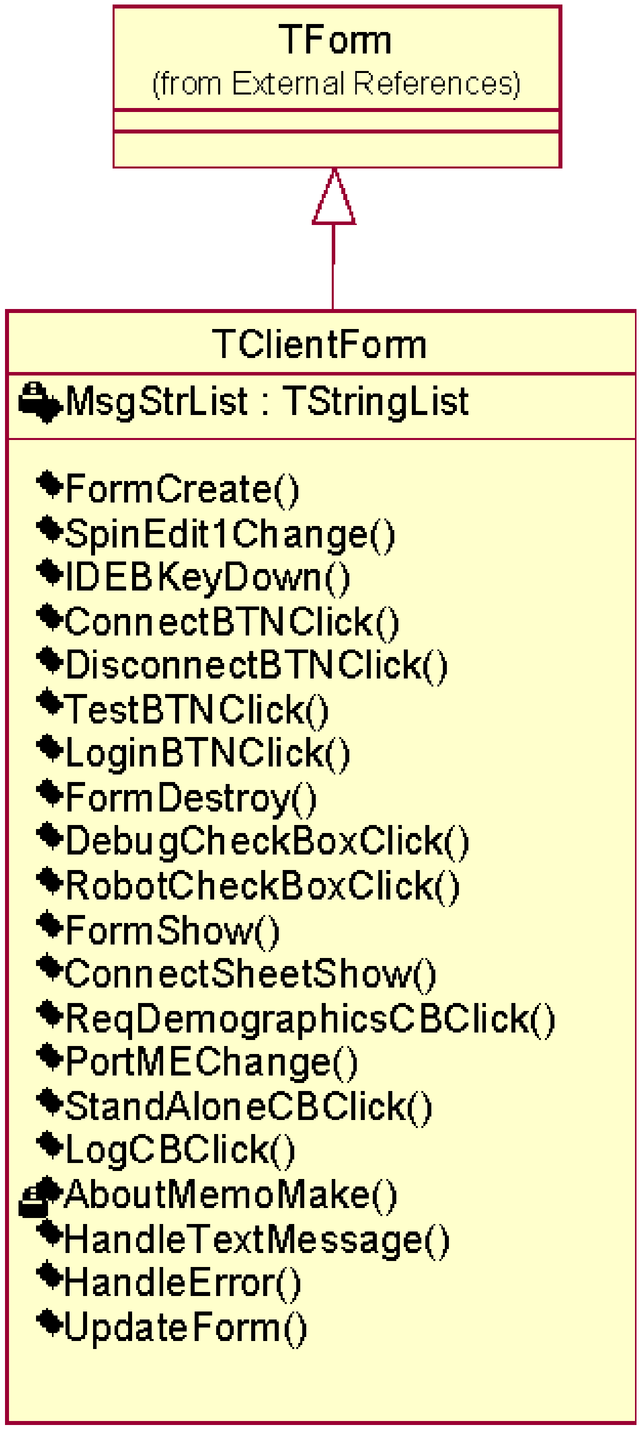


Figure E.33: ClientFormUnit

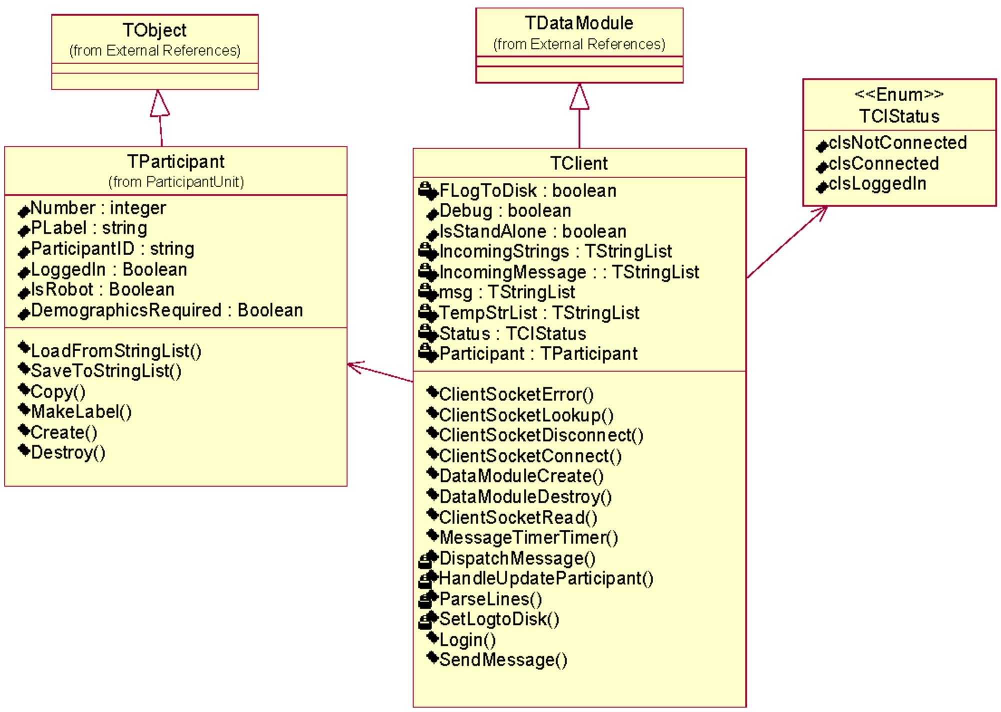


Figure E.34: ClientUnit

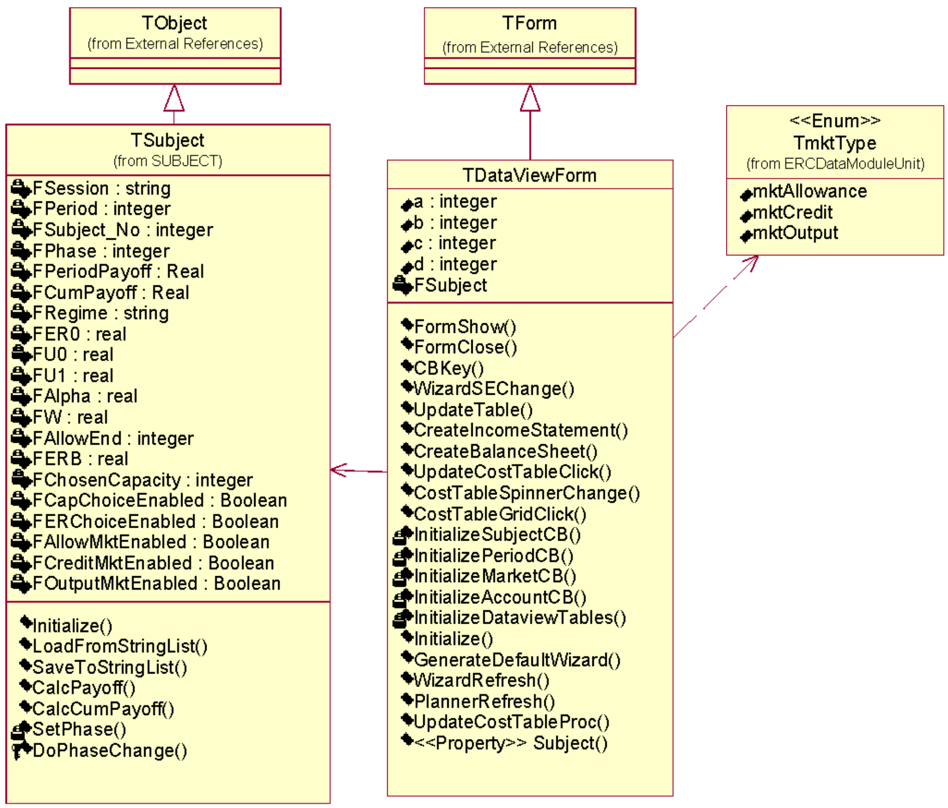


Figure E.35: DataviewFormUnit

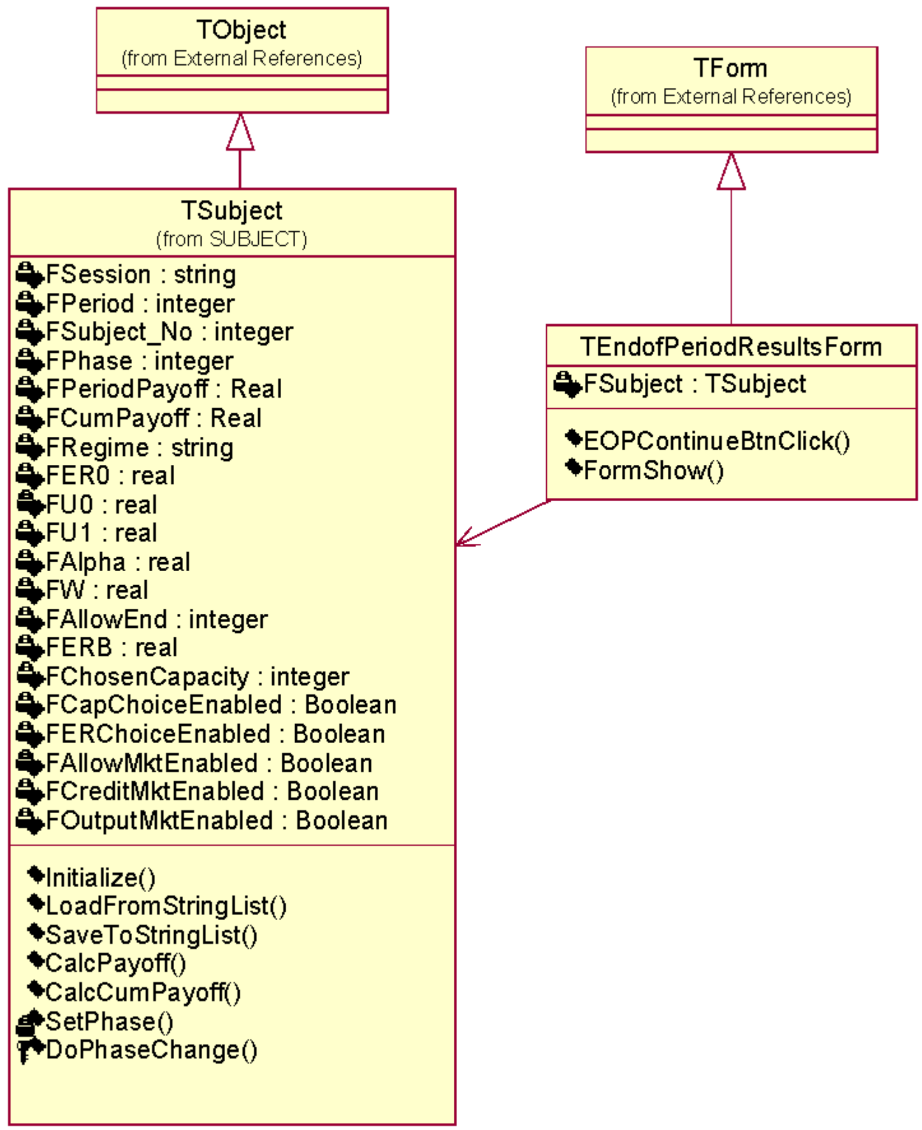


Figure E.36: EndofPeriodResultsFormUnit

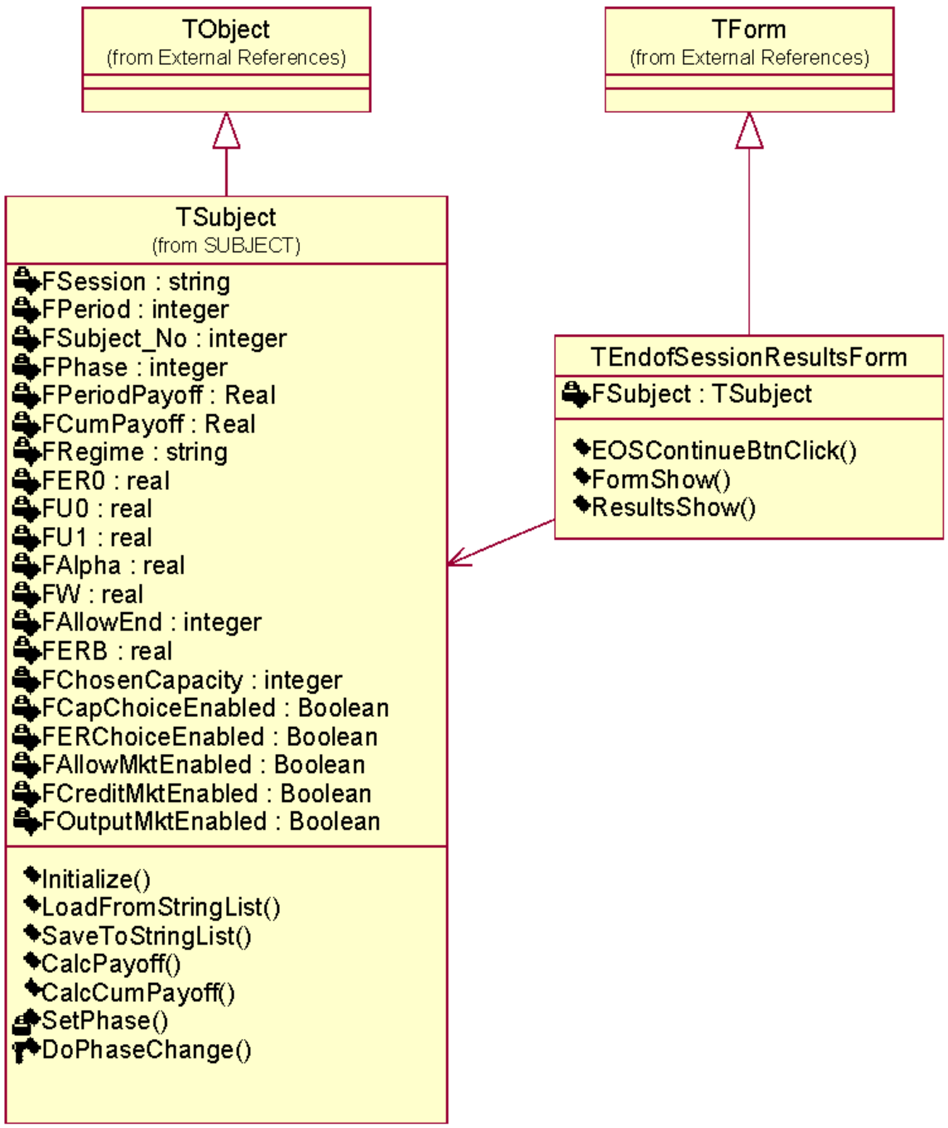


Figure E.37: EndofSessionResultsFormUnit

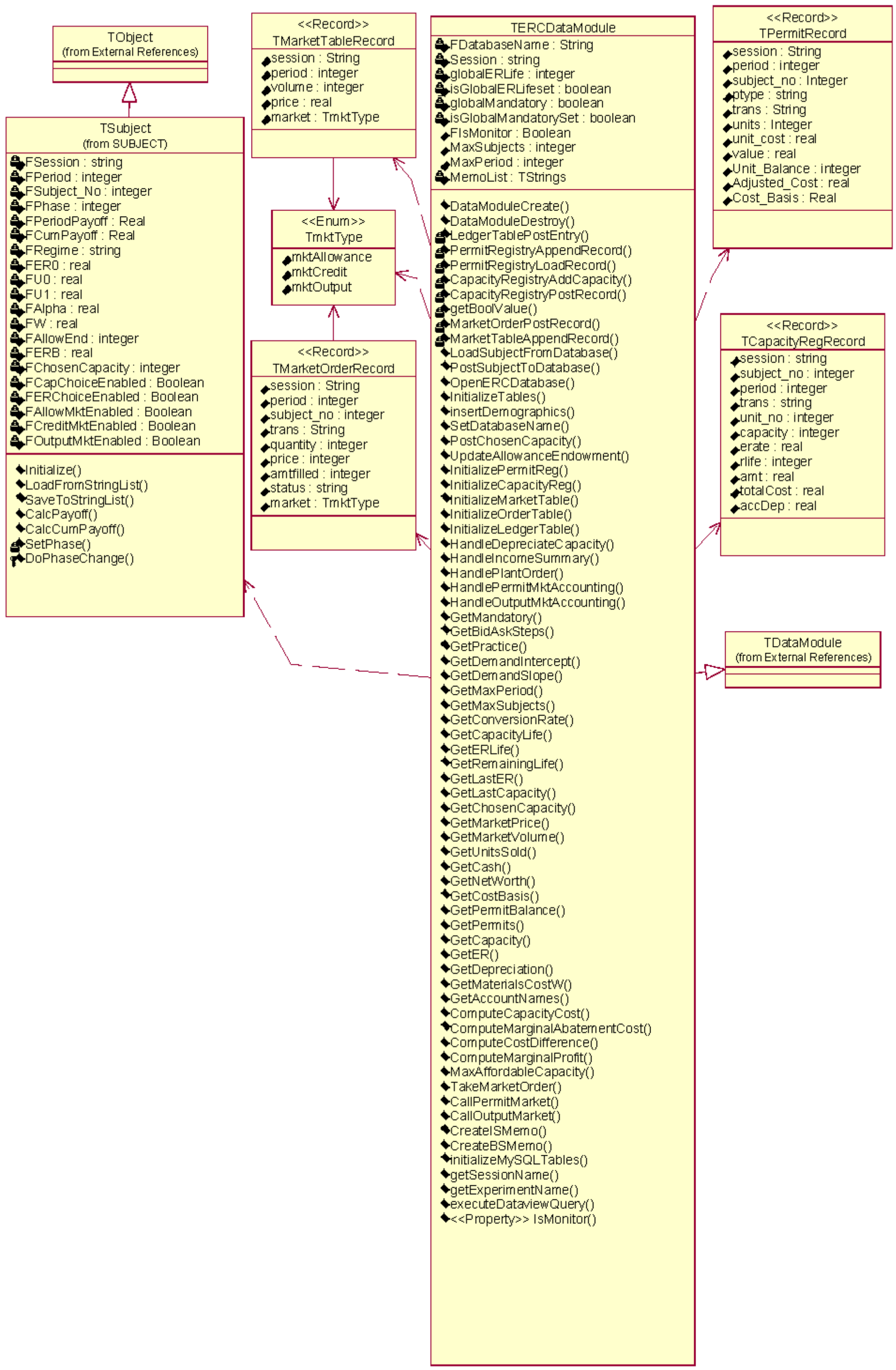


Figure E.38: ERCDataModuleUnit

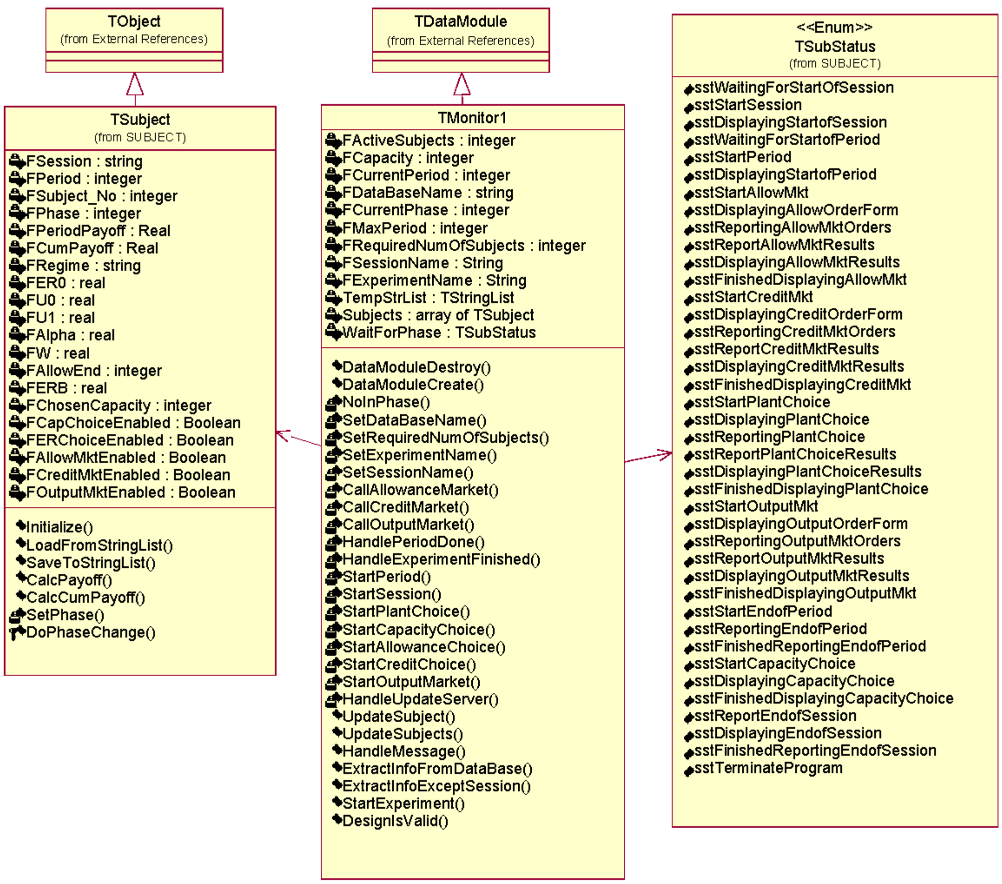


Figure E.39: MonitorUnit

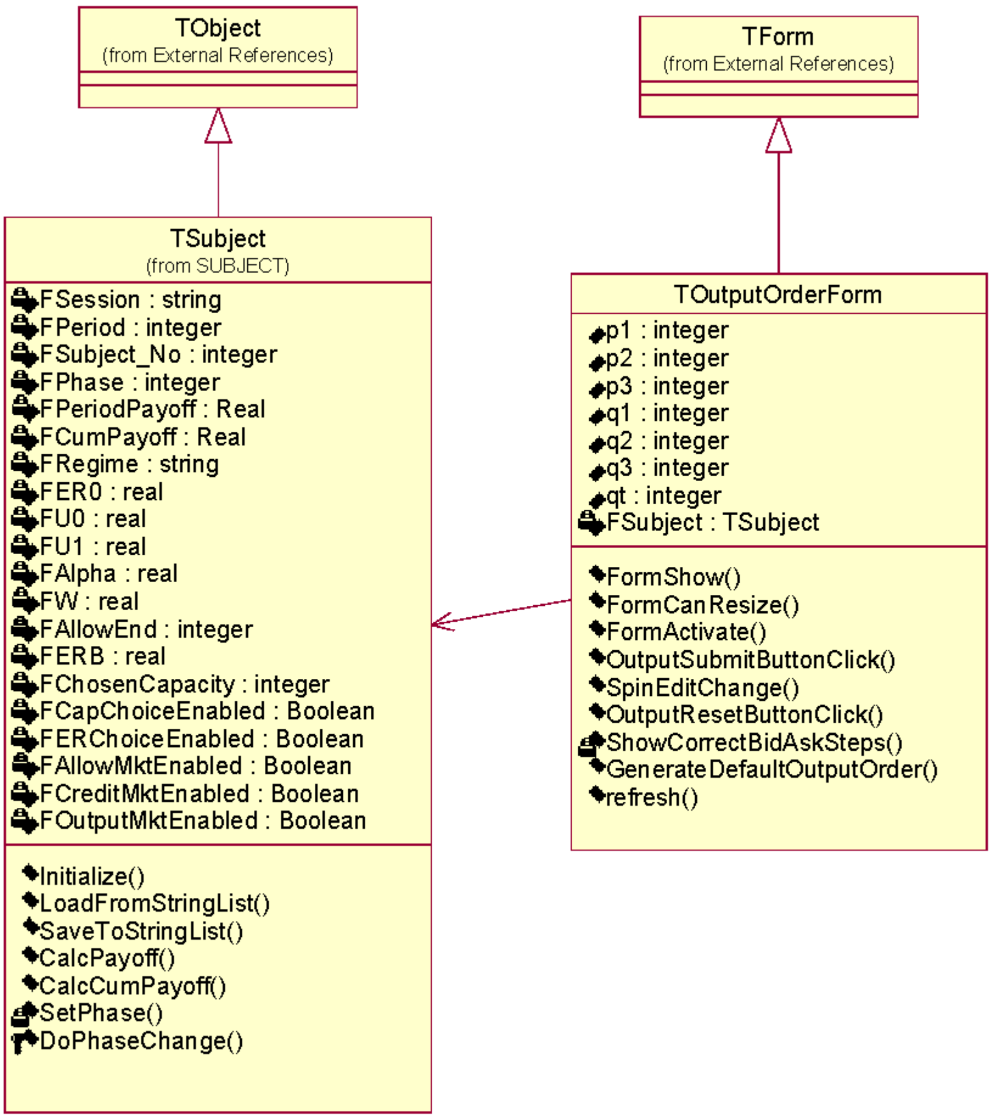


Figure E.40: OutputOrderFormUnit

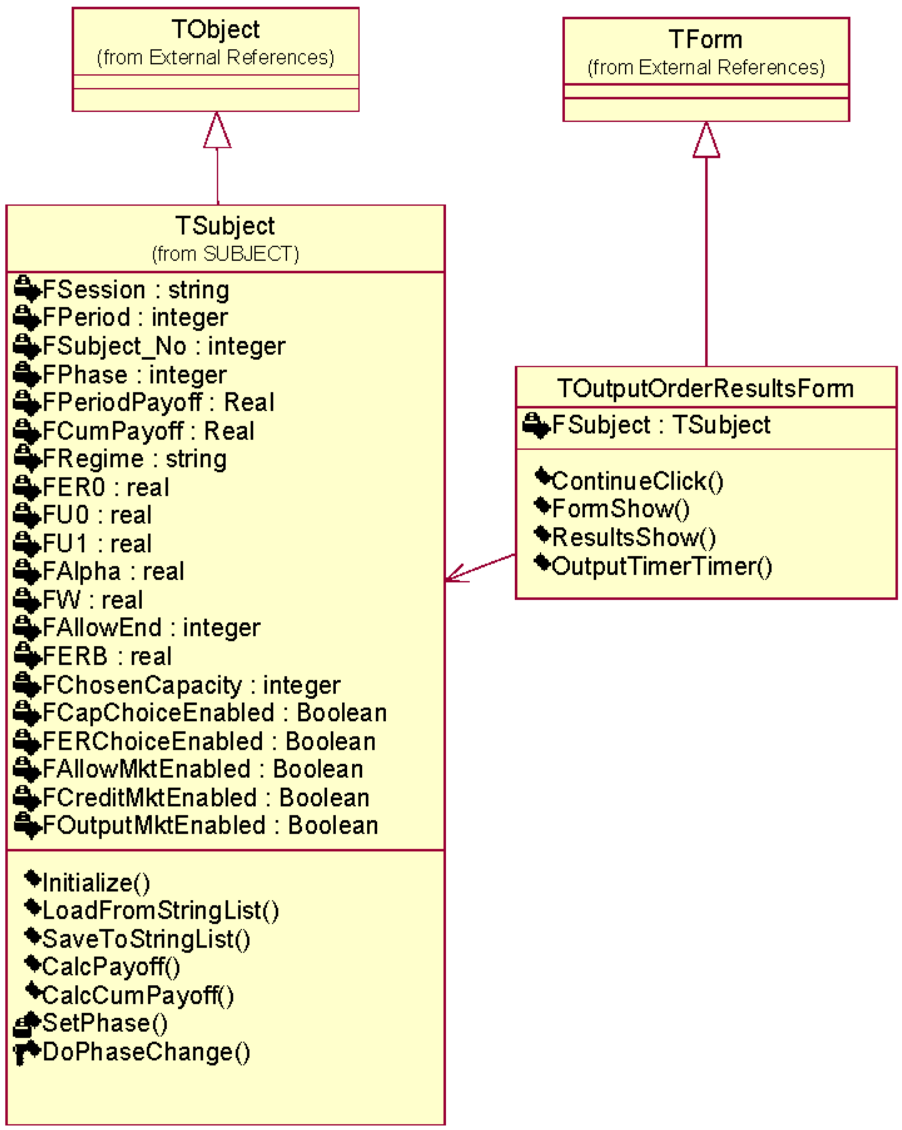


Figure E.41: OutputOrderResultsFormUnit

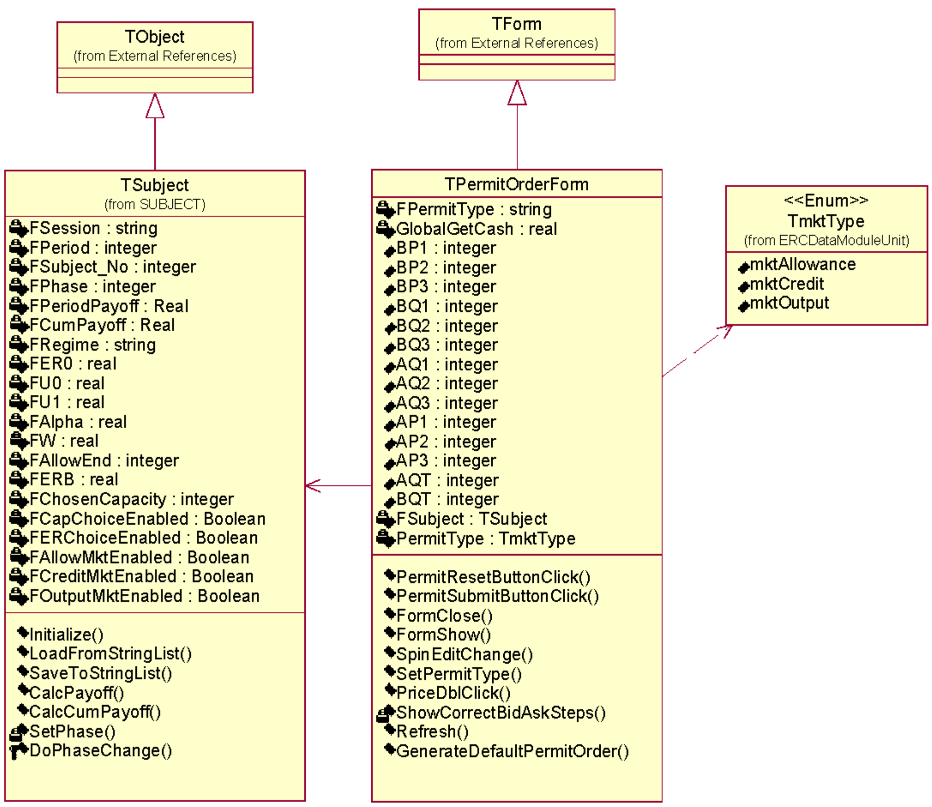


Figure E.42: PermitOrderFormUnit

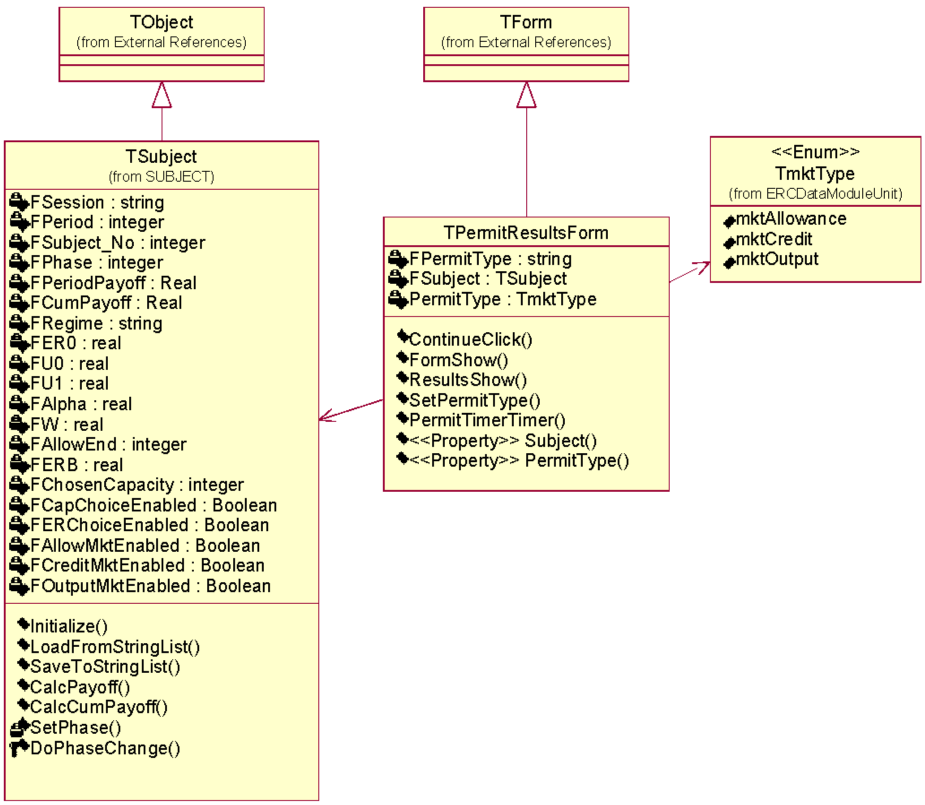


Figure E.43: PermitResultsFormUnit

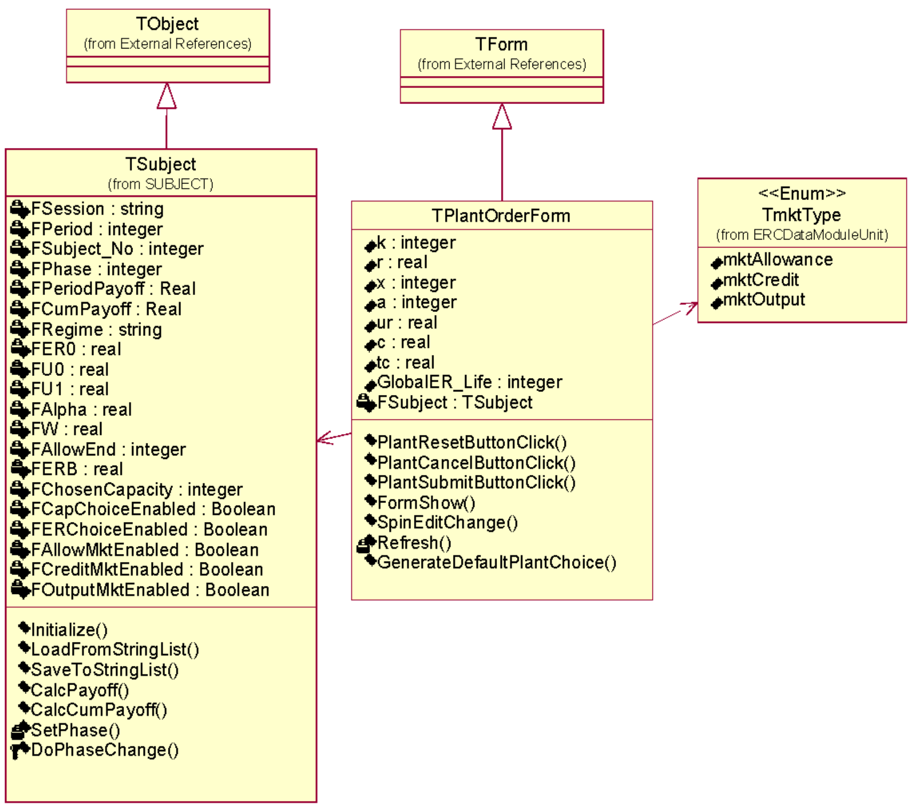


Figure E.44: PlantOrderFormUnit

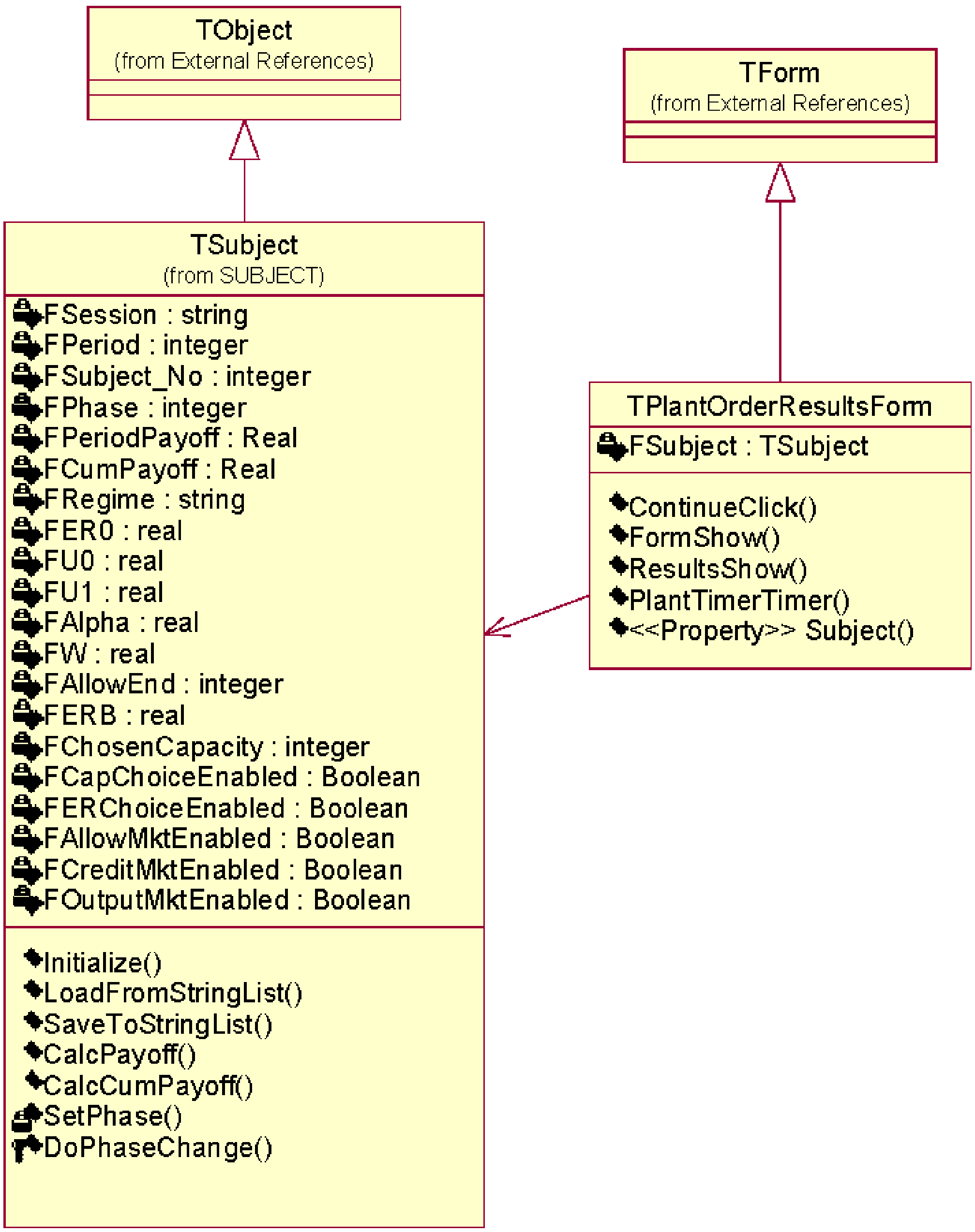


Figure E.45: PlantOrderResultsFormUnit

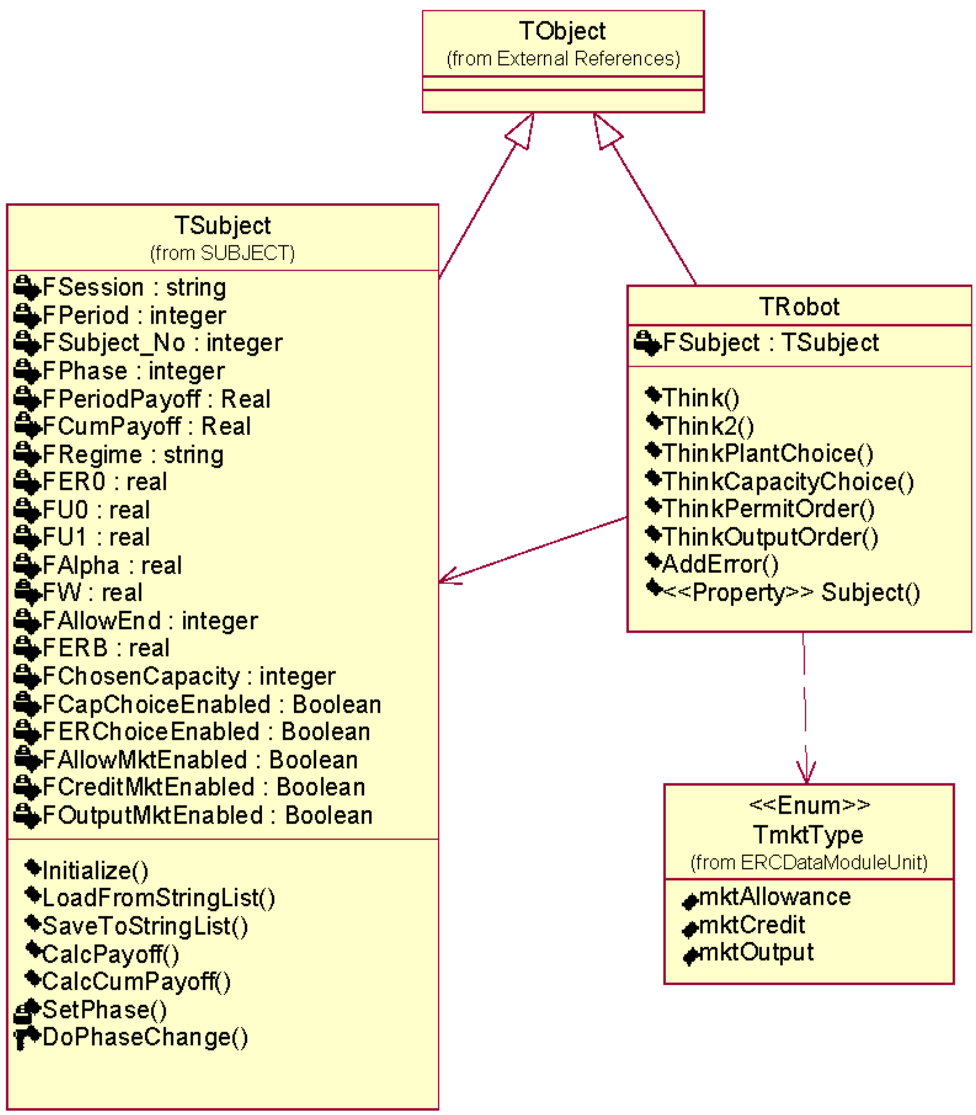


Figure E.46: RobotUnit

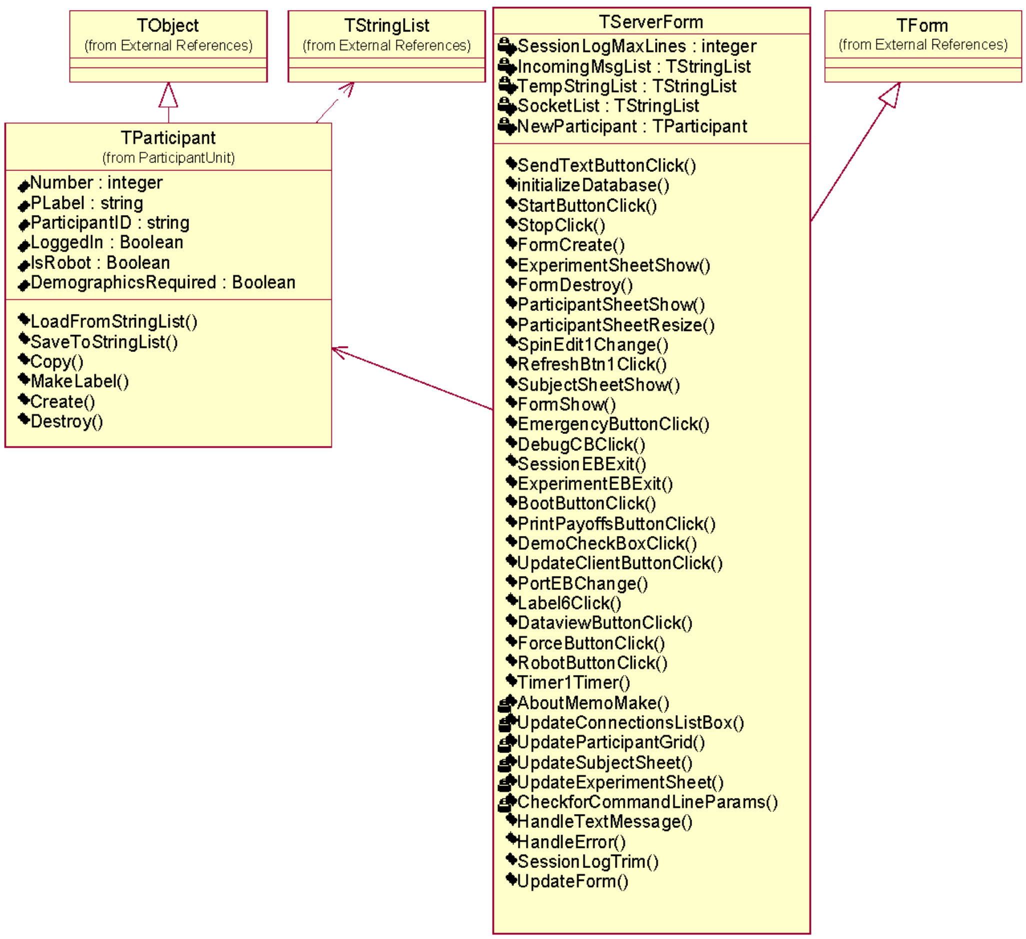


Figure E.47: ServerFormUnit

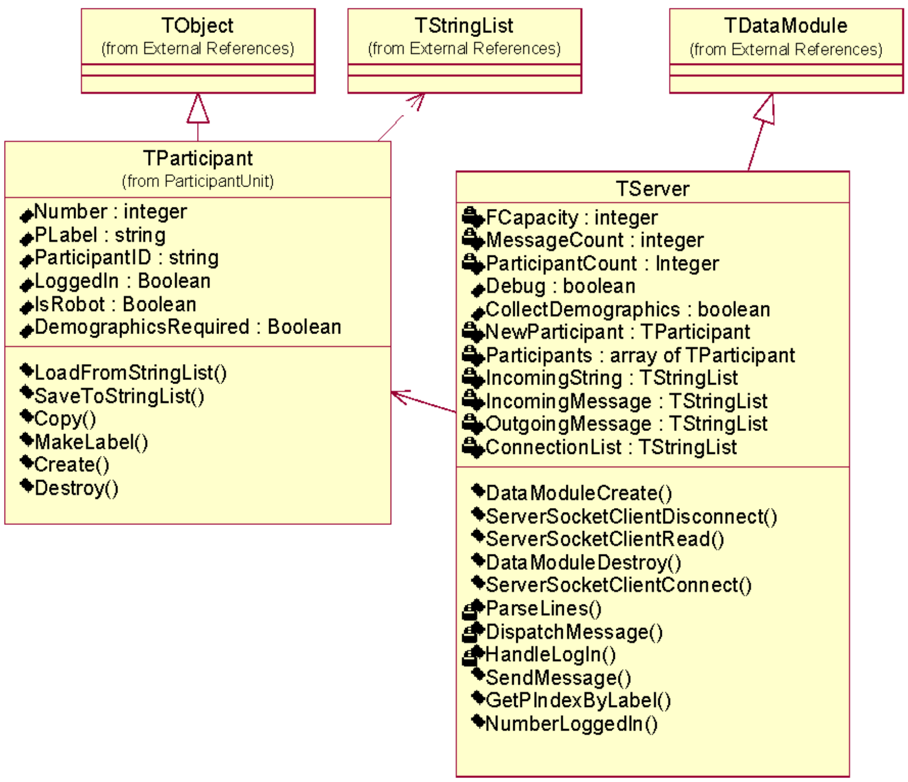


Figure E.48: ServerUnit

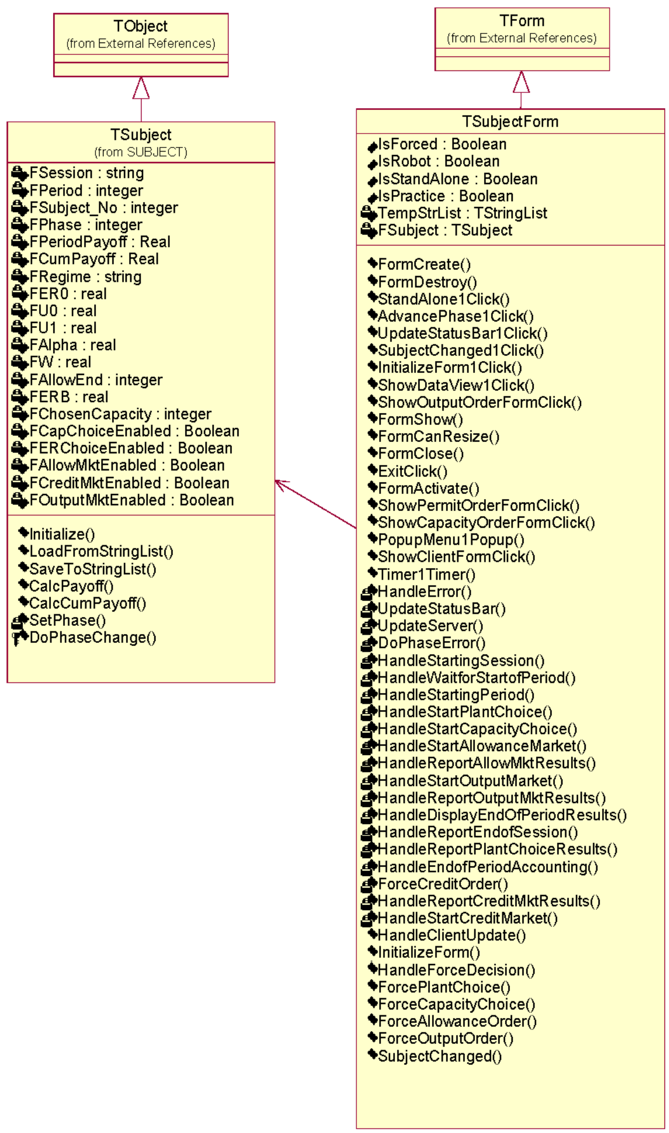


Figure E.49: SubjectFormUnit

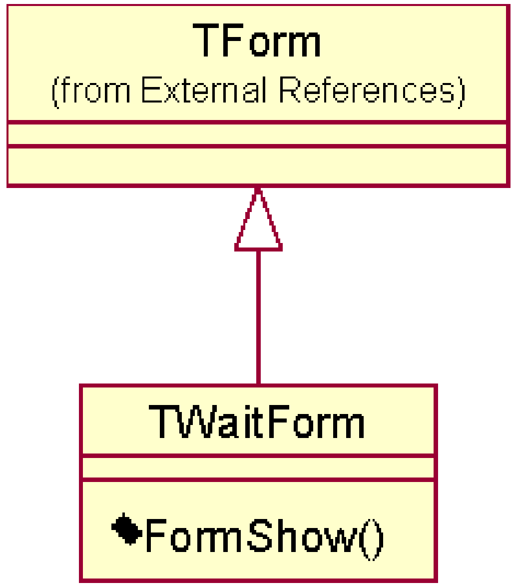


Figure E.50: WaitFormUnit

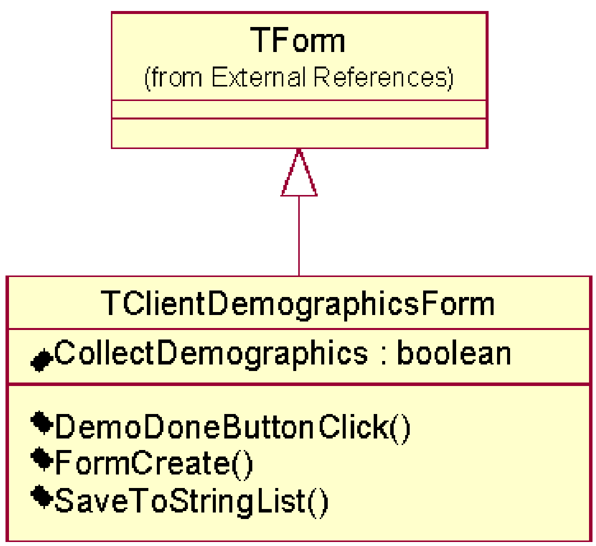


Figure E.51: ClientDemographicsFormUnit