MIT Joint Program on the Science and Policy of Global Change

Market Power in International Carbon Emissions Trading: A Laboratory Test

Björn Carlén

Report No. 96
January 2003

The MIT Joint Program on the Science and Policy of Global Change is an organization for research, independent policy analysis, and public education in global environmental change. It seeks to provide leadership in understanding scientific, economic, and ecological aspects of this difficult issue, and combining them into policy assessments that serve the needs of ongoing national and international discussions. To this end, the Program brings together an interdisciplinary group from two established research centers at MIT: the Center for Global Change Science (CGCS) and the Center for Energy and Environmental Policy Research (CEEPR). These two centers bridge many key areas of the needed intellectual work, and additional essential areas are covered by other MIT departments, by collaboration with the Ecosystems Center of the Marine Biology Laboratory (MBL) at Woods Hole, and by short- and long-term visitors to the Program. The Program involves sponsorship and active participation by industry, government, and non-profit organizations.

To inform processes of policy development and implementation, climate change research needs to focus on improving the prediction of those variables that are most relevant to economic, social, and environmental effects. In turn, the greenhouse gas and atmospheric aerosol assumptions underlying climate analysis need to be related to the economic, technological, and political forces that drive emissions, and to the results of international agreements and mitigation. Further, assessments of possible societal and ecosystem impacts, and analysis of mitigation strategies, need to be based on realistic evaluation of the uncertainties of climate science.

This report is one of a series intended to communicate research results and improve public understanding of climate issues, thereby contributing to informed debate about the climate issue, the uncertainties, and the economic and social implications of policy alternatives. Titles in the Report Series to date are listed on the inside back cover.

Henry D. Jacoby and Ronald G. Prinn,
Program Co-Directors

For more information, please contact the Joint Program Office

Postal Address: Joint Program on the Science and Policy of Global Change
MIT E40-271
77 Massachusetts Avenue
Cambridge MA 02139-4307 (USA)

Location: One Amherst Street, Cambridge
Building E40, Room 271
Massachusetts Institute of Technology

Access: Phone: (617) 253-7492
Fax: (617) 253-9845
E-mail: globalchange@mit.edu
Web site: http://mit.edu/globalchange/

Printed on recycled paper

Market Power in International Carbon Emissions Trading: A Laboratory Test

Björn Carlén†

Abstract

The prospect that governments of one or a few large countries, or trading blocs, would engage in international greenhouse gas emissions trading has led several policy analysts to express concerns that trade would be influenced by market power. The experiment reported here mimics a case where twelve countries, one of which is a large buyer (the mirror-image of a large seller), trade carbon emissions on an emissions exchange (a double-auction market) and where traders have quite accurate information about the underlying net demand. The findings deviate from those of the standard version of market power effects in that trade volumes and prices converge on competitive levels.

Contents

1. INTRODUCTION

Cost-effectiveness is likely to be an ambition in any international climate treaty aiming at substantial reductions of greenhouse gas emissions. Indeed, the need for cost-effectiveness was emphasized in the UNFCCC Article 3 (UN, 1992) and is facilitated by international emissions trading under Articles 6 and 17 of the Kyoto Protocol (UN, 1997). It is well known that competitive and well-functioning emissions trading allocates abatement efforts so as to minimize the total costs of attaining a given aggregate emission target. This outcome might be within reach, at least for the emissions of carbon dioxide (the single most important greenhouse gas) from combustion of fossil fuels, since these emissions can be monitored fairly easily by keeping track of countries' use of fossil fuels (IPCC, 1996).

The Parties to an international climate treaty would be governments, *cf.* the Kyoto Protocol. It is possible, perhaps even likely, that some (large) countries would choose to have their governments engage in international emissions trading. This prospect has led several analysts to express concern that market power would have a detrimental effect on the cost-reducing services of international emissions trading (*e.g.* IPCC, 1996, Westskog, 1996, Brown *et al.*, 1997, Baron,

---

† Wallenberg Fellow at MIT Joint Program on Science and Policy of Global Change, and Research Fellow at Department of Economics, Stockholm University. E-mail address: carlen@mit.edu.

1999, and Burniaux, 1999). One way of preventing this outcome would be to require (large) countries to delegate the right to trade internationally to domestic firms (ABARE, 1995). However, prior to limiting governments' policy options in such a way and thereby possibly making it more difficult for some countries to commit to an ambitious climate treaty, it is appropriate to investigate whether market power is likely to arise when governments trade.

So far, the discussion about market power in international emissions trading has been influenced mainly by standard economic theory, *i.e.*, studies as Hahn (1984) and Westskog (1996) predicting that a dominant seller (buyer)—or coalition of sellers (buyers)—would withhold supply (demand) from the market. Such behavior inevitably results in smaller aggregate cost savings than had the market been competitive. However, some of the assumptions underlying this prediction may be questioned, in particular the assumption that emissions trading would be governed by a set of rules (a "trading institution") according to which all trading would be conducted simultaneously at a uniform price and traders would be restricted to choosing only the quantity to supply or demand. Often this assumption is made to facilitate the analytical work and to allow clear predictions and not because such an institution is a good candidate for governing real-world emissions trading. International emissions trading would likely take place—at least, eventually—on an exchange and be governed by so-called double auction (DA) rules (Sandor, Cole and Kelly, 1994). Under DA rules, trade is sequential and traders can state bids and asks or accept (part of) other traders' bids and asks.[1] Hence, different transactions can be concluded at different prices. In this circumstance, the outcome of standard monopoly analysis is no longer the most profitable one for the dominant trader. Versions of the DA institution govern trade on exchanges such as the New York stock exchange and the major Chicago commodity exchanges (Friedman, 1993).[2]

Experimental methods have long been used to investigate the properties of the DA institution. The results of stylized laboratory experiments suggest that standard economic theory regarding market power may not be relevant for DA markets; trade tends to be efficient even when the market is monopolized. (See Smith (1981), Smith and Williams (1989), Ledyard and Szakaly-More (1994) and Muller, Mestelman, Spraggon and Godby (2001) for monopoly/monopsony experiments, and Plott (1989), Davis and Holt (1993) and Holt (1995) for reviews of the experimental literature on DA markets.) In these experiments, prices of initial transactions often deviate substantially from the efficient price level but they tend to converge to that level over time in, a potential reason for this being that initially traders only had private information about their own valuations/costs.[3]

---

[1] On a single (English) auction a set of buyers (sellers) bid for (offer) an object and the buyer (seller) with the highest (lowest) bid (offer) makes the transaction. On a double auction both these phenomena occurs simultaneously and a transaction is struck if the highest bid and the lowest offer coincide.

[2] Despite the importance and long history of DA-based markets no general theory regarding behavior under DA rules has yet emerged. Some contributions to such a theory have been made, though (*e.g.*, Friedman, 1991, Easley and Ledyard, 1993, and Gjerdstad and Dickhaut, 1995).

[3] Godby (1999) presents an experiment in which the presence of a monopolist (monopsonist) seems to have resulted in closing prices higher (lower) than the efficient level, although this did not substantially reduce efficiency attained, as compared to the case where permits were allotted in a way creating a competitive market environment. He offers two potential reasons for the observed outcome: (1) in contrast to the DA experiments referred to above the dominant trader here had full information about the small firms' costs while small firms

As explained in Section 2 below, traders that engage in *intergovernmental carbon emissions trading* are likely to have approximately common information about participating countries' marginal abatement costs (MACs) and, hence, about expected aggregate net demand for emission quota units. Experimental work regarding intergovernmental emissions trading is so far quite limited and the question of market power does not seem to have been explicitly addressed. The focus has been on either bilateral bargaining or trade on DA markets with several (large) traders on both sides of the market; see Bohm (1997), Bohm and Carlén (1999), Hizen and Saijo (forthcoming) and Søberg (2000). Although these studies employ different market configurations as well as different information structures, they all report outcomes of high efficiency. For a review of this literature, see Bohm (forthcoming).

The objective of the experiment reported in this paper is to test whether a large trader, facing an opposite side of the market that is fairly competitive, is able to exert market power under conditions likely to hold in intergovernmental carbon emissions trading on a DA market.
The approach taken here was to design a laboratory experiment that parallels the field to a greater extent than what has been common in Experimental Economics. The presumption is that, as compared to stylized experiments, such an experiment is more likely to produce relevant information regarding whether or not the phenomenon under investigation is likely to occur in the field, *cf*. Smith (1982).

The commitment/trading period in an international climate treaty is likely to span several years, such as the five years stipulated in the Kyoto Protocol. Uncertainty about MACs and the efficient price level could be considerable at the outset, but is likely to fall over time. The design of the experiment reported here corresponds to trade towards the end of the emissions trading period, when uncertainty and information asymmetries are likely to be small or even negligible. This final trading determines whether or not trading during the commitment period as a whole is efficient. Thus, focusing on the final trades allows a test of whether the presence of a dominant trader is likely to reduce market efficiency.

The paper is organized as follows. Section 2 outlines the trading situation likely to be faced by countries engaging in intergovernmental carbon emission quota trade and considers its implications for large countries' ability to exert market power. Section 3 describes the experimental design. Section 4 presents the competitive and the market power outcomes.
The results of the experiment are presented in Section 5. Concluding remarks are offered in a final section.

2. THE TRADING SITUATION

The analysis presented below takes as given a Kyoto-like climate treaty in which each of a set of industrialized countries is allotted an emission quota for the sum of its carbon emissions over a five-year long commitment period and the signatories—the governments—are allowed to trade

knew only their own costs; (2) several small firms were excluded from the market for a wide range of prices, or ran the risk of being so, something that may have reduced small firms' willingness to engage in the type of countervailing speculation discussed in Smith (1981). Although these circumstances may reflect conditions in real domestic emission permit trade amongst firms, they are not likely to be met in intergovernmental emissions trading.

quota units with each other.[4] Systems for monitoring of emissions and enforcement of compliance behavior are assumed to be viable. All quota-unit trade is governed by DA rules.

Figure 1 illustrates the underlying net demand of a country with a strictly binding emission quota (Q) and a MAC function that increases in emission abatements. The MAC function reflects the consumption value made available by efficient use of an additional carbon emission unit. By accepting the tradable quota (TQ), the country commits itself to an emission reduction equal to the difference between its business-as-usual (BAU) emission level Q^0 and Q. If the country accomplishes this emission reduction solely by the means of domestic abatements, its MAC would equal MAC(Q) and its cost of compliance would equal the area QQ^0MAC(Q). By engaging in emissions trade the country can reduce its compliance cost (make trade gains) either by replacing domestic "high cost" abatements with "low cost" abatements *via* purchase of quota units from other countries or by selling quota units at prices higher than MAC(Q). Thus, for prices below (above) MAC(Q) the country has a positive (negative) underlying net demand for quota units.[5] Hence, countries with strictly binding emission quotas will be net sellers for sufficiently high prices and net buyers for sufficiently low prices.

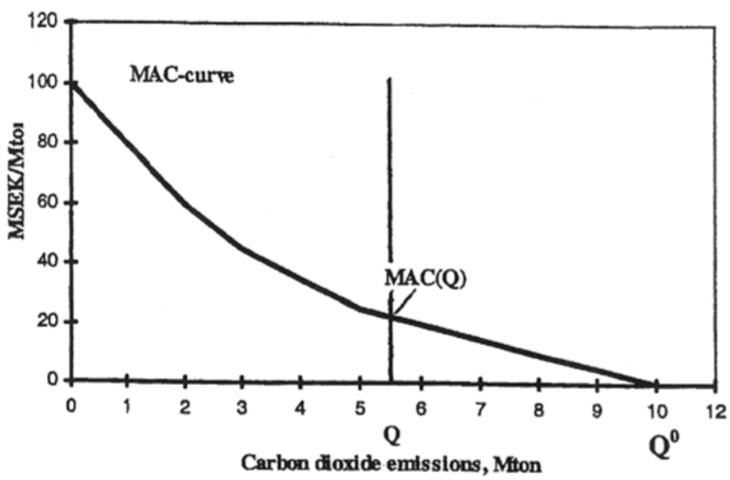


Figure 1. Illustration of a country's expected underlying net demand of carbon quota units.

Given the high values at stake in intergovernmental carbon emissions trading, countries would have strong incentives to try to conceal information about their own MACs as well as gather information about expected MAC functions of other countries prior to trading. However, each country's MAC function is estimated by means of market data and assessments of the performance of well-known technologies. Such information is obtainable at low costs also for observers outside an open economy, which makes it difficult for individual countries to conceal

---

[4] The kind of climate treaty discussed here might allow countries to bank and possibly also borrow (up to some limit) emission quota units to/from the next five-year budget period. Moreover, countries may have the opportunity to trade on futures markets, *i.e.*, trade quota units valid for the next budget period. These aspects of emission quota trade are not taken into account here.

[5] The concept of net demand is defined in relation to the country's "target level", *i.e.*, its initial quota Q *plus* net purchases of emission quota units. Figure 1 illustrates the underlying net demand of a country at the beginning of the trading period when the target level equals Q.

large parts of their abatement opportunities and associated costs other than for perhaps some limited time, should they want to do so.[6] Therefore, to a first approximation, participating countries would have roughly common information about each other's (and the aggregate) expected underlying net demand relationships for the commitment period as a whole. This implies that countries would have more or less common expectations about the efficient price level (p^*). As new information becomes available, countries would be able to update their expectations, so that towards the end (when, say, 4-6 months remains) of the five year long commitment period they would be likely to have even better information about everyone else's MAC functions. By then, all countries would thus be able to estimate p^* with a high degree of accuracy.

Countries that observe price levels deviating substantially from their current expectations would be likely to update their expectations regarding future price levels or, as long as their trading budget so allows, engage in speculative trade, or some combination thereof. This implies that even countries expected to act as large net sellers may for some time appear as buyers on the market and *vice versa*.

The trading situation outlined above has several implications for the ability of dominant countries to exert market power, three of which are highlighted here.

(1) On an emission quota market, in contrast to many other markets, countries may shift trading positions when prices change. Thus, even if a buyer country dominates the market at prices around p, there exist prices significantly below p which the dominant country would like to see materialize, other things equal, but which would turn "former" sellers into buyers, hence creating competition for the original buyer (*mutatis mutandis* for an original seller). Therefore, a tradable quota market for carbon emissions would not allow a country to remain in an equally dominant position when prices become increasingly favorable to it.

(2) Trade under DA rules is sequential and prices of different transactions may vary. Thus, a dominant trader can exert market power either by price discrimination or by withholding demand/supply from the market in order to influence prices, or some combination thereof. If a dominant buyer (seller) succeeds in carrying out inter-temporal price discrimination, transactions would be concluded at ascending (descending) prices over time. The fact that additional transactions do not affect the prices of already concluded transactions implies that, for every transaction, the dominant country's marginal expenditures (revenues) of an additional transaction equal the price of that transaction. This means that the dominant country has incentives to continue to trade until prices equal its MACs.[7] Similarly, a dominant buyer (seller) that—according to standard theory of market power—holds back demand (supply) to

[6] MAC functions of individual countries (or regions) are being assessed already today by research institutes and international organizations, *e.g.*, CICERO, MIT Joint Program on the Science and Policy of Global Change and UNEP. If intergovernmental emissions trading should materialize, efforts directed to such activities could be expected to increase substantially and, hence, so also the accurateness of the assessments.

[7] The discussion here presumes that quota-unit prices at the end of a commitment period do not influence prices in the succeeding commitment period to any significant extent. If they did, the dominant trader's value of additional emission quota holding in the current period would not equal its MACs for that period, and the dominant buyer (seller) would find further trade profitable only as long as the price is lower (higher) than its marginal valuation. However, in emissions trading of the type discussed here, prices in a five-year long trading period would likely be a function of expectations regarding end-prices in that period (discounted by the interest rate), rather than a function of end-prices in the preceding period. Thus, the assumption made seems justified.

competitive sellers (buyers), in an attempt to reduce (increase) prices, will find further trade profitable if the price falls below (exceeds) its MAC. Thus, regardless of whether the dominant trader exerts market power through price discrimination or by withholding quantities from the market the price level could be expected to approach p^*. Thus, even a dominant trader that is able to influence prices on a DA market is unlikely to cause the net trade volume—and all transaction prices—to deviate from the efficient level, see Plott (1989) and Holt (1995) for a discussion about experimental results.

(3) Given that experienced traders would be aware of the outcome in (2) above, and given that these traders would be equipped with more or less common and quite accurate information (and thus more or less common expectations) not even the early prices (during the end period trading in focus here) would be likely to deviate substantially from p^*. And even if they were to do so, speculation would likely drive the price back to p^*.

To sum up, in contrast to standard economic theory, the trading situation outlined for the end of the emission budget period leads to the hypotheses (i) that the presence of a dominant country will not prevent the market from being efficient, *i.e.*, reaching the cost-effective allocation of abatements, and (ii) that a dominant country will not be able to exert market power in the sense of establishing early prices that deviate substantially from p^*. Thus, it is hypothesized that the outcome of this kind of end period trade will be close to the perfectly competitive outcome even when a single trader dominates the market.[8]

The objective here is to test these propositions in an experimental setting.

3. EXPERIMENTAL DESIGN

3.1 Design Issues

The design of the experiment presented here differs in three major aspects from those commonly used in laboratory market experiments. First, the common approach of repetitive trade under stationary conditions, whereby subjects gain experience and the market conveys information to traders and thereby generate common expectations, is abandoned here. The reason is that this approach does not parallel the field. In case of real intergovernmental carbon emissions trading, governments would be likely to hire experienced traders to represent them, *i.e.*, individuals who have acquired their competence from trading in other commodities. Moreover, as argued earlier, these traders would likely form their *expectations* regarding the efficient price level at the end of a five-year long trading period on the basis of estimates of the countries' MACs functions, rather than on prices realized at the end of the preceding emission trading period. Therefore, prior to the experiment, subjects were given extensive written information consistent with such information gathering under the trading situation outlined in Section 2.

[8] Given a prediction based on this hypothesis, one may wonder why a large country, expected to dominate one side of the market, would accept a rule requiring all quota-unit trade to be conducted on a DA market. It should be kept in mind that the hypothesis stated here only regards trade during the end of a possible five-year long commitment period when expectations are common and accurate. Prior to that time, prices may well deviate (perhaps substantially) from what will turn out to be p^* and doing so in ways favorable to the dominant trader, as suggested by Muller *et al*.

Second, the standard procedure of creating “context-free” laboratory markets is abandoned here. This procedure aims at avoiding any information about the context that would influence the behavior of subjects in ways that add noise to or bias to the outcome. However, as discussed in Lowenstein (1999), Bohm (forthcoming) and Hertwig and Ortmann (2001) and the responses to that article, the absence of an explicit context may also affect subjects’ behavior. For instance, subjects may have difficulties grasping and solving abstract decision problems. Moreover, subjects may create their own contexts that trigger certain “modes of mind” which may or may not be relevant for the research question at issue. Thus, also the absence of an explicit context may affect behavior in ways that add noise to and even bias the outcome. Indeed, results from experiments regarding ultimatum and dictator games show that subjects’ behavior to a large extent may depend (in ways resistant to changes in incentive levels) on the context used to present the decision task, see *e.g.*, Hoffman, McCabe, Shachat and Smith (1994). Currently, we do not know to what extent this phenomenon transfers to the case of DA markets.[9] Therefore, subjects were here given instructions with the explicit context that drives the research question. To be sure, such instructions are lengthier and may take longer time for (some) subjects to digest than the context-free type commonly used to create laboratory markets. However, as explained below, subjects were here given ample time to study the instructions and work out strategies and, in addition, were trained in both context-free and context-filled lab markets.

Third, subjects were here given pecuniary incentives stronger than those regularly induced in lab markets. Thus, each subject faced higher costs of letting considerations other than profit maximization influence his/her behavior.

Information as to which countries would become pioneers in international emissions trading is not (yet) at hand, and even if it were, it would not be possible to forecast with any higher degree of accuracy the market structure that would emerge at the end of a five-year long trading period. Given the objective of testing for market power effects, the approach taken here was to assume a carbon emission quota market comprised of twelve industrialized countries—the US, Japan and ten EU countries (Belgium, France, Germany, Greece, Italy, the Netherlands, Portugal, Spain, Sweden and UK)—with one country, the US, standing out as a dominant buyer. Focus is here on buyer market power since it has been observed in DA experiments that subjects tend to perform better when acting as buyers than when acting as sellers (Smith and Williams, 1982). Otherwise, one would run the risk of not detecting market power because subjects who would play the role of the dominant trader have less experience as a seller than as a buyer.

After the conclusion of this experiment conditions important for emission trading under the Kyoto Protocol underwent changes. In particular, the US has announced that it will not ratify the Protocol. Thus, in the case where Russia ratifies and the Protocol enters into force, Russia would likely dominate the market as a seller. However, given the objective of testing market power at the end of a five-year long trading period these circumstances are of limited interest. Since the market structure during the end-period trade in focus here might deviate substantially from the one

---

[9] To the best of the author’s knowledge, there exist no systematic studies of this phenomenon on DA markets. The current view seems to be that instructions do not have important impacts on the outcome in DA experiments (Hoffman, McCabe and Smith, 2000). However, this conjecture is based on the results of DA-experiments providing only little, if any, variation in this dimension of subject instructions.

indicated by the sum of trade flows over the whole commitment period, the emergence of a dominant buyer at the end of that period cannot be ruled out. Moreover, a seller country in an equally dominant position would face similar incentives to exert market power as the buyer country in study here. Therefore, the outcome may be equally valid for the case of a dominant seller.

Furthermore, it is assumed that when 4-6 months of the commitment period remain, these countries' have a substantial "need" for additional net trade. More precisely, we assume that at this point in time each one of these countries would be on the order of 20% from full compliance of a Kyoto Protocol-like environment. These assumptions and estimates of these countries' MACs for the year 2010 (available in December 1997 when the design of this experiment was determined) yield a *market structure* at a hypothetical perfectly competitive equilibrium with nine expected net sellers and three expected net buyers.[10] The main buyer (the US) alone accounts for approximately 90% of the efficient net trade of approximately 400 (units) Mton carbon dioxide (CO_2).

Subjects were recruited among advanced undergraduate students in Economics or Finance, with one exception. In order to test for market power effects, it was crucial that subjects who represented the dominant country would be confident in this role. These subjects were therefore selected amongst Ph.D. students in Economics who had proved their negotiation skills in earlier laboratory experiments, *i.e.*, Bohm and Carlén (1999).

The *market institution* used was the computerized multi-unit double-auction (MUDA) market developed by Plott (1991). This institution was chosen because it allows subjects to trade without being assigned predetermined buyer or seller roles.

3.2 Experimental Procedures

Two days before the experiment, subjects received *instructions*[11] including:

- an introduction to the climate change policy issue,
- information about all countries' expected MAC functions and the competitive outcome calculated on basis of this information,
- the trading rules,
- the show-up fee and
- a statement that they could earn considerable amounts of money by trading emission quota units on the behalf of the (unidentified) country they would represent.[12]

The full instructions are reproduced in Appendix.

Subjects were also informed about the fact that countries' expectations regarding their MAC functions could be updated and that they would receive, as private information at the beginning

---

[10] Estimates of countries' MAC functions were collected from Capros, Georakopoulos, Katsoumili and Filippoupolitis (1997), EU (1996) and IPCC (1996).

[11] At this time subjects were not informed about which country they would represent. Given this procedure and the fact that during the experiment subjects would be anonymous and not allowed to communicate, the risk of collusion among subjects was deemed insignificant.

[12] During the experiment the countries were labeled country #0, #1, ... #11.

of the experiment, the relevant MAC function for the country they were asked to represent. It was stressed that only small *information asymmetries* were to be expected. Furthermore, to mimic the situation of experienced and well informed traders as outlined in Section 2, subjects were given information about the expected outcome on a DA market, *i.e.*, that final prices tend to end up near the efficient price level and that traders might engage in speculative trade if prices deviated substantially from their expectations.[13]

Prior to the experiment subjects participated in an extensive two-hour *training program*. The training program consisted of (i) an introduction to the computerized DA mechanism and the educational software included in MUDA, (ii) repetition of essential parts of the written instructions, and (iii) two training rounds in order to familiarize subjects with trading on a MUDA-based market and with interpreting the kind of underlying net-demand functions that would be used in the experiment. The parameter set-up in these training rounds differed substantially from those used in the experiment.[14]

Once a subject had been assigned the role of a particular country, he/she received as *private information* an updated version of that country's MAC function (*i.e.*, the country's underlying net demand function) and the size of that country's initial trading budget. No information was given whether other countries' MAC functions had been updated. (The distance—in terms of prices—between the expected and updated MAC curve of a country was never larger than 4% of the expected curve, a fact that was not disclosed to the subjects.) Each subject was given an initial trading budget. Thus, all subjects, including those representing expected net sellers, could engage in speculative trade from start.[15]

Incentives: In order to mimic a situation in which traders representing countries on a real market for carbon emissions would have incentives to try to maximize their respective countries' trade gains, subjects were paid a fraction of the trade gains they achieved for their countries. Since the underlying demand and supply conditions implied a highly unequal trade-gain distribution for a wide range of outcomes, including the case where traders behaved as if trading under perfect competition (see Tables I and II), differentiated personal payoff factors were used so as to produce a more even distribution of incentive payments.[16] The expected incentive

---

[13] As pointed out by a referee, also giving subjects representing the dominant trader information about the level of the expected monospony price might allow an even stronger test of market power effects. This was not done here for two reasons. First, given information about expected aggregate and individual net-demand relationships for carbon emissions and, hence, about the expected competitive price level, such additional information was not deemed necessary for subjects to be able to successfully work out market power strategies—something they had both capacity and time to do. Second, such information might draw subjects' attention away from the possibility of price discrimination.

[14] The first round amounted to a one-period replication of the stylized laboratory experiment presented in Holt, Langan and Villamil (1986) with pecuniary incentives. The second round introduced the type of continuous marginal-costs functions relevant for intergovernmental emissions trading, using oil trading as an example.

[15] Although a country's initial trading budget can be expected to vary positively with the size of the country and its expected net demand for quota units, there is no simple rule that can be applied. Here, each country's trading budget was set so as to correspond to the higher of the following two values, (1) its expected quota import expenditures in the competitive outcome *plus* 30% of that amount, and (2) two percent of its GDP.

[16] The subject representing country #0 received SEK 6 per SEK million of trade gains achieved for that country. The payoff factors for countries #1-#11 were SEK 3, 4, 2, 15, 7, 8, 8, 15, 1.5, 1 and 10, respectively. The likelihood that subjects would "play" against the experimenter by allocating trade surplus to the subject(s) with the highest

payment per subject and period, calculated on the basis that the outcome would be close to the competitive outcome, ranged from SEK 70 to SEK 130, in addition to a fixed payment of SEK 25 per period (over and above the show-up fee of SEK 200). (During the period the experiment was carried out, winter 1998 to spring 1999, SEK 1 ≈ USD 0.12.) Any net losses at the end of the period would be deducted from the fixed payment, up to a maximum deduction of SEK 25. Hence, although subjects could not lose money by participating in the experiment, they could "lose" money by engaging in trade. Moreover, they could gain considerable amounts of money, even in the event they initially made losses not exceeding the fixed payment by too much.[17] Subjects' experimental earnings turned out to range from SEK 3 to SEK 2,075 (net of the show-up fee and income taxes).

Each subject participated in one session that consisted of two 35-minute trading periods. The environment of the second period deviated only slightly from the one used in the first period. In order to reduce potential effects of multi-period game strategies, the subjects did not receive any information about the relevant situation for the second period until after the completion of the first period. Each subject played the role of the same country in each period.

4. BENCHMARK CASES

Given the hypotheses stated in Section 2, a natural benchmark is the competitive outcome. The rate of market efficiency is here defined as the achieved share of the maximum cost reduction (trade gains) from emission quota trading. The maximum cost reduction equals the difference in aggregate costs between the case in which all countries fulfill their commitments unilaterally and the case of efficient emissions trading, *i.e.*, the case where the countries' MACs have been equalized. The competitive outcome for the environments used in period 1 and period 2, respectively are shown **Tables I** and **II**. Both tables show

- the amount by which each country would need to reduce its emissions under unilateral emission reduction (column 2),
- the costs of these reductions (column 3),
- the emission reductions in the efficient-trade case (column 4),
- the cost of these reductions (column 5) and
- the resulting trade gains (column 6).

A country's efficient net export of emission quota units is given by the difference between columns 4 and 2. The trade gains of an exporting country are calculated as export revenues *minus* the additional abatement costs due to export activities. For an importing country, trade

payoff factor(s) was deemed low since (a) subjects knew only their own payoff factor, (b) each subject was anonymous to others when trading (only the country code was revealed to others) and (c) the subjects were not allowed to communicate in other ways than sending bids *via* the MUDA program.

[17] Despite the possibility of losing up to 25 SEK *plus* (in the period) already achieved trade gains, it is possible, perhaps even likely, that this limitation of the risk for the subjects lead to excessive risk taking. However, with a requirement that subjects are not allowed to lose money by participating in the experiment and a limited experimental budget this is unavoidable.

gains equal the abatement cost savings *minus* the expenditure on imported quota units. Efficient net trade in periods 1 and 2 reallocates 396 Mton carbon dioxide (CO_2) and 387 Mton CO_2, respectively, or approximately 14% of the aggregate emission reduction in each period. This trade would cut the cost of reaching the aggregate CO_2 emission reduction of 2,768 and 2,780 Mton by 18% and 17%, respectively, for the two periods. The competitive outcome gives 34% and 45% of the surplus to the buyers, respectively, for the two periods.[18]

Another benchmark of interest is the case where the major buyer (the US) acts in accordance with standard economic theory regarding market power in emissions trading (Hahn, 1984) and withholds demand while the other countries behave as price takers. In this case it is assumed that all trade is conducted simultaneously at *a uniform price*. Then, the US maximizes its gains by withholding demand in the amount of 117 Mton and 100 Mton, or by 33% and 29% of its "competitive" demand in periods 1 and 2, respectively. The resulting price equals SEK 1,178 per ton CO_2 and SEK 1,065 per ton CO_2, or 81% and 89% of the efficient price level in periods 1 and 2, respectively. In this case, the US's profits amount to SEK 152 billions and SEK 146 billions (144% and 119% of its competitive outcome) in periods 1 and 2, respectively. Aggregate trade gains of the other countries amount to SEK 133 billions and SEK 112 billions (56% and 66% of their competitive outcome) in periods 1 and 2, respectively. The efficiency of this monospony case is as low as 83% (period 1) and 89% (period 2).

Table I. Competitive outcome in period 1, Mton CO_2 and SEK billion, respectively

	p* = MSEK 1,450/Mton				
	Unilateral		Emission reduction *ex post* trade:		
	Emission reduction	Cost	Mton	Cost	Net gain
Belgium (#0)	12	2.20	34	20.9	13.2
Germany (#1)	220	66.0	285	128	32.6
Greece (#2)	0	0	21	10.3	20.1
Spain (#3)	0	0	60	35.2	55.8
France (#4)	25	12.7	35	25.0	2.30
Italy (#5)	80	32.0	110	65.8	9.80
Netherlands (#6)	30	11.2	46	27.4	7.10
Portugal (#7)	6	0.90	18	9.9	8.40
Sweden (#8)	15	18.0	9	6.5	2.80
UK (#9)	80	19.3	240	174	77.3
US (#10)	1,900	1,477	1,550	871	106
Japan (#11)	400	271	360	206	7.30
Total	**2,768**	**1,910**	**2,768**	**1,568**	**342**

[18] In DA experiments it has been observed that there is a tendency that prices converge towards p* from below/above if aggregate producer surplus (evaluated at the competitive outcome) exceeds/falls short of aggregated consumer surplus, the so-called convergence bias (Smith and Williams, 1982). This phenomenon has been observed in experiments where trade units have been distributed evenly among the subjects and, hence, its effects cannot be attributed to market power. Thus, a convergence bias could here be expected to generate price paths converging to *p** from below. However, given the induced information structure, it is hypothesized that the price path would be largely independent of the relation of buyers' and sellers' surpluses at price *p**. The opposite would imply that traders consciously give away (arbitrage) gains.

Table II. Competitive outcome in period 2, Mton CO_2 and SEK billion, respectively

	p* = MSEK 1,200/Mton				
	Unilateral		Emission reduction *ex post* trade:		
	Emission reduction	Cost	Mton	Cost	Net gain
Belgium	10	1.6 0	33	18.4	10.7
Germany	210	63.0	275	120	21.5
Greece	0	0	20	9.80	14.2
Spain	0	0	53	29.0	34.6
France	25	9.84	36	20.7	2.34
Italy	70	28.0	105	63.0	7.00
Netherlands	25	8.90	40	23.0	3.93
Portugal	10	2.10	20	9.80	4.28
Sweden	15	17.2	8	4.80	4.05
UK	85	18.1	240	144	60.1
US	1,950	1,352	1,600	810	122
Japan	380	223	350	182	5.25
Total	**2,780**	**1,724**	**2,780**	**1,434**	**290**

5. RESULTS

The experiment consists of five sessions. This relatively small number is due to budget reasons of two kinds. First, the available number of "uncontaminated" subjects was limited, allowing only one or two sessions per semester. Second, the chosen approach of testing emissions trading is rather expensive; the average cost per experimental session amounted to approximately USD 1,000. As mentioned above, each session consisted of two periods. However, period 2 of session 1 and period 1 of session 2 encountered problems not likely to arise in the case of real emissions trading.[19] Therefore, trading periods 1.2 and 2.1 have been omitted from the analysis. So, the experiment produced four independent period-1 observations and four independent period-2 observations.[20]

The outcome of the experiment is summarized in **Table III** below. Notable is the fact that in none of the four period-1 observations or the four period-2 observations did the US withhold demand to the extent predicted by standard economic theory. In fact, in all periods the quantities

[19] During period 2, session 1, network problems caused the MUDA program to duplicate automatically each transaction. Therefore, the *ex post* trade quota allocation differed substantially from the efficient one. Still, prices were close to *p**; on average 98% of *p**. In period 1, session 2, the subject representing Germany misunderstood the cost-schedule in a way that made him sell around two-third of Germany's initial quota. Therefore, prices were substantially below *p** (on average 53% of *p**) and those subjects who speculated in that prices eventually would approach *p** made losses.

[20] This low number of independent observations, which obviously limits the power of any statistical test, is not unusual in lab market experiments, although it perhaps should be. For instance, Ledyard and Szakaly-More (1994) and Godby (1999) each produced three independent observations of monopolized markets. Godby also produced three independent observations of monopsonized markets. Muller *et al.* (2001) yielded two independent observations of each one of four different series of monopolized, competitive and monopsonized markets, which, under the assumption of insignificant "learning effects" were treated as giving six observation each of monopolized and monopsonized markets, respectively.

imported by the US are closer to the efficient level than to the market power prediction. The hypothesis that US's net imports would equal the market power benchmark is rejected for the period-1 outcome as well as for the period-2 outcome by the t-test at less than the 1-% level in favor of the alternative of higher imports. The principal result of the experiment is therefore that of high efficiency. In six of the eight trading periods more than 95% of the potential (maximum) trade gains were realized.[21] The hypothesis that the efficiency outcome equals the market power benchmark is rejected in favor of the alternative of higher efficiency by the t-test only at the 10-% level for the period-1 outcome but at less than the 1-% level for the period-2 outcome. Given this result of high efficiency, it is not surprising that closing prices are near the efficient levels; the hypothesis that the closing price equals the market power benchmark is rejected at the 1-% level in favor of the alternative of a higher price (closer to *p**) for both the period-1 outcome and the period-2 outcome. However, we cannot reject that mean prices equal the monopsony price.

Table III. Outcomes in percent of competitive levels

	Monopsony		Trading period								Average		
	1	2	1.1	2.2	3.1	3.2	4.1	4.2	5.1	5.2	1	2	All
Efficiency	83	89	87	98	99	99	78	96	99	100	91	98	95
Closing price*	81	89	90	100	100	98	86	91	98	100	94	97	96
Initial price*	81	89	83	63	76	90	65	92	30	75	64	80	72
Average price	81	89	88	77	89	101	68	100	83	98	82	94	88
US quantity demanded	67	71	88	99	96	91	115	98	98	96	100	96	98
Profits													
US	144	119	158	150	143	104	270	150	189	101	190	126	158
Others	56	66	56	61	79	96	-8	56	59	99	46	78	62

* The average of the five first/lasts transactions.

Despite these similarities, the period-1 outcome and the period-2 outcome differ substantially with respect to how prices evolved. In three of the four period-1 observations prices converged to *p** from below, see **Figures 2–9**. The exception is period 1.1 where the outcome was a flat price path somewhat below *p**. In three of the four period-2 observations the outcome was a relatively flat price path quite close to *p**. The exception is period 2.2, in which prices set out from a low level and converged to *p** just before the market closed.[22] Given this difference in price paths[23] it is not surprising that the trade gain distribution is closer to the competitive case in the period-2

[21] The relatively low efficiency in periods 1.1 and 4.1 is to a large extent due to the behavior of subjects other than those representing the US. For instance, in period 1.1, the subject representing Sweden would have benefited from buying, but chose to sell emission quota units. Similarly, in period 4.1, the subject representing Japan sold large quantities of quota units. Due to the high MACs of Japan and Sweden, "low-cost" abatements were replaced with "high-cost" ones, which reduced market efficiency.

[22] Given the mistake made in period 2.1 by the subject representing Germany (see footnote 19), it can be questioned whether the outcome in period 2.2 should be interpreted as the result of emissions trading among experienced traders having common and accurate expectations regarding *p**.

[23] The hypothesis of the relative deviation of initial prices from *p** being equal in period 1 and period 2 is rejected by the so-called Permutaion tests in favour of the alternative of higher prices in period 2 at the 12.5-% level, the lowest possible level given the small number of observations available here. The same goes for average prices.

outcome than in period-1. **Tables IV** and **V** that show the outcomes in period 1 and period 2 in session 5, respectively, illustrate this result. Since essentially all potential cost savings were realized in these periods (99% and 100%, respectively) the difference in trade gains is mainly due to the differences in price paths, see Figures 8 and 9.

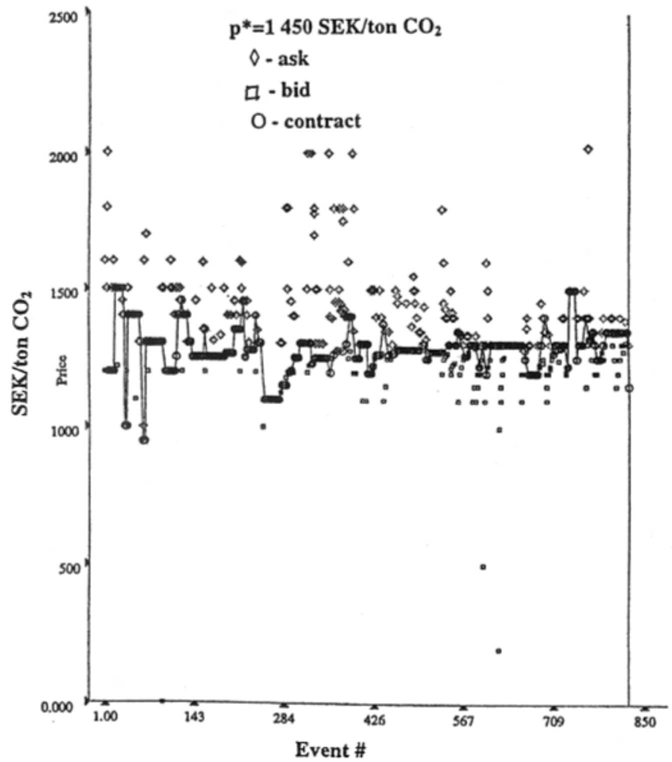


Figure 2. Period 1, Session 1

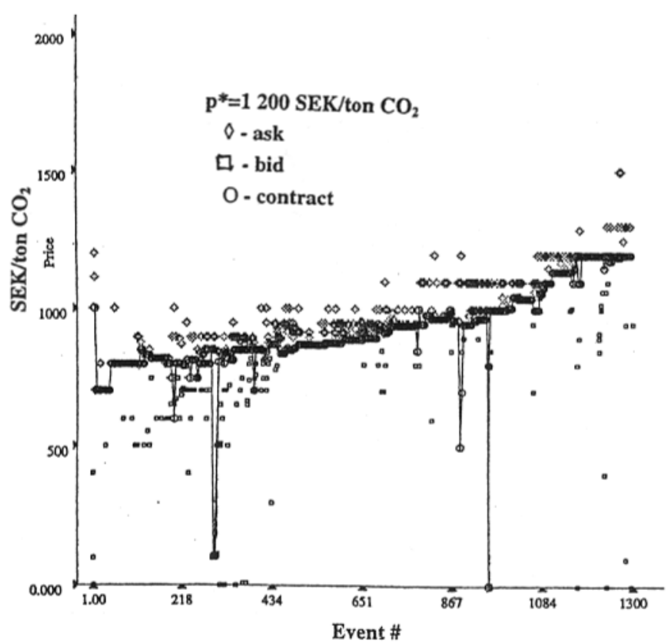


Figure 3. Period 2, Session 2

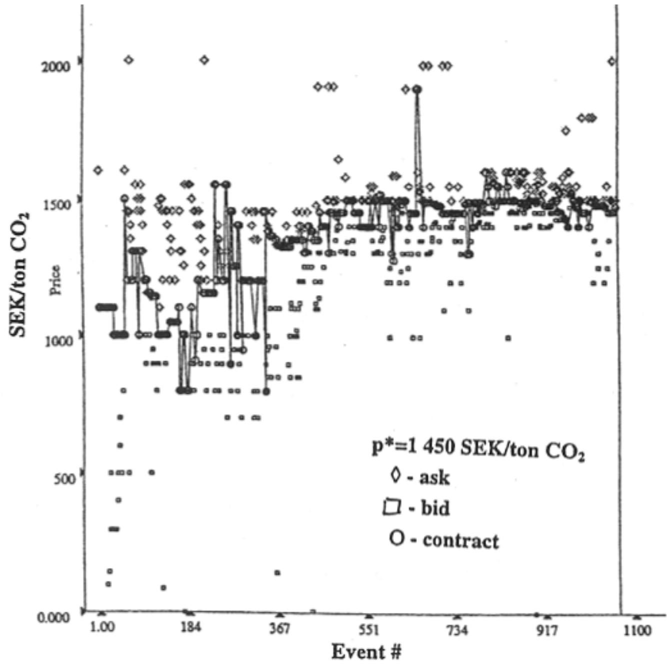


Figure 4. Period 1, Session 3

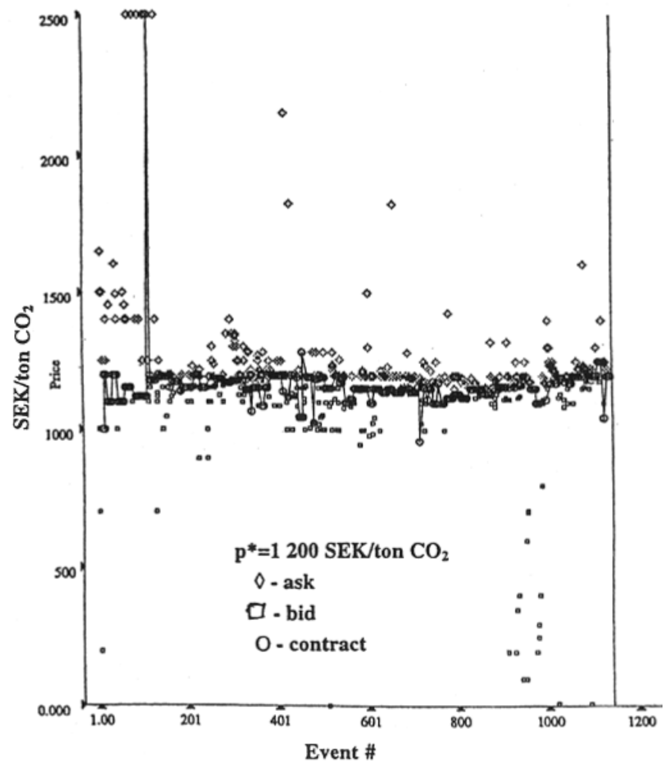


Figure 5. Period 2, Session 3

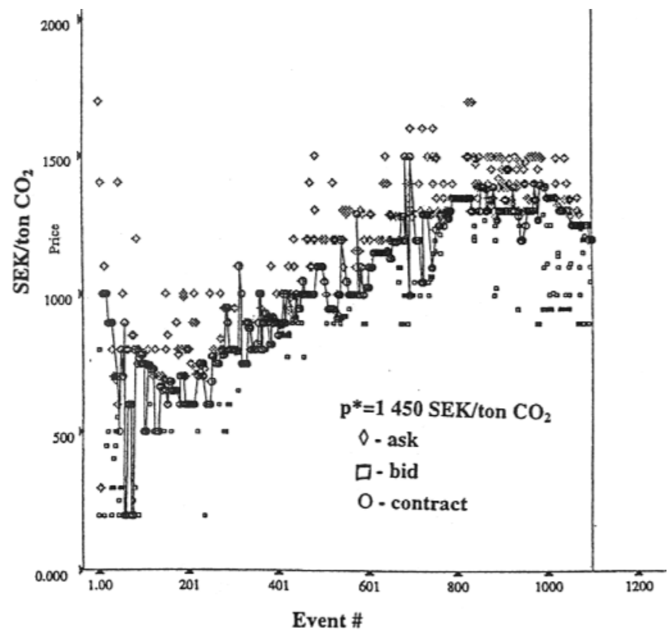


Figure 6. Period 1, Session 4

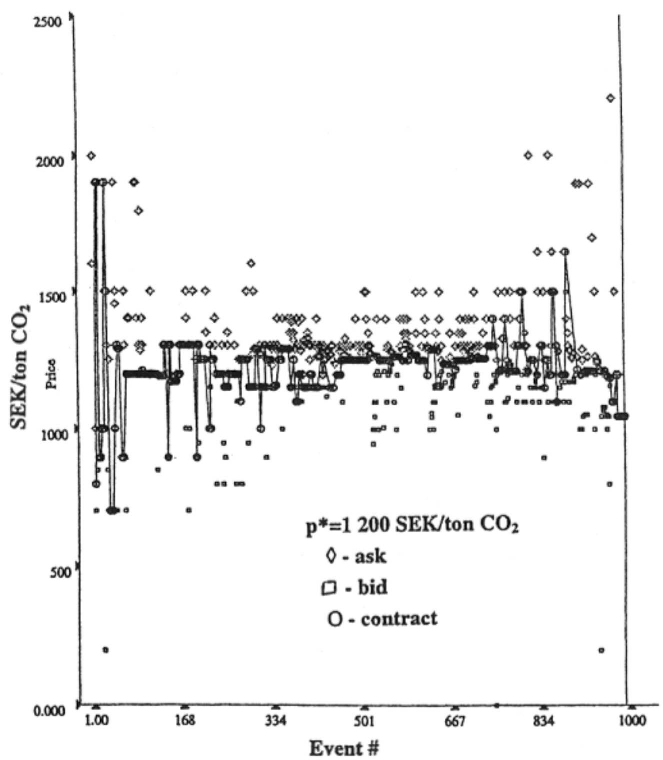


Figure 7. Period 2, Session 4

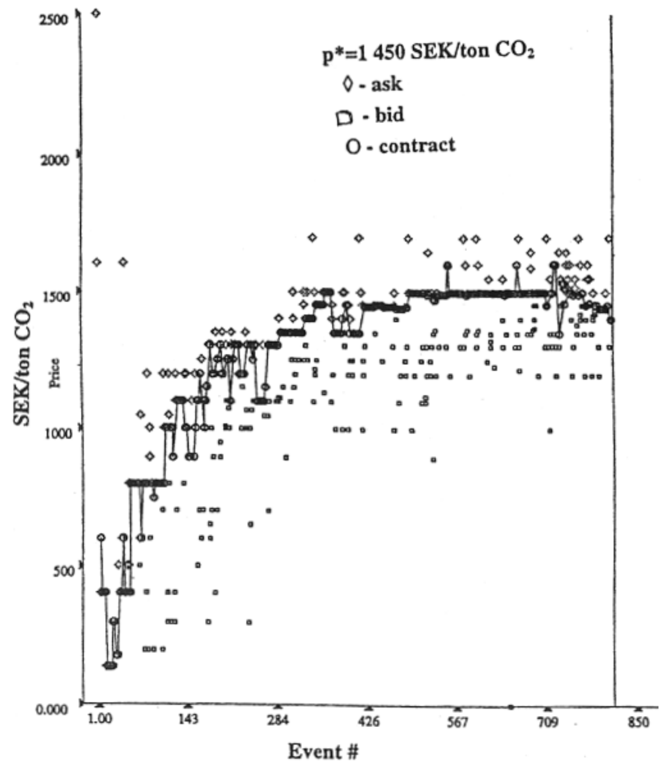


Figure 8. Period 1, Session 5

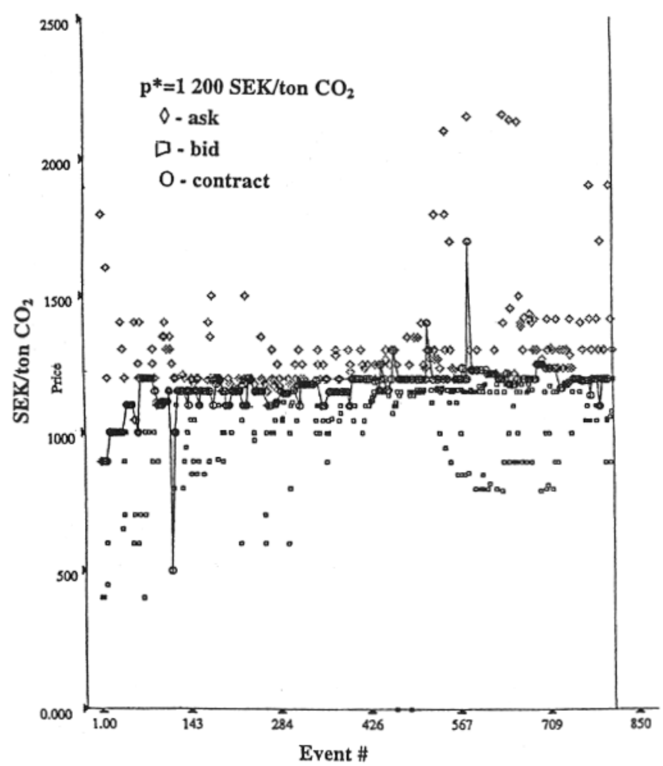


Figure 9. Period 2, Session 5

Table IV. Outcome in period 1, session 5, Mton CO_2 and SEK billion, respectively

	p* = MSEK 1,450/Mton				
	Unilateral		Emission reduction *ex post* trade:		
	Emission reduction	Cost	Mton	Cost	Net gain
Belgium	12	2.20	31	16.9	13.0
Germany	220	66.0	286	129	111
Greece	0	0	21	10.3	8.84
Spain	0	0	60	31.2	20.2
France	25	12.7	25	12.7	1.02
Italy	80	32.0	108	62.9	4.86
Netherlands	30	11.2	48	30.7	5.37
Portugal	6	0.90	18	9.88	0.50
Sweden	15	18.0	9	6.52	7.86
UK	80	19.3	244	180	-55.7
US	1,900	1,477	1,556	872	200
Japan	400	271	362	208	21.7
Total	**2,768**	**1,910**	**2,768**	**1,571**	**339**

Table V. Outcome period 2 in session 5, Mton CO_2 and SEK billion, respectively

	p* = MSEK 1,200/Mton				
	Unilateral		Emission reduction *ex post* trade:		
	Emission reduction	Cost	Mton	Cost	Net gain
Belgium	10	1.56	33	18.4	10.1
Germany	210	63.0	274	118	32.2
Greece	0	0	20	9.80	11.8
Spain	0	0	53	29.0	27.8
France	25	9.84	36	20.7	2.30
Italy	70	28.0	104	61.8	5.07
Netherlands	25	8.93	40	23.0	2.99
Portugal	10	2.08	20	9.80	2.86
Sweden	15	17.2	8	4.80	5.50
UK	85	18.1	240	144	58.2
US	1,950	1,352	1,615	828	123
Japan	380	223	337	167	7.60
Total	**2,780**	**1,724**	**2,780**	**1,435**	**290**

The period-1 outcomes seem to suggest that the dominant buyer was successful in conducting inter-temporal price discrimination. However, the fact that the prices paths in the period 2 results lie closer to the efficient level (with the exception of period 2.2.) indicates that even if the subject representing the dominant buyer was able to substantially manipulate the market to their advantage in the first period, they were not able to do so to the same extent in the second period. Still, we cannot reject the hypothesis that the mean price equals the monopsony price and the subjects representing the US were able to gain more than the competitive profit level. Further tests are needed to discriminate between potential reasons for this occurrence, which (besides market manipulation) include (i) that large traders have an advantage over small traders in speculative trade, (ii) the fact that the subjects playing the role of US were more sophisticated than those representing the other countries, and (iii) the fact that subjects have more experience as buyers than as sellers, as suggested by Smith and Williams (1982).

Given the extensive efforts made to train and inform the subjects in ways compatible with the field, but different from the approach commonly used in Experimental Economics, the stark difference between the period-1 outcome and the period-2 outcome is somewhat puzzling. The former resembles the outcomes observed in DA experiments where subjects only had private information regarding their MACs and, hence, no or only limited information about the efficient price level (see *e.g.*, the outcome in the early periods of Smith and Williams, 1989, and the outcome in Muller *et al*.). It may be the case that, in spite of the efforts made to train and inform them, the subjects needed an opportunity to trade at least once under conditions similar to those used in the test in order to acquire the competence of experienced traders and/or to learn to trust the information given to them. If so, only the period-2 outcome would reflect the case where experienced traders have accurate expectations.

If subjects in period 1 for some reason distrusted/disregarded the information about expected MACs and the competitive price,[24] another possible explanation would arise for the price paths observed in that period, namely that the they have been driven by the “convergence bias” phenomenon (discussed in Section 4) rather than by the dominant trader exerting market power. It is therefore interesting to note that Muller *et al*., which use a design that controls for convergence bias, find strong evidence of price discrimination in a situation where traders only know their own costs/values.

6. CONCLUDING REMARKS

The experiment reported here investigates a case of intergovernmental carbon emissions trading towards the end (say, the last six months) of a five-year-long compliance period with one country (the US) assumed to account for about 90% of the net-trade volume as a buyer. Trade is governed by double auction rules. Since a seller country in an equally dominant position would face similar incentives to exert market power as the buyer country studied here, the outcome of the experiment is taken to be valid also for the case of a dominant seller. The tested hypotheses were that if the end of the five year long compliance period is characterized by essentially complete information regarding the underlying net demand, (i) the presence of a large trader is not likely to create inefficiencies, and (ii) a large trader is not likely to be able to substantially influence prices to its advantage, during the end-period trading.

The main finding of the experiment is that trade is indeed highly efficient. In six of the eight trading periods of the experiment more than 95% of the potential (maximum) trade gains materialized. In other words, we do not observe that the dominant buyer country exerts market power by withholding demand from the market as predicted by standard economic theory.

[24] Presuming otherwise seems unreasonable since the period-1 outcome then would imply that subjects consciously gave away money to the dominant buyer.

Since the experiment presented here was designed to parallel important conditions of real intergovernmental emissions trading, the outcome casts doubts over the validity of assessments of market power effects in international carbon emissions trading that indicate substantial efficiency losses.

In four of the eight trading periods, trade generated rather flat price paths, quite near the competitive (efficient) price level. Three of these periods represented a second trading period of the experiment. In the other four periods, prices converged towards the efficient level from below giving the dominant trader substantially larger trade gains than had the market been perfectly competitive. The fact that three of these four cases represent the first trading period of the experiment indicates that even if the subjects representing the dominant buyer were able to substantially manipulate the market to their advantage in the first period, they were not able to do so to the same extent in the second period.

The difference between the outcomes in the first trading period and the second trading period may be because subjects, despite the extensive efforts made to train and inform them in ways compatible with the field, needed to trade at least once under conditions similar to those used in the test in order to acquire the competence of experienced traders and/or to fully trust the information given to them. If so, only the outcome in the second period would reflect trade between experienced traders equipped with accurate expectations regarding the efficient price level, as real-world trading would have it. Given the small number of observations produced here, further tests is needed to establish whether well-trained traders would tend to generate predominantly flat price paths close to the competitive level.

Acknowledgements

The author thanks Peter Bohm, Henry Jacoby, Svante Mandell, Ian Sue-Wing, and three anonymous referees for valuable comments. Financial support from the Swedish Energy Administration and the Knut and Alice Wallenberg Foundation is gratefully acknowledged.

7. REFERENCES

ABARE (1995). *Global Climate Change: Economic Dimensions of a Cooperative International Policy Response beyond 2000*, ABARE, Canberra.

Baron R. (1999). *Scooping paper on Market Power*, OECD paper, Economics Directorate, OECD, Paris.

Bohm P. (1997). *Joint Implementation as Emission Quota Trade: An Experiment Among Four Nordic Countries*, Nord 1997:4, Nordic Council of Ministers, Copenhagen.

Bohm P. (forthcoming). “Experimental Evaluation of Policy Instruments” in *Handbook of Environmental Economics* (K. G. Mäler and J. Vincent eds.), Elsevier.

Bohm P. and B. Carlén (1999). “Emission quota trade among the few: laboratory evidence of joint implementation among committed countries”, *Journal of Resources and Energy Economics* **21**: 43-66.

Brown S. et al. (1997). *The Economic Impact of International Climate Change Policy,* ABARE Research Report 97.4, Canberra.

Burniaux J-M. (1999). *How important is market power in Kyoto? An assessment based on the Green Model*, OECD paper, Economics Directorate, OECD, Paris.

Capros P. T., Georgakopoulos, S. Kotsomiti and A. Filippoupolitis (1997). *Macro-economic Implications of the "Kyoto" CO_2 Target for the EU*, Report to European Commission DG-XII under Climate Technology Strategy JOULE Project, National Technical University of Athens.

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

Easley D. and J. O. Ledyard (1993). "Theories of Price Formation and Exchange in Double Oral Auctions", in The Double Auction Market—Institutions, Theories and Evidence, Santa Fe Institute.

EU (1996). *Quantified Emission Limitation and Reduction Objectives within Specified Time Frames,* Ad Hoc Group on Climate Italian Presidency, Rome.

Friedman D. (1991). "A Simple Testable Model of Double Auction Markets", *Journal of Economic Behavior and Organization* **15**: 47-70.

Friedman D. (1993). "The Double Auction Market Institution: A Survey", in *The Double Auction Market—Institutions, Theories and Evidence*, Santa Fe Institute.

Gjerdstad S. and J. Dickhaut (1995). *Price Formation in Double Auctions*, Discussion Paper No. 284, Department of Economics, University of Minnesota.

Godby R. W. (1999). "Market Power in Emission Permit Double Auctions", *Research in Experimental Economics* **7**.

Hahn R. W. (1984). "Market Power and Transferable Property Rights", *Quarterly Journal of Economics* **99**: 753-65.

Hertwig R. and A. Ortmann (2001). Experimental Practices in Economics: A Methodological Challenge for Psychologists?, *Behavioral and Brain Science* **24**: 383-451.

Hizen Y. and T. Saijo (forthcoming). "Designing GHG Emissions Trading Institutions in the Kyoto Protocol: An Experimental Approach", *Environmental Modeling and Software*.

Hoffman, E., K. McCabe, K. Shachat and V. Smith (1994). "Preferences, Property Rights and Anonymity in Bargaining Games", *Games and Economic Behavior* **7**(3): 346-380.

Hoffman, E., K. McCabe and V. Smith (2000). "The Impact of Exchange Context on the Activation of Equity in Ultimatum Games", *Experimental Economics* **3**: 5-9.

Holt C. A. (1995). "Industrial Organization: A Survey of Laboratory Research", in *The Handbook of Experimental Economics* (J. H. Kagel and A. E. Roth eds.) Princeton University Press.

Holt C. A., L. Langan and A. Villamil (1986). "Market Power in Oral Double Auctions" *Economic Inquiry* **24**: 107-23.

IPCC (1996). *Climate Change 1995 - Economic and Social Dimensions of Climate Change,* Cambridge University Press.

Ledyard J. O. and K. Szakaly-Moore (1994). "Designing Organizations for Trading Pollution Rights", *Journal of Economic Behavior and Organization* **25**: 167-96.

Lowenstein G. (1999). “Experimental Economics From the Vantage-Point of Behavioural Economics”, *The Economic Journal* **109**: F25-F34.

Muller R. A., S. Mestelman, J. Spraggon and R. W. Godby (2001). “Can Auctions Control Market Power in Emissions Trading Markets?”, forthcoming in *The Journal of Environmental and Economic Management*.

Plott C. R. (1989). “An Updated Review of Industrial Organization: Applications of experimental methods”, in *Handbook of Industrial Organization*, vol. II (R. Schmalensee and R. D. Willig, eds.) Amsterdam: North Holland, 1109-76.

Plott C. R. (1991). *A Computerized Laboratory Market System and Research Support System for the Multiple Unit Double Auction,* Social Science Working Paper No. 783, Caltech.

Sandor R. L., J. B. Cole and E. M. Kelly (1994). “Model Rules and Regulations for a Global CO_2 emissions Credit Market”, in *Combating Global Warming*, United Nations, New York.

Siegel S. and N. J. Castellan Jr. (1989). *Nonparametric Statistics for the Behavioral Sciences*, McGraw-Hill International Editions.

Smith V. L. (1981). “An Empirical Study of Decentralized Institutions of Monopoly Restraint”, in *Essays in Contemporary Fields of Economics in Honor of E. T. Weiler (1914-1979)* (J. Quirk and G. Horwich, Ed.) West Lafayette: Purdue University Press, 83-106.

Smith V. L. (1982). “Microeconomic Systems as an Experimental Science”, *American Economic Review* **72**: 932-955.

Smith V. L. and A. W. Williams (1982). “The Effects of Rent Asymmetries in Experimental Auction Markets”, *Journal of Economic Behavior and Organization* **3**: 99-116.

Smith V. L. and A. W. Williams (1989). “The Boundaries of Competitive Price Theory: Convergence, Expectations, and Transaction Costs”, in *Advances in Behavioral Economics*, vol. 2, (Green L. and J. Kagel, Norwood, eds.), NJ, Ablex Publishing Co.

Søberg M. G. (2000). “Price Expectations and International Quota Trading: An Experimental Evaluation”, *Journal of Environmental and Resource Economics* **17**(3): 259-277.

United Nations (1992). *United Nations Framework of Climate Change Convention*, Rio de Janeiro.

United Nations (1997). *Kyoto Protocol to the United Nations Framework Convention on Climate Change*, Kyoto.

Westskog H. (1996). “Market Power in a System of Tradable CO_2 Quotas”, The *Energy Journal* 17(3): 85-103.

APPENDIX
Instructions

The subjects received written information on two occasions. Two days before the experiment, they were given information common to all subjects. At the beginning of the experiment, each subject received private information about which country he/she was assigned to, the updated abatement cost schedule of that country, and his/her payoff factor. This final section reproduces the information common to the subjects and, for illustration, the private information given to the subject representing country #0. Text in bold within parenthesis serves as explanations to the reader of this paper.

COMMON INFORMATION (TRANSLATED FROM SWEDISH)

A1. Background

You will participate in an experiment that seeks to shed some light on the possibilities to, by the means of so-called emission trading, reduce the costs of a climate treaty with the objective of preventing significant changes in the global climate.

> *Background*: The global community faces the following threat. The growing concentration of so-called greenhouse gases (GHGs) in the atmosphere runs the risk of leading to an increase in the average global temperature.[25] Such a climate change, if large, may give rise to rather drastic consequences, such as changes in the wind and sea currents, reduced food production, higher sea level, and a desertification. The conditions for localization of settlements, farming and industries would thereby be affected, resulting in possibly large population movements. The international community has taken this threat seriously. At the UN's conference on environment and development in 1992 in Rio de Janeiro, the so-called Climate Convention was adopted. The objective of the Climate Convention is to stabilize the concentration of GHGs in the atmosphere at such a level and within such a time frame that the above-mentioned changes will not be drastic and that the ecological systems can adjust more slowly.
>
> The single most important GHG is carbon dioxide (CO_2). CO_2 is emitted to the atmosphere mainly through combustion of fossil fuels. There exists no economically feasible technique to separate CO_2 from other emissions of fossil fuel combustion. Thus, in order to prevent climate changes the use of fossil fuels has to be reduced. A specific feature of GHGs is that their effect on the global climate does not depend, to any significant extent, on where the emission source is located.

Over 160 countries have signed the Climate Convention. In December last year (1997), these countries gathered in Kyoto, Japan, to negotiate over country specific emission targets for CO_2 for the period after the year 2000. The Kyoto-meeting resulted in a proposal to a climate treaty comprising a set of quantitative emission targets for the industrialized countries. If a sufficiently large number of countries ratify the proposal, the treaty will come into force. In what follows it is assumed that this is the case and that the Kyoto-protocol has entered into force. The emission quotas (targets) for the largest OECD-countries are presented in **Table A1** below.

---

[25] GHG are gases that restrict the radiation of heat from the earth.

The costs of reducing the CO_2 emissions differ between countries. A given aggregated emission target for a group of countries is attained at lowest possible cost when each country has reduced its emissions by the amount that yields equality in marginal abatement costs for all countries. Lower emissions of CO_2 presupposes a limitation of the use of fossil fuels, which dominates the majority of the industrialized countries energy system, whereby abatements of CO_2 are associated with large costs for these economies. Cost-effectiveness, *i.e.*, to minimize these costs, is therefore of great importance for international climate change policy.

The ambition of the Kyoto-meeting was to find an allocation of national emission quotas that as many countries as possible could accept. In order to facilitate a cost-effective allocation of the aggregated emission reduction the, Kyoto Protocol allows countries committed to binding emission targets to engage in emission trading. Countries with high marginal abatement costs can on such a market pay countries with lower costs to reduce their emissions by more than what their national emission quotas imply so as to make all involved countries gain from this trade. Trade with emission quotas does not differ in any important aspect from trade with other goods and services. On a competitive market an equilibrium price would be established so that the marginal abatement costs in different countries are equalized, *i.e.*, the cost-effective allocation of emission reductions is attained.

The objective of this experiment is to study the performance of trade with CO_2 emission quota units when trade is conducted on a stock-exchange kind of market and when the countries engaged in trading are of different sizes.

A.2 The Experiment

The experiment intends to mimic the following assumed situation. A group of 12 countries committed to the national emission targets allotted to them by the Kyoto-meeting (see Table A1) has decided to use the possibility that the Kyoto Protocol gives to emission trading and to establish an organized market for emission quota units. With this possibility to trade each country has to choose between:

(a) reducing its national emissions by more than necessary and sell the surplus of emission quota units to some other country(-ies),

(b) increase its own emission quota (target) buy paying some other country(-ies) to reduce their emissions, or

(c) attaining its emission target only by reducing its own emissions.

Trade with emission quota units will be governed by so-called double-auction rules. (The set of rules that governs the majority of the large stock exchanges and markets for primary goods throughout the world.) In the experiment, the market will be electronic, something that has been more and more common among the large stock markets. Each country is connected to the market through a computer terminal. When the market is open a country that wants to buy can *via* its computer send a buy order (unit price and number of units) to a central computer. A country that wants to sell can in the same manner send a sell order (unit price and number of units). The buy order with the highest price and the sell order with the lowest price are made public as the standing bids. This information is shown on each country's computer monitor. The standing buy order (sell order) is replaced when the central computer receives a higher (lower) buy order (sell order). This rule tends to give adjustments of declining sell orders and ascending buy orders until some agent accepts to trade to the standing sell/buy price. When a country accepts the standing buy (sell) order (or part thereof), this order is removed (or reduced by the accepted volume). All acceptances of standing sell/buy orders lead to binding transactions. This double-auction market does not use any order book/queue. The implication of this is that when the volume of a standing bid/ask has been accepted the next buy/sell order the central computer receives will be the standing bid. It is possible for a lower (higher) buy (sell) order to become the standing bid. The price levels at which emission quota units are traded can therefore increase and decline during the trading period.

On this market it is assumed that the trade unit is 1 Mton. That is, quantities offered/asked can be amounts such as 7 Mton, 3 Mton and 1 Mton. Prices can only be stated in terms of whole MSEK/Mton.

Countries that will engage in real emission trading have strong incentives to gather information about each other's expected emission levels. Table A1 presents the countries' expected CO_2 emission levels in year 2010 and their emission targets that year. The emission reduction each country is responsible for amounts to the difference between the expected emission level and the emission quota (target).

Table A1. Emission levels and emission reductions in year 2010, millions ton CO_2

	Emissions 2010	**Emissions target 2010**	**Emissions reduction 2010**
Country #0	112	100	12
Country #1	970	750	220
Country #2	90	90	0
Country #3	250	250	0
Country #4	395	370	25
Country #5	460	380	80
Country #6	170	140	30
Country #7	63	57	6
Country #8	80	65	15
Country #9	610	530	80
Country #10	6,500	4,600	1,900
Country #11	1,400	1,000	400
Total	**11,100**	**8,332**	**2,768**

The countries would also have strong incentives to collect information about each other's costs of reducing emissions of CO_2. It is unlikely that countries would be able to successfully disguise from other countries large abatement opportunities and the cost of these. Therefore, it is assumed that the countries have been so successful in gathering information about each other's costs measures that they have common expectations about these cost schedules.

With the concept of marginal abatement cost (MAC) is here meant the cost of reducing the emissions of CO_2 by one unit. MAC is the sacrifice (the value of the reduction in consumption and production) a country needs to do in order to reduce its emissions of CO_2. In Appendix 1 the countries' MACs are presented in diagrams. **Figure A1** below illustrates such a diagram for an assumed country.

Figure A1 illustrates country Xempel's net-demand curve for CO_2 emissions, equal to the country's marginal valuation (MV) of emissions. Without any climate treaty the country would increase its emissions until its valuation of further emissions equals zero, *i.e.*, the country's emission level would be where the MV-curve intersects the x-axis. This level is the forecasted emissions level and is labeled business-as-usual (BAU) level. Emission levels below the BAU level imply that incomes are sacrificed, *i.e.*, costs for the country. The costs of reducing emissions from the BAU level is indicated by the MV-curve read from right to the left. The curve thus, illustrates the country's marginal costs of reducing CO_2 emissions.

The vertical line in the diagram marked with target level (the target line) states the emissions level the country is committed to not to exceed. In case a country chooses to accomplish its emission target unilaterally, *i.e.*, only by domestic emission reductions, the country's MAC equals the level at which the MV-curve intersects the target line. A country's total cost of attaining its emission target unilaterally is given by the area under the MV-curve between the target level and the BAU-level (the shaded area).

In order to avoid talking about prices that can be perceived as related to the real experimental situation, we use in this and subsequent examples a hypothetical monetary unit, MFrang.

[*image intentionally omitted*]

Figure A1. Country Xmple's Marginal valuation (marginal cost) of emissions, MFrang/Mton CO_2. **(*For an illustration of this type of diagram the reader is referred to Figure 1 in the main text.*)**

The point of departure for interpreting this type of diagram is that the country in absence of trade will be at the point where the MV-curve intersects the target line. A country can make trade gains by purchasing emission quota units, *i.e.*, increasing its emission quota, to prices lower than the country's valuation of additional emissions (marginal cost of reducing its emissions). Similarly, a country makes trade gains also by selling emission quota units, *i.e.*, reducing its emissions by more than required by the emission target, to prices that are higher than the country's marginal abatement cost. Figure A1 shows that country Xmpel's MV-curve and target level give an underlying demand/supply schedule such that the country can make trade gains by selling quota units (go to the left from the target line) at prices above 300 MFrang/Mton and/or purchasing emission quota units (go to the right from the target level) at prices lower than 300 MFrang/Mton. Hence, whether country Xmpel will act as a seller or a buyer of emission quota units depends on the price levels that are established on the market. It is possible that the price path is such that country Xmpel finds it profitable to first act as a buyer and then as a seller, or *vice versa*.

As shown in Appendix 1, the expected MAC differs among the countries. These differences reflect *i.a.* differences in endowments of energy, geographical and economical conditions. If each country chooses to accomplish its emission target unilaterally, the MACs would vary between 0 MSEK/Mton (country #2 and country #3) and 2,400 MSEK/Mton (country #8). Hence, the aggregated emission target can be attained at lower costs if the countries engage in emission quota trade.

Maximum potential trade gains

Given information about the countries' expected MV-curves and emission targets (Table A1) the countries' expected underlying demand/supply schedules for emission quotas could be calculated. (Individual countries' as well as the aggregate underlying demand/supply conditions are presented in Appendix 1) Equipped with this information, it is possible to calculate the (expected) perfectly competitive outcome. This gives information about the expected efficient price (*p**), the countries' net demand and supply at this price level and an idea of how trade gains are distributed among countries in the case price levels on the market would not deviate much from the expected efficient level. Under perfect competition the market price is such that the countries' MAC would be equalized. The expected efficient price would amount to 1,500 MSEK/Mton and the trade among the 12 countries to 395 Mton. This trade and the associated surplus would be distributed as shown by Table A2.

Table A2. Trade under perfect competition, Mton CO_2 and SEK billion, respectively

			***p** = MSEK 1,500/Mton**				
	Unilateral		Emission reduction *ex post* trade:				
	Emissions reduction	Cost	Mton	Cost	Net gains:	% of unilateral cost	SEK per capita
#0	12	2.00	36	22.5	15.5	775	1,532
#1	220	66.0	285	131	32.2	49	396
#2	0	0	22	11.5	21.5		2,062
#3	0	0	59	33.3	55.2		1,410
#4	25	13.8	34	25.4	1.80	13	32
#5	80	32.0	110	66.5	10.5	33	184
#6	30	11.2	45	26.2	7.50	67	488
#7	6	0.90	17	9.50	15.6	878	1,574
#8	15	17.2	10	7.50	3.00	13	342
#9	80	20.0	240	180	80.0	400	1,370
#10	1,900	1,503	1 550	878	100	7	385
#11	400	275	360	207	8.00	3	64
Σ	**2,768**	**1 941**	**2 768**	**1,598**	**343**	**18**	**467**

The difference between column 2 and 4 states the countries' expected net trade under perfect competition. A negative value indicates that the country is a net seller and a positive value that the country is a net buyer. In the case illustrated in Table A2 three countries appear as net buyers (countries #8, #10 and #11) and nine countries as net sellers. Note that the buyer side is strongly concentrated with a single agent (country #10) answering for almost 90% of the demand at the efficient price level.

As indicated earlier, countries have strong incentives gather information about each other's underlying demand/supply conditions prior to the emission quota trade, whereby the remaining uncertainty would be quite small. Before trade begins on Wednesday (9/12) you will receive updated information about the underlying demand/supply schedule (the true MV-curve) for the country you will represent.

The trading situation/traders' information

It is not obvious that all, if any, trade will be conducted at *p** so that the outcome would be as Table A2 indicates. On an exchange as this one, different transactions can be concluded at different prices. Moreover, no agent can be taken as a price taker, no matter how small it is. Each\ country decides what price and quantity to bid (and at which point in time to send it) and at which price levels he/she is willingly to accept to buy/sell emission quota units. Thus, realized prices are determined by negotiations. At this market <u>all transactions are binding, *i.e.*, they cannot be annulled.</u> This means that additional trade will not affect revenues and expenditures of agreements already concluded. The implication of this is that each agent has incentives to buy/sell additional quota units as long as the standing sell/buy price (the price at which someone is willingly to sell/buy quota units) is lower/higher than the agent's MAC. This implies that <u>this type of market tends to generate buy/sell prices at the end of the market day that lie close to *p**.</u> It has been shown that this is true also for the cases where initial buy/sell prices deviate significantly from the efficient level.

In a real trading situation large values will be at stake. The countries can therefore be expected to engage experienced and competent traders to represent them at the market for emission quota units. As accounted for above, traders on this market can be taken to being well informed about other countries' expected underlying demand/supply conditions and thereby having a pretty good perception about *p**. Experienced traders are familiar with the functioning of this type of markets and, in particular, that it tends to generate end (marginal) prices close to the efficient level. Such traders are also aware of the <u>opportunity for profitable speculative trade that arises if the price would deviate substantially from *p**.</u>

By profitable speculative trade is meant the following. If the standing buy price during a period would be significantly higher than *p** and later on converge to that level, it would be possible to make trade gains by selling emission quota units during the "high-price" period and buy them back later on when the price has declined. Correspondingly, it would be possible to make profitable speculative trade if the standing sell prices during a period were lower than *p**. Experienced traders monitor the market carefully in order to trade at best possible prices and, when the opportunity arises, take advantage of price variations.

Hence, the scope of profitable speculative trade implies that a trader may have incentives to buy/sell larger volumes than his/her country's underlying demand/supply schedule actually indicates. A trader that represent a country with a large underlying net demand of quota units (at prices around *p**) and who is convinced that prices at the end of the trading period will be close to *p** might act as follows. At sell prices above *p** he/she will withhold demand and may even try to sell quota units if the price difference is sufficiently large, in order to buy emission quota units at lower prices later on. At sell prices below *p** the trader will buy large volumes, even more than the underlying demand/supply schedule actually permits, with the prospects of selling these units at higher prices later on.

Correspondingly, a trader representing a country with a large underlying supply (at the efficient price level) might act as follows: At buy prices below *p** the agent will withhold supply and it might even buy quota units in order to sell these units at a higher price later on. At buy prices that exceed the efficient level by much, the trader might try to sell large volumes, with the ambition to buy them back later on when the prices are lower.

To sum up: On this kind of exchange, the price of emission quota units can vary during the trading period. However, prices at the end of the trading period tend to lie close to the efficient price level. Real traders can be taken to observe the market carefully in order to trade at best possible prices and, if the opportunity arises, try to make speculation profits. So, current demand (supply) may deviate from the sum of all countries' underlying demand/supply schedules. With experienced and well-informed traders it is possible that the demand for quota units, when sell prices are below the efficient level, may well exceed the underlying demand of the market. At instances when buy prices are above the expected price, it is, correspondingly, possible that a supply far greater than the underlying supply of the market is materialized.

Please observe! Even if, as has been emphasized here, all traders/countries have strong incentives to collect information about other countries' MV-curves, it has to be stressed that no one with 100% certainty can know whether the available information is correct or if this information actually will guide the trade. Moreover, it is also possible, of course, that information about the conditions in other countries contains certain approximations. Political aspects of potential abatement measures in a country may lead to other decisions about such measures than those reflected by the calculated MV-curves. Even if these uncertainties, due to the incentives for information gathering, can be expected to be very small, it is possible that they affect the basis for the trade of marginal units, *i.e.*, when trade gains for involved parties according to the given information are small. So, there will be a remaining uncertainty about the efficient price level. This uncertainty is reflected on the market that you will trade on in the way that the information about the MV-curves of the countries that is presented in Appendix 1 may deviate somewhat from the true MV-curves. This means that each trader will, just before the market opens for trade, receive an updated version of the MV-curve of the country he/she will represent.

A3. Your Assignment

On Wednesday your will represent one of the above presented countries (country #0 - 11) on the market for emission quota units. Your assignment is to minimize your country's costs of achieving the emission target it is committed to through the Kyoto Protocol.

The point of departure is that the country has calculated the relevant costs for unilaterally attaining its emission target and has given to its trader, you, a trading budget that enables you to act on the market for emission quota units. If you accomplish the country's emission reduction at a lower cost than the one of attaining the target unilaterally by purchasing (selling) emission quota units at prices below (above) your country's MAC, *i.e.*, making trade gains, you will be paid a certain fraction of this trade gain. On Wednesday you will receive information about the size of this fraction. At that time you will also be given private information about which country (of the countries #0 - 11) you will represent and that country's true underlying demand/supply schedule. Your expected payment amounts to 400 - 500 SEK.

Below is presented, for the one that wishes to confirm that he/she has understood the text above, a stylized example of how country Xmpel can act on the emission quota market. As has been mentioned earlier, we use in our examples a hypothetical monetary unit, MFrang, in order to avoid talking about prices that can be perceived as related to the real experiment situation.

Example

Assume that you represent country Xmpel, which is committed to an emission reduction of 8 Mton and has MAC according to Figure A1. The costs of the country attaining its emission target unilaterally amounts to 1,2000 MFrang. (The shaded area.) A possible sequence of happenings is the following. At the beginning of the trading period you announce a sell order, which becomes the standing sell order: 1 Mton at the price 500 MFrang/Mton. This bid, if accepted, would give your country a trade gain of:

$$150\ MFrang\ (= 500\ MFrang \times 1\ Mton - \frac{(400 - 300) MFrang}{2} \times 1\ Mton - 300\ MFrang \times 1\ Mton,$$

where the first term states revenues and the other two the area beneath the MC-curve in the interval 16 to 17 Mton). Assume, however, that this bid was not accepted. We assume that you, after a relative short period find out that there exist countries willingly to sell quota units at prices around 200 MFrang/Mton, a price level at which you are prepared to buy 2 Mton. You send a bid with the content that you accept to buy 2 Mton at the price 200 MFrang per Mton, which is registered before any other buy bids/acceptances. Therefore, a transaction with that content is conducted. This trade gives your country a trade gain of:

$$100\ MFrang\ (= 200\ MFrang \times 2\ Mton + \frac{(300 - 200) MFrang}{2} \times 2\ Mton - 200\ MFrang \times 2\ Mton,$$

where the two first terms states the abatement costs country Xmpel avoids by conducting this trade and the third terms states the import expenditures.). Thereafter you find that the standing asks and bids lay around 200 MFrang, price levels which do not allow you to make any larger trade gains. After a while the market has closed. Your net trade is a purchase of 2 Mton for country Xmpels account, i.e., country Xmpel is allowed to emit 19 Mton instead of 17 Mton.

According to this example, Country Xmpel's trade gains (= avoided abatement cost – net expenditures) are 100 MFrang.

Thus, the result of this trade is that country Xmpel attains the emission reduction it is committed to at a lower cost than had the country attained its emission target unilaterally (*i.e.*, if it would have conducted the whole emission reduction solely by domestic actions). As mentioned above, your payment is proportional to the trade gain of the country you represent. Hence, the payment you receive after the experiment depends on how successful you are at the market for emission quota units.

It is not necessarily for you to continuously calculate your country's accumulated trade gains to be able to act successfully on the market. It suffices to be able to determine relatively fast whether or not your country will gain from conducting different transactions. The important thing is to be able to calculate how your country's abatement costs change due to the transaction. Therefore, we ask you to practice on how to calculate changes in the abatement costs.

A way to train on acting on this kind of market is that you by yourself play the role of a couple of typical countries and contemplate how you would act given different price paths.

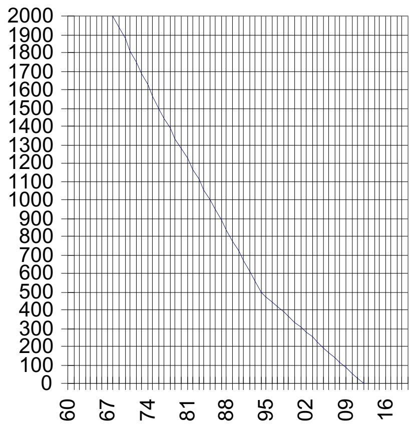
A4. Other Things

On Wednesday you will, prior to the experiment, be given the opportunity to practice on the type of electronic market that the emission quota trade will be based on. Before trade begins you will receive private information about which of the countries #0 -#11 you will represent, that country's true MV-curve as well as the fraction of the trade gains you are allowed to keep. At that time a short presentation of instructions will be held and any questions will be answered.

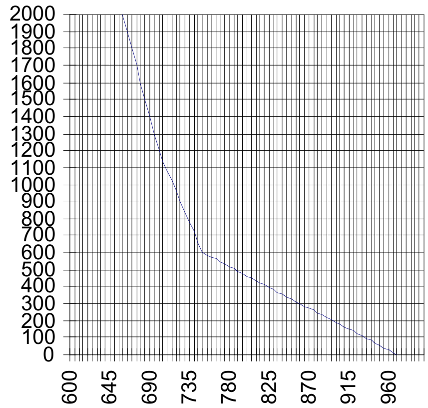
APPENDIX 1
(Appendix included in common instructions.)

(The diagrams show the expected MAC-curves of the twelve countries as well as expected aggregate net demand. The x-axis measures emission levels (Mton CO_2) and the y-axis values (MSEK/Mton). In the information given to subjects, vertical lines indicated countries' target levels. For these levels, see Table A1 above.)

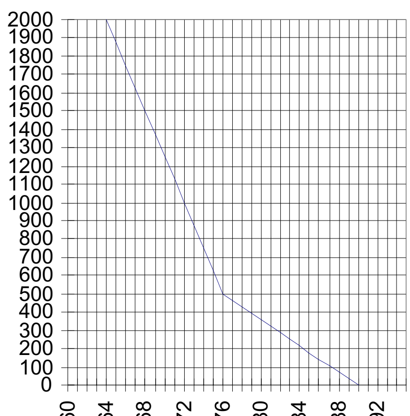
Country #0



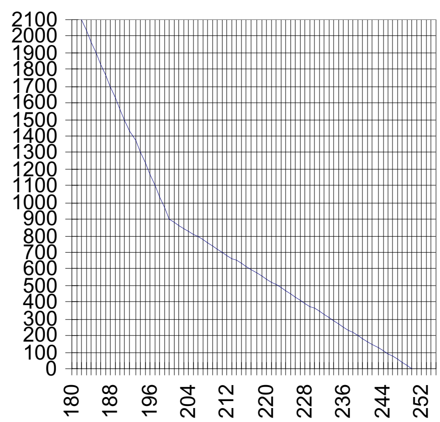
Country #1



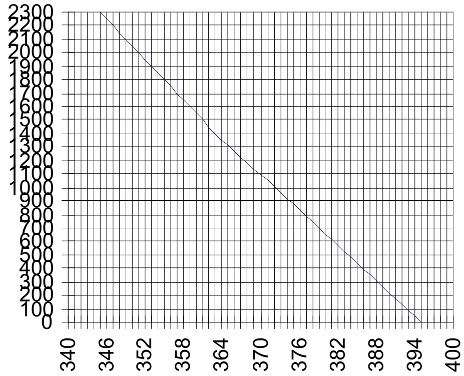
Country #2



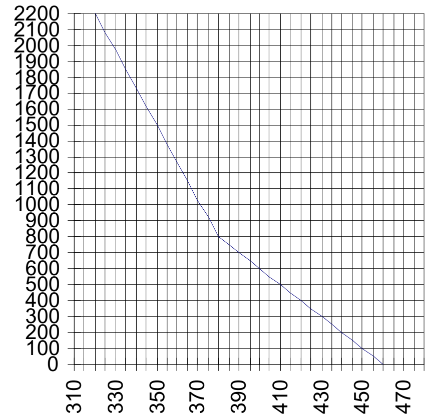
Country #3



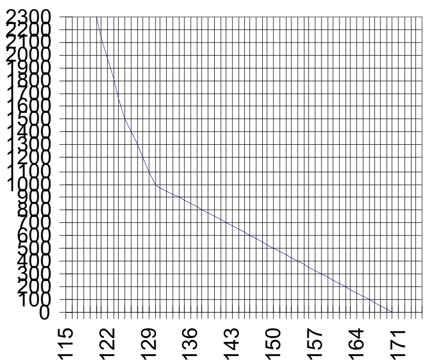
Country #4



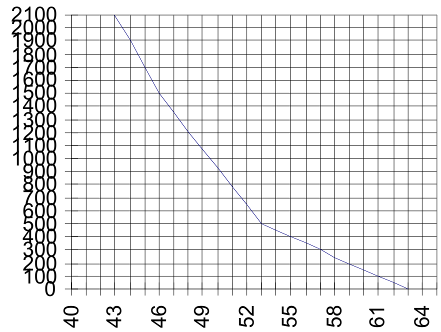
Country #5



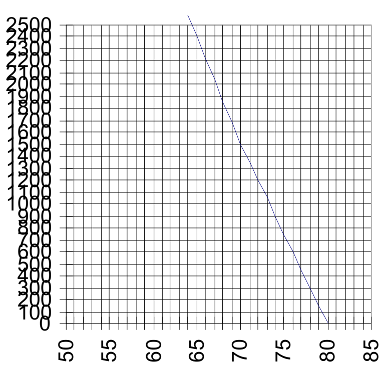
Country #6



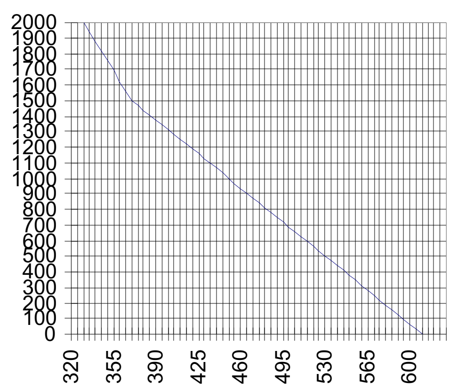
Country #7



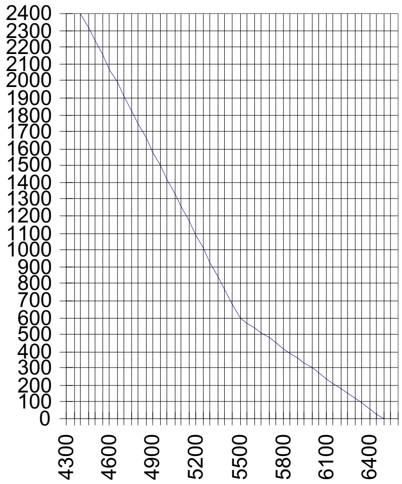
Country #8



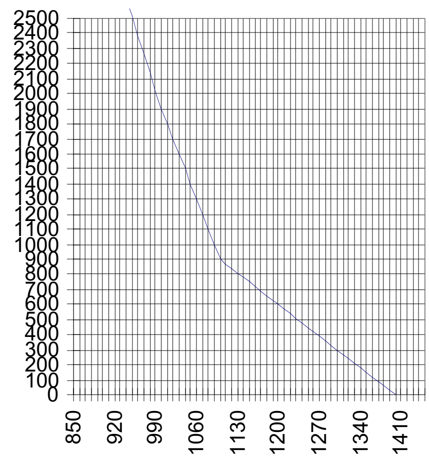
Country #9

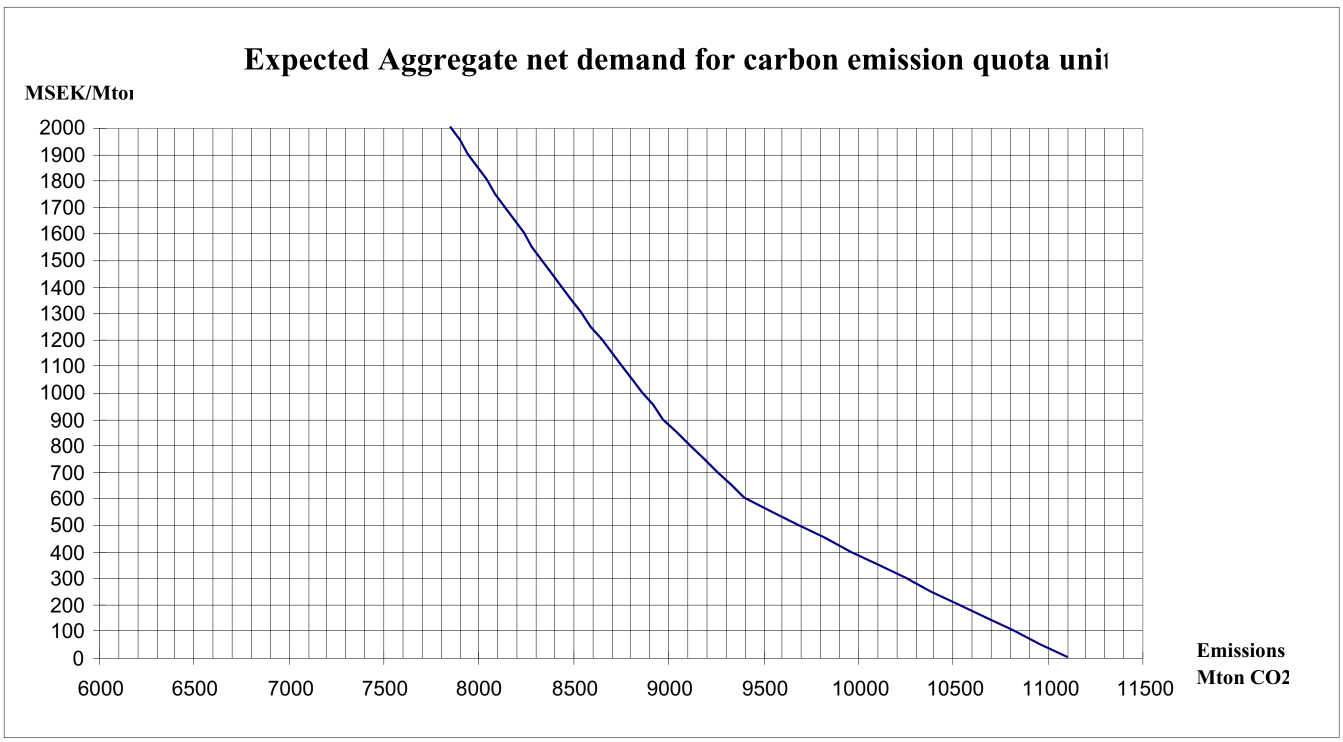


Country #10



Country #11





*

PRIVATE INFORMATION

(Example of the information given to the subjects at the beginning of the experiment.)

You have been appointed to negotiate for country #0. Your assignment is to minimize your country's cost for reaching the emission target the country by signing the Kyoto Protocol has committed itself to: <u>That by the year 2010 not emit more than 100 Mton CO_2 (=your country's</u>

initial inventory). The country's updated MV-curve (see the attached figure in which the largest changes are marked) indicates the BAU emission level to 112 Mton CO_2. Country #0 is thus committed to an emission reduction of the amount of 12 Mton CO_2.

The other countries' emission targets, expected BAU emission levels as well as the emission reductions they are expected to be committed to are presented in the common information you have received (Table A1). There you also find information about the other countries' expected marginal abatement cost schedules.

The cost of your country to unilaterally attain its emission target amounts to 2,200 MSEK (the area beneath your country's actual MV-curve—also it's MC-curve—in the interval the target level-the BAU level). By acting on the market for emission quota units it may be possible for your country to make trade gains.

You have at your disposal an amount of 19,000 MSEK(= your country's *initial cash on hand*). You can use this amount to buy emission quota units from other countries. Your are not allowed to buy emission quota units on credit. Hence, your expenditures cannot exceed your cash on hand. If you sell emission quota units your cash on hand increases with the sales revenues. Your cash on hand will automatically be updated when you transact at the market.

You are not allowed to sell more emission quota units than the country has at its disposal. Hence, your net sales of emission quota units cannot, at any time, be larger than 100 Mton (= your country's initial inventory). Moreover, your country has only calculated its marginal abatement costs over the interval 70-112 Mton CO2. This means that your country does not allow your net sale at the end of the trading period to imply an *ex post* trade emission quota that lies outside this interval. However, nothing stops you from leaving this interval temporarily during the trading period.

Your payment consists of a fixed fee (200 SEK which you will receive after the experiment) and an incentive payment. The incentive payment is calculated as follows: Prior to any trade it amounts to 25 SEK. For each 1,000 MSEK in trade gains you negotiate to your country the incentive payment increases with 6 SEK. (In case you would make losses it will be reduced by 6 SEK per 1,000 MSEK losses. The incentive payment can, however, never be lower than 0 SEK.)

Your country's trade gains are calculated as described earlier.

*

INFORMATION GIVEN FOR THE SECOND PERIOD

(Example of the information given to the subjects at the beginning of the second trading period.)

1. Your assignment

Also in this trading period you represent country #0. As before, your assignment is to try to minimize your country's net cost of reaching the emission target it is committed to through the climate treaty: The emission target equals 100 Mton CO_2 (= your country's initial inventory). Your country's updated MV-curve indicates as the BAU emission level 110 Mton CO_2, see Appendix 2.1. Your country is thereby committed to an emission reduction of 10 Mton CO_2.

The cost for your country of attaining this emission target unilaterally amounts to 1,562.5 MSEK.

You have at your disposal an amount of 19,000 MSEK (=your country's initial cash on hand).

For every 1,000 MSEK in trade gains you negotiate for your country you earn 8 SEK. In all other aspects the rules are as in the first period.

As you can see, the trading situation differ somewhat from the previous period in that the countries' BAU emission levels, emission targets and expected underlying demand/supply schedules are different. You can interpret this trading situation in the following way. Countries that year 2010 were committed to binding emission targets are taken to be committed also for subsequent periods. BAU and underlying demand/supply schedules for a later year, say 2015, are likely to differ from the conditions that prevailed the year 2010. It is also possible that the emission quotas for the year 2015 would be different than those for the year 2010. The countries would in such a sequential period utilize any lessons from earlier trading periods.

Below is given information about your country's and other countries' emission targets and forecasted emission levels (Table A1), expected underlying demand/supply conditions (Appendix 2.1) as well as the calculated perfectly competitive outcome (Table A2).

2. Common information

Table 1 Emission levels and emission reductions in the year 2010, millions ton CO_2 **(This Table is similar to Table A1 above)**

In case each country chooses to attain its emission target unilaterally, the expected MACs would vary between 0 MSEK/Mton (country #2 and country #3) and 2,400 MSEK/Mton (country #8).

The expected efficient price equals 1,200 MSEK/Mton and the net trade among these countries amounts to 387 Mton CO_2. This trade and the associated surplus would be distributed as is presented in Table 2.

Table 2 Trade under perfect competition, Mton CO_2 and MSEK, respectively **(Similar to Table A2 above)**

The difference between column 2 and 4 states the countries' net trade. A negative value indicates that the country is a net seller of emission quota units and a positive value that the country is a net buyer. In the case of perfect competition as illustrated in Table 2, three countries act as net buyers (countries #8, 10 and 11) and nine countries act as net sellers. Note that the buyer side is highly concentrated with a single buyer (country #10) accounting for about 90% of the demand at the expected efficient price.

Appendix 2.1: Expected MV-curves of all countries and the expected aggregated net demand. **(Not shown here. See Appendix 1 to common instructions for the same type of diagrams.)**

Appendix 2.2: Country #0's true MV-curve turned out to be the same as the expected MV-curve presented in Appendix 2.1.

(**The Private information given to subjects in the second round corresponds to the private information they received in the first round, see above.**)

REPORT SERIES of the MIT *Joint Program on the Science and Policy of Global Change*

1. **Uncertainty in Climate Change Policy Analysis** *Jacoby & Prinn* December 1994
2. **Description and Validation of the MIT Version of the GISS 2D Model** *Sokolov & Stone* June 1995
3. **Responses of Primary Production and Carbon Storage to Changes in Climate and Atmospheric CO_2 Concentration** *Xiao et al.* October 1995
4. **Application of the Probabilistic Collocation Method for an Uncertainty Analysis** *Webster et al.* January 1996
5. **World Energy Consumption and CO_2 Emissions: 1950-2050** *Schmalensee et al.* April 1996
6. **The MIT Emission Prediction and Policy Analysis (EPPA) Model** *Yang et al.* May 1996
7. **Integrated Global System Model for Climate Policy Analysis** *Prinn et al.* June 1996 (*superseded by No. 36*)
8. **Relative Roles of Changes in CO_2 and Climate to Equilibrium Responses of Net Primary Production and Carbon Storage** *Xiao et al.* June 1996
9. **CO_2 Emissions Limits: *Economic Adjustments and the Distribution of Burdens*** *Jacoby et al.* July 1997
10. **Modeling the Emissions of N_2O & CH_4 from the Terrestrial Biosphere to the Atmosphere** *Liu* August 1996
11. **Global Warming Projections: *Sensitivity to Deep Ocean Mixing*** *Sokolov & Stone* September 1996
12. **Net Primary Production of Ecosystems in China and its Equilibrium Responses to Climate Changes** *Xiao et al.* Nov 1996
13. **Greenhouse Policy Architectures and Institutions** *Schmalensee* November 1996
14. **What Does Stabilizing Greenhouse Gas Concentrations Mean?** *Jacoby et al.* November 1996
15. **Economic Assessment of CO_2 Capture and Disposal** *Eckaus et al.* December 1996
16. **What Drives Deforestation in the Brazilian Amazon?** *Pfaff* December 1996
17. **A Flexible Climate Model For Use In Integrated Assessments** *Sokolov & Stone* March 1997
18. **Transient Climate Change & Potential Croplands of the World in the 21st Century** *Xiao et al.* May 1997
19. **Joint Implementation: *Lessons from Title IV's Voluntary Compliance Programs*** *Atkeson* June 1997
20. **Parameterization of Urban Sub-grid Scale Processes in Global Atmospheric Chemistry Models** *Calbo et al.* July 1997
21. **Needed: A Realistic Strategy for Global Warming** *Jacoby, Prinn & Schmalensee* August 1997
22. **Same Science, Differing Policies; *The Saga of Global Climate Change*** *Skolnikoff* August 1997
23. **Uncertainty in the Oceanic Heat and Carbon Uptake & their Impact on Climate Projections** *Sokolov et al.* Sept 1997
24. **A Global Interactive Chemistry and Climate Model** *Wang, Prinn & Sokolov* September 1997
25. **Interactions Among Emissions, Atmospheric Chemistry and Climate Change** *Wang & Prinn* September 1997
26. **Necessary Conditions for Stabilization Agreements** *Yang & Jacoby* October 1997
27. **Annex I Differentiation Proposals: *Implications for Welfare, Equity and Policy*** *Reiner & Jacoby* October 1997
28. **Transient Climate Change & Net Ecosystem Production of the Terrestrial Biosphere** *Xiao et al.* November 1997
29. **Analysis of CO_2 Emissions from Fossil Fuel in Korea: 1961–1994** *Choi* November 1997
30. **Uncertainty in Future Carbon Emissions: *A Preliminary Exploration*** *Webster* November 1997
31. **Beyond Emissions Paths: *Rethinking the Climate Impacts of Emissions Protocols*** *Webster & Reiner* November 1997
32. **Kyoto's Unfinished Business** *Jacoby, Prinn & Schmalensee* June 1998
33. **Economic Development and the Structure of the Demand for Commercial Energy** *Judson et al.* April 1998
34. **Combined Effects of Anthropogenic Emissions & Resultant Climatic Changes on Atmosph. OH** *Wang & Prinn* April 1998
35. **Impact of Emissions, Chemistry, and Climate on Atmospheric Carbon Monoxide** *Wang & Prinn* April 1998
36. **Integrated Global System Model for Climate Policy Assessment: *Feedbacks and Sensitivity Studies*** *Prinn et al.* June 1998
37. **Quantifying the Uncertainty in Climate Predictions** *Webster & Sokolov* July 1998
38. **Sequential Climate Decisions Under Uncertainty: *An Integrated Framework*** *Valverde et al.* September 1998
39. **Uncertainty in Atmospheric CO_2 (Ocean Carbon Cycle Model Analysis)** *Holian* October 1998 (*superseded by No. 80*)
40. **Analysis of Post-Kyoto CO_2 Emissions Trading Using Marginal Abatement Curves** *Ellerman & Decaux* October 1998
41. **The Effects on Developing Countries of the Kyoto Protocol & CO_2 Emissions Trading** *Ellerman et al.* November 1998
42. **Obstacles to Global CO_2 Trading: *A Familiar Problem*** *Ellerman* November 1998
43. **The Uses and Misuses of Technology Development as a Component of Climate Policy** *Jacoby* November 1998
44. **Primary Aluminum Production: *Climate Policy, Emissions and Costs*** *Harnisch et al.* December 1998
45. **Multi-Gas Assessment of the Kyoto Protocol** *Reilly et al.* January 1999
46. **From Science to Policy: *The Science-Related Politics of Climate Change Policy in the U.S.*** *Skolnikoff* January 1999
47. **Constraining Uncertainties in Climate Models Using Climate Change Detection Techniques** *Forest et al.* April 1999
48. **Adjusting to Policy Expectations in Climate Change Modeling** *Shackley et al.* May 1999
49. **Toward a Useful Architecture for Climate Change Negotiations** *Jacoby et al.* May 1999
50. **A Study of the Effects of Natural Fertility, Weather & Productive Inputs in Chinese Agriculture** *Eckaus & Tso* July 1999
51. **Japanese Nuclear Power and the Kyoto Agreement** *Babiker, Reilly & Ellerman* August 1999
52. **Interactive Chemistry and Climate Models in Global Change Studies** *Wang & Prinn* September 1999

Contact the Joint Program Office to request a copy. The Report Series is distributed at no charge.

53. **Developing Country Effects of Kyoto-Type Emissions Restrictions** *Babiker & Jacoby* October 1999
54. **Model Estimates of the Mass Balance of the Greenland and Antarctic Ice Sheets** *Bugnion* October 1999
55. **Changes in Sea-Level Associated with Modifications of Ice Sheets over 21st Century** *Bugnion* October 1999
56. **The Kyoto Protocol and Developing Countries** *Babiker, Reilly & Jacoby* October 1999
57. **Can EPA Regulate GHGs Before the Senate Ratifies the Kyoto Protocol?** *Bugnion & Reiner* November 1999
58. **Multiple Gas Control Under the Kyoto Agreement** *Reilly, Mayer & Harnisch* March 2000
59. **Supplementarity: *An Invitation for Monopsony?*** *Ellerman & Sue Wing* April 2000
60. **A Coupled Atmosphere-Ocean Model of Intermediate Complexity** *Kamenkovich et al.* May 2000
61. **Effects of Differentiating Climate Policy by Sector: *A U.S. Example*** *Babiker et al.* May 2000
62. **Constraining Climate Model Properties Using Optimal Fingerprint Detection Methods** *Forest et al.* May 2000
63. **Linking Local Air Pollution to Global Chemistry and Climate** *Mayer et al.* June 2000
64. **The Effects of Changing Consumption Patterns on the Costs of Emission Restrictions** *Lahiri et al.* August 2000
65. **Rethinking the Kyoto Emissions Targets** *Babiker & Eckaus* August 2000
66. **Fair Trade and Harmonization of Climate Change Policies in Europe** *Viguier* September 2000
67. **The Curious Role of "Learning" in Climate Policy: *Should We Wait for More Data?*** *Webster* October 2000
68. **How to Think About Human Influence on Climate** *Forest, Stone & Jacoby* October 2000
69. **Tradable Permits for GHG Emissions: *A primer with reference to Europe*** *Ellerman* November 2000
70. **Carbon Emissions and The Kyoto Commitment in the European Union** *Viguier et al.* February 2001
71. **The MIT Emissions Prediction and Policy Analysis (EPPA) Model: *Revisions, Sensitivities, and Comparisons of Results*** *Babiker et al.* February 2001
72. **Cap and Trade Policies in the Presence of Monopoly and Distortionary Taxation** *Fullerton & Metcalf* March 2001
73. **Uncertainty Analysis of Global Climate Change Projections** *Webster et al.* March 2001
74. **The Welfare Costs of Hybrid Carbon Policies in the European Union** *Babiker et al.* June 2001
75. **Feedbacks Affecting the Response of the Thermohaline Circulation to Increasing CO_2** *Kamenkovich et al.* July 2001
76. **CO_2 Abatement by Multi-fueled Electric Utilities: *An Analysis Based on Japanese Data*** *Ellerman & Tsukada* July 2001
77. **Comparing Greenhouse Gases** *Reilly, Babiker & Mayer* July 2001
78. **Quantifying Uncertainties in Climate System Properties using Recent Climate Observations** *Forest et al.* July 2001
79. **Uncertainty in Emissions Projections for Climate Models** *Webster et al.* August 2001
80. **Uncertainty in Atmospheric CO_2 Predictions from a Parametric Uncertainty Analysis of a Global Ocean Carbon Cycle Model** *Holian, Sokolov & Prinn* September 2001
81. **A Comparison of the Behavior of Different Atmosphere-Ocean GCMs in Transient Climate Change Experiments** *Sokolov, Forest & Stone* December 2001
82. **The Evolution of a Climate Regime: *Kyoto to Marrakech*** *Babiker, Jacoby & Reiner* February 2002
83. **The "Safety Valve" and Climate Policy** *Jacoby & Ellerman* February 2002
84. **A Modeling Study on the Climate Impacts of Black Carbon Aerosols** *Wang* March 2002
85. **Tax Distortions and Global Climate Policy** *Babiker, Metcalf & Reilly* May 2002
86. **Incentive-based Approaches for Mitigating GHG Emissions: *Issues and Prospects for India*** *Gupta* June 2002
87. **Sensitivities of Deep-Ocean Heat Uptake and Heat Content to Surface Fluxes and Subgrid-Scale Parameters in an Ocean GCM with Idealized Geometry** *Huang, Stone & Hill* September 2002
88. **The Deep-Ocean Heat Uptake in Transient Climate Change** *Huang et al.* September 2002
89. **Representing Energy Technologies in Top-down Economic Models using Bottom-up Information** *McFarland, Reilly & Herzog* October 2002
90. **Ozone Effects on Net Primary Production and Carbon Sequestration in the Conterminous United States Using a Biogeochemistry Model** *Felzer et al.* November 2002
91. **Exclusionary Manipulation of Carbon Permit Markets: A Laboratory Test** *Carlén* November 2002
92. **An Issue of Permanence: Assessing the Effectiveness of Temporary Carbon Storage** *Herzog et al.* December 2002
93. **Is International Emissions Trading Always Beneficial?** *Babiker et al.* December 2002
94. **Modeling Non-CO_2 Greenhouse Gas Abatement** *Hyman et al.* December 2002
95. **Uncertainty Analysis of Climate Change and Policy Response** *Webster et al.* December 2002
96. **Market Power in International Carbon Emissions Trading: A Laboratory Test** *Carlén* January 2003