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Testing the dynamic theory of emissions trading: Experimental evidence for global carbon trading

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Contents

Abstract

Simulation models and theory prove that emission trading converges to market equilibrium. This paper sets out to falsify these results using experimental economics. Three experiments are conducted for the six largest carbon emitting industrialized regions. Two experiments use auctions: the first a single-bid auction and the second a Walrasian auction. The third relies on bilateral, sequential trading. The paper finds that, in line with the standard theory, both auctions and bilateral, sequential trading capture a significant part (88 to 99 percent) of the potential cost savings of emission trading. As expected from dynamic trade theory, all experiments show that the market price converges (although not fully) to the market equilibrium price. In contrast to the theory, the results also suggest that not all countries will gain from trading. In both the bilateral trading experiment and the Walrasian auction, one country will actually be worse off with trade. In particular, bilateral, sequential trading leads to a distribution of gains significantly different from the competitive market outcome. This is due to speculative behavior, imperfect foresight and market power.

Acknowledgments

This idea behind the experiments in this paper was based on an experiment originally designed by Peter Bohm at Department of Economics of Stockholm University. The cost functions used here are derived from those in the POLES model developed by EPEE in Grenoble, France. We would also like to acknowledge our appreciation to the students from Colorado College, Groningen University and IIASA-ECS colleagues for their participation in the experiment.

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Testing the dynamic theory of emissions trading: experimental evidence for global carbon trading

Ger Klaassen, Andries Nentjes and Mark Smith

1. Introduction

There is general agreement among environmental economists that emission trading is well suited to restrict the emissions of a uniformly dispersed pollutant such as CO_2 emissions (Tietenberg, 1985; Klaassen, 1996). The idea that international emission trading between parties creates flexibility, and thus allowing lower total abatement costs, has been the basis for incorporating emissions trading in the Kyoto protocol. Numerous publications have calculated the expected cost savings of international carbon trading, taking into account different market structures and restrictions on trade (see Yamin *et al.*, 2001 for a survey). The common characteristic of these simulation studies is that they use a static framework and assume market equilibrium will be realized.

Assuming well-behaved emission abatement cost functions, initial grandfathering of emission permits and price taking behavior of trading parties, the proof that an emission market equilibrium exists is relatively straightforward (Montgomery, 1972). However, it leaves the question unanswered whether starting from disequilibrium and in a context where bilateral trades are made sequentially at changing non-equilibrium prices, the market indeed converges to an equilibrium. Recently, Ermoliev *et al*. (2000) tackled this problem and proved that sequential bilateral trading of emissions converges to a cost minimizing emissions market equilibrium. The trading scheme only requires sources to bilaterally state their demand price (as buyers) and supply price (as sellers), and agree on price and quantity in bilateral negotiations and contracts. This reflects what is done in existing markets, where brokers have an important function in bringing together the relevant information.

If emission reductions are implemented immediately by sources after each round of trade, they are tied up into sunk cost. These sources may not be willing to participate in subsequent rounds of trades, which may require reversing earlier decisions on emission levels. If so, the result will not be cost-efficient. Therefore, the dynamic market model, as specified by Ermoliev *et al*. (2000) assumes reversibility before irreversible real decisions are taken, by separating the price formation stage from the actual implementation stage.

An alternative to a decentralized search for the cost-effective vector of emissions is a Walrasian auction of emission permits (Ermoliev *et al*, 2000). Such an auction also results in minimizing total emission control cost. The auction consists of two stages: a search stage, in which the auctioneer searches for the equilibrium price; and a second stage, in which transactions are made at the market equilibrium prices. The search stage is opened by the auctioneer who announces the permit price. Each participant then knows the price to pay for an extra unit of emission reduction or to receive for each additional unit of emission reduction. If the price is higher than the participant's current marginal cost, he will decide to reduce his emissions below his initial emissions level and sell permits. He will inform the auctioneer how many emission permits he wants to sell. On the other hand, when the emission price is below the marginal cost of emission reduction, the source has an incentive to increase its planned emissions; it will state its demand for emission permits. The auctioneer then calculates market demand and revises the price upwards when demand exceeds supplies and downward when supply exceeds demand. It should be noted that sources have to state only the number of permits they are willing to sell or to buy at the price proposed by the auctioneer. Only the auctioneer has knowledge of demand and supply for permits. The procedure converges to an equilibrium with cost efficient emissions.

The above theoretical contributions to the dynamics of emission markets may be logically correct, that does not mean they are also true. The real world can differ from what theory predicts. The purpose of this article is to falsify the theory using the methods of experimental economics and apply these to international carbon trading under the Kyoto Protocol.

Analyzing proposed policies in which critical institutional design issues confront policy makers is an obvious task for experimental methods (Smith, 1994; Issac and Holt, 1999). Experimental methods have been used to examine policy proposals ranging from electricity rate design (Elliott *et al*., 2000) to scheduling cargo regimes on the space shuttle (Banks *et al*., 1989). Following Montgomery's (1972) seminal theoretical work on emissions trading, experiments on mechanisms for trading emissions permits began with the work of Plott (1983). With the passage of the Clean Air Act Amendments of 1990 by the U.S. Congress, experimenters had a real market to help design. Funded by the U.S. Department of Energy, teams at the University of Colorado and University of Arizona began to work on auction mechanisms and permit allocation schemes, which eventually led to the U.S. Environmental Protection Agency (EPA) sponsored auction for sulfur dioxide (Bjornstad *et al*., 1999). Contributors to Issac and Holt's (1999) edited volume on emissions permits experiments addressed potential problems for the U.S. sulfur dioxide program including speculation (Cason *et al*., 1999), market power (Godby, 1999) and permit banking (Cronshaw and Kruse, 1999a and 1999b). With the adoption of the Kyoto Protocol in 1997, the potential for trading greenhouse gases has now taken on an international dimension.

Our carbon emissions trading experiments differ from the existing literature (Bohm, 1997; Bohm and Carlé, 1999; Baron and Cremades, 1999; Soberg, 2000) and laboratory evidence on emission quota trade in the following ways:

- Information on source pollution control costs is not regarded to be common knowledge, not even within a certain range of uncertainty; sources have only private information on their own cost function;
- Both bilateral sequential trading and auction mechanisms are tested.

The structure of the paper is as follows. Section 2 describes the design of the experiment. Section 3 presents the results and section 4 concludes.

2. Design

2.1. Introduction

The purpose of the experiment is to gain understanding of how emissions trading might work in practice and how markets for carbon emission reductions (including price developments) would evolve over time. For this purpose, information has been made available to the participants in two forms: common knowledge and private knowledge. Common knowledge consists of information on the Kyoto Protocol, knowledge on emissions trading and the concept of marginal abatement costs as well as on the specific rules guiding emissions trading in this experiment. Abatement cost functions for individual countries are regarded as private information. We will first discuss these types of knowledge and then we proceed to discuss the two sets of trading rules used to guide the auction and the bilateral trading experiment.

Common knowledge

At the Conference of the Parties in Kyoto, Japan at the end of 1997 a number of countries agreed to reduce their emissions of a number of greenhouse gases among them CO2. The industrialized countries (Annex I countries) agreed in principle to reduce their emissions during the period 2008-2012. These targets are country specific and are specified as percentage reductions compared to the base year (in general 1990). Countries have the option to meet their targets through reductions in domestic emissions. The draft protocol however also includes a number of so called flexibility mechanisms. Among them is emission trading. Emission trading allows (Annex I) countries to meet their targets by purchasing emission reductions from other countries with quantitative targets. The amount bought from other countries would be reduced from their own target. Buying emission reductions from other countries is financially attractive where it is cheaper to buy emission reductions from other countries than reduce domestic emissions. A country that sells emission reductions to another country must make sure that it meets its agreed target plus the additional emission reductions it agreed to sell to other parties. In the remainder of the report, we will assume that countries agreed to meet their target in 2010.

In the experiment the goal of each country team is to achieve the emission target for the country as agreed in Kyoto at minimum costs. Countries can achieve this goal by either reducing emissions domestically or buying emission reductions from other countries. Total cost consists of the costs of domestic emission control plus the cost of buying emission reductions elsewhere minus the revenues received from selling emission reductions.

Emission trading takes place only between six countries or country regions: Japan, Central and Eastern Europe (CEE, which includes the Czech Republic, Hungary, Poland, Slovakia, Bulgaria and Rumania), the EU-15, Russia, the Ukraine and the USA. It is common knowledge among these negotiating teams that the marginal costs of meeting the Kyoto target are relatively high in the EU, Japan and the USA and are relatively low in the CEE, Russia and the Ukraine.

Table 1 gives the assumed emission targets for the year 2010 as well as the base year emissions for 1990. The 1990 emissions are energy related carbon emissions only and are based on the model used to derive the abatement cost-functions (Gusbin *et al*., 1999). The absolute targets for the year 2010 are slightly rounded.

A generic cost function was shown and discussed with the participants to ensure a proper understanding of the function.

Table 1: Emission targets and reductions in 2010.

	Emissions in 1990 MtC	Reduction in 2010 % of 1990	Emission target in 2010 MtC
USA	1411	6	1325
EU	946	8	867
Japan	319	7	295
Russia	650	0	650
Ukraine	178	0	178
CEE	284	6	267
Total	3788	5	3582

Private information

Information on regional (country) cost functions was only given to the participants representing that specific country. Countries thus only possessed (perfect) knowledge on their own carbon abatement costs. The cost function was supplied several days before the experiment was run. Each negotiating team had to study its own domestic cost function and the domestic marginal costs for meeting its agreed emission reduction target. It also had to decide whether it should buy or sell and at which possible price. The team was also instructed to keep track of the emission reductions sold to and bought from other countries to remain informed on the level of domestic reductions (still) needed to meet the Kyoto target. The cost functions used in the experiment were based on the POLES model (see Gusbin *et al*., 1999). The cost functions for Russia and Ukraine were derived from the POLES cost function for the Former Soviet Union using additional information on energy and related carbon emissions in these countries (see Victor *et al*, 1998).

Trading rules

In total, three trading experiments with three different types of market design, and three different groups of participants were carried out, with two groups of students from Colorado College (USA) and one group from Groningen University (The Netherlands). The three trading schemes were:

1. Bilateral, sequential trading;
2. Single-bid auction; and
3. Auction with a tâtonnement process in which tentative market clearing prices are called out.

Group 1 followed a process of bilateral trading. Each country was free to choose a trading partner and negotiate the terms of trade (volume and price). If agreement had been reached, then the trading authority had to be informed. In this case, information on prices and traded volumes of individual trades was regarded as private information and not made available to other parties. The trading scheme resembles the scheme investigated by Ermoliev *et al* (2000). The difference is that Ermoliev *et al*. supposed that participants would only have information on prices in their last bilateral trade. In our experiment, more information was available since the trading authority announced, at regular intervals the total volumes traded and the average price on the market. This, of course being more in line with current practice in the US regarding sulfur trading where brokers supply information on average prices of bilateral trades (Joskow *et al*., 1998).

Group 2 traded with the use of an auctioneer. The auctioneer collected written bids for selling, and offers for buying emission reductions from the countries, and at regular intervals determined equilibrium prices and quantities. The auctioneer constructed the (piece-wise linear) supply and demand curve in each single round based on the bids and offers for that round and determined the equilibrium price. Volumes were sold at the equilibrium price for that round. This process of collecting bids and offers, and fixing a new equilibrium price was repeated until the end of the negotiating period (after 2.5 hours). In this process, information on equilibrium prices and volumes traded was made available to all participants**.**

Members of Group 3 participated in a Walrasian auction in which tentative market prices are called out in the search stage. The price adjustment rule applied by the auctioneer was that the percentage change in price was equal to [excess demand/ (sum of demand and supply)] x 100 percent. After a price was called out, participants submitted their bids (on closed leaflets) to the auctioneer who made public total demand, total supply and the new price. The auction is similar to the scheme discussed in Ermoliev *et al*. (2000).

In the three cases, trading took place during one morning or afternoon and was finalized after 2.5 hours. Each participant of the winning team obtained a reward in kind. The winning team was the team that achieved the highest cost savings relative to the potential savings under the competitive market equilibrium. This took into account the fact that the potential gains (in absolute dollars) of some countries were much bigger since these countries emitted more, had a more beneficial initial allocation of emission targets or had lower marginal costs. In the two US experiments in addition to this 10 percent of the grade for the course depended on participation in the experiment and on the extent to which the participant's team achieved the potential cost savings of its country. Finally, bilateral contracts agreed could not be annulled and bids and offers made for auctions could not be withdrawn.

3. Results

3.1. Introduction

This section presents the results of the experiments. First we will introduce the potential cost savings of emission trading that would result from a static perfect, competitive equilibrium situation. These results will than serve as reference point for discussing the actual costs savings as well as their distribution for the three emission trading mechanisms.

Perfect market equilibrium

Table 2 shows the cost savings that would result under a perfect equilibrium if one makes the usual assumptions of perfect information, absence of transaction cost and price taking behavior. In this situation, the market equilibrium price would be $38.7/ton carbon (tC). 376 million tons C (MtC) would be exchanged in arriving at the equilibrium starting from the initial allocation of permits. Without trade, the Kyoto Protocol would cost $36.05 billion. Trading allows cost savings of $28.4 billion, a seventy nine percent reduction in compliance costs. The potential cost savings (in absolute terms) would be highest in Russia (around $8 billion) followed by Japan and the EU. The large potential Russian gain is due to the high levels of emissions in Russia, the initial allocation of permits and the fact that, even without explicit pollution control, carbon emissions in Russia are expected to be lower than their agreed target in 2010 as a result of industrial restructuring.

Table 2: Cost savings under the market equilibrium.

	Marginal costs Kyoto $/tC	Marginal costs optimum $/tC	Kyoto total abatement costs million $	Equilibrium total abatement costs million $	Potential net cost savings million $[a]	Emissions after trade MtC	Traded Amount MtC[c]
USA	75	38.7	12988	3901	2805	1487	162
EU	125	38.7	12325	1732	5348	1003	136
Japan	250	38.7	10738	549	7178	373	78
Russia	0	38.7	0	906	8049	419	-231
Ukraine	0	38.7	0	250	2217	114	-64
CEE	0	38.7	0	312	2803	187	-80
Sum[b]		38.70	36051	7650	28400	3582	376

[a]Abatement costs plus revenues from selling emission permits minus expenditures on selling emission permits
[b]Sum of volume of emissions sold (or bought)
[c]+ indicates net demand, - indicates net supply

Bilateral trading experiment

Table 3 gives the costs savings resulting from the bilateral trading experiment. A number of points are worth noting. The costs savings achieved are $27.3 billion. This is around 96 percent of the potential cost savings (compare Table 2). The distribution of the gains (control cost savings plus revenues from selling emission reductions minus expenditures on buying emissions reductions) differs significantly from the competitive equilibrium outcome (Table 2); Ukraine, Russia and the CEE (the net sellers) gain much more (a factor 2 to 3) and, more surprisingly, the EU even turns out to be a net looser. Especially the latter, counterintuitive result begs an explanation.

Table 3: Cost savings bilateral trade.

	Abatement Costs million $	Net trade payments million $	Net costs million $	Net gain from trade million $	Actual gains % of potential	Emission after trade MtC	Traded[a] amounts MtC
USA	4062	6710	10772	2216	79	1445	120
EU	2484	13555	16039	-3714	-69	985	118
Japan	313	7375	7688	3050	42	380	85
Russia	0	-13665	-13665	13665	170	475	-175
Ukraine	863	-8100	-7237	7237	326	105	-73
CEE	1055	-5875	-4820	4820	172	192	-75
Sum	8777	0				3582	3
Cost savings	27273				96.0%		

[a]Sum depicts gross trade (all volumes sold or bought). Regional amounts are net trade (bought minus sold)

Table 4 assists in finding the explanation. Table 4 shows that 18 bilateral trades occurred with a total volume of 348 MtC being traded. The weighted average price was nearly $86/tC. This high average price is twice as high as the market equilibrium price of around $38/tC. The high price is largely due to the fact that the EU bought 58 MtC from the Ukraine at a price of $112/tC. Three explanations can be offered for this high price. First, the Ukraine and Russia exerted market power and agreed secretly to not sell their permits below a certain price (of around 110 $/tC)**.** Secondly, although the EU team knew it was loosing money on this particular deal it speculated that the price would increase and they could resell at a higher price. Finally, the EU did not know when it bought from the Ukraine that both the CEE and the Ukraine had already made bilateral agreements to sell at much lower prices of $60 respectively $68/tC since this was private information. This means that Ukraine agreed a cartel price with Russia but then cheated.

Table 4: Overview of bilateral trades.

Trade number Model	Volume Mtc	Price $/tC	Seller	Buyer	Expenditure million $
1	30	60	CEE	Japan	1800
2	30	68	Russia	USA	2040
3	58	112.07	Ukraine	EU	6500
4	25	142	Russia	EU	3550
5	20	90	Russia	Japan	1800
6	20	110	Ukraine	Japan	2200
7	25	115	Russia	USA	2875
8	10	115	CEE	EU	1150
9	15	105	CEE	Japan	1575
10	10	105	CEE	EU	1050
11	10	110	USA	EU	1100
12	10	85	Russia	Ukraine	850
13	35	42	Russia	USA	1470
14	10	42	Russia	EU	420
15	5	50	Ukraine	USA	250
16	5	43	EU	USA	215
17	20	33	Russia	USA	660
18	10	30	CEE	USA	300
Sum	348	85.65			29805

As can be seen from Figure 1 the EU expectations turned out to be wrong. The permit price remained at a very high level during the first half of the bilateral trades. The price only started dropping (even below the equilibrium price) during the last 6 trades. Remarkably, the lack of price information had no significant effect on the overall efficiency although it did have significant effects on the distribution of gains. This stands in sharp contrast to the usual findings of economic theory and simulation models. However, the result is in agreement with the dynamic market theory of Ermoliev *et al*. (2000), which predicts that prices and quantities will converge towards the static market equilibrium price. Figure 2 shows that for all trading blocks except Japan the prices move towards the optimum price of $38.7, although with bumps, and after 18 rounds, the allocation of emissions has come close to the cost effective allocation. The perhaps high prices paid by Japan should be compared with the extremely high marginal costs of 250$/tC without trading which explains the interest of Japan pay seemingly excessive high prices of over 100 $/tC. The largest discrepancies between bilateral trading and the perfect market equilibrium show up for Ukraine with actual sales equal to 68 percent of the optimal sales and US with actual purchases equal to 74 percent of the optimum.

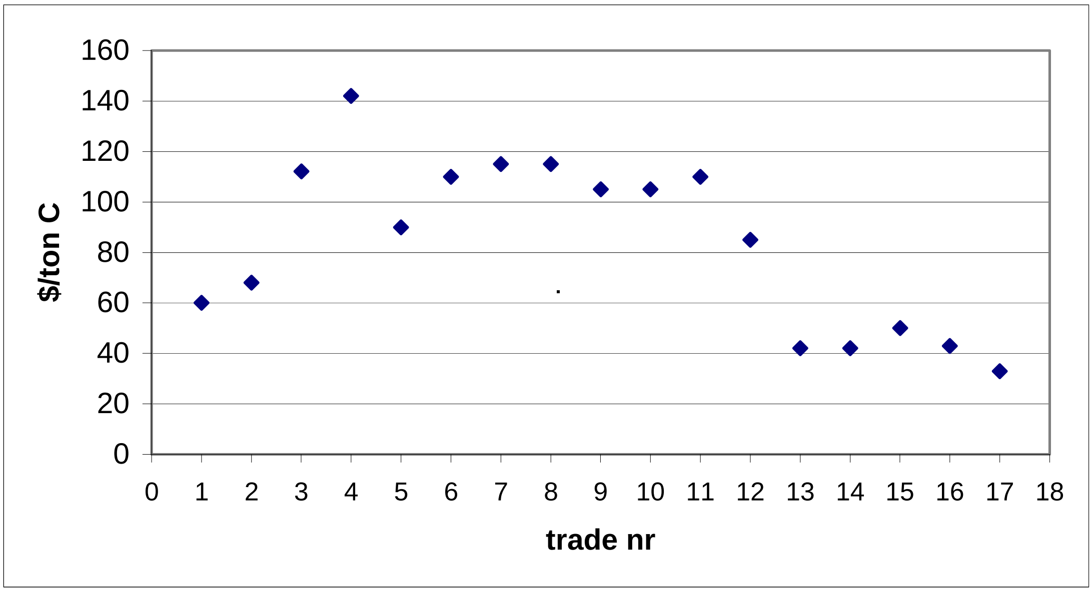

Figure 1: Bilateral trade prices.

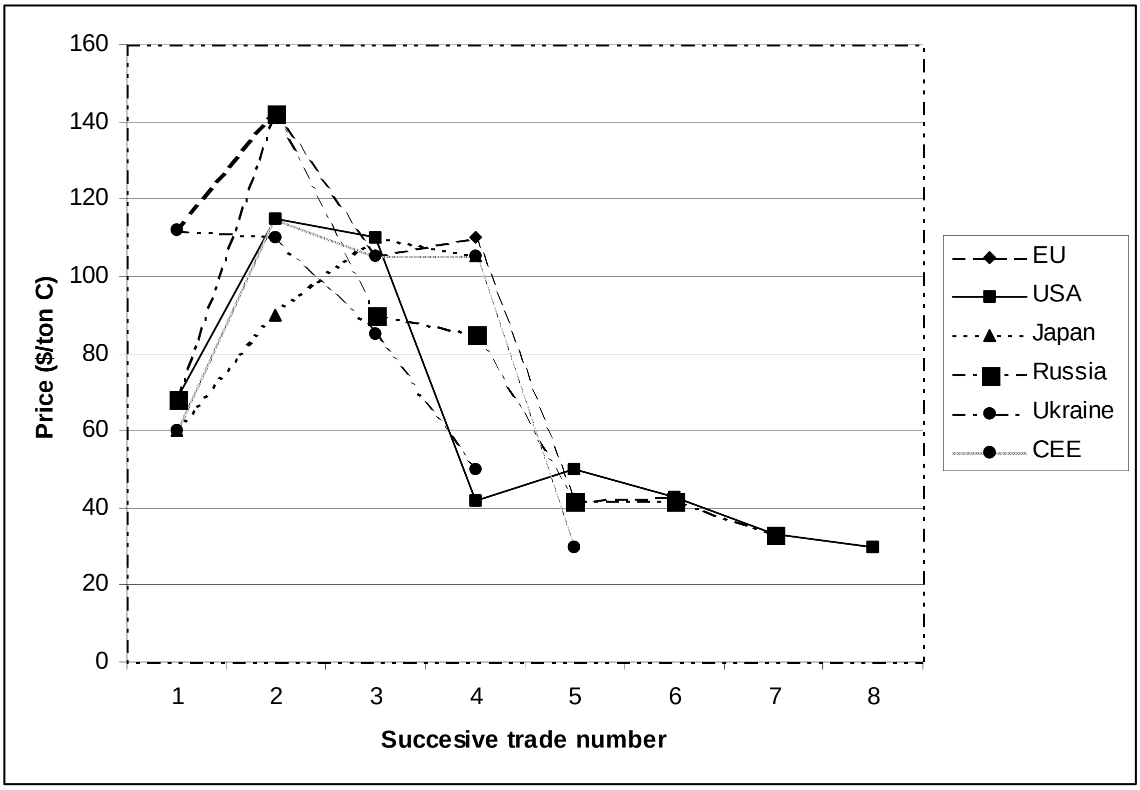

Figure 2: Successive prices bilateral, sequential trading.

Single bid auction experiment

In the available time of 2.5 hours, only 4 successive auction rounds were possible. However, in each round all parties could participate. At 98.5 percent of the potential cost savings, the auction achieves cost savings slightly higher than those of the bilateral trading regime

(Table 5). This is not so significantly different from the bilateral results. What does differ significantly though is the distribution of gains (control cost saving + net revenue of permit expenditures) over the countries involved. Table 5 shows that under the auction every country stands to gain from trading. The Russian gains are slightly higher (a factor 1.4) than the gains under the perfect market equilibrium and the EU gains are slightly lower than those in a perfect market. The differences are much smaller than under the bilateral regime. The auction does not only appear to fulfill an important role in creating an appropriate price signal but also creates an environment that ensures a more even distribution of the gains from trade. This is clearly due to the fact that price information is transparent and the development of prices becomes more predictable (see Figure 3 and Table 6).

Table 5: Cost savings single bid auction.

	Abatement costs million $	Net trade payments million $	Net costs million $	Net gains from trade million $	Actual gains % of potential	Emission after trade MtC	Traded amounts MtC
USA	3836	6800	10636	2352	84	1489	164
EU	2725	5940	8665	3660	68	980	113
Japan	313	4505	4818	5919	82	381	86
Russia	550	-11725	-11175	11175	139	430	-220
Ukraine	528	-2587.5	-2059	2059	93	109	-69
CEE	114	-2932.5	-2819	2819	101	193	-74
Sum	8067	0				3582	363
Costs saved	27984				98.5%		

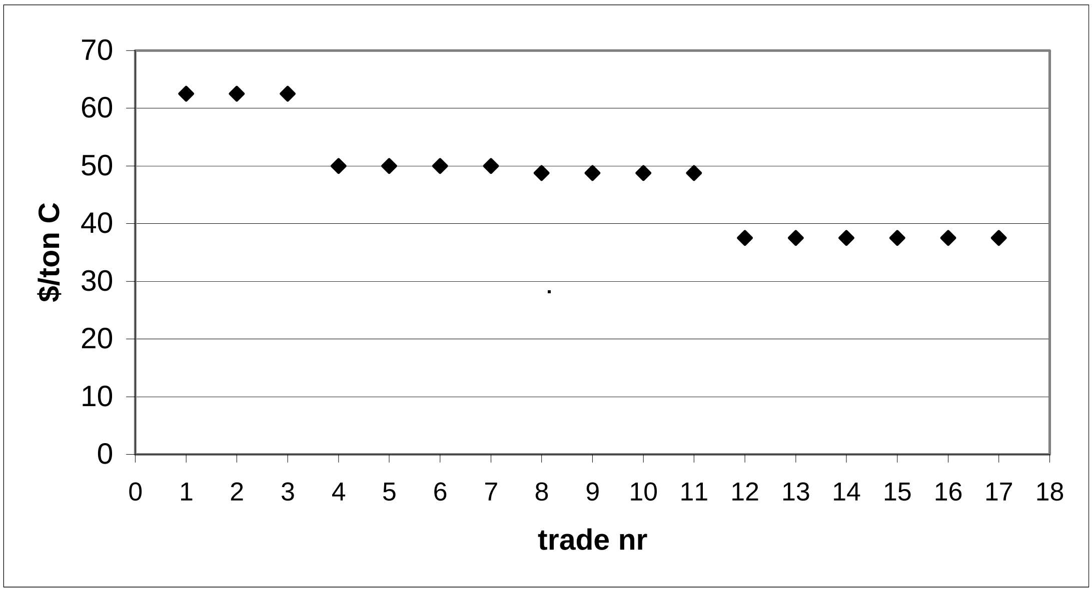

Figure 3: Prices at the single bid auction.

Table 6: Overview of single bid auction results.

Trade number	Volume MtC	Price $/tC	Seller	Buyer	Expenditure million $
1	70	62.5	Russia		4375
2	38	62.5		Japan	2375
3	32	62.5		EU	2000
4	120	50	Russia		6000
5	21	50		Japan	1050
6	47	50		EU	2350
7	52	50		USA	2600
8	20	48.75	Russia		975
9	14	48.75	CEE		682.5
10	6	48.75		Japan	292.5
11	28	48.75		EU	1365
12	60	37.5	CEE		2250
13	10	37.5	Russia		375
14	69	37.5	Ukraine		2587.5
15	21	37.5		Japan	787.5
16	112	37.5		USA	4200
17	6	37.5		EU	225
Sum	363	47.61			17245

The auction price gradually drops from a level of $62/tC (auction 1) to a level of $50 to $55/tC (auctions 2 and 3) to stabilize at a level of $38. This is slightly below the static equilibrium price of $38.7/tC.

Walrasian repetitive auction experiment

Table 7 and Table 8 present two possible outcomes of the repetitive auction. Two outcomes must be considered in this case because Ukraine oversold permits and a compliance problem arises. After trade, it should reduce its emissions to 62.48 MtC, but only a reduction down to 88 million ton is technically feasible. In this case, the results depend on the effectiveness of the non-compliance regime. In Table 7, it is assumed that total global emissions will exceed the global emission target by 25.52 MtC, due to Ukraine overselling. The cost savings are then 91.2 percent of the potential if one assumes that the marginal costs of the reductions beyond the technically feasible minimum level are free (while sold without detection or enforcement penalty). In the second case (Table 8), it is assumed, perhaps more realistically that the buyers have to make additional emission reductions in proportion to their purchases to compensate for Ukraine's overselling. That implies that a total volume of around 26 million ton of carbon emission permits sold by the Ukraine to the various buyers was invalidated. For each buying country, a similar percentage (of the total volumes bought in the last auction) was invalidated. As a result the global emission target is realized, but cost savings are a bit lower under this buyer beware liability regime: 88 instead of 91 percent of the potential cost savings. A comparison with Table 5 makes clear that the distribution of gains is also very different from the results of the single bid auction.

Table 7: Cost savings in the Walrasian auction if Ukraine overselling.

	Abatement costs million $	Net trade payments million $	Net costs million $	Net gains from trade million $	Actual gains % of potential	Emission after trade MtC	Traded amounts MtC
USA	2816	6223	9039	3949	141	1518	193
EU	1326	4742	6068	6257	117	1014	147
Japan	449	2601	3050	7687	107	376	81
Russia	709	-7318	-6608	6608	82	423	-227
Ukraine	4450[a]	-3732	718	-718	-32	62	-116
CEE	401	-2517	-2116	2116	75	189	-78
Sum	10151	0				3582	
Costs saved	25889				91.2%		

[a.] Assumes marginal costs of zero for each reduction beyond the technical minimum. If one assumes similar marginal costs as the last technical feasible reduction abatement costs would be 13,389 million $ for the Ukraine Net costs would be 5207 million $. Overall, costs saved would only be 16,950 million $ (or 59.7 percent of the potential savings).

Table 8: Cost savings in the Walrasian auction without Ukraine overselling due to buyer liability.

	Abatement costs million $	Net trade payments million $	Net costs million $	Net gains from trade million $	Actual gains % of potential	Emission after trade MtC	Traded amounts MtC
USA	3214	5849	9058	3930	140	1506	181
EU	1642	4454	6095	6230	116	1005	138
Japan	637	2443	3079	7658	107	371	76
Russia	709	-7318	-6608	6608	82	423	-227
Ukraine	4450	-2907	1543	-1543	-70	88	-90
CEE	401	-2517	-2116	2116	75	189	-78
Sum	11052	0				3582	
Costs saved	24998				88.0%		

Table 9 shows how the price evolved in the six rounds that were necessary to detect the market-clearing price of $32.7/tC. The initial price of $100 was set by the auctioneer. Applying the price adjustment rule, the price was reduced to $30 in the second round and then raised to $33 in the third round. Quite unexpectedly, demand increased enormously in the third round in response to the higher price. In the reconstruction of events after the game, it turned out that Ukraine had successfully tried to raise the price by coming out as a purchaser instead of a seller. As a result, the price jumped up to $44 in the fourth round. Demand dropped again because Ukraine was afraid that in the end it might have to conclude a purchase contract at a rather high price instead of ending up as a seller. The price then converged quite quickly to the market-clearing price of $32.2. The price is too low compared to the perfect market equilibrium and total trade of 420 MtC (with Ukraine overselling) or 414 MtC (with buyer liability) is higher than the volume of 376 MtC that is efficient (see Table 2). In the reconstruction, it appeared that after abandoning its strategy of driving up the price Ukraine had made a calculation error in determining its optimal emission reduction and sales, using a wrong baseline. Therefore, Ukraine supplied more than what would have been efficient. Consequently, the price is lower than the efficient price and Ukraine itself is the major victim. Table 7 and Table 8 show that Ukraine in the end has higher cost with emission trade than without. Despite this ‘market failure’ carbon trading in Kyoto Protocol using the Walrasian auction realized actual cost savings equal to 88 percent of the potential cost savings (Table 8).

Table 9: Bids in the Walrasian auction (with Ukraine overselling).

Auction Round	Price $/tC	Supply MtC	Demand MtC	Supply-demand MtC
1	100	496	80	416
2	30	301.8	363.8	-62
3	33	305.3	500.3	-195.0
4	44	431.0	244.1	186.9
5	32	419.7	428.1	-8.4
6	32.3	420.0[a]	425.7	-5.7

[a]With buyer liability supply of the Ukraine would be reduced by around 25.5 MtC reducing the total supply down to 394.5 MtC.

4. Conclusions

This paper set out to examine the efficiency of bilateral, sequential trading and trading using auctions so as to validate the conjectures of economic theory in a laboratory context. For this purpose three experiments were run: one using bilateral, sequential trading and two using auctions.

The paper finds that, in line with the standard theory, both the auctions and the bilateral, sequential trading (with regular information on average prices) are able to capture a significant part (88 to 99 percent) of the potential cost savings of emission trading (see Table 10). In contrast to the usual findings, the results also suggest that not every country might gain from trading. Under the bilateral trading regime, each participant realizes substantial savings on control cost, but for some parties total expenditure turned out to be higher than when emission trading is prohibited. This is due to combination of imperfect information, speculative behavior and market power. The losses for one party are reflected in windfall profits for others. Activities such as speculation, collusion and cheating played a role especially in the bilateral trade experiment and in this respect behavior differed from the assumptions in Ermoliev *et al*. (2000). Yet the prediction that bilateral trade will converge to the cost-effective allocation is supported by the experimental evidence. The single bid auction appears does not only to fulfill an important role in achieving the potential efficiency gains from emissions trading but also serves to distribute the gains from emissions trading so that they are closer to the expected equilibrium outcome. The Walrasian auction shows that although the market clearing price was found quite quickly calculation errors, leading to non-cost minimizing behavior of individual participants affect the actual total savings on abatement cost and can make parties worse off than they would have been without trading. In spite of this the distribution of the gains in the Walrasian auction differs less from the perfect equilibrium than the distribution under bilateral, sequential trading. In the theoretical model of Ermoliev *et al*., (2000), it was assumed that all parties calculate correctly and do not try to affect the market price and therefore the market-clearing price is always the efficient price.

Table 10: Summary of results.

	Bilateral, sequential trade	Single bid auction	Walrasian Auction[a]
Costs savings % of potential savings	96	98.5	88
Distribution of gains % of potential gains[b]			
- Highest	326	139	140
- lowest	-69	68	-70

[a]With buyer-liability and Ukraine not overselling.
[b]Minus sign indicates net loss after permit trading.

Two points of discussion seem to be relevant. First, the fact that the distribution of the gains from bilateral trading differs more from the perfect equilibrium outcome than under the auctions might be relatively robust. Test runs of the bilateral trading scheme showed that the winner gained twice as much as the perfect market solution and the country with the smallest gains gained only 40 percent of the possible gains. In this case, only 76 percent of the potential gains were realized. This suggests that the auctions might not only distribute gains more evenly but may also be more efficient. Secondly, market power also occurred in the test runs. Russia, CEE and the Ukraine colluded and initially, agreed not to sell below 125$/ton C. This strengthens our conclusion that market power is an important factor to take into account when designing the carbon market. We do point out however, that in reality the number of sellers and buyers might be much bigger than in our experiment especially if developing countries such as China and India participated, or permits were traded between companies rather than countries. Thus, we might exaggerate the occurrence of market power. We do think that this affects our major finding that both auctions and bilateral trading are likely to be very efficient in practice and that the distribution of the gains might differ significantly from the perfect equilibrium outcome, in especially under bilateral trading, due to market power, speculation and imperfect foresight.

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