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Experimental Methods for Research into Trading of Greenhouse Gas Emissions

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Thank you for inviting me to discuss experimental methods for research into trading of greenhouse gas emissions. I will organize my comments around three themes: first, some comments on the experimental method generally, secondly a quick review of some of the things we have learned from experimental economics in this area, and thirdly, a few comments on research gaps that remain.

Why conduct experiments?

Why should we conduct experiments in economics? Ultimately, we wish to test whether the predictions developed through *a priori* economic reasoning can safely be applied in field conditions that are generally much more complicated than the abstract environment in which the theorizing occurred. To test the theory we must collect data. Frequently naturally occurring data is not appropriate for testing theory. There may be too little variation in the variables of interest or too many extraneous variables changing. Experiments are conducted to provide the investigator with control over the conditions under which data are collected. This allows the investigator to ensure sufficient independent variation in significant variables and to hold extraneous influences constant. For example, an investigator interested in the effect of banking tradable emission permits can set up a laboratory environment in which all agents have known costs, all agents are motivated by monetary rewards, and all the features of the trading environment are fixed. He can then vary whether banking of coupons is permitted or not. Comparison of outcomes under these two treatments permits very strong statistical conclusions. These conclusions can often be reached by simple graphical or tabular summaries of the data, without recourse to elaborate econometric techniques.

It is worth distinguishing field experiments from laboratory experiments. Field experiments are conducted in naturally occurring environments. For example, low income families can be randomly assigned to alternative income support programs and their experience tracked over a number of years. Well designed experiments of this kind are invaluable in assessing policies under actual field conditions. However, they are expensive and often politically difficult to implement. It is difficult, for example, to picture how one could have conducted field trials of alternative rules for the sulphur dioxide allowance trading introduced by the US EPA (see Schmalensee, 1998). Moreover, it is hard to maintain experimental control over all factors that may affect the outcome of the experiment. A cheaper, more flexible complement for field experiments is needed. This is provided by laboratory experiments.

In laboratory experiments human subjects are brought together to interact under strictly defined conditions. For example, eight subjects may participate in a double auction which reflects the key characteristics of an emissions trading market. Subjects are motivated by being paid substantial rewards which are dependent on their performance in the market. Data on the performance of the market under alternative trading rules are easily collected and outcomes under the alternatives easily compared. This approach to testing theory is cheaper and more flexible than field experimentation.

Experimentalists differ as to how closely the laboratory environment should resemble the field. It is clearly impossible, and probably undesirable, to mimic the field environment precisely. Some researchers have tried hard to make their laboratory environments parallel to the field. For example, Peter Bohm (1997a, 1997b) has conducted emissions trading experiments in which the distribution of permits is closely patterned after the allocation expected under the Kyoto protocol. In contrast, some argue that the role of experimentation lies chiefly in testing the relevant theory or institution without trying too hard to mimic other aspects of the field. My colleagues and I, for example, closely modelled some policy suggestions for trading both long term shares and annual permits under an emissions trading plan but we did not attempt to implement them in an environment reflecting conditions in any actual market (Godby *et al.*, 1997). Laboratory experiments will yield information about probably field outcomes to the extent that their design parallels the field. It is a matter for each investigator to determine the nature of that parallelism.

What then are the best uses of laboratory experimentation? Friedman and Sunder (1994) consider this issue at length. From their list, I would identify three as particularly appropriate to emissions trading. First, laboratory markets can be used to test the applicability of known theory. For example Cason and Plott (1996) test a specific theory about the influence of EPA trading rules on the transactions prices for emission permits. Second, experiments can provide heuristic exploration of possibilities where theory is weak For example, one can investigate whether the double auction institution can constrain market power in the context of emissions trading (e.g. Muller *et al.*, 1999). Finally, one can try to capture the key features of a proposed institution and test whether it will work as forecast in a market that resembles the expected field environment. (see Hong and Plott 1982, Bohm 1997a, 1997b). This last application is often called “test-bedding”.

What have we Learned From Emissions Trading Experiments?

A substantial number of laboratory experiments related to emissions trading have been undertaken over the past ten years or so (Muller and Mestelman 1998). What have we learned from them? Basically, they demonstrate the importance of three market design issues that are frequently ignored or down-played in discussions of emissions trading programs. First, the design of the instrument being traded matters. Secondly, the market institution in which trading occurs matters. Finally, market power on either the buying or selling side of the market matters.

Market Instruments Matter

I would like to give you a brief flavour of the evidence supporting these three lessons. Consider the first: market instruments matter. By market instrument I mean the contract which conveys the right to emit a specified quantity of a pollutant. Two dimensions of the market instrument are whether or not the permits for any one time period can be banked for use in a subsequent period and whether or not time streams in entitlements to future permits can be traded. My colleagues and I report an experiment designed to investigate the effect of these two dimensions of instrument design on the performance of emissions trading markets (Godby *et al.*,1997) . In our study annual permits were called coupons. Entitlements to a time stream of permits were called shares. Each share entitled a subject to two coupons in the first four periods of the experiment and one coupon per period in the last. Subjects' control over their emissions was imperfect; accordingly, they sometimes needed to purchase extra coupons in a reconciliation market at the end of each compliance period.

Figure 1 shows that the choice of instrument affects price stability and trading volumes. The small dots represent contract prices for two different sessions. Under a no banking, no share trading treatment there is a high volume of trade. Prices converge to the predicted equilibria, rising rapidly after the fifth period to reflect the increased scarcity of coupons. There are large price spikes in reconciliation periods. When banking and share trading are allowed, prices stabilize at the predicted levels, trading volume is much reduced, and the price spikes are greatly reduced.

Figure 2, drawn from the same experiment, shows that the choice of instrument affects efficiency, measured by the gains from trading realized by the subjects expressed as a percentage of the maximum available gains. Efficiency in the no banking sessions is low because coupon endowments are misallocated across time. If we correct for this reduction, we see that coupon trading actually achieved a very high fraction of the gains that were available solely from trading within individual periods. Banking increases apparent efficiency by allowing intertemporal reallocation of coupons, but actually decreases the percentage of available gains realized by the traders. The striking finding in this experiment was that share trading enhanced efficiency, especially in the presence of banking. There was no obvious theoretical reason why this should be so. Thus testbedding of the share trading instrument demonstrated an advantage that had not previously been predicted.

Market Institutions Matter

Other experiments have shown that outcomes in emission permit markets depend on the nature of the market institution through which trades are conducted. Figure 3 (drawn from Muller and Mestelman 1998) shows the efficiency of seven experimental emissions trading markets conducted at various laboratories in the United States and Canada using three different market institutions. All but one of these experiments used the same set of underlying cost parameters. Four used the University of Arizona's RNA (revenue neutral auction) institution, which attempted to model proposals for the US EPA Sulphur Dioxide allowance market. A key feature was the expected co-existence of a private market with an official EPA revenue neutral sealed bid auction in which all permit holders would be required to offer a specified fraction of their permit holdings. The private market was represented by a double auction. The efficiencies of the four experiments using this dual institution (FIPR2A, FIPR2C, CEVM-USC and CEVM-UM) are the four lowest in Figure 3 [1]. An alternate representation of the EPA market, which allowed a revenue neutral sealed bid auction but no double auction (CBK) achieved somewhat higher efficiencies[2]. The two highest efficiencies (experiments ET1 and ET3) were gained in market institutions

[1]The studies were Franciosi *et al*., 1993, Franciosi *et al*., 1999, and Cason *et al*., 1999.

[2] See Cronshaw and Brown Kruse, 1999.

which used the same cost parameters as the other experiments but allowed double auction trading of shares and coupons[3]. The wide variation in observed efficiencies can most credibly be ascribed to differences in the market institutions.

Cason and Plott (1996) provide further evidence of the importance of market institution in determining the outcome of emissions trading market. This experiment investigated a special feature of the US EPA sulphur dioxide auction. This is a sealed bid auction, in which buyers and sellers of emission permits submit bids and asks describing their offered price for specified quantities of units. The EPA prescribed a discriminative auction, in which bids and asks are ranked in descending or ascending order respectively, highest bids are matched with lowest prices, and the buyer pays his offered price. Cason and Plott compared this market institution with a uniform price auction (UP) in which bids and asks are aggregated to determine a market clearing price at which all transactions occur. Figure 4 shows that the UP auction led to the prices predicted for perfect competition, with essentially complete revelation of demand and supply schedules. The EPA auction, however, provides an incentive for both buyers and sellers to understated their true values. This experiment led supported Cason and Plott's argument that relatively low observed prices in the field could be explained by peculiarities of the EPA's market institution.

Market Power Matters

The third lesson from laboratory experiments is that market power can affect the outcome of emissions trading markets. Some have argued that double auction markets provide a degree of protection against monopolistic or monopsonistic manipulation. Several experiments suggest this many not be true. Figure 5 (drawn from Brown Kruse, *et al.* 1995, see also Godby 1997) shows a competitive price level of 105. When there is one seller, the predicted price is 110, except when the seller has the opportunity to manipulate a downstream market by withholding emission permits from his rivals. In this case the predicted price is 180. Similar predictions of 75 and 90 (with and without downstream manipulation) can be derived for a single seller. Observed prices tend to agree very much with theoretical predictions. This experiment clearly suggests that market power in emissions trading markets may not be constrained by the double auction institution. Note that monopsonists were particularly successful in maintaining low prices relative to competitive levels.

This finding of market power seems robust. Godby (1997) replicated and extended the Brown Kruse design, finding the similar results. Ledyard and Szakaly-Moore (1994) also found some evidence of successful exercise of market power in double auction markets. In recent work, Hizen and Saijo (1998) and Carlén (1998) find some evidence that a monopsonist reaps higher than competitive profit levels in the context of emissions markets modelled after the Kyoto agreement.

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[3] See Muller and Mestelman (1994) and Godby *et al.* (1997)

Research Gaps

In this brief presentation I have tried both to motivate the use of laboratory experiments as vital tool in testing proposed institutions for emissions trading and to give a flavour of some of the results obtained from past experiments. Much work on emissions trading systems remains to be done, of course, and I believe that laboratory experiments can be a useful tool in approaching it. I will content myself with pointing out two general areas that would repay systematic investigation.

The first is further investigation of market instruments. Two of the three flexibility mechanisms under the Kyoto Protocol, namely Joint Implementation and the Clean Development Mechanism, envisage trade not in actual quotas for the discharge of greenhouse gases, but of emission reduction credits that reflect deviations in an agents GHG emissions relative to a specified baseline. Although these instruments have similar theoretical properties in the context of a single period trading system with fixed baselines, they may have quite different results in a market in which the baselines vary with growth of output in the affected industries. Integration of credit systems with traditional cap-and-trade systems poses further problems. Here is an opportunity for effective testbedding of proposed designs.

A second area for further investigation relates to the role of market power in emissions trading markets. Further investigation is required into the ability effect of alternative institutions to constrain the exercise of market power, especially on the buying side of the market. Recent experiments by Hizen and Saijo (1998), Carlén (1998) and by Muller *et al*. (1999) move in this direction. Since so many factors interact in determining the extent of market power, a well-funded systematic investigation into the area might reap economies of scale from exploiting factorial and partial factorial designs.

To conclude, laboratory experiments are particularly well suited for heuristic exploration of complex trading environments and for testbedding proposed market institutions. Past experiments have shown clearly that market instruments, market institutions, and market structure all influence the outcome of emissions trading markets. Finally, high priority research directions include investigation of the properties of emission reduction credits trading plans, investigation of market institutions for the control of market power, and large scale testbedding using powerful experimental designs.

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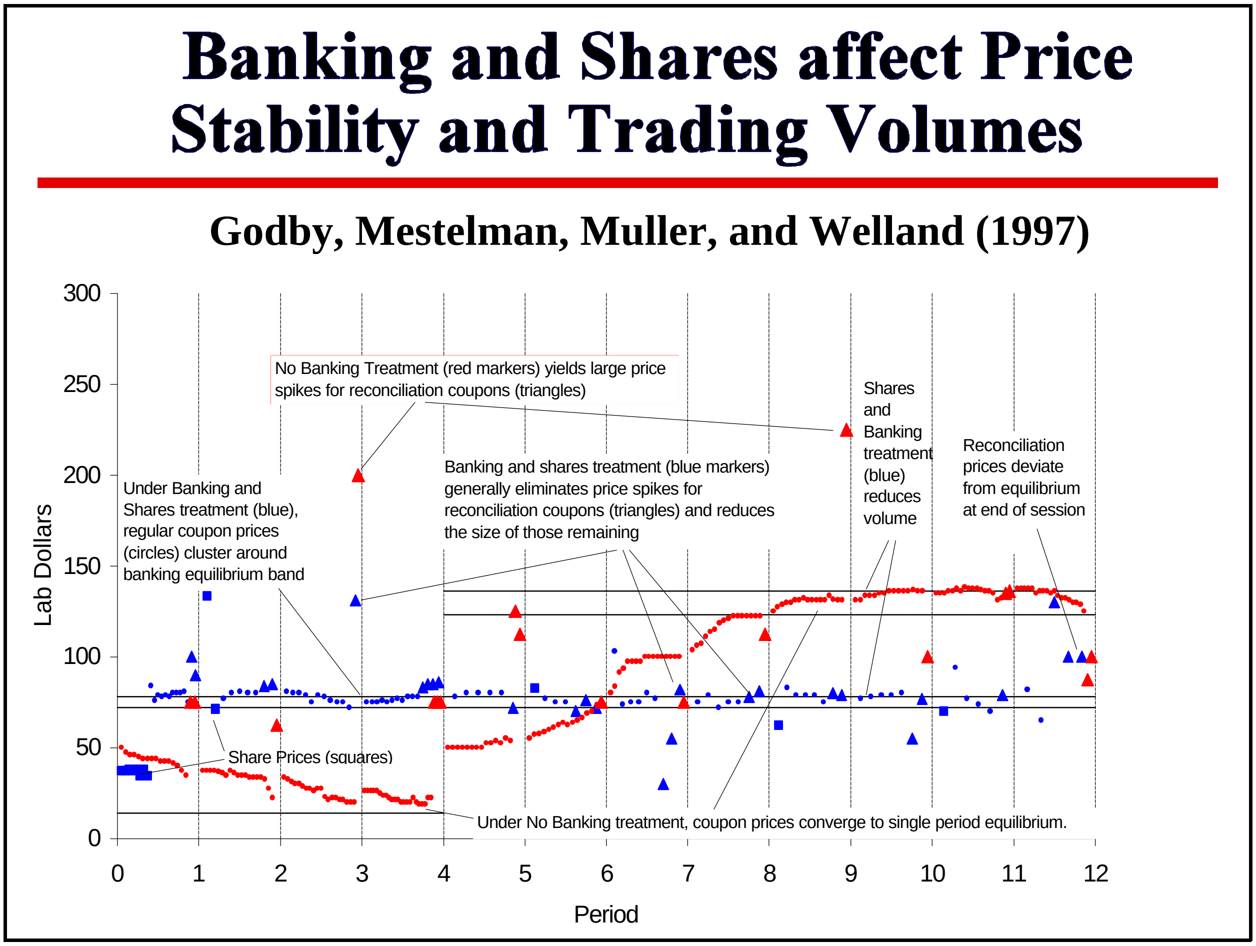

Banking and Shares affect Price Stability and Trading Volumes
Godby, Mestelman, Muller, and Welland (1997)
Lab Dollars
300
250
200
150
100
50
0
Period
0 1 2 3 4 5 6 7 8 9 10 11 12
No Banking Treatment (red markers) yields large price spikes for reconciliation coupons (triangles)
Shares and Banking treatment (blue) reduces volume
Reconciliation prices deviate from equilibrium at end of session
Under Banking and Shares treatment (blue), regular coupon prices (circles) cluster around banking equilibrium band
Banking and shares treatment (blue markers) generally eliminates price spikes for reconciliation coupons (triangles) and reduces the size of those remaining
Share Prices (squares)
Under No Banking treatment, coupon prices converge to single period equilibrium.

Figure 1

Banking and Shares affect Efficiency

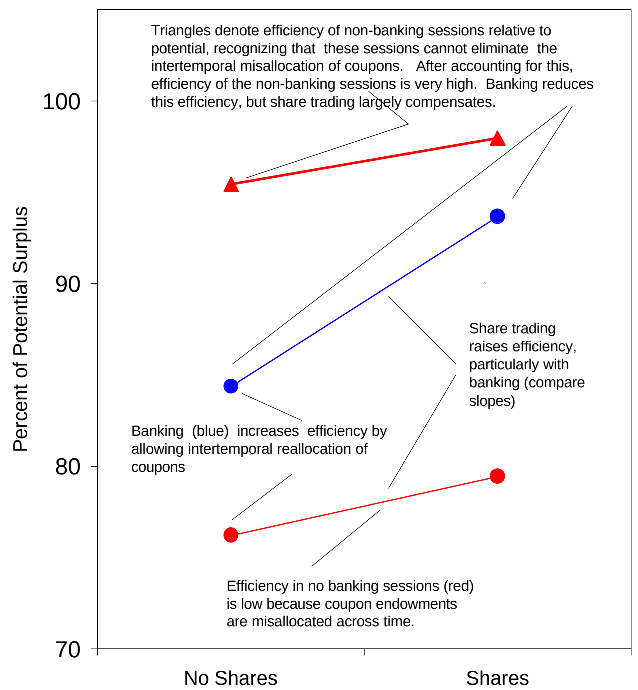


Figure 2

Efficiency Varies with Auction Institution

Testbedding Permit Markets With Banking

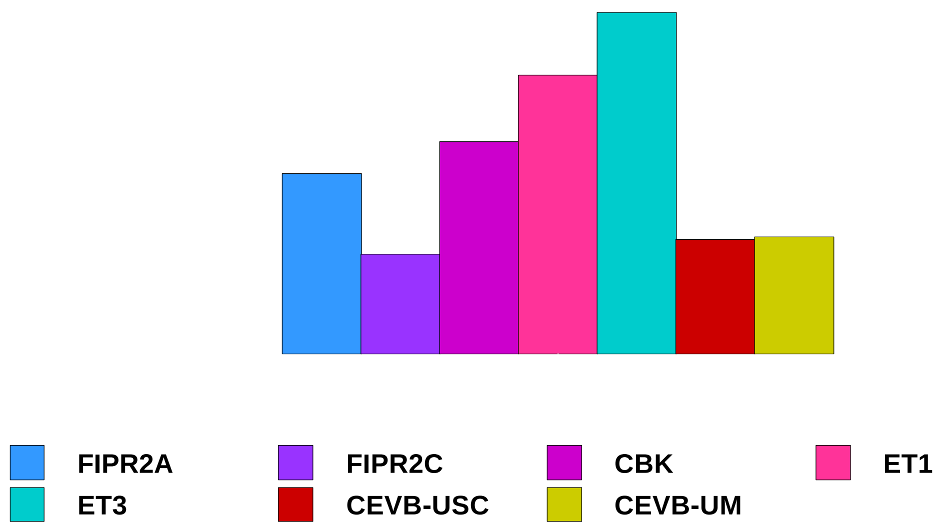
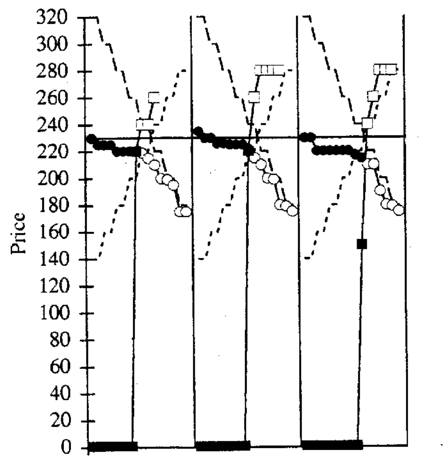


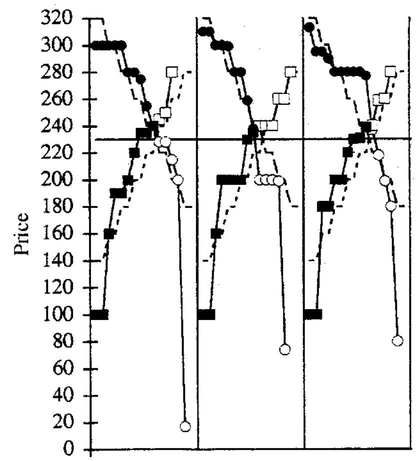
Figure 3

Further Evidence on Auction Markets

Cason and Plott (1996)



EPA Auction, Periods 9-11



UP Auction, Periods 9-11

Figure 4

Market Power Can Emerge in Double Auctions

Brown-Kruse, Elliott, and Godby (1995).

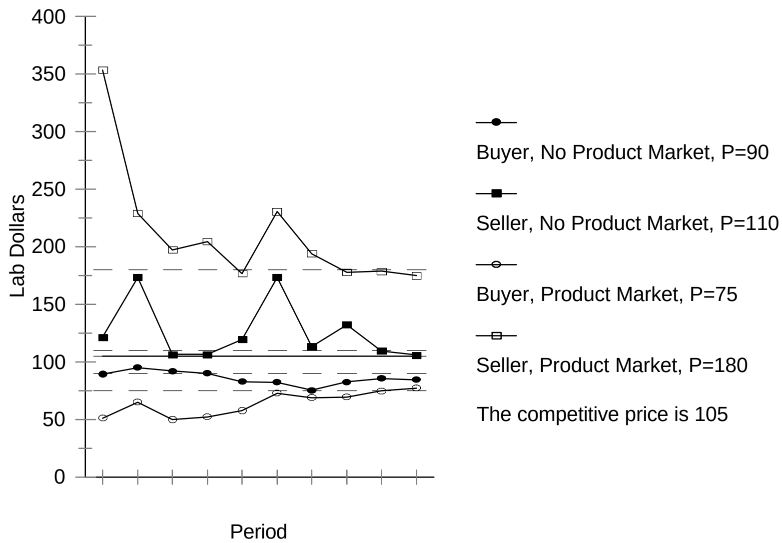


Figure 5

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