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Modeling emissions markets experimentally: The impact of price uncertainty

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Abstract: Combating climate change requires deep cuts of greenhouse gas emissions. It is crucial that policies intended to implement these cuts be efficient and drive investment in carbon reducing technologies. Experiments are being increasingly used as test beds for government policy to efficiently reduce emissions.

Emissions trading schemes increasingly being implemented all over the world, including planned schemes in Australia. The schemes should lead to efficient emissions reductions (Montgomery, 1972) , but this result rests on strong assumptions, such as no transaction costs, perfect information, and most importantly to the current study, risk neutrality of participants. These assumptions do not always hold in the field. For example, firms, even those owned by well-diversified stockholders, still exhibit risk-averse strategies. Do emissions trading schemes still lead to efficient outcomes when Montgomery's stringent assumptions are being relaxed?

We simulate a carbon emissions market experimentally. All firms in the system are allocated emissions permits for free. The total number of permits corresponds to policy makers' overall emissions target. Since the adoption of emissions reduction technologies often involve high initial investments for the long term, such decisions are modelled as irreversible for the time of the experiment.

In a well-functioning permit market the efficiency gains are reached since firms able to invest in emissions reduction at relatively low cost ("net sellers") do so. They then sell the emission permits originally allocated to them. Buyers are firms with relatively high emissions reduction costs ("net buyers"), for whom it is less costly to acquire additional permits than to invest in emissions reduction technologies. The study examines how uncertainty about the price of emissions permits affects market volume and firms' decisions to invest in long-term emissions reduction technologies.

Results support recent theoretical results by Baldursson & von der Fehr (2004) and Ben-David et al. (2000) which suggest that firms' uncertainty aversion depresses the volume and efficiency of emissions markets. If the market price of permits is uncertain, "net sellers" tend to under-invest in abatement technologies and place fewer than expected permits on the market, while net buyers over invest in excessively costly emissions reductions technologies. Results also indicate that a market for future permits (a kind of forward market) which could reduce uncertainty would not alleviate the problem.

Results are discussed in light of the challenges that the measurement of risk attitudes generally presents.

Keywords: *Investment decisions, risk attitudes, tradable permits, climate policy; experiment; efficiency;*

1. INTRODUCTION

Emissions Trading Schemes (ETS) have become a panacea for governments aspiring to reduce greenhouse gas emissions efficiently. Most ETS today allocate the majority of the permits for free to firms. Based on Montgomery (1972) the allocation method – if permits are handed out for free or auctioned off - should not have an impact on the cost savings achieved by such schemes: Firms with low emissions reduction costs (“**net sellers”)** will invest in abatement technologies and sell any surplus emission permits allocated to them. Firms with high emission reduction costs **(“net buyers”)** should buy these additional permits instead of investing in too-costly abatement technologies. However, Montgomery obtains his formal results with the aid of strong assumptions, such as risk-neutral participants, no transaction costs, and perfect competition with perfect information and hence no market uncertainty. In the real world those market imperfections may impact on firms behaviour and may reduce schemes’ efficiency.

1.1 Models of risk averse buyers and sellers of permits in emissions markets

Are firms ever risk-averse? It is not irrational for smaller, single-owner firms to be so and individuals certainly are (See, e.g., Kahneman & Tversky, 1979). However, even firms owned by well-diversified stockholders do take costly actions to reduce risk (See, e.g., Ogden & Connor, 2002, pp. 86–88). Baldurson & von der Fehr’s (2004, henceforth BF) theoretically examine the behavior of risk averse firms in a permit market with uncertainty, and conclude that due to uncertainty in both trading volume and price,

- Net sellers invest less in emissions reduction technologies than would be efficient, adopt a “wait and see” attitude and in the meantime simply use the permits allocated to them.
- Net buyers on the other hand invest more in emissions reduction technologies than would be efficient. The extra expense affords them independence from an uncertain and potentially volatile (hence risky) market and at the same time helps them avoid penalties for excess emissions with certainty.

BF suggest that *forward markets* for permits would counteract but not entirely eliminate the combined effects of market uncertainty and risk aversion on scheme efficiency.

Ben-David, Brookshire, Burness, McKee, and Schmidt (2000) examine the impact of price uncertainty and firms’ risk aversion on the US SO_2 market. Like BF, they conclude that

- Risk-averse net sellers wish to avoid uncertainty with regard to permit prices, do not reduce their emissions enough, and therefore have fewer permits to sell. This leads to an inward shift of the supply curve for permits.
- In order to gain independence from a potentially volatile market, risk averse net buyers respond to price uncertainty by investing in relatively costly emissions reduction technologies (leading to an inward shift of the demand curve for permits).

In Ben-David et al.’s model permit prices are approximately[1] the same under what they term “price certainty “and “price uncertainty”, but uncertainty reduces trading volumes and efficiency. The authors test their model experimentally but only manage to show that permit prices are indeed the same under their “price certainty” treatment and “price uncertainty” treatment. Their hypothesis that price uncertainty reduces trading volume is not supported. We think that this is due to a problem with the experimental design: Ben-David et al.’s baseline condition already involves price uncertainty since both price and volume uncertainty are present in every market, particularly in a newly designed market, or, for that matter, in a short-lived laboratory market. Ben-David et al.’s treatment meant to specifically model uncertainty of the total number of available permits involves a rather weak manipulation: it merely increases the baseline condition’s uncertainty by a small margin thru relatively small changes in regulator’s behavior over experimental rounds.

1.2 An alternative explanation for low trading volumes without reference to risk attitudes

Murphy and Stranlund (2005) are skeptical of the claim that risk aversion is responsible for reduced trading volumes in an ETS. They tentatively speculate low trading volumes could also result from an endowment effect (see, e.g., Kahneman, Knetsch & Thaler, 1990) toward the permits allocated to firms. They correctly argue that risk attitudes are hard to control for, so that alternative explanations for low trading volumes could become plausible. Two facts must be considered here:

[1] The effect can not be determined with precision since the exact rate of the inward shift of demand and supply curves may differ due to individual risk attitudes.

- The usually observed increase in real-world emissions market volume over time (see, e.g., Convery & Redmond 2007) indicates initial hesitation due to initial uncertainty and a lack of pressure to rather than an endowment effect. This is because the latter is a stable psychological human tendency which affects how they evaluate goods in the market. It does not dissipate over time.
- There is mounting evidence that risk attitudes are indeed extremely hard to control for since such attitudes are very situation specific. Hence, a particular test may not capture such attitude beyond the decision situation which the test itself represents (see, e.g. Isaac & James, 2000; Harrison, 1995; for recent overviews see Friedman & Sunder, 2009; Masclet, Loheac, Denant-Boemont & Colombier, 2009). This presents a big challenge to experimenters intent upon showing the impact of risk attitudes on behavior. Risk attitudes impact behavior, but such attitudes are hard to asses independently and apparently risk-averse behavior therefore remains open to alternative explanations.

1. 3 A forward market for permits valid in future years might reduce market uncertainty

BF suggest that forward trading alleviates price uncertainty and increases scheme efficiency since it provides both net sellers and net buyers with price and volume information about an otherwise uncertain future. Net sellers could for example gage the price of their excess permits in the future if they decide to invest now in emission reduction technologies that usually have high initial fixed costs and a long life span. Net buyers, on the other hand could buy future permits in the current period and thus be certain that their future emission targets will be met, hence no need for them to invest in costly (and inefficient) emissions reductions technologies in order to gain the certainty they seek. In sum, a forward market should lower uncertainty around future prices and market volume, and should increase trading volume if participants are risk-averse. In addition to a "spot" market for current-year permits, we therefore experimentally examine such a forward market for permits.

1.4 Hypotheses

If participants are risk averse, price and volume uncertainty in the permit market should result in:

1. Less investment in emissions reduction technologies by net sellers, and an inward shift in the supply curve for permits
2. Increased emissions reduction by buyers, and an inward shift in the demand curve for permits.
3. A lower trading volume than in the competitive market equilibrium.
4. Higher overall emissions reduction costs compared to the optimum.
5. Adding a well functioning forward market for future-vintage permits should reduce market uncertainty and increase efficiency since
    a. net sellers invest more in emissions reduction technology and overall trading volume is higher since there are now more opportunities to trade,
    b. net buyers reduce less since they can buy future vintages at lower costs on the market
    c. prices are less volatile since there is now a price-discovery mechanism for permits in upcoming years.

2. METHOD

2.1 Design

There were two experimental conditions. In the baseline (**spot**) condition participants traded permits for the current year only. In the "**forward vintage**" condition permits for the current year as well as permits valid in all future periods of the experiment were traded. There were four experimental sessions per condition, with each session compromising eight participants (four net buyers and four net sellers).

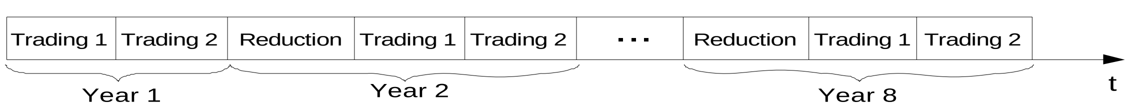

Figure 1, Experimental stages and "Years"

2.2 Procedure

After payment of their show-up fee, subjects were seated at visually separated computer terminals which contained their written instructions. The instructions were also projected on large screen to make clear that they were common information. Additionally, each participant received a sheet with her private information (see Sec. 2.3). It was common information that this private information existed, and that it differed between participants. At the end of the experiment, experimental earnings were converted from EX$ into AUS$ and privately paid to participants.

2.3 Emissions trading experiment details and parameters

In order to contribute to a coherent body of experimental findings on ETS schemes, we follow the setup of Ehrhart, Hoppe & Schleich (2005, EHS), but with some minor differences. In order to reflect the Australian ETS proposed design, permits in our experiment are modelled as yearly permits with "vintages", which indicate the date they become valid (Parliament of the Commonwealth of Australia, 2009).

- *Objective*. Maximization of the firm's total profits over the experimental session.
- *Specific context*. The experimental instructions refer explicitly to CO_2 emissions trading. Each participant represents a firm which generates CO_2 emissions (Table 1 Col. 4) and is given an initial cash allocation at the out start (Table 1 Col. 3).
- *Experiment time line*. See Fig. 1. Each of eight experimental "years" consists of a period in which firms decide on whether to implement emissions reduction technologies, followed by two separate periods for trading permits. Each stage lasted for a maximum of four minutes. Each experimental session lasted for approximately 2.5 hours.
- *Emissions reduction technologies*. Each firm has three different emissions reduction technologies at its disposal. They differ in their yearly costs. At the beginning of each year from year 2 onward, firms decide whether to implement any such measure in the "reduction" stages (Fig. 1). Once implemented a technology reduces the firm's CO_2 emissions by a fixed yearly amount and cannot be switched off, reflecting the irreversibility of reduction measures common to many technologies. See Table 1 Col. 7 for the varying cost of the technologies.
- *Permit allocation*. All permits are allocated to firms for free at the beginning of the experimental session and become valid in specified "Years". Each permit corresponds to one ton of CO_2. The quantities of permits allocated decreases from Year to Year, that is, the emissions target (cap) is tightened over time. See Table 1 Col. 5.
- *Modeling firms as Net Buyers or Net Sellers*. Firms' "yearly" emissions are identical in every year and across all players (Table 1 Col. 4). In order to create a strong incentive to trade, each firm is further characterized as a Net Buyer or a Net Seller:
    - The initial cash budget is higher or net buyers facilitating their permit purchases (Table 1 Col. 3)
    - The mean cost of its three emissions reduction technologies is higher for a net buyer firm which is thus better off buying permits than implementing their expensive technologies. (Table 1 Col. 7).
    - Table 1 Col. 5 shows that net buyers are also allocated fewer permits than net sellers, further increasing net buyers' need to make use of the market.
- *Trading*. Each trading stage (Fig. 1) is a uniform-price double auction; players simultaneously submit their price-quantity bids and asks. The market price, established at the end of the period, is the price that maximizes a period's trading volume.
- *Forward trading condition*. This treatment allows simultaneous trading in up to eight markets (corresponding to the different "years"). The yearly permits are date-stamped. The first year in which they become valid is their "vintage".
- *Borrowing* of permits (using permits valid in upcoming years in the current year) is not possible.
- *Banking* of permits between years is allowed.
- *Sanctions*. At the end of each "year", participants surrender the number of permits corresponding to their firm's CO_2 emissions (which will include the implemented reduction technologies) that "Year", or else are fined 100 EX$ per missing permit. The missing permits are also withdrawn from next year's allocation.[2]

[2] This way, sanctions do not constitute as a cap on permit prices.

- <u>*Information structure*</u>
  - *Private information* on a participant's private information sheet consisted of the firm's initial cash endowment (Table 1 Col. 3), projected emissions (Table 1 Col. 4), quantity of permits allocated for each year (Col. 5), and the volume and costs of the emissions reduction technologies available to it (Col. 7). Participants were informed that the private information sheets differed between subjects.
  - *Common information* included the number of Years and periods, the number of buyers and sellers, the system's overall emissions in the preceding Year, projected emissions in the current Year,[3] the sum total of allocated permits per Year, the number of reduction technologies available to each player, their uniform distribution and maximum and minimum cost,[4] and the latest price and quantity traded for each type of permit. In the forward vintage treatment all subjects were able to look up the past quantities and prices for each vintage in all trading stages.
  - *End of period feedback.* After each trading stage firms were informed of their own traded volume and the permit price of the last trading session, and of the overall market volume and price. In the forward vintage treatment this information was provided for each vintage separately. After an implementation stage firms were given a list of their implemented emissions reduction technologies, their costs and the reductions achieved. In addition, they were informed about their monetary balance. The next segment started after all players had acknowledged this information (Fig. 1).
  - *Endgame*: Since an emissions scheme is usually expected to continue beyond its 8th year, and in order to avoid end game effects, after the last period remaining are bought back at a price of 80% of weighted (by trading volume) mean market price of two randomly chosen trading stages. [5]

1	2	3	4	5	6	7		
Firm Nr.	**Net buyer/ net seller**	**Initial cash allocation (EX$)**	**Projected emissions per trading period [tons CO_2]**	**# permits allocated from first to last period [tons of CO_2]**	**Reduction volume per period of each measure [tons of CO_2]**	**Annual cost of emissions reduction technologies [Ex$ per ton of CO_2]**		
1	NS					4	32	36
2	NS	20000	200	220, 210,…, 150	30	8	28	40
3	NS					12	24	44
4	NS					16	20	48
5	NB					52	80	84
6	NB	32000	200	200, 190,…, 130	30	56	76	88
7	NB					60	72	92
8	NB					64	68	96

Table 1, experiment parameters.

3. RESULTS

3.1 Benchmarks

The optimum is the efficient cost-minimal solution, characterized by a specific time path of technology investments over "years". The overall least expensive technologies must be implemented and for this, a certain number of trades are required. In every year, the most expensive technology implemented thus serves as a characteristic value for the scarcity of permits and their current market price: The market price for a given period's permit should lie between the cost of the most costly technology implemented, and the least costly of the technologies not yet implemented. It can be deduced from Table 2 that in our case the seven cheapest technologies should be implemented at the start of Year 2 (the earliest point in time at which any technology can be activated). At the start of Year 4, one more technology needs to be implemented. Under the parameters in Table 2, net buyers should not implement any technologies, and purchase permits instead. Net sellers should each implement two out of their three technologies. The market price for a permit should lie between 28 EX$ and 32 EX$ until Year 3, and between 32 EX$ and 36 Ex$ thereafter. The minimum total cost of achieving the given target over all periods is 28,320 EX$.

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[3] This information is excluding any reduction technologies implemented at the beginning of the current year by other firms (Table 1).
[4] Subjects thus knew the global balance with a lag of one year. The global balance is the sum total of the system's emissions in a given year minus all activated emissions reduction technologies.
[5] This prevents hoarding of permits, and the random choice of two trading stages prevents price manipulation of the final payout.

The command and control benchmark (CCB) is the situation where each firm achieves its annual emissions target based only on the initial allocation of technologies and permits, without trading or banking of permits.

3.2 Risk attitudes

In spite of our caveats in Sec. 1.2, we did attempt to measure subjects' risk attitudes using Holt & Laury's (2002) test adapted by Gandhagaran & Nemes (2005). This is because Lee, Deck, Reyes and Rosen (2008) recently suggested that this particular test could serve a measure of risk attitudes toward investment decisions more generally. One might argue that activating emissions reduction technologies constitutes an investment. However, the test did not predict technology investment behavior in the current study.

3.3. Experimental results

Result 1: Net sellers implement reduction technologies never, or significantly later than prescribed in the optimum and instead use up the permits allocated to them in order to achieve their emissions targets. Net buyers, who should not implement any of their technologies, do in fact implement those rather than buying permits in the market. Table 2 shows the divergence from the optimum timing of implementation for each of the three technologies, separately for net sellers and net buyers. The absolute size of any deviation score can be interpreted as an expression of discomfort with the uncertain market or possibly, the reaction to the thin trading volume caused by the actions of one or the other group.

Net Seller or Net Buyer	Reduction technology	Diff. between mean implementation stage and optimum*
NS	T1	2.13 (late) **
	T2	2.72 (late)**
	T3	-0.84[1] **
NB	T1	-5 (early) **
	T2	-0.81 (early) **
	T3	-0.38 (early) **

**** p [1-sample, 1-sided] < 0.01**

Table 2, mean difference between the optimal implementation stage of a technology and its mean observed implementation stage.

* Positive difference scores show delayed implementation, negative scores accelerated implementation compared to the optimum. NB scores are all negative because in the optimum their technologies are never implemented.

Result 2: Trading volume is lower and overall emissions reduction costs are higher than in the optimum. Forward vintage trading does not improve the scheme's efficiency.

Table 3 shows in all sessions and in both conditions there are fewer trades and higher total emissions reduction costs than in the optimum, and that efficiency does not differ between the spot market and the forward market. Subjects hardly traded future vintages. With the wide range of Years for which permits could be traded on the vintage market, there may not have been enough interested parties to effectively match bids and asks for a particular vintage, something to explore in future experiments.

	Trading Volume [tons of CO_2]			**Reduction Costs [Ex$ per ton CO_2]**			**Efficiency**[6]
Condition	**Mean**	**Optimum**	**CCB**	**Mean**	**Optimum**	**CCB**	
Current year permit trading only	**680**	**1,120**	**0**	**9,310**	**3,540**	**13,410**	**0.42**
s1	871	1,120	0	8,205	3,540	13,410	0.53
s2	736	1,120	0	8,175	3,540	13,410	0.53
s3	582	1,120	0	9,311	3,540	13,410	0.42
s4	529	1,120	0	11,550	3,540	13,410	0.19
Current and future year permit trading	**763**	**1,120**	**0**	**9,360**	**3,540**	**13,410**	**0.41**
f1	933	1,120	0	10,485	3,540	13,410	0.30
f2	392	1,120	0	8,850	3,540	13,410	0.46
f4	795	1,120	0	8,940	3,540	13,410	0.45
f5	932	1,120	0	9,165	3,540	13,410	0.43

Table 3, Emissions reduction volumes, costs and efficiency per experimental session

[6] Calculated by comparing the scheme's observed emissions reduction costs (RC_A) to its optimum costs saving (RC_O) and to the CCB's reduction costs (RC_{CCB}): $[(RC_{CCB}) - (RC_A)]/[(RC_{CCB})-(RC_O)]$ (Godby , Mestelman, Muller & Welland, 1997).

4. CONCLUSION

Our findings are in accordance with the theoretical prediction of Ben-David et al. (2002), and BF (2004), that because participants are risk-averse, ETS schemes are subject to market imperfections which reduce their effectiveness compared to what was originally suggested by Montgomery (1972). Is risk aversion the determining factor? Strictly speaking, this remains to be established, due to the increasingly obvious general problems with the independent measurement of situation-specific risk attitudes. We can however say that compared to the theoretical optimum, net sellers of permits invest less in emissions reduction technologies, and net buyers invest more in technology than they should. Both groups make insufficient use of the market, behaviors typical of risk averse market participants.

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