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Pricing Strategies under Emissions Trading

An Experimental Analysis

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RESOURCES FOR THE FUTURE

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Abstract

An important feature in the design of an emissions trading program is how emissions allowances are initially distributed into the market. In a competitive market the choice between an auction and free allocation should, according to economic theory, not have any influence on firms' production choices nor on consumer prices. However, many observers expect the method of allocation to affect product prices. This paper reports on the use of experimental methods to investigate behavior with respect to how prices will be determined under a cap-and-trade program. Participants initially display a variety of pricing strategies. However, given a simple economic setting in which earnings depend on this behavior, we find that subjects learn to consider the value of allowances and overall behavior moves toward that predicted by economic theory.

Key Words: carbon dioxide, climate change, emissions trading, distributional effects, electricity, allocation, auctions

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Executive Summary

An important feature in the design of an emissions trading program is how emissions allowances are initially distributed into the market. In a competitive market, the choice between an auction and free allocation should, according to economic theory, not have any influence on the firms' production choices nor on consumer prices. However, many observers would not expect firms to raise product prices if they receive emissions allowances for free and would expect them to do so if they purchased those allowances in an auction.

Throughout much of Europe and the United States, energy markets have been deregulated or are in the process of moving toward market liberalization. If market behavior does not conform to predictions of behavior in a competitive market, this may say a great deal about the nature of market liberalization in energy markets as well as about the behavior of environmental markets. For instance, if firms are able to voluntarily moderate commodity prices to be below competitive levels, it suggests an ability of these entities to exercise market power or collude—even if this is motivated by a desire to hold back and not pass through the value of emissions allowances in product prices.

This paper reports on the use of experimental methods to investigate behavior with respect to how prices will be determined under a cap-and-trade program. Participants in the experiments employ various approaches. Some participants initially recognize the opportunity cost of emissions allowances and include them in their economic choices regardless of how the allowances are obtained, and other subjects initially do not. However, given a simple economic setting in which earnings depend on this behavior, we find that subjects learn to consider the value of allowances and overall behavior moves toward that predicted by economic theory.

The observations from the experiments may help to understand the ongoing public debate over the interaction of the EU ETS and energy markets. Emissions allowance markets are a new

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phenomenon to many politicians, firms and policy officials. In addition, the deregulation of energy markets is a relatively new process and progress is not uniform across countries, resulting in markets in different stages of liberalization. When one considers this, it is not surprising that the public and political intuition of how markets ‘should’ work may diverge from economic theory, much in the same way as it initially did for the subjects in our experiments.

If the observation of ongoing learning is correct, there are grounds to be optimistic about the future development of the energy system. On the other hand, there are proposals from important member states in the EU and states within the U.S. to protect energy customers from price increases through re-regulation of energy markets. If measures to limit the level of pass-through of emissions allowance costs become widespread, it could threaten the process toward a more integrated and competitive energy markets.

Introduction

Policymakers are increasingly turning to the use of economic instruments for environmental regulation, especially for regulation of air pollution. One prominent example is the adoption of emissions cap and trade programs that limit the total amount of emissions from regulated sources. An emissions cap introduces scarcity for the right to emit. The value of that scarce right is reflected in the price of an emissions allowance, which may be bought or sold by participants in the market.

The EU Emission Trading Scheme (ETS) is the world's largest market for emissions allowances and it establishes a cap-and-trade program for carbon dioxide (CO_2) emissions for the electricity sector and large industrial emitters for 25 member states of the EU. The price of an allowance to emit one ton has hovered around 25 Euro per ton through 2008. The allowances can be banked for use in a future year. Each year a new emissions cap is applied, new emissions allowances are introduced and the scarcity value of those allowances is created anew.

An important feature in the design of the emissions trading program is how emissions allowances are initially distributed into the market. In the first phase of the ETS from 2005–2007 approximately 99 percent of the allowances were distributed for free to incumbent emitting firms, and in the second phase from 2008–2012 approximately 96.5 percent will be distributed for free. Free allocation has come under scrutiny stemming from critical analyses of economic efficiency, administrative efficiency and distributional fairness, prompting the EU to decide in favor of the use of an auction for the majority of allowances going to the power sector beginning in 2013, and an expansion of the auction from 20 percent in 2013 to the entire market by 2027 for the industrial sector, with some exception for sectors at risk of competition from industries abroad that do not have climate policies in place. This evolution is presaged by the implementation of an auction to distribute about 85 percent of the emissions allowances in the Regional Greenhouse Gas Initiative in the northeast United States, which takes effect in 2009, and a general shift toward the use of auctions in various national climate cap-and-trade legislative proposals in the United States.

A central consideration in this policy shift away from free allocation to an auction is the influence this decision will have on the determination of retail prices. Most economists feel that, at least in competitive markets, the choice of allocation mechanism should make no difference in retail prices. This view reasons that the economic value of emissions allowances depends on

their scarcity in the market, not on how the allowances were acquired initially. In a competitive market firms are expected to set retail prices so as to recover this economic value.

Many others do not expect firms to raise product prices to include the value of emissions allowances they receive for free. This reasoning would expect product prices to be lower under free allocation than under an auction. The requirement to pay for allowances in an auction reflects a change in the variable costs of production, and hence it is reasoned that the introduction of an auction will raise product prices. Occasionally, industry has reinforced this view. One energy company official told Point Carbon "If EUAs (emissions allowances) are auctioned that will only lead to 100 per cent of the carbon price being priced into the electricity price, and thus increase it (electricity price)."[1]

In the presence of opposing views, the fundamental question is an empirical one. Bunn and Fezzi (2007) conduct time series econometric analysis on the UK electricity market and Fell (2008) conducts analysis in the Nordic market. Both studies attempt to determine the influence on electricity price of changes in the price of factors of production including fuel and emissions allowances. In an analysis involving econometric and simulation methods, Sijm et al. (2006) find a response in the short-run electricity price in the markets in the Netherlands and surrounding countries. These studies find that in these three relatively competitive electricity markets electricity prices respond to a change in the price of emissions allowances, suggesting that consumers pay for a significant portion of the value of emissions allowances even when industry has received them for free. However, there remains ambiguity about how much pass-through of allowance value that has occurred in practice or how much one should expect.

The approach we use is to examine the behavior of firms through the use of experiments in a laboratory setting. In these experiments, individuals are given a chance to make decisions in a structured environment resembling the decisions faced by firms in real markets. Individuals earn real money according to their performance in the experiment, creating a substantial incentive to make profit maximizing decisions. Experimental economics is particularly useful for exploring this type of issue because in a laboratory setting researchers can control and isolate various aspects of the decision problem including the structure of costs and emissions rates, etc. In our experiments, participants make production or pricing decisions for products that require two inputs: fuel and an emissions allowance. In some treatments they receive emissions

[1] "Member States look to deal with windfall profits," *Carbon Market Europe, Point Carbon*, October 14, 2005, p. 6.

allowances for free and in others they must purchase them. Players profit maximize by choosing to produce the product at prices that reflect the value of both the fuel and the emissions allowance, regardless of how the allowance was acquired.

In brief we find that participants initially exhibit a range of behavior consistent with the range of expectations about how an emissions market would perform. That range encompasses full or nearly full pass through of allowance value regardless of how allowances are distributed by some participants, and little or no pass through when allowances are given away for free by other participants. Participants make decisions that are closer to economic theory (profit maximizing) when they have to purchase allowances than when they receive them for free. Participants that maximize profits receive greater earnings, and we find there is learning in that over time participants make decisions that are closer to profit maximizing levels in treatments both with and without free allocation. Players who receive information on their earnings relative to others (i.e. more transparent market conditions) have a stronger improvement in profit-maximizing behavior over time.

The remaining paper is structured as follows: Section 2 gives a brief introduction to emissions allowance trading along with a non-technical discussion about how allowance trading may affect retail prices. We then set forth the hypotheses, procedures and results in sections 3-5. Section 6 reviews evidence from existing policies and markets, and Section 7 contains conclusions and some further discussion.

Emissions Allowance Trading and its Effect on Product Prices

There are numerous ways that the emissions allowances may be allocated initially. They can be distributed for free, for instance based on past emissions, or market participants may have to pay for them. In the latter case, selling the allowances in an auction is usually a suitable approach. The public finance literature finds undisputed benefits from auctioning allowances as compared to giving them away for free in that the government's revenues from the auction may be used to decrease distorting taxes thereby lowering the overall social cost of the policy, the so-called double dividend.[2] Many have argued there are also administrative advantages to the use of an auction (Binmore and Klemperer, 2002). However, if there is some other negative effect from

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[2] Bovenberg, A.L., and Goulder, L.H. 1996; Bovenberg, A., and de Mooij, R. 1994; Goulder, L. H. et al. 1999; Parry, I. A. W. et al. 1999. Smith, A.E., et al. 2002.

auctioning, the government must take caution so it does not outweigh the positive effects from the double dividend. As discussed in the introduction, one such negative effect often discussed in the public debate is the possibility that since firms have to pay for the allowances they may be forced to increase consumer prices in order to cover their additional costs. As higher prices harm consumers *ceteris paribus*, such a claim must be seriously considered.

To comply with the requirements of an emissions trading program, a firm may choose to reduce its own emissions (by using a less polluting production process and/or reducing production) or to use more allowances and effectively compensate another firm for reducing emissions. Typically we would expect a little bit of both such that the cost of further decreasing emissions is equal to the price of an allowance. It is thus the case that the firm's costs are increased by the presence of an emissions allowance trading scheme and that if possible firms will increase prices to cover this additional cost. However, what is not true—according to economic theory—is that the increase in consumer prices follows from the way in which emissions allowances are allocated initially.

Using an allowance to cover emissions represents a cost because if the allowance is not used it may be sold on the market. Economic theory states that a rational agent should take such 'opportunity costs' into consideration when making decisions, *e.g.*, about how much to produce and/or what price to charge for their product. It is the fact that allowances have a valuable alternative use that may lead to higher prices for consumers. The choice between an auction and free allocation as we have described it should, according to economic theory, not have any influence on the firms' production choices nor on consumer prices.[3] In either case, the firm in a competitive market will charge its customers for the use of allowances as an input to production just as it will charge for fuel or labor used for its production activities.

The economic theory of behavior in a competitive market does not remove the ambiguity about how much pass through one could expect to observe in product prices. One source of ambiguity has to do with the heterogeneity of technologies within the market, and another has to do with competition from producers outside of the market. An example of ambiguity due to the heterogeneity of technology is the electricity sector, which has been at the core of previous emissions trading programs and where there exists a diversity of long-lived generation

[3] Theory suggests there are ways free allocation can affect production decisions, for example when allocation is contingent on production (Fischer and Fox 2007).

equipment. Technologies differ with respect to the marginal cost of producing one additional unit of electricity and with respect to their emissions rate. In most wholesale power markets each electricity producer receives the same price per unit produced, which depends just on the bid of the last generator, *i.e.* the one with the highest marginal cost needed to meet demand at any point in time. Hence, even if one expected to observe 100 percent pass through of allowance value in the bids of generators (regardless of whether they were grandfathered or auctioned), the change in revenues from the sale of electricity could be greater or less than the market value of allowances used in the market, depending on the characteristics of the marginal generator. For example, in a market in which non-emitting technologies such as nuclear and wind provide the first 50 percent of the power in a market due to low marginal cost, and an emitting source such as natural gas with high marginal cost provides the other half. Full pass through of allowance value would lead to a change in revenues that is twice the value of allowances actually used in electricity generation because half the generation has no emissions. Conversely, if the non-emitting technologies have the highest marginal cost and thus are the last units to be put into production, their bids would set the price in the market and the price would not include allowance costs.

A second source of ambiguity does not require heterogeneity in costs, but hinges instead on heterogeneity in regulation—e.g. whether regulated firms face competition from a global market with firms that are not included under the emissions cap. If firms regulated through the trading scheme are competing with firms outside the scheme they may be unable to pass through any of their costs for the emissions allowances in the price whether allowances are received for free or in an auction because the market price is set in a global market. In the short run a regulated firm cannot choose its price and has as its only option the possibility of a decrease in production. Alternatively, if all of the competition is regulated under the cap the market price would be expected to increase.

The decision for firms competing globally is, at least in its stylized form, simpler than for firms competing locally. The global actors have no other choice than to take the world price as given and act accordingly. However, when all the firms are regulated the actors know that their competitors also face the regulation and consequently the market prices will increase following from the regulation. However, they do not know in advance the extent of this increase, and it might take longer to find a new equilibrium in the local market case than in the global case, simply because the problem faced by firms acting locally is more complex than for firms acting globally.

In sum, there are two entangled issues; first, how much of the allowances' value is passed through by an individual generator in its bids and, second, to what extent these pass-through strategies affect the product price, e.g. the price of electricity. In this paper we are primarily interested in the first of these issues and we use laboratory experiments to disentangle the two effects and target the pass-through strategy issue only.

Hypotheses

The experiments we conduct put individuals into a decision context that resembles the situation a firm faces in a market where it has costs of production and has to surrender an allowance for emissions associated with production. The subjects receive allowances in two ways: either as a free endowment received before the start of the experiment, or by purchasing them at a pre-announced price during the experiment. In each case any unused allowance has a pre-specified resale value that the subject can receive for any allowance not used in production.

As indicated above, economic theory suggests that the subjects in the experiment will take the opportunity cost of allowances into consideration in their production decisions. However, as there are very different viewpoints in evidence about what to expect, we cannot take it for granted that economic intuition is shared by all participants. We expect that:

1) *Participants display a variety of decisions in initial stages of the experiment.*

As we describe below, the experiments are structured to provide participants with a financial incentive to behave in accord with economic theory – doing so can lead to substantially greater earnings. However, even if the subjects embrace a strategy that maximizes their payoffs, they may require repeated rounds of the experiment before they learn to do so. One reason may be that subjects do not behave initially according to economic theory but that they are disciplined by the structure of the problem and the payoff opportunities and so they learn to change their behavior. An alternative reason may be the task is not trivial and subjects learn about the task over time. We expect that, at least for some subjects, an iterative process may be needed in order to reach the strategy that maximizes the payoff (the efficient strategy):

2) *Subjects improve their payoff over multiple rounds of the experiment.*

There is ample evidence that people view free allocation differently from an auction. There are two potential underlying ideas that may explain this. The simpler is that if the subjects pay for allowances they may take this into consideration in their production decision in the same way that they consider the cost of other inputs to production. That is, subjects may not need to grasp the idea of opportunity cost to arrive at the efficient strategy. A somewhat more complex

line of argument is that it is hard to know the correct value of an allowance before the market is fully established. Previous experience in allowance markets indicates an auction has played an important role in the discovery of the price of allowances (Ellerman et al. 2000). An initial auction provides a signal about this value, which will make it easier for the subjects to correctly take the opportunity cost into consideration. In the experiments we have focused on the former explanation by explicitly stating the market price of allowances to the subjects in advance of their decisions. We conjecture:

3) *Agents can more easily identify the optimal pricing strategy under an auction than under free allocation.*

Finally, we consider the role of information about one's performance relative to the performance of others. One of the ways that firms learn, especially in a new market environment, is by watching the performance of other firms. For example, firms benchmark themselves against competitors and hire management consultants who provide advice about how to perform in a particular market based on other firms' strategies, all in order to maximize shareholder value in the firm. Consequently, we conjecture that if participants receive information about their payoffs relative to the performance of others in the experiment they will adapt their strategy more quickly. Thus:

4) *A more transparent market helps agents to identify the optimal pricing strategy*.

Procedures

In our experiments, participants had the role of producers with the capacity to produce up to three units of a product. Each unit produced required the use of a unit of fuel and an allowance. Fuel cost increased for each unit produced, reflecting for instance differing marginal cost among three different production facilities. In some treatments three allowances were given to the producer for free and in other treatments allowances had to be purchased. In contrast to the fuel input, the cost of using each allowance did not depend on the number of units produced but instead there was a single market price, and allowances could be bought or sold at that price. If subjects did not produce all three of their capacity units, they automatically received the market price for any unused allowances that they possessed. The production costs and allowance price were announced at the beginning of each round of the experiment, but they varied across rounds.

Experiments were run in two different production choice environments. In the first environment, which we refer to as the **quantity-choice environment**, subjects were informed of the market price for their product and they had to decide whether or not they wanted to produce

each of their three production units. The market prices were randomly determined for each round so that previous production decisions did not affect future prices. The incentives for subjects were straightforward; they should produce a unit as long as it is more profitable than not producing.

In the second environment, which we refer as the **price-choice environment**, subjects were asked to specify the lowest price that they would be willing to accept (WTA) in order to produce each of their three possible units. If the WTA for an individual production unit was less than or equal to a randomly determined market clearing price, then that unit was produced and the subject received the market price. Otherwise, the unit was not produced. This mechanism for eliciting WTA is known as the Becker-DeGroot-Marshak (BDM) mechanism (Becker et al., 1964), which theoretically is incentive compatible and involves only individual choice meaning that individuals have the incentive to truthfully reveal their WTA.[4] The BDM also has the feature that its random element makes the decision context complicated and subjects have to make an effort to identify their best strategy.

For each of the two experimental designs, we investigated the effect of relative performance information on production decisions. After each round, subjects were told what their profits were. In some treatments, subjects were informed how their profits ranked compared to the other subjects in the room. All subjects faced the same prices and costs, and the subjects knew that any differences in profits were strictly attributable to differences in production decisions.

Twelve subjects were recruited for each experimental session.[5] Market clearing prices were determined randomly in the interval $1–$10; the price changed between rounds, but was the same for all subjects within a round. We ran treatments using a 2x2x2 experimental design. For each of the two production choice environments, we ran sessions with and without relative information and with and without free allocation, for a total of 8 design treatments. We used two different seeds for the random price and cost draws in each design treatment, for a total of 16 sessions overall. By using the same random draws across treatments we ensure that the differences that we find are attributable to treatment differences rather than the individual market

[4] Irwin et al. (1998) find also that in an experimental environment it is cognitively transparent and neutral, meaning that it does not give the subject any unintended feedback.

[5] Two of the sessions using the BDM mechanism contained 11 subjects and one contained 13 subjects.

clearing prices. We also use multiple seed values to replicate our findings so that they can be generalized for more than one set of prices. Subjects in the quantity choice experiments were undergraduate and graduate students at the Royal Institute of Technology in Stockholm, and subjects in the price choice experiments were students at the University of Virginia in Charlottesville. Subjects' earnings in experimental dollars were converted to real currency and given to them at the end of the experiment.[6]

There were some differences in how we ran the experiments for the two different production choice environments, as summarized in Table 1. In both cases the subjects played multiple rounds. However, in the quantity-choice environment the experiments lasted for 10 rounds, while in the price-choice environment we used 20 rounds (with a change of treatment from round 11 onwards). In the quantity-choice environment, the fuel input costs were $1, $3, and $5 for production units 1, 2, and 3 respectively while the allowance prices were invariant at $4 per allowance. In the price-choice environment their fuel input costs and the allowance prices were stochastic, that is, they changed between rounds. However, the expected values correspond to those in the first environment. The fuel input prices ranged from $0.50–$1.50, $2.50–$3.00, and $4.50–$5.50 for units 1, 2 and 3 respectively and the allowance price was between $3.50 and $4.50. In each round, each of these four input values was randomly determined with each $.50 increment in the range being equally likely. In addition, at the end of the price choice treatments subjects filled out a questionnaire with several cognitive questions. This was not done in the quantity choice environment.

[6] In Charlottesville (US), the exchange rate between experimental dollars and US dollars was 0.1. In Stockholm (Sweden) an exchanged rate of 1 SEK for 1 experimental dollar was used. At the time of the experiment US $1 approximately corresponds to 7 SEK.

Table 1. Payoff structure for the two treatments.

Sequence	Quantity Choice	Price Choice
Initial information	$\left\{E_a, w_a, w_f^i, p_g^r\right\}$	$\left\{E_a, w_a^r, w_f^{r,i}, \tilde{p}_g\right\}$
Decision	$\hat{q}$	$\hat{p}_g^i$
Realization of uncertain variables		p_g
Production level	$q = \hat{q}$	$q = \max i : \hat{p}_g^i \leq p_g$
Profits	$\sum_{i \leq q}\left(p_g - w_f^i\right) - \left(q - E_a\right) w_a$	$\sum_{i \leq q}\left(p_g - w_f^{r,i}\right) - \left(q - E_a\right) w_a^r$

Where:

E_a = endowment of allowances

w_a = price of allowances

w_f = price of fuel

p_g = price of produced good

$\hat{q}$ = quantity bid (in quantity choice experiment)

q = quantity produced

$\tilde{p}_g$ = random price of produced good (in price choice experiment)

$\hat{p}_g$ = bid price of produced good (in price choice experiment)

and superscripts denote:

i = production opportunities, $i \in \{1, 2, 3\}$

r = round, $r \in \{1, ..., 10\}$

The experiments conducted are similar to those in a study by Plott (1983), which reports on a laboratory study of behavior when limited and tradable licenses were required for economic activity that imposed an externality on others. The value of the licenses was created by their scarcity and reflected in a market in which licenses could be bought or sold. In this setting, even when licenses were distributed initially for free, the price of production reflected opportunity costs. Moreover, the licenses ended up being used in an approximately efficient manner by producers who valued them most. However, one aspect of the experiments was not general in that licenses were distributed at zero initial cost, unlike what has occurred in previous actual allowance markets where allowances have been distributed in approximate proportion to their

ultimate use. In the experiments, licenses were distributed initially so that the maximum efficiency of the original allocation was 46 percent, had no trading occurred. Consequently, producers had to engage actively in the secondary market for licenses in order to maximize profits from production, and this was likely to contribute to the discovery and recognition of the market-driven opportunity costs of the licenses. Plott acknowledges that the efficiency of a license policy “might be affected by the initial distribution of licenses by placing them in the ‘right hands’ initially” (p. 118). In our experiment when allowances were distributed for free subjects had sufficient allowances to cover production, perhaps making it more difficult for subjects to recognize their opportunity cost and encouraging them to use different decision rules in determining their production activities.

Experiment Results

Results are reported for each of the experimental settings, beginning with the quantity-choice environment and followed by the price-choice environment.

The quantity choice environment

In the quantity-choice environment we ran 8 sessions, each of which had 12 participants making 10 individual production decisions. As described above, we ran sessions with free allocation of emissions allowances and sessions where allowances had to be purchased. We denote free allocation as GF (for grandfathering). Sessions that provided relative earnings information are denoted RI. In these sessions the subjects received information about their earnings and their ranking relative to others after each round, and in the other sessions, subjects only knew their own earnings.

To formally test whether different treatments have a different impact on pricing behavior we perform the non-parametric Wilcoxon rank sum test. A particular benefit of this test as compared to others such as standard *t*-tests is that it requires no assumption about the underlying distribution of the population of subjects. For this test we used individual participants as observations, and the measure of their performance was the number of errors that they made over a group of 5 rounds (i.e. if they produced units when it was more profitable not to and vice versa). The test answers the question whether a difference in the number of errors made by individuals when comparing two treatments is statistically significant or if it may be explained by natural variations due to the selection of the subject sample. Table 2 contains the results both for rounds 1 to 5 and for rounds 6 to 10.

Table 2. Quantity choice experiment: results from the Wilcoxon rank sum test.

	Rounds 1 to 5			*Rounds 6 to 10*	
	W	*p-value*		*W*	*p-value*
Effect of Grandfathering	1840	p<=.000354***	*Effect of Grandfathering*	2243	p<=.5358
Effect of Relative Info	2271.5	p<=.6816	*Effect of Relative Info*	2178	p<=.2733

Note, *=significant on the 10 % level, **=significant on 5% level and *** = significant on 1 % level.

Result #1: In early rounds in the quantity choice environment, participants that have to purchase emissions allowances outperform participants that receive them for free, but in the later rounds this difference goes away.

The Wilcoxon test for GF vs. no GF was statistically significant for rounds 1–5, but not rounds 6–10. The difference in early rounds suggests that the profit-maximizing strategy may be more transparent when the cost of an emissions allowance is a direct cost rather than an opportunity cost of production. The fact that the difference is gone in the last 5 rounds suggests that subjects in free allocation treatments learn to incorporate the opportunity cost and profit maximize over time.

Result #2: In the quantity choice environment, when participants receive information about their relative performance compared to others, it does not change their performance.

The results of the Wilcoxon tests for treatments with RI vs. no RI were insignificant, indicating that relative information did not appear to improve individual performance in early or late rounds of the experiments.

Result #3: In the quantity choice environment, subjects in all treatments learn to profit maximize quickly.

A central question is whether learning is facilitated by having to pay for allowances and/or the presence of relative information. Figure 1 below depicts the sum of the errors made by the 12 participants in each of the 10 rounds. Each data point is the average of the values for the two replications that we did using different seeds. In the first round there are about twice as many errors made in treatments with grandfathering than in treatments with no grandfathering. As indicated by the Wilcoxon rank sum tests, this difference dissipates over time. In fact, there appears to be learning across all four of the treatments with fewer errors in the later rounds.

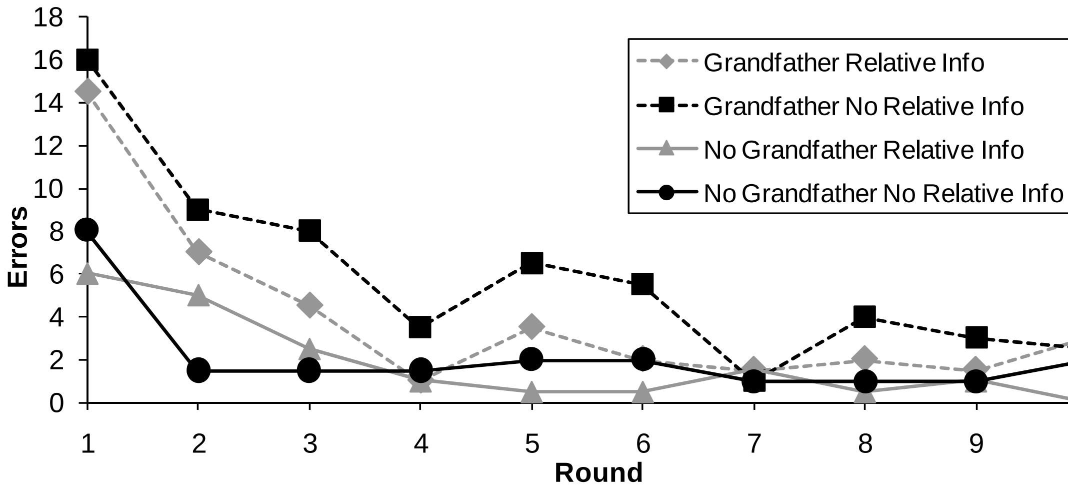

Figure 1. Average number of errors made in each round by treatment type in the quantity choice experiment

A more formal test of this is performed by looking at each individual's pricing behavior in the first three rounds compared to the last three rounds (Round 8–10). If there is a learning effect, subjects would price optimally in the latter rounds and, thus, for a majority of the subjects we expect to see a positive difference between deviations in early compared to late rounds. Table 3 reports the result of the Wilcoxon Matched–Pairs Signed Rank test, for all four possible combinations of treatments.

Table 3. Quantity choice experiment: Wilcoxon matched-pairs signed rank test, all subjects

	W+	*W-*	*p-value*	*n*
Grandfathered, No Relative Info	186	4	0.0000267***	19
Grandfathered, Relative Info	137.5	15.5	0.00209***	17
Not Grandfathered, Relative Info	78	0	0.0004883***	12
Not Grandfathered, No Relative Info	70.5	7.5	0.009272***	12

Note, *=significant at the 10 % level, **=significant at 5% level and *** = significant at 1 % level.

By comparing the number of observations with a positive difference in deviation between early and late rounds (W+ in Table 3) to those with negative difference (W-), it is the case that for all treatments the number of positive cases dominates. This is in line with a learning effect.

The difference is large enough to be statistically significant for all treatment types, indicating that subjects learned to profit-maximize in all of the treatments.

The price choice environment

In the quantity choice environment, subjects are presented with a price and they have to make a binary decision to produce or not. In the price choice environment, the decision is more open ended; participants choose a price from a broad range. The data therefore allow us to do some richer analyses. Also, at the end of these treatments subjects filled out a questionnaire with several cognitive questions, adding another dimension to our investigation.

Figure 2 illustrates the pricing behavior showing the average absolute deviation[7] from the theoretical optimum, *i.e.*, the average absolute value of the asking price minus the sum of fuel cost and value of an allowance, for the four different treatments in the price choice environment. With the possible exception of the group who had to pay for allowances and received no relative information (No GF No RI), all groups exhibit rather clear learning effects in that the lines in the upper graph all show downward sloping trends.[8]

[7] In most subsequent analyses we use absolute deviation as this greatly simplifies the presentation. It should be noted that only a minority (17 %) of the observations is associated with asking prices above the optimal price.

[8] The sessions included a second treatment that was implemented in round 11-20, in which the allowance allocation mechanism changed. For example, if the first ten rounds had No GF, the next ten rounds had GF. We do not report the data here as performance in the second treatment was influenced by the first treatment. However, it is noteworthy that we did observe that at the beginning of the second treatment, there were substantially increased deviations relative to the end of the second treatment, especially for the groups who had to pay for allowances in the first treatment and were now receiving them for free. Since, by this time participants were familiar with the set up, we feel the change beginning in round 11 is attributable to their production strategy rather than potential misunderstanding of the experimental design.

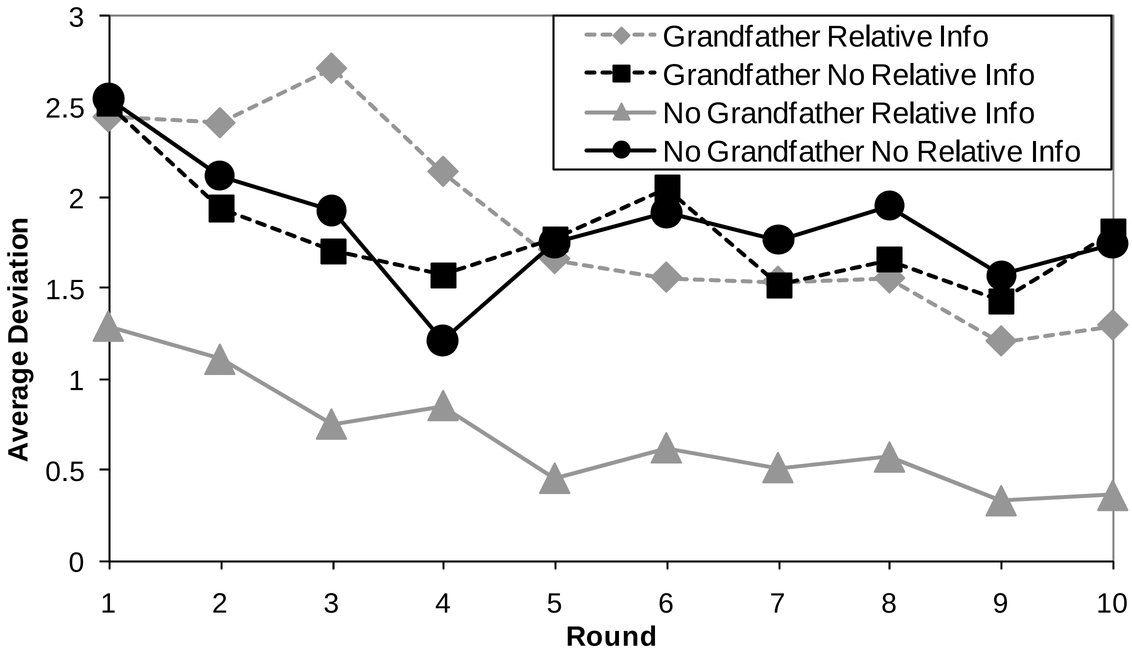

Figure 2. Average absolute deviation from theoretical optimum by round

Result #4: In the price choice environment, there is more variation in bidding behavior in early rounds.

Looking more closely at the data, the standard deviation of the deviation from theoretical optimum is 1.91 for round 1 and 1.81 for rounds 6 to 10. Thus, there is a smaller variation in latter rounds, but the difference is not large. The share of bid prices that is more than 2 experimental dollars below (above) optimum is 50 percent (0.6 percent) in round 1 and 25 percent (2 percent) for rounds 6 to 10.[9] This supports the general impression that the subjects price in a more optimal way in latter rounds, *i.e.*, there is a learning effect.

Result #5: In the price choice environment, when participants have to buy allowances rather than receiving them for free, they price closer to the profit maximizing price.

[9] The corresponding values that are more than 1 experimental dollar below (above) optimum is 64 % (1 %) for round 1 and 35 % (5 %) for round 6-10.

To formally test whether different treatments have a different impact on pricing behavior we turn again to the non-parametric Wilcoxon 2 tail rank sum test. Table 4 contains the results both for round 1 to 5 and for round 6 to 10.

Table 4. Results from the Wilcoxon two tail rank sum test

Rounds 1 to 5			*Rounds 6 to 10*		
	W	*p-value*		*W*	*p-value*
Effect of Grandfathering	1943	p<=.001405***	Effect of Grandfathering	2069	p<=.01731**
Effect of Relative Info	2575	p<=.3745	Effect of Relative Info	2704.5	p<=.006421***

Note, *=significant on the 10 % level, **=significant on 5% level and *** = significant on 1 % level.

From the first row in Table 4 we see that grandfathering yields absolute deviations that are statistically higher than the alternative where the subjects must buy allowances. This is the case both for the first 5 rounds and for the last 5 rounds. That is, having to pay for allowances helps the subjects in pricing optimally. The second row in Table 4 shows that relative information has a statistically significant impact on absolute deviation for rounds 6–10, but not for rounds 1-5. This indicates that relative information helps the subjects in their pricing decisions in later rounds indicating that relative information affects learning. This result differs from what we found in the quantity choice environment—no difference between treatments with RI and treatments without. This difference may stem from the BDM mechanism used in the price choice environment not being as straightforward as the binary decision mechanism in the quantity choice environment so that relative information has a stronger impact in the less transparent environment.

Result #6: In the price choice environment, when participants receive information about their relative performance compared to others, it facilitates learning.

We assessed learning in the price choice environment using the Wilcoxon Matched-Pairs Signed Rank Test. Again, we compared a participants’ performance in the first three rounds with the last three rounds. Table 5 below shows a rather clear and interesting picture in that there is a highly significant learning effect in the two treatments that include relative information, as seen from row 2 and 3. However, neither of the treatments without relative information shows a

significant learning effect. This result differs from our findings in the quantity choice environment that all treatments exhibit significant learning. Again, here it is possible that the decision environment was more difficult for subjects to figure out, so fewer subjects learned the profit-maximizing strategy and relative information had a much stronger effect on behavior.

Table 5. Wilcoxon matched-pairs signed rank test, all subjects

	W+	*W-*	*p-value*	*n*
GF, no RI	192	84	.1037	23
GF, RI	506	55	.00005816***	33
no GF, RI	150	3	0.00007629***	17
no GF, no RI	160	71	0.1262	21

Note, *=significant on the 10 % level, **=significant on 5% level and *** = significant on 1 % level.

Controlling for Cognitive Ability

The results reported in Table 4 and Table 5 suggest there is an influence both from the choice of allocation approach and from the relative information in the price choice environment. They also suggest that relative information facilitates learning, while the allocation process seems to have an absolute impact on pricing behavior. As the task the subjects perform in the experiment is obviously not trivial, it would be interesting to see whether subjects that are trained for, or in other ways are skilled in, performing more analytical assignments manage to price in a more optimal way than other subjects.

In order to measure problem-solving skills, the subjects were asked to answer seven questions directly after the last round in the experiment, see Appendix A. For this analysis, we focus on three of the questions (2–4) that make up a Cognitive Reflection Test (CRT) as presented in Frederick (2005), with wording adapted from a baseball to hockey motif for the Swedish audience. As defined by Frederick, “CRT measures ‘cognitive reflection’—the ability or disposition to resist reporting the response that first comes to mind.” A high performance on the CRT test is strongly correlated with high performances on other tests of cognitive abilities. We found that participants with low CRT scores (0–1) deviated further from profit-maximizing pricing than did participants with high CRT scores (2–3) (Wilcoxon rank sum, $W = 2570$, $p <= .000003128$).

In one of our treatments (no GF, RI), participants performed particularly well on the CRT test with 20 out of 23 receiving a high score. Because this sample is somewhat biased, it was particularly important to control for high scores in some of our analyses. Repeating the Wilcoxon

Matched-Paired tests comparing performance in rounds 1-3 to rounds 8-10 for the High CRT–group yields mainly similar results but with a few notable differences (see Appendix B). First, the impact from relative information is no longer significant, neither for all ten rounds nor for the last five rounds. This suggests that this group does not benefit as much from relative information. Second, the High CRT–group shows significant learning in the GF no RI treatment (corresponding to the first row in Table 3). We return to these findings later in this section.

Regression Analysis

To analyze the data further, we estimated the following error components model with random effects:

$$
\begin{aligned}
Absolute\,Deviation = \alpha + \beta_1 * Round + \beta_2 * Round^2 + \beta_3 * GF \\
+ \beta_4 * GF * Round + \beta_5 * RI + \beta_6 * RI * Round + \varepsilon + \mu
\end{aligned}
\qquad (1)
$$

The variable *Round* is used to capture learning effects. As seen from (1) we allow for learning to be non-linear by also including *Round squared*. The first 10 rounds are used to estimate the model. *GF* takes on the value 1 if the subjects receive allowances for free during these rounds and zero otherwise. *RI* takes on the value 1 if the subjects receive relative information. We allow for the choice of allocation and the presence of relative information to influence learning[10]. This will be captured by β_4 and β_6, respectively. Any absolute effect from allocation choice or relative information will be captured by β_3 and β_5, respectively and μ represents random effects and ε represents the idiosyncratic component of the error

As discussed above, we expect to see learning in all treatments, but probably at a decreasing rate. That is, as the explained variable is measured in absolute terms, β_1 is expected to be negative. If the learning effect decreases over rounds, which is a reasonable expectation, β_2 should be positive but, in absolute terms, less than β_1. Furthermore, we expect that having to pay for allowances facilitates optimal pricing. That is, when *GF*=1 (allowances are received for free) absolute deviations are expected to be higher than otherwise. Thus, the expected sign of β_3 is positive. It may be the case that the subjects who receive allowances for free initially show a higher deviation from optimal pricing but learn to price more optimally over time. If this is the case, β_4 is negative. Finally, a negative value on β_5 implies that relative information facilitates an

[10] We only allow for these effects to be linear. Also including the variables *GF*Round*^2 and *RI*Round*^2 results in a negligible increase in the model's explanatory power but yields no further insights than the model given by (1).

optimal pricing behavior. However, the nature of the relative information suggests that it rather would facilitate the learning process. That is, we expect β_6 to be negative, *i.e.*, with relative information learning per round is greater than without.

The results are given in Table 6, which contains three regressions. The first model uses all data, the second only data from subjects who scored high on the cognitive test and the third uses data for subjects with low scores on the cognitive tests.

Table 6. Regression results (run with robust estimators)

	All subjects		***High CRT score***		***Low CRT score***	
	Coefficient	*St. error*	*Coefficient*	*St. error*	*Coefficient*	*St. error*
Constant	2.017***	.326	1.6554***	.435	2.7522***	.467
Round	-0.182***	.0572	-0.1830***	.0668	-0.2286**	.0986
Round^2	0.0131***	.0131	0.0101**	.00473	0.01737**	.00735
GF	0.8313***	.265	1.0373***	.340	-0.1121	.413
Round*GF	-0.0389*	.0211	-0.0707***	.0246	0.06336	.0398
RI	-0.0982	.267	-0.2425	.306	0.7274*	.377
Round*RI	-0.0723***	.0215	-0.00187	.0263	-0.2024***	.0348
R-squared	0.092		0.105		0.068	
n	3150		1860		1290	

Note, *=significant on the 10 % level, **=significant on 5% level and, *** = significant on 1 % level.

As seen in Table 6, the explanatory power of the model is low. Subjects seem to use a lot of trial-and-error, which causes noise in the data. This conjecture is further strengthened by the observation that the explanatory power is higher for the high CRT score group than for the group with low scores.[11]

Looking at the model that utilizes all available data, we see that it supports our expectations as described above. First, there is a clear evidence of learning in that *Round* has a highly significant negative coefficient. It is also evident that the rate of learning decreases in the number of rounds played, since *Round squared* has a positive and highly significant coefficient.

[11] We also ran regressions using all subjects with the above explanatory variables as well as binary variables for each question in the cognitive test; “1” for a correct answer and “0” for an incorrect answer. The coefficients for questions 2 and 5 were significant, suggesting that correct answers to these questions had the highest correlation with pricing strategies that maximized earnings in the experiment.

Note, however, that learning happens throughout all ten rounds as the positive impact on deviation from *Round squared* never outweighs the negative impact from *Round*[12].

The impact on pricing from the choice of allocation mechanism is also as expected. Deviations from optimal pricing are significantly higher when allowances are received for free, as seen by the coefficient for *GF*. The effect is rather large. In the first round deviation is almost 0.8 experimental dollars higher under free allocation, which corresponds to one fifth of the expected value of an allowance. However, this effect decreases during the experiment, *i.e.*, subjects learn to take the opportunity cost into consideration. This is seen from the negative and highly significant coefficient for *Round*GF*. After ten rounds almost half (45 percent) of the effect seen in the initial round has disappeared. Much as expected, relative information has no initial impact on pricing behavior (the coefficient for *RI* is not significant) but it shows clear evidence of facilitating learning as *Round*RI* is highly significant and negative. The effect of relative information after 10 rounds is of the same magnitude as the initial effect of having to pay for allowances.

Result #7: Overall, information about relative performance has a higher impact on the pricing behavior of participants that have a low score on the cognitive test than those that have a high score.

For the group with high CRT scores, most effects are of the same magnitude as for the entire group. The main difference lies in the impact from relative information. This group shows a small initial effect from having relative information, which is very close to not being significant even at the 10 percent level. More interestingly, the presence of relative information does not help this group's learning process, which is seen from that *Round*RI* is not significant. A possible explanation of this lies in the nature of the information. As this group generally performed better, *i.e.*, showed less deviation from optimal pricing, they probably ranked high. A low ranking sends a clear signal that you should change behavior, a high ranking however signals that you should probably stick to your strategy. In that sense, this result is not surprising.

Looking at the highly significant coefficients for *Round* and *Round squared* for the group with low CRT score we observe a higher initial learning effect. Interestingly and rather surprisingly, the rate decreases faster over rounds than for the entire group. By round 10, the impact on learning from playing another round is of the same magnitude as for the entire group.

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[12] At Round = 10 we have that 10*-0.182+10^2*0.0131=-0.51.

When it comes to allocation this low CRT group shows no effect from having received allowances for free or not. The learning effect shows only weak significance and has an unexpected sign. A positive interpretation of this is that this group immediately and correctly took the opportunity cost into consideration. If so, they would have priced optimally both when they had to pay for allowances and when they received them for free. Unfortunately, looking at the data another explanation seems more plausible. Namely that, on average this low CRT group priced far from optimal in both allocation treatments. The relative information, on the other hand, seems to have a substantial impact on learning for this group. There is an initial effect that, even though it is only weekly significant, has an unexpected sign. However, the learning effect from having relative information over rounds has the expected sign and is rather large such that after four rounds it outweighs the initial effect. Even though the sign of the initial effect is surprising and hard to explain, the general fact that this group is highly influenced by the presence of relative information seems very plausible. This group is likely to rank low in relative earnings and the relative information thus sends a clear signal to change strategy to the next round.

Lessons from Existing Policies and Markets

In a simple economic setting like the one embodied in our experiments, the profit maximizing decision would lead firms (subjects in the experiments) to maximize their profits by including the value of emissions allowances in their decisions about price and production. We find that this behavior is not intuitive for many subjects in the experiments. What perspective does one find in the policy community?

There are several high profile examples that highlight the different expectations that exist around what an efficient—and “fair”—market behaviour constitutes. Regulations, institutions, social norms and reputations may cause firms to deviate from a simple strategy of including the economic value of allowances in retail prices. These differences exist even at the highest political and industrial level. In 2005, companies in the electricity-intensive sector of the German economy complained to the Bundeskartellamt (the German Federal Cartel Office) about the practices adopted by the electricity companies in CO_2 emissions trading. In simplified terms, the Bundeskartellamt took the view that since utilities such as RWE and E.On had received emissions allowances for free, not only was it unethical for them to pass the opportunity cost on

to consumers, but also illegal. In a "warning letter"[13] to RWE in December 2006, the office states that "the industrial electricity prices charged by RWE in 2005 were abusive as the company had passed on more than 25 percent of the value of its CO_2 emissions allowances within its electricity prices."

The Bundeskartellamt recognized the economic insight that opportunity costs are in principle taken into account in a business calculation. However, the authority took the view that since the allowances allocated for free were necessary for the electricity generation of RWE, they were not actually available for sale and thus would not have a full opportunity cost associated with them. In addition, the Bundeskartellamt noted that the dominant positions of RWE and E.On could enable them to abuse their market power. To support this view, they refer to a comparative survey of other sectors in the emissions trading system, concluding that in a fully competitive market, the opportunity cost of allowances given for free cannot be passed on to customers.

For this reason, the Bundeskartellamt did not object to up to 25 percent of the allowance value being passed on within the electricity price. This figure was established by taking into account a conversion factor for all types of fuel and a "relevance surcharge". The passing through of any amount exceeding this figure would, according to the decision, constitute an abuse of market dominance.

This claim suggests RWE should be expected to exercise some self restraint in the market and to modify its ability to maximize profits. The irony should not be lost. The regulator is concerned about the exercise of profit-maximizing behavior in an electricity market that is ostensibly a competitive market. If RWE were able determine a rate of pass-through other than that suggested by competitive theory, then it would be *prima facie* evidence that RWE had the ability to manipulate prices in the market.

A more recent example is currently unfolding in the UK. The backdrop is a widespread concern over increasing 'fuel poverty', *i.e.* the share of the population that spends a large proportion of their disposable income on energy. As fuel prices have increased, energy bills have followed. The discussion on how to alleviate fuel poverty is heated, and UK Prime Minister Gordon Brown's office is under significant pressure to do something about the deteriorating

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[13] See press release December 20, 2006, URL: www.bundeskartellamt.de/wEnglisch/News/Archiv/ArchivNews2006/2006_12_20.php

situation for many low-income households. Part of the price increases can be linked to the EU ETS, where utilities have received free allowances, a feature of the ETS that has aggravated many observers. There also seems to be a widespread perception that utilities were not been hit particularly hard by soaring fuel prices in recent years, but in fact have earned constant or even increasing profits in the electricity industry.

There are several layers to the UK case, but a recurring concern is that the EU ETS has caused electricity prices to rise without the firms incurring additional costs. This reasoning is analogue to the German case, although in the UK the distinction between effects of rising fuel prices and of the cost of emissions allowances are often lost.

The possibility of windfall profits associated with environmental regulations dates back to the implementation of the 1987 Montreal Protocol on Substances that Deplete the Ozone Layer. In a subsequent amendment to the protocol in 1990, the United States and 22 other countries agreed to a full phase out of chlorofluorocarbon (CFC) and halons, as well as a phase out of “other CFCs”, by 2000. In implementing the agreement, the U.S. Environmental Protection Agency (U.S. EPA) distributed allowances for free to companies that produced or imported CFCs and halons based on 1986 market shares to 5 CFC producers, 3 halon producers, 14 CFC importers, and 6 halon importers. However, it was recognized that the restrictions on the quantity of CFCs and halons would lead to rapidly escalating prices that potentially would yield windfall profits. It also might decrease incentives to develop substitutes if the allowance market served as a barrier to competitive market entry. Consequently, an excise tax on CFC production intended to capture the assumed windfall profits was implemented that raised $2.9 billion in its first five years.

Conclusion and Discussion

The theory of incentive-based environmental regulations such as cap and trade is one of the most important contributions from the field of environmental economics to public policy, but how cap-and-trade programs are implemented and actually work remains a subject of much interest. The determination of prices for emissions allowances and for downstream products is important to the distributional and efficiency consequences of a cap-and-trade program.

This paper reports on the use of experimental methods to investigate behavior with respect to how prices will be determined under a cap-and-trade program. We find participants in the experiments initially employ various approaches. Some participants initially recognize the opportunity cost of these allowances and include them in their economic choices, and other

subjects initially do not. However, given a simple economic setting in which pay-offs depend on this behavior, we find that subjects learn to consider the value of allowances and overall behavior moves toward that predicted by economic theory.

Empirical evidence suggests that product prices in electricity markets do adjust to reflect the opportunity cost of emissions allowances that have been given away for free, but there remains ambiguity about the degree of that adjustment. Moreover, this kind of pricing behavior is unexpected and criticized by some regulators.

Theoretically, full pass through of the cost of emissions allowances would be expected in a competitive market. If empirical evidence indicates the determination of product prices does not conform to a simple prediction of profit-maximizing behavior, one is compelled to search for alternative explanations for observed behavior. If firms are able to voluntarily moderate commodity prices to be below competitive levels, it suggests an ability of these entities to exercise market power or collude—even if this is motivated by a desire to hold back and not pass through the value of emissions allowances in product prices. This may have important implications for understanding the behavior of energy markets, which are most directly affected by the application of emissions allowance trading, and which also are under scrutiny with respect price determination. Throughout much of Europe and the United States, energy markets have been deregulated or are in the process of moving toward market liberalization. If market behavior does not conform to predictions of behavior in a competitive market, this may say a great deal about the nature of market liberalization in energy markets as well as about the behavior of environmental markets.

Further, the observations from the experiments may help to understand the ongoing public debate over the interaction of the EU ETS and energy markets. The ferocity of that debate, and in particular the resistance to auctioning of allowances motivated by concerns over increased electricity prices, may surprise economists. The problem is almost trivial from a theoretical point of view, but still there are large differences in how it is perceived by different stakeholders. To a purist this may be both disappointing and surprising. However, emissions allowance markets are a new phenomenon to many politicians, firms and policy officials, and one which they are not used to dealing with. In addition, the deregulation of energy markets is a relatively new process and progress is not uniform across countries, resulting in markets in different stages of liberalization. When one considers this, it is less surprising that the public and political intuition of how markets 'should' work may diverge from economic theory, much in the same way as it initially did for the subjects in our experiments.

On the bright side, there are signs that a learning process going on, analogous to the one observed in our experiments. This would mean that a greater understanding of how markets work may be expected to evolve over time and as markets are increasingly liberalized. Indeed, one may detect such a trend in Europe already. Resistance to auctioning motivated by pass-through effects was strong when the EU ETS was conceived. This resistance has decreased significantly in many member states and in the European Commission, perhaps demonstrated most clearly by the EU decision to auction the majority of allowances to electricity companies starting in 2013.

If the observation of ongoing learning is correct, there are grounds to be optimistic about the future development of the European energy system. On the other hand, there are proposals from important member states that energy customers be protected from price increases through re-regulation of energy markets, for instance by limiting the level of pass-through of emissions allowance costs. If such measures become widespread, the process towards a more integrated and competitive European energy market is under threat. It remains to be seen which route politicians choose to take.

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Appendix A. Questions in the Cognitive Test

1. On the street where you grew up most of the people knew each other. True or False?
2. A hockey stick and puck cost 110 Canadian dollars in total. The stick costs 100 more than the puck. How much does the puck cost?
3. In a lake, there is a patch of lily pads. Every day, the patch doubles in size. If it takes 48 days for the patch to cover the entire lake, how long would it take for the patch to cover half of the lake?
4. If it takes 5 machines 5 minutes to make 5 widgets, how long would it take 100 machines to make 100 widgets?
5. A person drives 60 kilometers at 60 kilometers per hour, and then turns around and drives back to the starting point at 20 kilometers per hour. What was the average speed?
6. You attend a dinner party, where gifts from the host are drawn from a hat. You draw a gift certificate worth $30 at a coffee shop that you like. The gift certificate, however, is doubled to $60 for someone whose birthday is in September, which yours is not. The person sitting next to you has a birthday in September, but their gift does not appeal to you. So you decide to offer to sell your gift certificate to that person. How much would you ask for the gift certificate?
7. Suppose that you are the owner of a company with $900,000 in annual revenues and $600,000 in annual costs. You have been managing the company yourself without charging a salary, and keeping the $300,000 profit each year. Now you receive an outside offer to work for another company for $200,000 per year. If you take this offer, you would have to hire a good manager for your company, which would cost $100,000 annually. How will your earnings from profit and salary change if you take the outside offer?

Appendix B. Non-parametric tests on the High CRT-score group

Table B1. Results from the Wilcoxon Rank Sum test. subjects with High CRT-scores

Rounds 1 to 10			*Rounds 6 to 10*		
Treatment 1	*Treatment 2*	*p-value*	*Treatment 1*	*Treatment 2*	*p-value*
GF no RI	GF RI	p<.7921	GF no RI	GF RI	p<.79
GF no RI	no GF no RI	p<.9264	GF no RI	no GF no RI	p<.5588

Note, *=significant on the 10 % level, **=significant on 5% level and *** = significant on 1 % level.

Table B2. Wilcoxon Matched-Pairs Signed Rank test, subjects with High CRT-scores

Wilcoxon Matched-Pairs Signed Rank

	W+	*W-*	*p<=*	*N*
GF NO RI	76	2	.001465***	12
GF RI	124	12	.002136***	16
NO GF RI	102	3	.0006103***	14
NO GF NO RI	36	9	0,1289	9

Note, *=significant on the 10 % level, **=significant on 5% level and *** = significant on 1 % level.