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1616 P St. NW
Washington, DC 20036
202-328-5000 www.rff.org

RESOURCES FOR THE FUTURE

An Experimental Study of Auctions versus Grandfathering to Assign Pollution Permits

Jacob K. Goeree, Charles A. Holt, Karen Palmer, William Shobe, Dallas Burtraw*

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Abstract

We experimentally study auctions versus grandfathering in the initial assignment of pollution permits that can be traded in a secondary spot market. Low and high emitters compete for permits in the auction, while permits are assigned for free under grandfathering. In theory, trading in the spot market should erase inefficiencies due to initial mis-allocations. In the experiment, high emitters exercise market power in the spot market and permit holdings under grandfathering remain skewed towards high emitters. Furthermore, the opportunity costs of "free" permits are fully "passed through." In the auction, the majority of permits are won by low emitters, reducing the need for spot-market trading. Auctions generate higher consumer surplus and slightly lower product prices in the laboratory markets. Moreover, auctions eliminate the large "windfall profits" that are observed in the treatment with free, grandfathered permit allocations. (JEL: C92, D43, D44, Q58)

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*Goeree: Division of the Humanities and Social Sciences, California Institute of Technology, Mail code 228-77, Pasadena, CA 91125, USA, and Institute for Empirical Research in Economics, University of Zürich, Blümlisalpstrasse 10, CH-8006, Zürich, Switzerland; Holt: Department of Economics, University of Virginia, Monroe Hall, McCormick Road, Charlottesville, VA 22903, USA. Burtraw and Palmer: Resources for the Future, 1616 P Street NW, Washington, DC 20036, USA; Shobe: Center for Economic and Policy Studies, University of Virginia, 2400 Old Ivy Road, Charlottesville, VA 22903, USA. We gratefully acknowledge financial support from the Dutch National Science Foundation (VICI 453.03.606), the Bankard Fund for Political Economy, Mistra's Climate Policy Research Forum (Clipore) and the US Environmental Protection Agency. We would like to thank Helen Bernhard, Noémi Nagi, Thomas Neumeyer, Nina Spiri, and Sean Sullivan for their help with the experiments, and participants at the European Economic Association Meetings (Barcelona, August 2009) for useful comments.

1. Introduction

One of the most important and contentious issues for any cap-and-trade emissions policy is the initial allocation of allowances or "permits." The solution that is generally favored by the regulated firms is to allocate the limited number of permits at no cost in proportion to past emissions levels. This process, known as "grandfathering," is typically justified on the grounds that if you make firms pay for permits, the result will be a run-up in downstream product prices, e.g. electricity. A simple market-based alternative for the initial assignment is to use regularly scheduled auctions.

In the initial phase of the European Emissions Trading System (EU-ETS) greenhouse gas cap-and-trade program,[1] the participating countries were required to use auctions for at most 5% of the permit allocations. The resulting "windfall profits" from free allocations created some public dissatisfaction with the cap-and-trade approach to greenhouse gas emissions controls. For instance, one of Europe's largest carbon emitters, the Germany based RWE, collected windfall profits of about $6.4 billion in the first three years of EU-ETS. RWE received 30% of all permits given out, more than any other company in Germany, and was reprimanded by the German antitrust authority in response to complaints about rising electricity prices (at 5% per year). RWE acknowledged charging its customers for the emission permits, saying that "...while it may have received them for free from the government, they still had value in the market place."[2]

In contrast, the 2008 Regional Greenhouse Gas Initiative (RGGI) required the use of auctions for a minimum of 25% of the allocation to electricity producers in 10 northeast states in the United States. In fact, about 90% of the permits have been sold by auction in the first year of this program, and the auction revenues are being used for "strategic energy initiatives." The EU plans to initiate auctions for a majority of the permits for electricity producers beginning in 2013 and switch to 100% auctions by 2020. In the US, the Obama administration favors auctions, but the legislation being considered in Congress at this point is largely based on free allocations.

The initial design of cap-and-trade policy was heavily influenced by political tradeoffs needed to obtain support for strict emissions controls, but a longer-term perspective should be based on economic considerations. A comparison of different allocation methods is com-

[1]The EU-ETS is the world's largest carbon-trading market with a trade volume of $80 billion in 2008. The price of a permit to emit one ton of CO_2 was approximately 25 Euro in 2008.

[2]See http://www.nytimes.com/2008/12/11/business/worldbusiness/11carbon.html.

plicated by the fact that economic and regulatory conditions are changing over time as is the mix between auctions and grandfathered allocations. This paper uses laboratory experiments to evaluate the economic effects of grandfathered and auction-based allocations, holding the underlying structure of the market constant. We consider two main issues: 1) will auction-based allocations result in higher prices for the product being produced (i.e. pass through of permit costs)? and 2) will grandfathered allocations based on historical emissions levels lead to inefficiencies in the way that emissions reductions are spread between high-emitting and low-emitting producers?[3]

The argument that selling permits will raise downstream product prices is inconsistent with economic theory; tradable permits have an opportunity cost, i.e. the price they sell for in secondary markets, even if they are received for free, and this opportunity cost will be reflected in product prices (e.g. Burtraw et al. 2002). The opportunity cost argument is sometimes viewed with skepticism by regulators. Even when the argument is recognized, the resulting windfall profits are viewed with antagonism, as illustrated by the aforementioned RWE example. Another regulatory concern is the possibility that firms with high emissions levels may exploit the market power associated with high permit allocations in the secondary market for permits.

2. Experimental Design and Procedures

We conducted a total of 14 sessions, seven in which the initial permit assignment was decided by auction and seven in which it was decided by grandfathering.[4] In each session, six subjects participated. Upon entering the lab, subjects were told they were not allowed to communicate with each other and they could use the computers only for the purpose of the experiment. Subjects received detailed instructions on their computer screens, which were read aloud. The instructions typically took 30 minutes, and the 9-period experiment added another 45-60 minutes. Average earnings were approximately $50 (including a show up fee).

In the experiment, three subjects played the role of low emitters and three that of high emitters. Low emitters required one permit for each unit produced and high emitters required

[3]Hahn (1984) theoretically shows that free allocations can cause inefficiencies, especially when a firm with market power receives more (or fewer) allowances than its cost effective allocation. In an experimental paper, Hahn (1983) finds that when the initial allocation deviates from the least cost allocation, a zero-revenue auction is less susceptible to market power than free distribution. Liski and Montero (2005) extend Hahn's work by looking at initial allocations over time and allowing banking of permits using a dominant firm/competitive fringe model.

[4]The experiments were conducted at the University of Virginia using the VeconLab emission permit auction program, accessible at http://veconlab.econ.virginia.edu/ep/ep.php.

two permits per unit produced. Each producer had a capacity limit of four units, with the marginal production costs for each the four units being randomly drawn and known only to the producer. The cost draws were independent across producers and periods. Marginal production costs for low emitters were uniformly distributed on [8,12] and those for high emitters were uniformly distributed on [4,8].[5] With a capacity of 4 units for each producer, permits would not be scarce if there were 36 or more (since the three low emitters would use at most 12 permits and the three high emitters would use at most 24 permits). Our design choice was to reduce the number of permits to 50% of this level, i.e. a cap of 18 permits, which shifts supply away from high emitters as we explain below.

Each period of the experiment consisted of three stages: (1) the assignment stage (grandfathering or auction), (2) a spot market, and (3) the product market. We next describe each stage in detail. In the assignment stage of the grandfathering treatment, each low emitter was endowed with 2 permits and each high emitter with 4 permits. No initial endowments were assigned in the auction treatment. Instead 18 permits were offered for sale in a uniform-price auction in which bids were ranked from low to high with the top 18 bids winning and the uniform price that winners paid being determined by the highest losing bid (i.e. the 19-th highest bid).

After subjects had been informed about their initial endowments, or after they had learned the outcome of the auction, they were given the opportunity to trade permits in a spot market. The spot market was introduced to correct for initial mis-allocations. The spot market was modeled using a single-round, limit-order call market in which each producer was provided with a single opportunity to submit buy and/or sell orders. A buy order consisted of a quantity and a bid price equal to the maximum a producer was willing to pay for a permit.[6] Likewise, a sell order specified a quantity and an ask price, which was the minimum a seller wanted to receive for a permit.[7] The bid and ask prices were then ordered to form a demand and supply curve respectively, and their intersection determined the market-clearing price. Buy orders with bid prices above the market-clearing price transacted, as did sell orders with ask prices below the market-clearing price. Once the market-clearing price and transactions had been determined, producers were informed about their new cash and permit holdings.

Finally, in the product market all six producers could specify sell prices for each of their four capacity units. If a producer preferred not to sell one or more units, then this could be

[5]The auction and grandfathering sessions were "paired" in the sense that random cost draws used in an auction session were also used in a grandfathering session. We used new random cost draws across different auction sessions, so in total there were seven independent auction/grandfathering pairs.

[6]The total dollar amount of a buy order could not exceed a subject's cash holdings.

[7]The total number of permits listed in a sell order could not exceed a subject's permit holdings.

done by selecting the "no bid" option from a drop-down menu of possible sell prices. The sell bids were ranked to form a supply curve, which was intersected with a commonly known demand function, $D(p) = 36 - p$, to determine the equilibrium price in the product market. Only orders that specified prices less than the equilibrium price sold, and producers' cash and permit holdings were updated accordingly (where for each unit sold by a low emitter one permit was deducted and for each unit sold by a high emitter two permits were deducted).

In the product market, the permit constraint was not binding, i.e. producers were allowed to be "non-compliant" by selling more units than they had permits for. If producers sold fewer units than they had permits for, then the unused permits would carry over to the next period, i.e. "banking" of permits was possible. However, in periods 3, 6, and 9 of the experiment, the program checked automatically for compliance: a producer who had a permit deficit in any of these periods was charged a penalty of 16 for every missing permit (twice the permit equilibrium price, as we show next).

3. Theoretical Predictions

The competitive equilibrium prices in the permit spot market and the product market, denoted r and p respectively, follow from a set of coupled demand-and-supply equations. Consider a low emitter with marginal cost $8 \leq c \leq 12$ for the first unit. Selling this unit results in a profit of $p - r - c$, since a low emitter needs one permit for each unit produced. Hence, a low emitter would sell the unit if and only if $p - r > c$. Since a low emitter's cost distribution is uniform on [8,12], the expected supply of a low emitter is

$$S_L(p,r) = \begin{cases} 0 & \text{if} \quad p - r < 8 \\ p - r - 8 & \text{if} \quad 8 \leq p - r < 12 \\ 4 & \text{if} \quad 12 \leq p - r \end{cases} \tag{3.1}$$

Likewise, supply of a high emitter is

$$S_H(p,r) = \begin{cases} 0 & \text{if} \quad p - 2r < 4 \\ p - 2r - 4 & \text{if} \quad 4 \leq p - 2r < 8 \\ 4 & \text{if} \quad 8 \leq p - 2r \end{cases} \tag{3.2}$$

Competitive equilibrium prices now follow from the requirement that demand equals supply in the product market, $D(p) = 3S_L(p,r) + 3S_H(p,r)$, and that the total number of permits used is

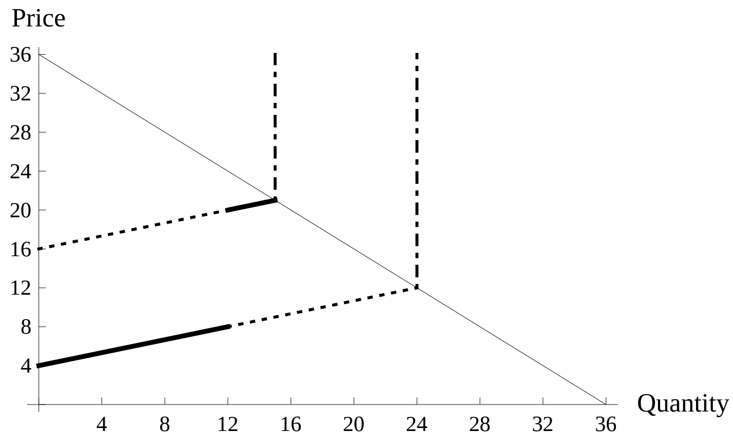

Figure 1. Demand (thin downward sloping curve) and predicted supply for a cap of 18 (upper supply curve) and 36 (lower supply curve). High emitters' supply is shown by the solid lines and low emitters' supply by the dotted lines. The vertical dot-dashed lines reflect producers' capacity or permit constraints.

equal to the cap, $3S_L(p,r)+6S_H(p,r)=18$. It is readily verified that equilibrium price levels are $p=21$ and $r=8$. At these price levels, a low emitter produces 4 units (i.e. at full capacity) and requires 4 permits while a high emitter produces 1 unit and needs 2 permits.

The introduction of a cap of 18 permits shifts supply away from high emitters, see Figure 1. Demand is shown by the downward sloping thin black line, and supply is shown by the dotted lines for low emitters and by the solid lines for high emitters. When the cap is non-binding (i.e. 36 or more permits so $r=0$), the high emitters are on the bottom part of the supply curve since they have lower marginal production costs, as shown by the lower supply curve. However, with a binding cap of 18 permits and a resulting equilibrium permit price of $r=8$, the low emitters have lower per-unit costs, as shown by the upper supply curve. The vertical line at a quantity of 24 reflects the production capacity constraint of 4 units for each of the six producers. The vertical line at a quantity of 15 reflects the permit constraint: the three low emitters have 12 permits and, hence, can produce 12 units, and the three high emitters have 6 permits and, hence, can produce only 3 units.

The profits of low and high emitters under the competitive equilibrium benchmark depend on how permits are initially assigned. Under grandfathering, a high emitter sells 2 permits at a price of $r_S=8$ in the spot market, and sells one unit at a price of 21 in the product market. The expected value of the lowest marginal cost of a high emitter is 4.8, so the high emitters' product market profits are 16.2, and hence, total profits are 32.2. A low emitter sells 4 units in the product market for a profit of $4(21-10)=44$ and the low emitter acquires two permits in the spot market, so total net profits are $44-16=28$. In the auction, a low emitter is predicted to acquire 4 permits and a high emitter two permits at a unit price of $r_A = 8$. Since allocations after the auction are optimal, there is no predicted activity in the spot market. Total profits for low and high emitters are now $44-32=12$ and $16.2-16=0.2$ respectively.[8]

The competitive equilibrium predictions are shown in the top panel of Table 1. The Prices column shows the permit price (r_A in the auction, r_S in the spot market, and NA is short for "not applicable") and the product market price (p). The Permits column shows permit holdings of the low and high emitters after the assignment stage and after the spot market. Producers' overall profits are shown in the Profits column, and the final two columns show consumer surplus and government revenue (from the auction or non-compliance penalties).

The competitive equilibrium benchmark assumes price taking behavior, which is not realistic if traders can exercise market power in the permit or product markets.[9] As another benchmark, suppose no trade occurs in the spot market so that final allocations under grandfathering are equal to the initial allocations. High emitters will then produce 2 units in the product market and so will the low emitters, yielding a product market price of 24 and profits of $48-4.8-5.6=37.6$ for high emitters and $48-8.8-9.6=29.6$ for low emitters, see the middle ("No Trade") panel of Table 1. The no-trade outcome occurs, for instance, if permit prices in the spot market are driven up to 16, i.e. the penalty incurred for non-compliance.

4. Results

Aggregate statistics for the auction and grandfathering treatments are shown in the bottom ("Observed") panel of Table 1. The numbers represent data averages for the final five periods (periods 5-9) of the seven sessions in each treatment.

The auction permit price (7.2) is lower than the theoretical prediction (8.0) and the resulting allocation of permits, 9.3 permits for low emitters and 8.7 permits for high emitters, reveals that too few permits are won by low emitters. This mis-allocation is not corrected in the spot market where trading volume is very low. On average only 0.46 permits are traded: 0.26 permits are bought by emitters of the same type (i.e. a low emitter buying from another low emitter, or a

[8] In order to negate the effects of possible low earnings, we gave each high emitter an initial payment of $60, whereas each low emitter only received $10. These initial payments were the same in both treatments and were private information. After each session, subjects were paid in cash at a rate of 30% of experiment earnings.

[9] Or if they expect "information rents" resulting from private information about production costs, see Myerson and Satterthwaite (1983).

	Prices	Permits (Low, High)		Profits	Consumer	Government
	r_A, r_S, p	Assignment	Spot Market	Low, High	Surplus	Revenue
Competitive Equilibrium						
Grandfathering	NA, 8, 21	6, 12	12, 6	28, 32.2	112.5	0
Auction	8, NA, 21	12, 6	12, 6	12, 0.2	112.5	144
No Trade						
Grandfathering	NA, NA, 24	6, 12	6, 12	29.6, 37.6	72	0
Auction	8, NA, 21	12, 6	12, 6	12, 0.2	112.5	144
Observed (periods 5-9)						
Grandfathering	NA, 11.0, 22.6	6, 12	8.2, 9.8	28.4, 35.7	90.0	0
Auction	7.2, 8.4, 21.9	9.3, 8.7	9.4, 8.6	14.2, 4.5	100.3	133.8

Table 1. Theoretical predictions and experimental outcomes.

high emitter buying from another high emitter), 0.06 permits are bought by high emitters from low emitters, and 0.14 permits are bought by low emitters from high emitters. So the net permit transfer from high to low emitters is only 0.08. As a result, permit allocations are almost unaffected by the spot market: the low emitters hold 9.4 permits on average, and the high emitters 8.6. The average spot market price (8.4) is higher than the auction price, which reflects a higher willingness-to-pay of producers who were unsuccessful in the auction and need additional permits to avoid the penalty. The post spot-market permit holdings explain why observed output in the product market (14.1) is less than the competitive equilibrium output (15.0). The associated higher product price of 21.9, lowers consumer surplus (100.3) and benefits producers. The observed profit for a low emitter is 14.2 while high emitters make a small profit of 4.5, partly because they incur an average compliance penalty of 3.7. Finally, the average auction revenue is 130.1, which translates into a government revenue of $130.1 + 3.7 = 133.8$.

With grandfathering, on average 3.7 permits are being traded in the spot market, resulting in a net transfer of 2.2 permits from high to low emitters (1.3 permits are traded are among high emitters only or among low emitters only, and 0.1 permits are bought by high emitters from low emitters). So the spot market corrects the initial mis-allocation to some extent (low emitters' holdings are increased from 6 to 8.2 permits) but not nearly as much as a competitive equilibrium analysis predicts. The spot-market price for permits is 11.0, which is higher than in the auction. Output in the product market is 13.4 and the product price is 22.6, with low consumer welfare (90.0) and high profits as a result (28.4 for low emitters and 35.7 for high emitters). There are no non-compliance penalties so government revenue is 0.

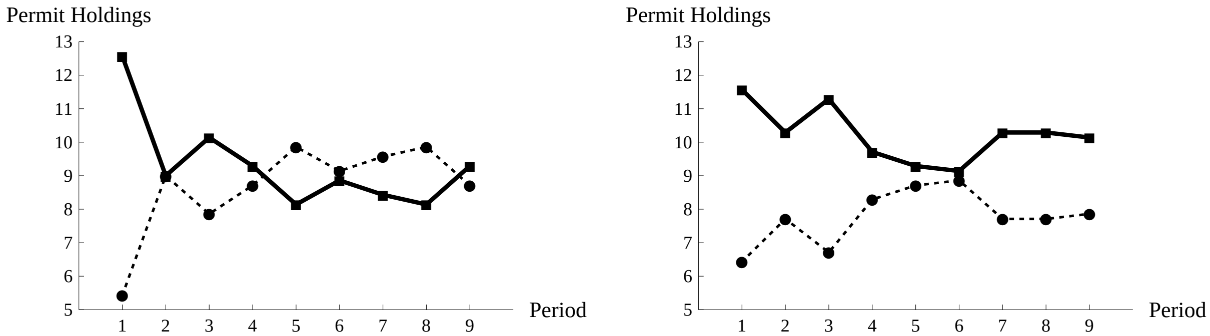

Figure 2. Permit holdings using auctions (left) and grandfathering (right). High (low) emitters' after-spot-market holdings are shown by the solid lines with square markers (dotted lines with circle markers).

A more disaggregated view of the data is provided by Figure 2, which displays post spot-market permit holdings of low emitters (dotted line with square markers) and high emitters (solid line with circle markers) in each of the nine periods of the experiment. The left panel covers the auction treatment and the right panel the grandfathering treatment. Note that in the final five periods, low emitters tend to hold the majority of the permits when they are initially assigned by auction, while the reverse is true with grandfathering.

Figure 3 shows prices for the different stages in both the auction (left panel) and grandfathering (right panel) treatments. The top solid lines with circle markers correspond to prices in the final product market, and the dashed line at a price level of 21 is the theoretical prediction. Note that with grandfathering, product prices are somewhat higher than with an auction. The reason is that more permits are owned by high emitters and, as a result, total output is less. The bottom solid line with diamond markers in the left panel shows the permit prices in the auction, and the dashed line at a price level of 8 is the theoretical prediction. Finally, the dotted lines with square markers show the permit prices in the spot market. Note that with the auction, spot prices are too high but drop towards the equilibrium level of 8 in the final periods. In contrast, with grandfathering, high emitters exercise their bargaining power in the permit market and drive up the permit price (close) to 11 in the second half of the experiment.

Figures 2 and 3 provide some evidence for adjustments in subjects' behavior over time (learning). For example, in the auction treatment, high-emitters post spot-market holdings drop dramatically over the first four periods. Likewise, spot prices in the grandfathering treatment show a significant time trend up to period 5 after which they level off at high levels. For these reasons, the aggregate statistics reported in Table 1 are based only on the final five periods of the experiment for which behavior seems to have stabilized.

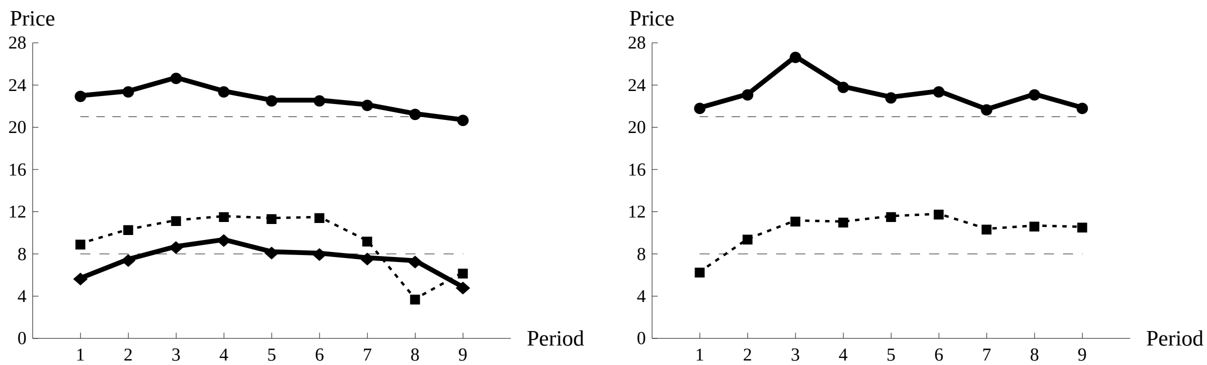

Figure 3. Permit and product prices using auctions (left) and grandfathering (right). The solid line with diamond markers show auction permit prices, the dotted lines with square markers show spot-market permit prices, and the solid lines with circle markers show product prices. The thin dashed lines show theoretical predictions.

5. Exercising Market Power

In this section we consider the following three questions, raised by the experimental results reported above. In the auction, why are too few permits won by low emitters? Under grandfathering, why are too few permits traded from high to low emitters? What is the degree of pass through under grandfathering where permits are obtained for free?

Figure 4 shows demand for permits in the auction by low emitters (middle panel), high emitters (bottom panel), as well as aggregate demand (top panel). In the top panel, for instance, the thick solid line represents demand of low and high emitters and the dashed line gives the theoretical prediction when demand is "truthful," i.e. when bids are equal to values. In the aggregate, observed demand is close to predicted demand (there are differences for quantities higher than 20, but since the cap was set at 18 permits these differences are immaterial). However, the disaggregated demand curves shown in the middle and bottom panels indicate that low emitters showed "monopsonist" behavior while high emitters "overbid." Since they are the larger buyers in the auction, low emitters strategically withheld demand so as to push down the price. In contrast, high emitters submitted bids that exceeded their values, at least for low quantities, to ensure they received *some* permits.[10] Consequently, high emitters won more than

[10]High emitters may have bid more than the permit's value to increase the chance of winning that permit while expecting to pay a low price (i.e. the market-clearing price set by the marginal unit that transacts). This reasoning is flawed, of course, since an increase in one's bid only changes the outcome if the bid becomes the marginal bid that determines the price, in which case bidding above one's value leads to a sure loss. Nevertheless, bidding above value is commonly observed in second-price auctions where the high bidder wins and pays only the second-highest bid, e.g. Kagel and Levin (1993).

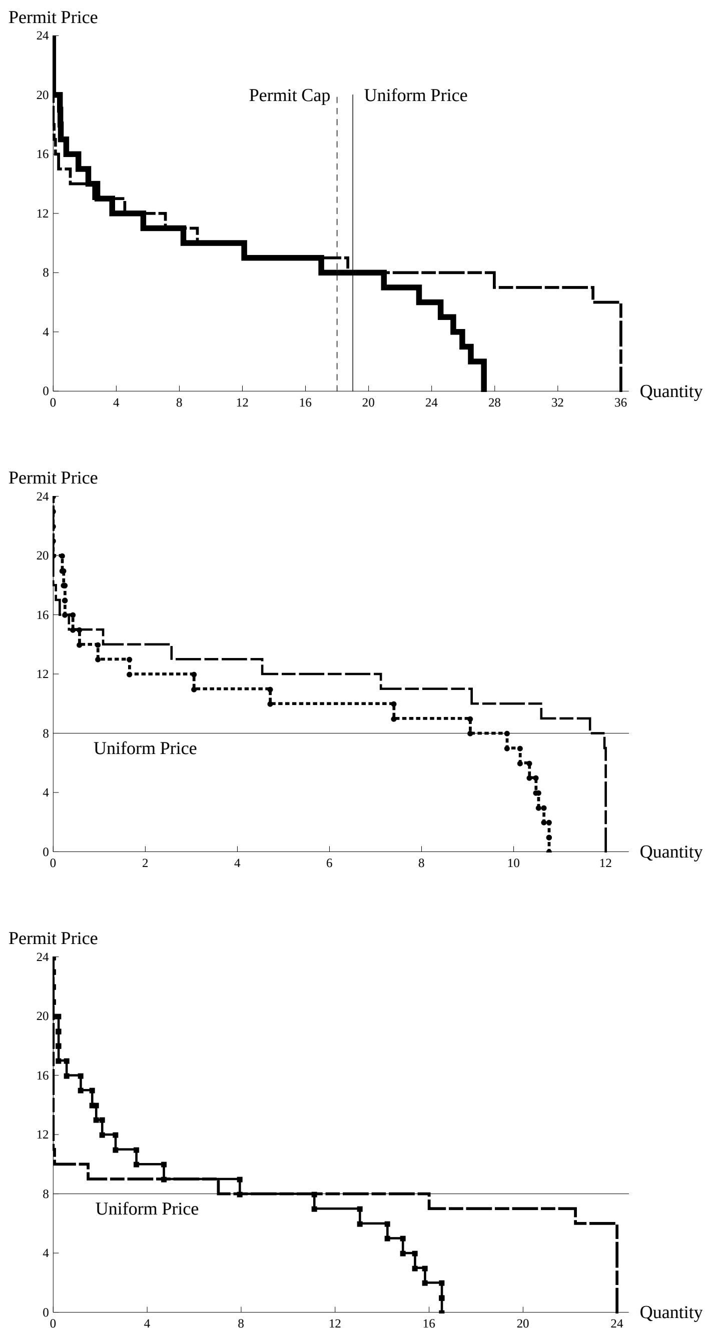

Figure 4. Demand for permits in the auction. The thick solid line in top panel shows shows demand aggregated over low and high emitters, the dotted line with circle markers in the middle panel shows demand of the low emitters, and the solid line with square markers in the bottom panel shows demand of the high emitters. In all three panels, the dashed line shows theoretical predictions based on truthful bidding. In the top panel, the dashed vertical line at 18 is the permit cap, the thin solid line at 19 determines the uniform price (equal to the highest-losing bid). The resulting uniform price of 8 is shown by the horizontal lines in the middle and bottom panels.

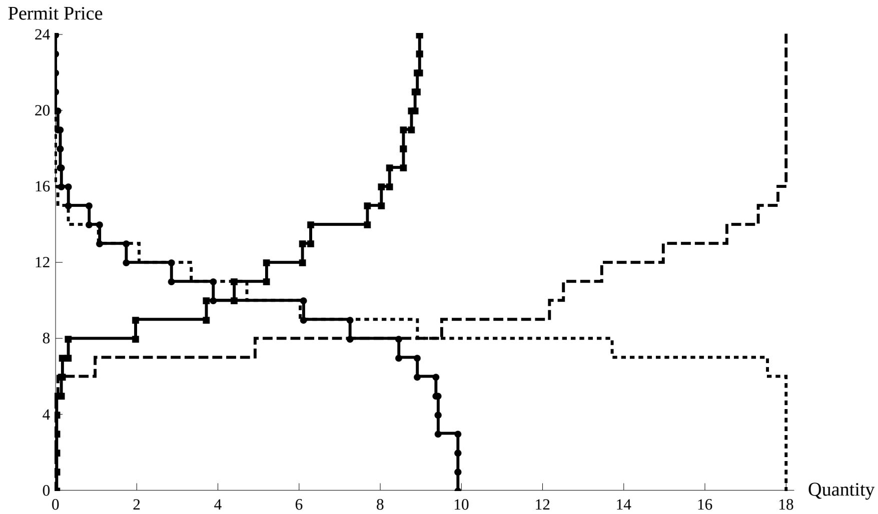

Figure 5. Demand and supply curves in the spot market. The solid lines represent observed demand and supply, aggregated over low and high emitters (although most demand comes from low emitters and most supply from high emitters). The dotted line is the theoretical demand curve, constructed by equating bids to values, and the dashed line is the theoretical supply curve, constructed by equating asks to values.

the predicted number of permits, as can be seen from intersecting the horizontal line at a price of 8 with the relevant demand curves, yielding 9.3 permits for low emitters and 8.7 permits for high emitters. To summarize, while the auction awards the majority of the permits to the low emitters, there is some degree of mis-allocation because of strategic demand reduction by the low emitters (monopsony power) and some overbidding by high emitters.

Figure 5 shows demand and supply in the permit spot market. The solid downward sloping line with circle markers represents demand of mostly low emitters, and the upward solid line with square markers shows supply of mostly high emitters. They intersect at a price in the 10-11 range, see also Table 1. The dotted downward sloping curve is demand in the permit market when bids are equal to values, and the dashed upward sloping curve is supply when asks are equal to values. Notice that observed demand is close to truthful, but that observed supply differs starkly from predicted supply. High emitters who hold the majority of permits are exercising their market power. A standard markup-over-cost computation yields

$$\frac{p-c}{p} \times 100\% = 16\%$$

where p is equal to the observed ask price and c is equal to the true value of the permit. To summarize, the reason that the spot market does not fully correct the initial mis-allocation under grandfathering is that high emitters exercise their market power in the permit market.

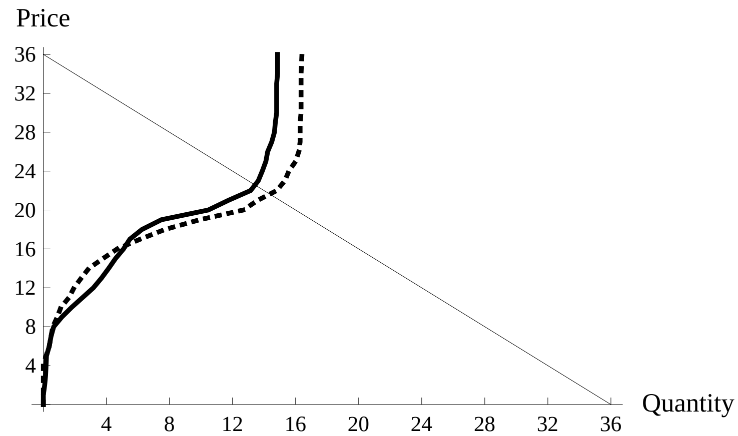

Figure 6. Empirical supply functions (aggregated over low and high emitters) for the auction (dotted) and grandfathering (solid) treatments with a cap of 18.

Finally, in the discussion about auctions versus grandfathering, one of the main issues is that of pass through, i.e. whether auctions will cause producers to charge higher prices to recover permit costs (which are zero under grandfathering). Figure 6 shows the distribution of ask prices in the auction (dotted line) and grandfathering (solid line) treatments. These empirical supply curves were constructed by considering the ask prices from both low and high emitters and taking an average over the final five periods of each of the seven sessions within a treatment. Note that for some of the inframarginal units (corresponding to very low marginal costs of production), the ask prices under grandfathering are indeed lower. However, for marginal units, which determine consumer prices, the opposite is true and ask prices are *higher* with grandfathering. In other words, the opportunity costs of "free" permits were fully "passed through" to the product market, resulting in large increases in producer profits in these sessions: earnings of low emitters doubled with free allocations, and earnings of high emitters increased even more sharply.[11] These results are consistent with observed practices in the European carbon-trading market where Germany-based RWE collected billions of dollars in windfall profits from having obtained permits for free, and yet raised consumer electricity prices to reflect the permits' opportunity costs (see the Introduction).

[11]The degree of pass through that we observe is somewhat more pronounced that what was observed by Wråke et al. (2009) in a simple "individual decision" design in which the markets for permits and the downstream product were simulated exogenously. In the Wråke et al. experiment, some subjects had difficulty recognizing the opportunity cost of permits that were received for free, although behavior tended to get closer to theoretical predictions with experience. Benz and Ehrhart (2007) also study the effects of initial permit allocations in an experiment, but the issue of pass through was not addressed, since there was no product market (producers were given exogenously determined production levels).

6. Conclusions

The laboratory experiments reveal that even free allocations of emissions permits result in dramatic increases in downstream product prices. It would be a mistake to adopt grandfathered procedures in the hope that the effects of cap-and-trade regulations will have no price consequences. In our laboratory markets, the price effects of free allocations were exaggerated by the tendency for high emitters, with large "history-based" permit allocations, to exercise some market power in the secondary markets for permits that preceded the clearing of the product market. The permit prices in these spot markets were well above competitive (supply and demand) predictions. As a result, high emitters, who began with high allocations, entered the production phase with more permits than was optimal, which tended to reduce output and raise product prices. In contrast, permit prices tended to converge to competitive levels when permits were assigned by auction. The initial assignments resulting from the auction were more favorable to low emitters, which resulted in slightly lower product prices and higher consumer welfare. The main effect of the auction is to transfer the windfall profits of (high) emitters into government revenue.

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