Dynamic Efficiency of Emission Trading Markets: An Experimental Study

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Abstract

This study investigates the dynamic efficiency of an emission regulation regime where companies competitively pay for emission licences. We embed the emission licence market in a Cournot model where the price of emission licences is subject to strategic tradeoff between licences and abatement technologies. Unlike the standard Cournot model, agents have two action parameters, quantities bought on the licence market and investments into abatement technology. We want to investigate the implications of this market design on the strategic behavior regarding companies' incentives to invest in those technologies. Data from a series of laboratory experiments supports the theoretical predictions for subjects' investment into abatement technology. With respect to the adaptation process of individual quantities for licences we find that a majority of subjects adjusts on the market by imitation while a minority entertains a trial and error notion.

Keywords: Cournot market, emission regulation, experimental economics, dynamic efficiency, learning
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1 Emission Regulation Instruments

The public regulation of emissions is a topic which has recently generated heated political discussion in the European Union. At the center of the debate are tradable emission licences that have been implemented with some success in the United States[1] and are incorporated in the Kyoto Protocol as well as in European Law.[2] Many economists consider them one of the best ways to solve the fundamental problem of the internalization of externalities caused by emissions.

With respect to static efficiency, i.e., the level of social costs given that firms' emission-abatement technologies are not subject to change, ecological economists typically consider licence markets to be superior compared to the traditional taxation regime (e.g., Plott, 1983). This is because on markets for tradable licences, unlike in a tax environment, allocations of emission volumes are based on prices determined by companies' different abatement costs. The concept of static efficiency, however, does not take into account the long-term effects of different policies on companies' incentives to invest in abatement technology. This question is addressed by the concept of dynamic efficiency. There is a broad theoretical literature on both the static efficiency of licence and taxation regimes (see the survey article by Muller and Mestelman, 1997) as well as on their dynamic efficiency (e.g., Downing and White, 1986, Parry, 1995, Keohane, 1999, Denicolò, 1999, Montero, 2002, Fischer et al., 2003, Schleich et al., 2002). However, empirical data on dynamic efficiency (e.g., Hemmelskamp, 2000) is rare, and the theoretical analyses neglect the strategic tradeoff between investment into abatement technologies and the licence price. To our knowledge there is no laboratory data on the subject to date. In order to isolate the effects of the license regime on dynamic efficiency we develop a simple Cournot market model that allows us to investigate the strategic interaction of market

[1] In the regulation of SO_2 emissions. See Hanley et al. (1997) pp. 136 - 138.

[2] See Directive 2003/87/EC of the European Parliament and of the Council.

participants, and test this model with respect to individual adaptation strategies. Specifically, we focus on two questions: First, we will test whether laboratory markets reach the theoretically predicted equilibria though subjects have two action parameters, market quantities and investments. Second, we investigate which strategies subjects choose in adjusting their market quantities. The analysis of individual adaptation strategies allows us to conclude which kind of long term market scenario is most likely for licence markets.

Therefore, this article is organized as follows: Section two presents a model of the strategic interaction between licence markets and investments into abatement technologies. Section three interprets the resulting equilibria and adaptation strategies. Section four reports on a series of laboratory experiments. Section five contains conclusions drawn from the model and the experiments.

2 A Simple Model of Emission Markets

In our analysis we consider two regional monopolists[3] who produce a uniform good in a single period and are subject to a linear price function. If player i produces x_i units, the price she receives for each unit is

$$p(x_i) = \alpha - x_i. \tag{1}$$

For each unit of the good companies produce, they emit one unit of pollution. This is regulated by a common institution (the government) such that a licence must be bought from the government for each unit emitted. The firms have the option to avoid buying licences by investing in I units of reduction technology, where each unit has a constant cost c and enables them to produce one unit of the good without causing emissions.

[3]By reducing the game to two persons we were able to model a situation in which investment is neither an 'all-or-nothing' decision nor limited to one player; *both* firms have the choice *how much* to invest. At the same time model is still sufficiently simple to allow laboratory testing.

We model the licence market where both competitors interact as a simple symmetric Cournot model.[4] The regulation of emissions by the governmental institution introduces scarcity on emission permits. Thus, market demands are substitutes such that higher demand by either player leads to a higher price for all agents. For individual demands λ_i, λ_j of player i and player j the price per licence is calculated as

$$L = (\beta + \lambda_i + \lambda_j) \tag{2}$$

where β is constant. Buying a licence for each unit that she produces and does not compensate by investment, player i's profit is

$$\pi_i(x_i,\, I_i,\, \lambda_i,\, \lambda_j) = x_i\,(\alpha - x_i) - \lambda_i\,(\beta + \lambda_i + \lambda_j) - c\, I_i. \tag{3}$$

In order to allow plausible economic interpretations we assume that $\alpha > c > \beta \geq 0$. We also restrict $I_i \geq 0$ and $\lambda_i \geq 0$, the latter condition being equivalent to the condition that companies are not allowed to sell superfluous licences.[5]

3 Equilibria and Predictions

The price function and revenues are assumed to be ex-ante common knowledge (as they were in the experiment). From the assumptions follows that for rational companies $x_i \geq I_i + \lambda_i$. On the other hand production is restricted by the permissable amount of emissions, i.e. $x_i \leq I_i + \lambda_i$, and so the licence demand of company i can be written as

$$\lambda_i = x_i - I_i \geq 0. \tag{4}$$

Therefore, profits of company i are given by

$$\pi_i(x_i,\, I_i,\, \lambda_j) = x_i\,(\alpha - x_i) - (x_i - I_i)\,(\beta + (x_i - I_i) + \lambda_j) - c\, I_i. \tag{5}$$

[4] In the interest of simplicity, we abstracted from licence trading among firms and do not allow banking or similar instruments enabling companies to buy licences for future periods.

[5] This rule, too, was introduced to preserve simplicity.

Partial differentiation respect to x_i and I_i yields the standard monopoly solution for the production quantity

$$x_i^\star = \frac{\alpha - c}{2}, \tag{6}$$

and for the investment level the reaction function

$$I_i^\star = \frac{1}{2}\,[\alpha + \beta + \lambda_j] - c. \tag{7}$$

Thus, investment and licence demand are subject to strategic interaction (but not production volumes). One can easily see from (7) that with $\lambda_j = x_j - I_j$ one has the spill-over effect , as $\frac{\partial I_i^\star}{\partial I_j} = -\frac{1}{2}$. If any one player invests, she emits less and her valuation of licences decreases. This induces a drop in the licence price and so the other player also benefits from her investment.

Economic theory on repeated Cournot markets (e.g., Huck, Normann & Oechssler, 2000) offers three different equilibria concepts, the Nash equilibrium, the competitive equilibrium, and the collusive outcome.[6] The Nash equilibrium assumes that agents optimally respond (with respect to equation (7)) on the optimal behavior of their opponents, while the collusive outcome relies on a joined maximization of profits. Finally, the competitive outcome assumes that agents increase their quantities as long as the market price does not exceed marginal costs. In our model those costs correspond to the opportunity costs of abatement technology, (i.e., $c > \beta + \lambda_i + \lambda_j$). Consequently, assuming symmetry, one obtains the symmetric Nash equilibrium for the investment strategy (I^N) and the corresponding licence demand (λ^N)

$$I_j^N = I_i^N = \frac{1}{2}\,\alpha + \frac{1}{3}\,\beta - \frac{5}{6}\,c \;\text{ and }\; \lambda_i^N = \lambda_j^N = \frac{1}{3}\,(c - \beta). \tag{8}$$

A joined maximization yields for the collusive investment strategy (I^C) and the licence demand (λ^C)

$$I_j^C = I_i^C = \frac{1}{2}\,\alpha + \frac{1}{4}\,\beta - \frac{3}{4}\,c \;\text{ and }\; \lambda_i^C = \lambda_j^C = \frac{1}{4}\,(c - \beta). \tag{9}$$

[6]Note that the last concept is not an equilibrium in the strict game theoretical sense.

Finally, the competitive investment strategy (I^K) and licence demand (λ^K) equals

$$I_j^K = I_i^K = max(\frac{\alpha + \beta - 2c}{2}, 0) \text{ and } \lambda_i^K = \lambda_j^K = min(\frac{c - \beta}{2}, \frac{\alpha - c}{2}). \quad (10)$$

It follows directly from (8), (9) and (10) $I^K < I^N < I^C$.

We modelled the licence regime as an interactive market with substitutive actions, however, unlike the standard experiments on Cournot markets, we have a two-stage process. Our equilibrium predictions rely on optimal production levels. Therefore, we first have to test experimentally

Hypothesis 1: *Agents learn to choose the optimal production level in the course of the experiment.*

Of course, Hypothesis 1 is not more than a prerequisite for predictions on the licence market. Most important for the institution that introduces a licence market (e.g. the government on a national level) is, how this market evolves and which equilibrium is reached. Following Bosch-Domènech & Vriend (2003), increasing complexity favors imitation as the strategy of volume adaptation. One may argue that the two-stage process of licence markets is more complex than the standard Cournot markets, so that we will test for

Hypothesis 2a: *Agents adapt their licence quantities by imitation.*

Recent theoretical results show that the assumption that agents (loosely) imitate more successful opponents implies that quantities on Cournot markets tend to drift to competitive outcomes (Vega-Redondo, 1999). Thus, we will analyze experimental data for

Hypothesis 2b: *Agents coordinate licence demand on the competitive equilibrium.*

On the other hand, if we consider as complex the environment within which the agents interact, it seems reasonable to assume that they do not entirely understand the interactive market mechanism. Then one should expect some kind of trial and error process for the adjustment of quantities on the licence market. The learning direction theory (Selten & Stöcker, 1986) offers the idea that agents try to develop a model on the structure of the problem by (systematic) exploitation. In more detail we will test the laboratory data for

Hypothesis 3a: *Agents explore the space of licence quantities in trial and error processes.*

However, as suggested by Huck, Normann & Oechssler (2004), trial and error adaptation tends to lead to the collusive outcome on the market. Therefore we will analyze data for

Hypothesis 3b: *Agents coordinate licence demand on the collusive equilibrium.*

4 Experimental Results

The experiments were conducted in Jena in February 2004 using the z-Tree software package (Fischbacher, 1999). In total, three groups of 24 subjects participated in the experimental sessions, largely undergraduate students of Business Administration or Economics at the University of Jena. During the experiments subjects were given an initial endowment equivalent in value to 2.00 euros and then interacted in anonymous pairs for three phases of ten rounds each. For a total of 30 paying periods subjects required approximately ninety minutes and received an average payment of 9.69 euros (with a range of the payment from 8.01 euros to 11.03 euros). In order to allow adaptation, but also to observe progress in the adaptation process (restart effect), pairs played together in one group for the ten periods of a phase, giving them time to approach equilibria before being assigned a new partner. Before the experiment began participants were asked to answer a short seven-item questionnaire to ensure their understanding of the instructions. Answers were explained where there was uncertainty. In each round the single strategic decision was broken down into three screens: investment (called "purchase of free tickets" in the experiment to avoid priming), the purchase of licences and the level of production.[7] Between the licence demand and the production screens subjects were informed of their competitor's licence demand, the resulting licence price and the entire amount they had spent on licences. At the end of each round they were informed of their profit in the round and their total current profit, which was calculated as the cumulative sum of their profits in previous rounds plus the initial endowment.

The parameters chosen for the experimental sessions were $\alpha = 24$, $\beta = 2$ and $c = 13$. This implied a symmetric equilibrium in production $x^\star = 5.5$, and the following values for the different equilibrium concepts: $I^N = 1.833$, $\lambda^N = 3.66$, $I^C = 2.75$, $\lambda^C = 2.75$, and $I^K = 0$, $\lambda^N = 5.5$.[8] In the subsequent sections we have termed a pair of players bidding for licences a 'group' and refer to the 10 rounds which groups played in partner design as 'subsessions'.

Let us first analyze the data for Hypothesis 1. As shown in Figure 1, the average production quantities approach the optimal quantity in the course of the experiment. However, a statistical comparison reveals a significant distance[9] between the averages of the subsessions and the optimal value. In particular, the average production quantity in subsession 1 exceeds the optimal quantity by 0.86 units (standard deviation 1.678), in subsession 2 by 0.38 units (standard deviation 1.306), and in subsession 3 by 0.18 units (standard deviation 1.195). Consequently, we cannot strictly statistically confirm Hypothesis 1. Although the optimal adjustment of production quantities is a rather simple, independent decision problem, it seems that subjects considered this problem less trivial in combination with the licence market. However, especially in subsessions

[7] We introduced the production level in order to double-check the participants understanding of the game. Of all production decisions 1,7% were below the permissible amount (and thus suboptimal), so that with the exception of two subjects who made multiple errors and obviously did not understand the game (but were nonetheless included in the data) we put them down to typing errors.

[8] Note that for some values subjects could not reach these exact points as they were between feasible points of their action space. However, this does not restrict our interpretations of the data. It simply means that the minimal achievable distance to a given equilibrium is non-zero.

[9] All averages are greater than the optimal value on an $\alpha = 5\%$ level.

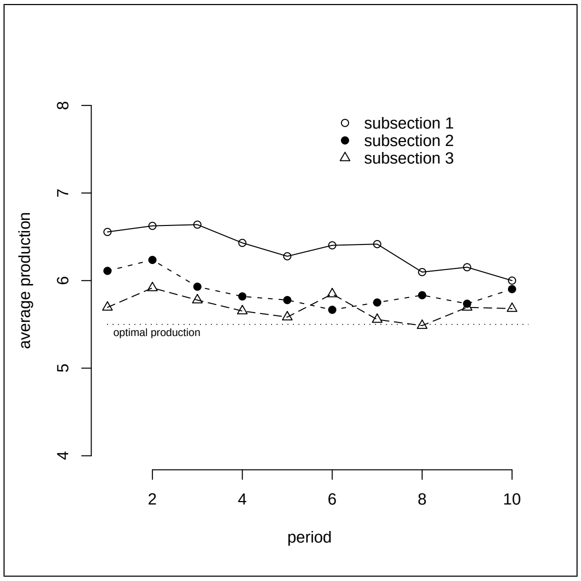

Figure 1: *Average production quantities over periods*

2 and 3 the distance to the optimal is rather low, and less important for the further analysis.

Let us now focus on the tradeoff between emission licence markets and abatement investments. With respect to the averages over subsessions, the data indicates that both investments and licence demands approach the Nash equilibrium solution. Figure 2 shows the average development of (a) licence demand and of (b) investments over periods. With respect

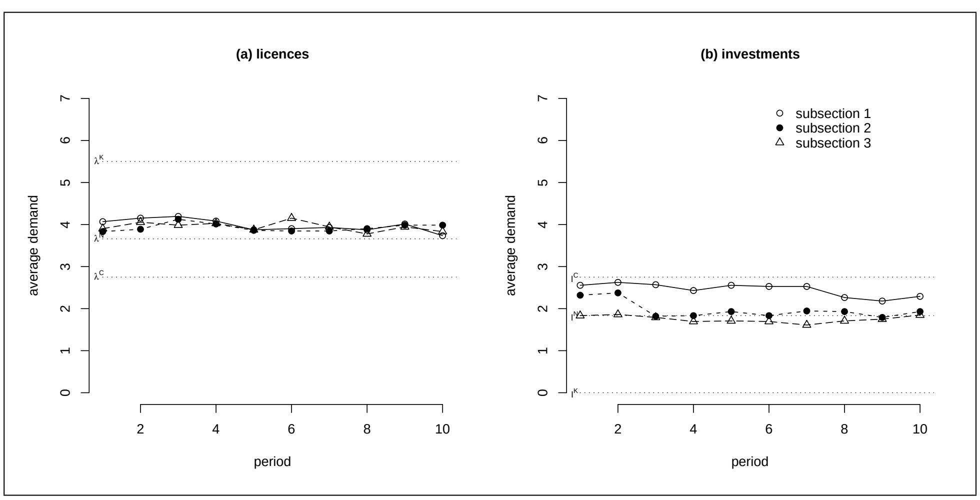

Figure 2: *Average (a) licence demand and (b) investments over periods*

to the Nash equilibrium the demand for licences exceeds the optimal demand for all subsessions by 0.3 units.[10] This distance is rather small but remains constant. To the contrary, average investments in subsession 1 are closer to the collusive equilibrium, but decrease to the Nash equilibrium in subsession 2. The average investment exceeds the Nash equilibrium by 0.62 units in subsession 1, by 0.14 units in subsession 2, and falls below the Nash equilibrium by 0.08 units in subsession 3,[11] while the average of subsession 1 stays 0.3 units below the collusive equilibrium.[12] Consequently, we can neither confirm Hypothesis 2b nor Hypothesis 3b. Although average investments in subsession 1 tend to be closer to the collusive equilibrium than to the Nash equilibrium, subjects coordinate in the course of the experiment both, investments and licence demands close to the Nash equilibrium. However, these results are based on aggregated data, so that we next have to analyze individual decisions and adaptation rules.

For the analysis of individual adaptation rules we will exclusively focus on decisions where action parameters were changed. Also, we exclude the data for the first two periods of each subsession form the analysis since opponents change in that period and the adaptation strategies represent reaction rules on own and/or opponents behavior. First we focus on the licence demand. In 42.5% (735 of 1728) of all individual periods licence demands were changed. As predicted in Hypothesis 2a, one expects a high rate of adaptation by imitation of best actions in a complex environment. On the other hand, Hypothesis 3a suggests that subjects engage a trial and error adaptation process. Finally we will test for a simple best reply rule that represents so kind of normative benchmark where subjects optimally respond to opponents licence demand from the previous round with respect to equation (7). In order to test individual behavior for adaptation strategies we follow a technique

[10]The exact numbers are 0.32 for subsession 1, 0.27 for subsession 2, and 0.29 for subsession 3. All differences are significantly different from 0 on a $\alpha = 0.01$ level.

[11]Note that for the latter two results the difference is insignificantly on a $\alpha = 0.01$ level.

[12]But this difference is significantly ($\alpha = 0.01$ level) different from 0.

suggested by Huck, Normann and Oechssler (2000). We calculate the absolute distance between the observed demand λ_i^t and the prescribed demand according to imitation λ_{imi}^t, and get a distance measure

$$d_{imi}^t = \sum_i |\frac{\lambda_{imi}^t - \lambda_i^t}{\lambda_{imi}^t}| \tag{11}$$

The distance is a number between zero and one where zero indicates cases where actual play follows prediction. For the myopic best response we computed a similar d_{br}^t. For trial and error adaptation we face the problem that the learning rules are of qualitative nature. In more detail, we test for the model

$$sign(\lambda_i^{t+1} - \lambda_i^t) = sign(\lambda_i^t - \lambda_i^{t-1}) \times sign(\pi_i^t - \pi_i^{t-1}). \tag{12}$$

Thus we can only predict the direction of adaptation. Of course, correct prediction for the trial and error model are easier to derive compared to the other models. Therefore, we assign a large distance when the trial and error model fails. In order to make all models comparable we assign

$$d_{tr}^t = \sum_i \delta_i^t \; for \; \delta_i^t = \begin{cases} 0 & \text{if equation (12) is true} \\ 1 & \text{otherwise.} \end{cases} \tag{13}$$

Figure 3 shows the average distances for subsessions 1 to 3, (a)-(c). A statistical analysis using the Mann Whitney test of the averages distances indicates that the imitation model clearly outperforms the other two.[13]

Of course, one can also compute the average distance per subject (e.g., $d_{imi,i} = \sum_t |\frac{\lambda_{imi}^t - \lambda_i^t}{\lambda_{imi}^t}|$). We find the interesting result that for the majority, imitation adaptation best describes behavior (50 of 72 subjects). For 20 subjects the average distance between actual behavior and myopic best reply/trial and error adaptation falls below the distance to imitation.[14] However, we want to stress two points. First, the performance of the trial and error model crucially depends on the distance one assigns

[13] Distances are smaller on an $\alpha = 1\%$ level for subsessions 2 and 3, and on an $\alpha = 5\%$ level for subsession 1.

[14] Behavior of 2 subjects does not favor one specific adaption rule.

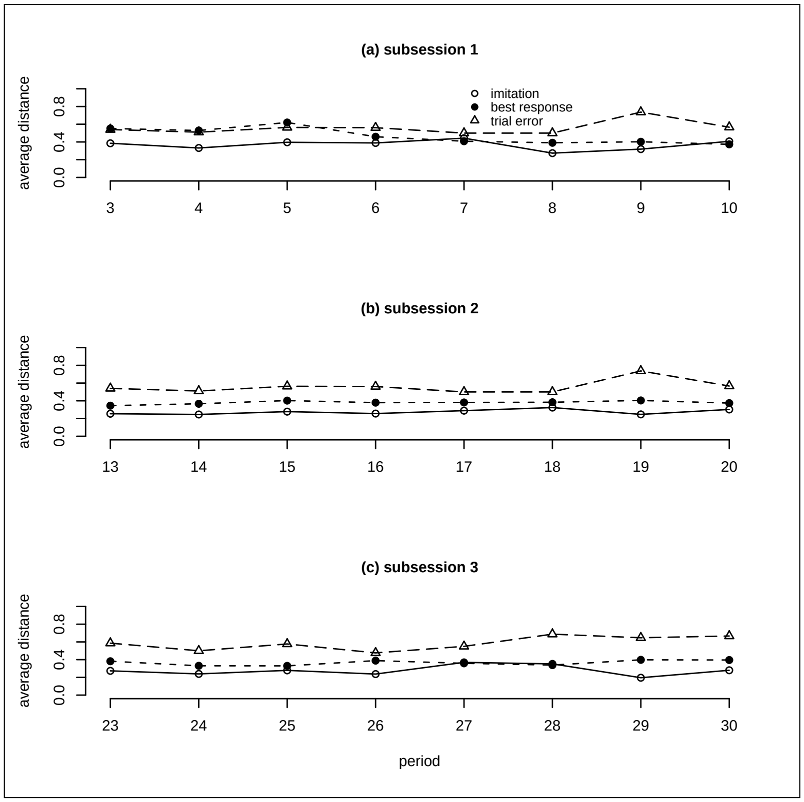

Figure 3: *Average distance of adaptation strategies*

in case of wrong prediction. Second, the performance of all adaptation models is rather poor, since the minimal average distance per period never falls below 0.1 and we only find one subject whose distance is less than 0.1. In summary, we conclude that there is mixture of adaptation strategies in the population. Consequently, we can neither support Hypothesis 2a nor 3a, but find evidence that we have to separate groups within a population that engage individual adaption rules.

For abatement investments we observe in 34.6% (598 of 1728) of all periods changes. The analysis of individual adaption rules we again use the previous technique of averaged distances between actual behavior and predictions from two models, the trial and error model and the myopic best response. Of course, imitation learning cannot take place here, since subjects are not informed of the investments of their opponents. Both for the aggregation over periods and the computation per person shows that a majority adapt in a way better described by myopic best response. In more detail, a Mann Whitney test shows that the averages distances for best response outperforms the distance for the trial and error model in all subsessions.[15] Individual behavior of 51 subjects is closer to myopic best response than to a trial and error adaptation, while 19 subjects seem to entertain a notion by trial and error adaptation.[16] Since we find licence demands that approximately equal the Nash equilibrium, subjects choose best responses for the investments. It seems that individual investment behavior respond to the development on the licence market.

5 Conclusions

The aim of our study was to investigate the development of emission licence markets with respect to their dynamic efficiency, i.e. their interaction with investments into abatement technologies. Within our simple licence market model the investment in abatement technology is subject to a strategic interaction. On an aggregated level we find that markets approach in the course of the experiment the Nash equilibrium predictions for the one-shot game. In more detail, we find evidence that demands on the Cournot market for emission licences are slightly more competitive than the Nash prediction. This result corresponds to earlier experiments on Cournot markets (e.g., Bosch-Domènech & Vriend, 2003) where subjects can sufficiently cope with markets of this complexity.

Second, we wanted to investigate which strategies subjects choose the adjust their market quantities in order to develop an idea how influential a single agent is on the formation of prices on licence markets. Based on our experimental data, we find that the majority of subjects adapt their licence demands by imitation of successful opponents while only a minority actively explore the set of action parameters. The investment decision responds to the development on the licence market. Thus, an

[15] Distances are smaller on an $\alpha = 5\%$ level.

[16] Again, behavior of 2 subjects does not favor one specific adaption rule.

individual decision of the minority is very influential on the result of the entire market and investment decisions. As such we can identify a second spillover effect. The first one, that investment by any company lowers the market price for licences, is explicitly modelled in the market mechanism. The second reflects the adaptation rules of a majority of agents in such an environment. An individual licence demand (if successful) is very likely to be imitated. For the long term dynamic efficiency of emission licence markets it follows that a market scenario which approaches the competitive equilibrium, and, therefore, provides strong incentives for very little investments in abatement technology is not unlikely.

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Appendix: Instructions

Thank you for participating in our experiment! We would ask you please not to make public remarks or speak with your neighbours during the experiment. Should you disregard this rule we will be forced to exclude you from the remainder of the experiment. If you have any questions, please raise your hand and one of the experimenters will clarify them with you.

In this experiment you will participate in three phases. In each of these you will be randomly assigned a partner who has received the same instructions as you and you will anonymously interact with him for 10 periods. After each phase you will be randomly assigned a different partner. Altogether the experiment will be 30 periods long.

You are in the position of a company that earns revenues by producing a good. The price you receive for each unit sinks for each additional unit you produce. Thus in every round the choice of how many of units you want to produce simultaneously determines the price per unit. In Table 1 you can see which prices and revenues you will receive for different amounts produced. In the first column is the number of units you produce. From that we have calculated the price you receive for each unit in the second column.[17] Your revenue is the amount you produced multiplied with the price for each unit. It is given in the third column. In the fourth column you can see how much additional revenue you made with the last additional unit produced.

Example for Table 1

If you produce 5 units, you receive a price of 19 ECU for each one and thus make a revenue of (19 * 5) = 95 ECU. If you had produced 4 units, you would only have made a revenue of 80 ECU. Thus, with the last additional unit produced you made 95 - 80 = 15 ECU additional revenue.

[17] Although the price as a function of production is given in the header of the table, we did not provide it in the text, as it caused confusion in the pilot experiment.

Before you can produce goods, however, you must buy licences from the government. In each round you may only produce as many units of the good as you previously bought licences. The price for licences results in each round from your own demand L_E and your competitor's demand L_W.[18] The more licences you purchase, the more expensive they become for you and for your competitor. On the other hand the less licences you (or your competitor) demand, the lower the price per licence. The price for each licence is calculated as

Licence price = 2 + (your demand) + (competitor's demand).

Table 2 shows how much you have to pay altogether for a certain number of licences. The rows represent the different levels of your own demand and the columns represent the levels of your competitor's demand. The black numbers are the licence price (which results from the two demand levels) multiplied by your demand, and give your total costs for the indicated number of licences. The grey rows ("Delta") indicate your additional cost for the last additional licence bought, given constant demand by your competitor.[19] After you have decided on the number of licences you would like to buy you may not change it in the current round.

<u>Example for Table 2</u>
If your demand is 6 and your competitor's is 7, each licence costs (2 + 6 + 7) = 15 ECU. Thus for 6 licences you have total costs of 6 * 15 = 90 ECU. If your competitor's demand remained at 7 but you only wanted 5 licences, you would only have to spend 70 ECU. The additional cost for the last additional licence is therefore 90 - 70 = 20 ECU.

Alternatively to buying licences you have a second possibility to produce goods. In each period you can buy from 0 to 5 free tickets for 13 ECU each. For each free ticket you can produce one unit of the good without having to buy a licence for it. Your competitor's behaviour has no influence on the price of the free tickets.

Free tickets and licences are only valid for the current period and can not be carried forward to later periods. Your profit in each round is calculated as

[18] 'E' and 'W' for 'Eigen' and 'Wettbewerber', German for 'own' and 'competitor' respectively.

[19] The rows giving the Δ's were gray in the original instructions.

Profit = your revenue
- your expenditure for licences
- your expenditure for free tickets

In each round you make the following decisions:

1. The number of free tickets you want to buy (from 0 to 5).
2. Your licence demand.
3. You receive the following information: Your and your competitor's licence demand, the resulting licence price and (given your demand) the amount you spent on licences.
4. The number of units of the good you want to produce (maximally the sum of your licences and free tickets).
5. You are informed of your profit in this round.

Example for profit calculation
You decide to buy 3 free tickets and 4 licences. Your competitor buys 5 licences. Thus, the licence price is 2 + 5 + 4 = 11 ECU. You use all your production capacities and produce 3 (allowed by free tickets) + 4 (allowed by licences) = 7 units of the good. Your profit in this round is Profit = 7 * (24 - 7) - (4 * 11) - (3 * 13) = 7 * 17 - 44 - 39 = 36 ECUs

You will be given an initial endowment of 300 ECU. Your profit for the entire experiment is the sum of your profits from the individual rounds and your endowment. If in one round you make a loss it will be absorbed in your profits from other rounds. At the end of the experiment you will be paid your total profit, exchanged at a rate of

$$150 \text{ ECU} = 1 \text{ EUR.}$$

If you make an overall loss, you will be paid only 2,50 EUR for your participation in the experiment.

Before you begin with the experiment, we would ask you to complete a questionnaire in order to help you familiarise yourself with the rules. Please answer the questions carefully.

x	Price	Revenue	Limit revenue for last unit
	P = 24 - x	E = P * x	
1	23	23	-
2	22	44	21
3	21	63	19
4	20	80	17
5	19	95	15
6	18	108	13
7	17	119	11
8	16	128	9
9	15	135	7
10	14	140	5
11	13	143	3
12	12	144	1
13	11	143	-1
14	10	140	-3
15	9	135	-5

Table 1: *Price and revenue for different production levels*

	λ_E										
λ_W	0	1	2	3	4	5	6	7	8	9	10
0	0	3	8	15	24	35	48	63	80	99	120
Δ	0	3	5	7	9	11	13	15	17	19	21
1	0	4	10	18	28	40	54	70	88	108	130
Δ	0	4	6	8	10	12	14	16	18	20	22
2	0	5	12	21	32	45	60	77	96	117	140
Δ	0	5	7	9	11	13	15	17	19	21	23
3	0	6	14	24	36	50	66	84	104	126	150
Δ	0	6	8	10	12	14	16	18	20	22	24
4	0	7	16	27	40	55	72	91	112	135	160
Δ	0	7	9	11	13	15	17	19	21	23	25
5	0	8	18	30	44	60	78	98	120	144	170
Δ	0	8	10	12	14	16	18	20	22	24	26
6	0	9	20	33	48	65	84	105	128	153	180
Δ	0	9	11	13	15	17	19	21	23	25	27
7	0	10	22	36	52	70	90	112	136	162	190
Δ	0	10	12	14	16	18	20	22	24	26	28
8	0	11	24	39	56	75	96	119	144	171	200
Δ	0	11	13	15	17	19	21	23	25	27	29
9	0	12	26	42	60	80	102	126	152	180	210
Δ	0	12	14	16	18	20	22	24	26	28	30
10	0	13	28	45	64	85	108	133	160	189	220
Δ	0	13	15	17	19	21	23	25	27	29	31

Table 2: *Costs for demanded numbers of licences, given competitor's demand. Limit costs for the purchase of the last licence bought. [Exact: Price per Licence = 2 + L_E + L_W; Costs given here = Licence price * your licence demand]*