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A Theoretical and Experimental Analysis

by

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Endogenous Price Leadership - A Theoretical and Experimental Analysis

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Abstract

We present a model of price leadership on homogeneous product markets where the price leader is selected endogenously. The price leader sets and guarantees a sales price to which followers adjust according to their individual supply functions. The price leader clears the market by serving the residual demand. As price leaders, firms with different marginal costs induce different prices. We compare two mechanisms to determine the price leader, majority voting and competitive bidding. According to the experimental data at least experienced price leaders with lower marginal costs choose higher prices. In the bidding treatment, compensation payments to the price leader crowd in efficiency concerns.

Keywords: Price leadership, majority voting, bidding, experimental economics

JEL Classification: D43, D74, L11

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1. Introduction

In many situations, groups elect one member as their leader, authorizing him to make decisions affecting them all. Leadership is often associated with positive attributes. But what is good for the group, may not be good for the leader and vice versa. Furthermore, heterogeneous group members usually perform differently as leaders. Whether the best candidate is selected when the leader is determined endogenously, will be analyzed theoretically and experimentally.

To study the selection of a leader in a heterogeneous group, we rely on an industrial organization model of endogenous price leadership. The literature on this subject is vast. Using an endogenous timing game, van Damme and Hurkens (1999) analyzed duopolistic quantity competition in the case of homogeneous products with linear demand and constant unit cost, with one firm being more efficient than the other. They show that risk dominance suggests that the more efficient firm will take up the leadership position. Van Damme and Hurkens (2004) addressed the same question in the context of price competition in a duopoly with substitutable products, linear and symmetric demand, and constant unit cost. Again, the more efficient firm emerges as the endogenous price leader. Taking capacity constraints into account, Deneckere and Kovenock (1992), Furth and Kovenock (1993) and Canoy (1996) show in a variety of circumstances that in a duopolistic setting both firms prefer the more efficient firm to lead.

We deviate from this strand of literature in at least three ways. First, by relying on the model of a dominant firm with competitive fringe, we extend the price-leadership model along the lines suggested by Ono (1982) or Güth et al. (1989) and allow for more than two firms in the market, but restrict ourselves to the case of three firms in order to experimentally implement the model. Second, we account for increasing unit cost. Third, since our focus is on the incentives for voluntary cooperation via price leadership, we enrich the setup by two alternative mechanisms to endogenously select the price leader, namely majority voting and competitive bidding. By implementing the enriched model experimentally, we provide additional empirical findings to the already available experimental evidence (see, e.g., Kübler and Müller, 2002).

In our model, the price leader sets a price to which all other competitors, the followers, adjust their sales amount optimally according to their individual supply functions. To guarantee his price choice, the leader serves the residual demand.[1]

[1] Rather than justifying quantity setting by tatonnement adjustment or fictitious auctioneers

Obviously, followers are interested in a high price. The highest price occurs when the lowest cost competitor acts as price leader. Asking a competitor to act as price leader is justifiable since the price leader is not forced to choose a higher than competitive price.[2] Furthermore, followers could reward the price leader by smaller than optimal quantities in case of higher than competitive prices. In line with the price leadership literature the leader is assumed to credibly commit to his price.

More basically, leadership refers to a more or less hierarchical structure of interaction. In modern market economies, entrepreneurs or chief executive officers mostly play the role of a decisive leader. Other examples are technological leaders or simply sellers who, as in our model, precommit before others. Whereas our model assumes that leader and followers determine different action variables, namely the uniform price respectively their sales quantities, most other leadership models rely on the same type of choices by leaders and followers, e.g., on markets with quantity competition or in public good experiments with "leading by example" (see Capellen et al., 2013). In the latter type of experiments, unlike in our scenarios, the benchmark solution, which is based on common opportunism, fails to predict voluntary cooperation via leadership.

We compare two mechanisms[3] to award the leadership role in price setting, one mechanism where no other reciprocation is possible than via sales reduction and one allowing to monetarily reward the price leader: majority voting (the firm with the most votes becomes price leader) and competitive bidding (sellers determine monetary compensations for the price leader). Both mechanisms share the intuition that a lower cost competitor is the more likely price leader, whereas compensation payments in the bidding treatment are expected to crowd in efficiency concerns of price leaders.

The remainder of the paper is structured as follows: In Section 2, we introduce a triopoly model of price leadership. In Section 3, we endogenize price leadership by a voting and a bidding scenario. Section 4 describes the experimental protocol. The experimental findings are presented in Section 5. Section 6 concludes.

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or, more ingeniously, by first-capacity-then-price-setting models (see Kreps and Sheinkman, 1983), the model of price leadership justifies quantity competition by all but one seller (e.g., Güth et al., 1989).

[2]Choosing the competitive price allows the leader to sell his optimal quantity at this price.

[3]With unbiased random assignment as default.

2. The price leadership model

We focus on a homogeneous product market with three asymmetric seller firms $i = 1, 2, 3$. Market demand is assumed to be linear

$$D(p) = \max\{0, \alpha - \beta p\}\ ; \qquad \alpha,\ \beta > 0,$$

with $D(p)$ denoting total demand at sales price p. We rely on firm-specific quadratic cost functions

$$C_i(q_i) = (c_i + dq_i)q_i\ , \quad 0 \le c_i \le \alpha/\beta\ , \quad d > 0\ ,$$

with q_i denoting the quantity produced and sold by firm $i = 1, 2, 3$. Of course, asymmetry of cost could also rely on different coefficients of the quadratic term, but as in the experiment, this generalization is avoided here to limit complexity. Firms $i = 1, 2, 3$ earn profits

$$\pi_i = pq_i - C_i(q_i)\ .$$

For a given price, $p > c_i\,\forall\, i = 1, 2, 3$, each firm i would like to sell according to its individual supply function

$$q_i(p) = (p - c_i)/(2d).$$

Clearing the market by equating aggregate supply

$$S(p) = (3p - \sum_{i=1}^{3} c_i)/(2d)$$

and market demand $D(p)$ determines the competitive price

$$p^c = \frac{\alpha + (\sum_{i=1}^{3} c_i)/(2d)}{\beta + 3/(2d)}\ .$$

Depending on the coefficient d, the competitive price is restricted to the interval $p^c \in \left[\sum_{i=1}^{3} c_i/3,\ \alpha/\beta\right]$ such that all sales amounts are positive. From the perspective of methodological individualism, simply assuming that p^c will result is rather unsatisfactory. Price leadership does not only explain and justify market clearing prices but also allows all firms to earn more than when selling at the competitive price p^c.

Price leadership requires one seller, the price leader $\ell \in \{1, 2, 3\}$, to set the common sales price p^ℓ. This allows all other sellers $j \neq \ell$ to freely adjust their sales quantities q_j. This quantity-setting behavior of followers suggests

Hypothesis 1. *Followers choose optimal supply quantities given the leader's price choice.*

To guarantee his choice p^ℓ, the price leader has to clear the market by selling the residual quantity

$$q_\ell = D(p^\ell) - \sum_{j \neq \ell} q_j \ .$$

By anticipating the optimal supply quantities $q_j(p) = (p - c_j)/(2d)$ of all followers $j \neq \ell$, the residual demand for the price leader is

$$q_\ell(p^\ell) = \alpha - \beta p^\ell - \frac{(2p^\ell - \sum_{j \neq \ell} c_j)}{2d} \ .$$

The price p^ℓ maximizing

$$\pi^\ell = p^\ell q_\ell(p^\ell) - C_\ell(q_\ell(p^\ell))$$

by anticipating the quantity decisions of the followers can be derived as

$$p^\ell = \frac{(3 + 2\beta d)\alpha + (\beta + 3/(2d)) \sum_{j \neq \ell} c_j + (\beta + 1/d)c_\ell}{2(\beta + 1/d)(2 + \beta d)} \ .$$

It can be shown that $p^\ell > p^c$ for all $\ell \in \{1, 2, 3\}$, i.e., any price leader will set a price above the competitive one. Hence, all firms, i.e., the leader and the followers, gain from price leadership. Further, the lower the price leader's marginal costs, the higher is the resulting equilibrium price. The reason for this somewhat counter-intuitive effect is that higher marginal costs of rivals imply a higher residual demand for the price leader.

This leads us to

Hypothesis 2a. *Price leaders set prices optimally by anticipating the followers' quantity reaction.*

and

Hypothesis 2b. *Price leaders with lower marginal costs set higher prices.*

In our experiment, we use the parameter values $\alpha = 400, \beta = 1, c_1 = 0, c_2 = 100, c_3 = 200, d = 1$, implying the competitive price $p^c = 220$, the corresponding sales amounts $q_1^c = 110, q_2^c = 60, q_3^c = 10$, and profits $\pi_1^c = 12100, \pi_2^c = 3600, \pi_3^c = 100$. In case of price leadership, the outcome depends on which competitor takes on the role of the leader. Table 1 summarizes the results for all three possible price leaders, where π_i^ℓ denotes firm i 's profit given that firm ℓ is price leader.[4]

leader	p^ℓ	q_1^ℓ	q_2^ℓ	q_3^ℓ	π_1^ℓ	π_2^ℓ	π_3^ℓ
$\ell = 1$	229	92.0	64.5	14.50	12604.00	4160.25	210.25
$\ell = 2$	225	112.5	50.0	12.50	12656.25	3750.00	156.25
$\ell = 3$	221	110.5	60.5	8.00	12210.25	3660.25	104.00

Table 1: Numerical results for all possible price leaders $\ell = 1, 2, 3$

The comparison of a firm's profit as price leader with the alternative profits this firm realizes when another firm is in the leadership role illustrates the disincentive to become price leader. Table 2 depicts column-wise the cases $\ell \in \{1, 2, 3\}$ and row-wise the gains or losses if instead of the respective firm another firm is price leader.

leader ℓ / alternative leader	1	2	3
1		410.25	106.25
2	52.25		52.25
3	-393.75	-89.75	

Table 2: Gains or losses if another firm becomes price leader

Consider, for example, firm 1 as the price leader (first column). It would gain $\pi_1^{\ell=2} - \pi_1^{\ell=1} = 52.25$ if firm 2 was price leader instead, while it would be worse off if firm 3 became price leader, $\pi_1^{\ell=3} - \pi_1^{\ell=1} = -393.75$.

Regarding the endogenous determination of the price leader, these profit differences can be regarded as compensations rendering a firm indifferent between becoming leader or follower. Therefore Table 2 reflects the incentives as to which firm to establish as price leader: while firms 1 and 2 prefer own leadership over seller 3 being leader, firm 1's disincentive to become price leader rather than firm 2 is only marginal, compared to what firms 2 and 3 gain by firm 1's price leadership.

This gives us

Hypothesis 3. *The two firms with higher marginal costs establish their lowest cost*

[4]For the experimental implementation we rounded prices to the next integer and used these integer numbers to calculate all other values. The precise values are $p^{\ell=1} = 229.167$, $p^{\ell=2} = 225.000$ and $p^{\ell=3} = 220.833$.

competitor as price leader.

3. Endogenizing price leadership

How can firms establish such a price leadership from which all firms gain? If $c_\ell < c_{\ell'}$ for $\ell, \ell' \in \{1, 2, 3\}$ with $\ell \neq \ell'$, then it holds that $p^\ell > p^{\ell'}$. Thus the usual intuition that a lower (marginal) cost induces a lower price does not extend to our price-leadership model. Due to the theoretical result, we nevertheless expect the lowest cost seller to become price leader more often than his two competitors. It is, however, less obvious how competing sellers can coordinate and agree on establishing one of them as price leader. Since this is a burden, one wonders not only about the mechanism for determining a price leader but also how such a price leader may be compensated for accepting this burden. Regarding the mechanism, we are not aware of any empirical evidence on how leadership is (tacitly) implicated in asymmetric markets. The usual intuition is that the seller with a dominant market share serves as leader, mostly but not always coinciding with our theoretical result that the seller with the lowest cost should be selected for price leadership. In view of a lack of guidance in terms of empirical facts, we do not focus on just one mechanism but compare two such mechanisms differing in how the price leader can be rewarded for accepting the burden of price leadership: one where followers can compensate the price leader only by selling less than optimal quantities and one where followers can also directly compensate the price leader monetarily what might enhance efficiency concerns. In the following, we assume either of the two mechanisms as exogenously given and accepted by all sellers. The first mechanism we analyze is the

Voting Treatment V: All three firms $i \in \{1, 2, 3\}$ suggest a price leader $\ell \in \{1, 2, 3\}$, and the firm with a majority of votes becomes price leader. In case of no majority, the price leader is randomly selected with equal probabilities among all candidates with the highest number of votes.

Specifically, it is an equilibrium outcome that at least the two high cost sellers vote for the competitor with the lowest cost. If, for instance, the two high cost sellers vote for the low cost seller and the lowest cost seller votes for himself, no firm would gain by unilaterally deviating. As is typical for majority voting, other equilibria exist:[5] whenever all three sellers unanimously vote for the same candidate ℓ, no individual seller i can gain by deviating from unanimity. For strict majorities (only

[5] See Güth et al. (1985) for applying the Harsanyi and Selten (1988) theory of equilibrium selection to resolve strategic uncertainty in such voting games.

two voters agree) the deviating seller should not induce a majority voter to join him. There exists an abundance of (pure and mixed) strategy equilibria featuring different sellers as price leaders. However, among all these equilibria, establishing the low cost type as price leader is clearly focal and obviously justifiable by equilibrium selection.

We compare this voting treatment with the

Bidding Treatment B: All firms $i \in \{1,2,3\}$ place a bid $b_i \in \mathbb{R}^+$, stating how much they would suffer from being price leader, $i = \ell$. The seller placing the lowest bid becomes price leader with unbiased random selection among those with minimal bids. More formally, each seller $i = 1,2,3$ chooses a bid $b_i \in \mathbb{R}^+$, and the price leader ℓ satisfies $b_\ell \leq b_j$, $j \neq \ell$. The two other sellers $j \neq \ell$ compensate the price leader by paying him the nonnegative difference between their own bid and the bid of the price leader, $\Delta_\ell^j \equiv b_j - b_\ell$. Thus the price leader ℓ receives in total

$$\sum_{j \neq \ell} \Delta_\ell^j = \sum_{j \neq \ell} b_j - 2b_\ell$$

from his rivals. The profit functions including these transfer payments for the followers are

$$\tilde{\pi}_j^{\ell \neq j} = p^\ell q_j(p^\ell) - C_j(q_j) - \Delta_\ell^j \qquad \text{for } j \in \{1,2,3\}, \;\; j \neq \ell,$$

and the price leader's profit amounts to

$$\tilde{\pi}^\ell = p^\ell q_\ell(p^\ell) - C_\ell(q_\ell(p^\ell)) + \sum_{j \neq \ell} \Delta_\ell^j \quad .$$

For an illustration of the bidding mechanism consider the differences in profits between being leader or follower in Table 2. Given our numerical example and our experimental setting, where bids can be varied only in discrete steps $\epsilon = 1$, the only pure strategy equilibrium is that firm 1 bids zero and firms 2 and 3 bid marginally above zero, i.e. $b_1 = 0$, $b_2 = b_3 = \epsilon = 1$. Firm 1 will not increase its bid as this would involve the risk of firm 3 becoming price leader. Firms 2 and 3 have no incentive to deviate because they prefer firm 1 as price leader.

The profit differences in Table 2 reflect how much a firm is maximally willing to pay for not having to take on the burden of price leadership. We expect these differences to be relevant in the experiment, even if bidding strategies relying on profit differences do not constitute an equilibrium. We will elaborate on this point in more detail when discussing the experimental results below.

One may object that both mechanisms, *voting* and *bidding*, do not require the consent of the chosen price leader ℓ, i.e., they do not grant veto power. However, the price leader is not forced to set a price p^ℓ higher than the competitive price p^c. Specifically, by setting $p^\ell = p^c$ each seller could guarantee that he sells his most preferred amount at price p^c. In this sense, neither mechanism violates voluntariness since price leaders can always induce the competitive price.

From a behavioral perspective, participants in our experiment will usually be either incapable or unwilling to engage in backward induction analysis, especially when the different stages feature different tasks of independent choice making as in our setup (see, e.g., Binmore et al., 1985, and Johnson et al., 2002). One could have avoided backward induction by robot decision making in one or two of the three stages, for example, by implementing rational decision making in those stages. We are, however, interested in the behavior in all stages, namely in

- who is determined as price leader in the voting or bidding stage, respectively (**Hypothesis 3**),
- whether the optimal price is chosen in the price setting stage (**Hypothesis 2a**),
- whether price leaders with lower marginal costs set higher prices (**Hypothesis 2b**) and
- whether followers choose optimal sales amounts (**Hypothesis 1**).

Altogether, we expect to confirm, at best, qualitative effects of the benchmark solution such as establishing the lowest cost seller as price leader more often. As usual, the benchmark also provides a nice way to experimentally describe the observed behavior via the direction and extent of how it deviates from the benchmark.

4. Experimental design and setup

We implemented both mechanisms, *voting* and *bidding*, as between-subjects treatments and included a control treatment where price leadership was established randomly. The experimental instructions differ only in the paragraph on how to determine the price leader (see the instructions in Appendix A). To allow for learning, the game is played 10 times using a random strangers matching protocol. More specifically, in each session 27 participants took part, divided into three matching groups of 9 participants each. Since we assigned constant roles (participants were assigned constant marginal costs, called "z-values" 0, 100, and 200, respectively), a matching group consisted of three participants for each of the three z-values.

Participants were not informed about the restricted rematching within matching groups to weaken possible repeated game effects. Throughout the experiment, payoffs were calculated in Experimental Currency Units (ECU), which were converted into euros at a given exchange rate (500 ECU = 1 euro) at the end of the experiment. Participants were informed about the exchange rate in the experimental instructions.

Each of the 10 rounds consisted of three successive stages: In the first stage, price leadership was established (participants chose one participant to take on "role X"). In the *voting* treatment, participants simply indicated which z-value participant they wanted to take on role X, i.e. price leadership. In the *bidding* treatment, we imposed $b \in [0, B]$ with $B = 2,000$ to reduce the multiplicity of equilibrium bid vectors $b = (b_1, b_2, b_3)$. Immediately after bidding or voting, participants were informed which z-seller was established in role X. Additionally, in the *bidding* treatment, the compensations that the participant in role X received from the other two participants were displayed. In the second stage, the price leader set the price ("x-value") within range $p^{\ell} \in$ [210, 240]. The software allowed the price leader to calculate the payoffs for hypothetical quantity choices by the other participants. In the third stage, the followers ("role Y") chose their sales quantity ("y-value") within range $q \in$ [0, 115]. Followers could also compute their payoffs before submitting their definitive decision to help them cope with the nonlinear profit functions.

All sessions started with a set of control questions concerning *(i)* the different decision tasks in the three stages of the experiment and *(ii)* how to calculate payoffs. The experiment started when all participants had answered all control questions correctly. After completion of the 10 rounds, participants were asked to fill out a post experimental questionnaire designed to collect demographic information and assess their risk tolerance and decisiveness (see Holt and Laury, 2002).[6]

Besides a show-up fee of 2.50 euros, participants received the payoff earned in one randomly chosen round of the experiment as well as the reward for the lottery question in the post experimental questionnaire. The experiment was programmed in z-tree (see Fischbacher, 2007). We ran 9 sessions (3 for each treatment) with 27 participants each, i.e., 9 independent matching groups for each treatment. On average, one session lasted about 110 minutes, and the average payment of participants amounted to 15.28 euros.

[6]Since the model is deterministic, these questions serve to identify personality traits and should not be interpreted as assessing risk attitude in the sense of expected utility theory.

5. Experimental results

5.1. Determination of the price leader

Hypothesis 3 predicts that the two sellers with higher marginal costs try to establish their low cost competitor as price leader.

In the *voting* treatment, the low cost competitor ($c = 0$) is established as price leader in 38.2% of cases (see Table 3). In 32.2% of cases price leaders were of the high cost type ($c = 200$) and in 29.6% of cases price leaders were of the medium cost type ($c = 100$). Considering only the last three rounds, the low cost type is established as price leader substantially more often (49.4%), while the medium and the high cost type each receive just about half as many votes.

cost type	price leader
low	38.2% (49.4%)
medium	29.6% (27.2%)
high	32.2% (23.4%)

Table 3: Relative frequencies of cost types in the role of the price leader in the *voting* treatment, (in brackets: last three rounds)

Table 4 illustrates the voting behavior of the different cost types, i.e., who voted for whom. Interestingly, the main diagonal has the lowest frequency row- and column-wise, i.e., participants seem to understand that becoming price leader is a burden rather than a blessing.

type \ voted for	low cost type	medium cost type	high cost type
low cost type	24.4% (27.2%)	43.3% (45.7%)	32.2% (27.2%)
medium cost type	45.2% (48.1%)	14.8% (12.3%)	40.0% (39.5%)
high cost type	49.3% (61.7%)	35.6% (37.0%)	15.2% (1.2%)

Table 4: Relative frequencies of votes given the different cost types in the *voting* treatment (in brackets: last three rounds)

Instead, we find both high cost type competitors to vote mostly for the low cost type as price leader: 45.2% of participants with medium marginal costs and 49.3% of participants with high marginal costs voted for the low cost type as price leader, thereby supporting Hypothesis 3.

Result 1a. *In the* voting *treatment, sellers with higher marginal costs try to establish their low cost competitor as price leader.*

Surprisingly, in the *bidding* treatment the high cost type is established as price leader in the majority of cases (47.4%), while only 16.7% of the low cost type participants are elected as price leaders. If we account for learning effects, this result remains nearly unchanged (see the percentages in brackets in Table 5).

cost type	price leader
low	16.7% (16%)
medium	35.9% (37%)
high	47.4% (47%)

Table 5: Relative frequencies of cost types in the role of the price leader in the *bidding* treatment (in brackets: last three rounds)

Comparing the average bids placed by the respective cost types (see Table 6), we find the mean bid of 178.6 of the high cost participants to be far (slightly) below the mean bid of 539.5 (189.6) of the low (medium) cost type participants.

cost type	obs.	min. bid	max. bid	mean	std. dev.
low	270 (81)	0 (0)	2000 (1988)	539.5 (378.9)	574.8 (434.4)
medium	270 (81)	0 (0)	1999 (520)	189.6 (104.8)	323.6 (128.9)
high	270 (81)	0 (0)	2000 (2000)	178.6 (121.5)	382.8 (322.3)

Table 6: Descriptive statistics concerning bids (in brackets: last three rounds)

Thus participants' bidding behavior deviates from equilibrium. Possibly participants' strategies are associated with the maximal willingness to pay to avoid the burden of price leadership. According to Table 2, the maximal willingness to pay for the medium cost type is given by his payoff increase of 410.25 when the low cost type becomes price leader instead of himself. Hence, the willingness of the medium cost type to compensate the low cost type for taking over price leadership should not exceed 410.25. Given that participants associate their bidding strategies with the values given in Table 2, the relative ordering of bids should follow the pattern: bids(medium cost type) $>$ bids(high cost type) $>$ bids(low cost type).

While absolute bids are not in line with what Table 2 suggests, regarding the *relative* ordering of bids, we find partial support for the predicted pattern: a comparison of the bidding behavior of the different cost types reveals that the bids of the low cost types exceed those of the medium cost types (p-value < 0.01, Mann-Whitney ranksum test), the bids of the medium cost types exceed those of the high cost types (p-value < 0.05), and the bids of the low cost types exceed those of the

high cost types (p-value < 0.01). Thus we find the pattern:
bids(low cost type) $>$ bids(medium cost type) $>$ bids(high cost type).

Hence, the low cost types bid significantly more than the higher cost types. A consequence of the significantly higher bids of low cost types is that higher cost types are not able to establish the 0-cost seller as price leader.

Two patterns of participants' bidding behavior suggest that their strategies nevertheless approach the benchmark strategies, at least as they become more experienced. First, the absolute bids of all cost types significantly decrease over the ten rounds of the experiment (linear regression of round number on absolute bids, p-value< 0.05), and second, compensation payments significantly decrease over the rounds of the experiment (linear regression of round number on compensation payments, p-value< 0.01). Decreasing compensation payments reflect that the difference between leader and follower bids decreases, suggesting that participants learn to bid only slightly more than the price leader, as proposed by the benchmark solution. As we find that compensation payments are significantly lower for price leaders of the low cost type (Mann-Whitney ranksum tests, p-value < 0.01), this effect seems to be stronger for constellations where the low cost type is established as price leader.

These considerations are summarized in

Result 1b. *In the* bidding *treatment, firms with higher marginal costs are not able to establish their low cost competitor as price leader. With experience, bidding strategies approach the theoretical benchmark.*

While, from a behavioral perspective, the bidding treatment might have cognitively overburdened participants, experience seemingly helps them to better understand the strategic aspects of the game.

5.2. Price choices

Hypothesis 2a claims that price leaders set optimal prices. To admit noise in setting optimal prices, we rely on the notion of ϵ-equilibria (see Radner, 1980) and allow a 3% variation in payoff space around the optimum. For the three possible scenarios (low, medium, or high cost type is price leader), this variation has to be calculated separately. In case of the medium cost type being price leader, the optimal price choice ($p_\ell = 225$) would lead to a profit of 3,750 for the price leader, and a 3% tolerance of deviations from optimality would render the range of profits between 3,637.5 and 3,750 as nearly optimal. This range is reached for price choices between 220.7 and 229.3, which we therefore consider as (nearly) optimal price choices in the following analysis.

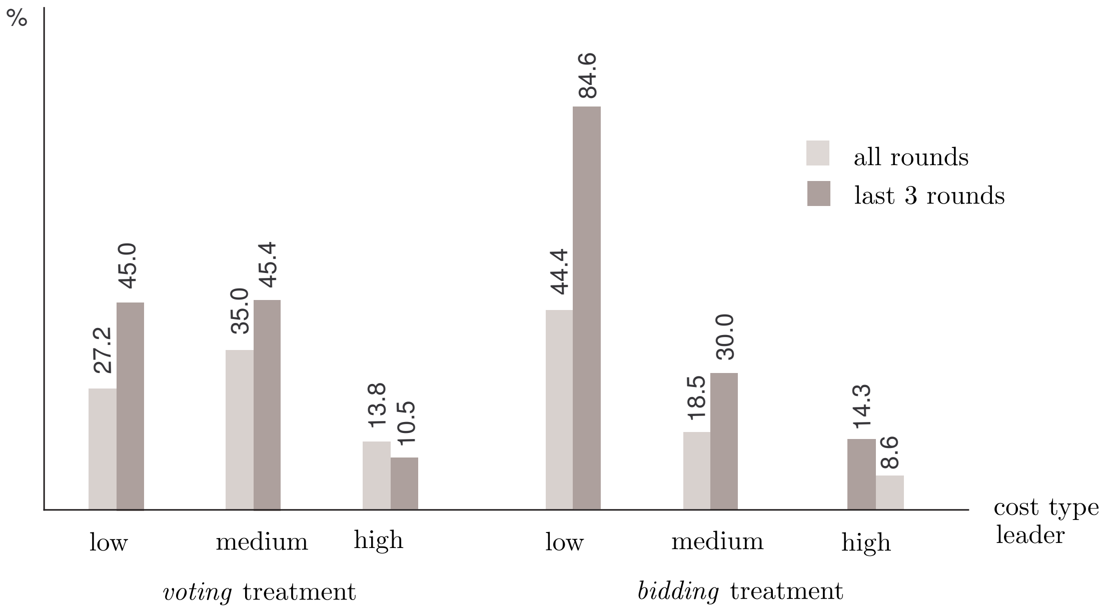

Figure 1: Percentage of price leaders with nearly optimal price choice (with 3% tolerance for deviations from optimality)

Figure 1 displays the percentage of leaders with a nearly optimal price choice given their cost type. The difference between the treatments is greatest for the low cost type: taking learning effects into account by considering only the last three rounds, 84.6% of all leaders of this cost type make nearly optimal price decisions in the *bidding* treatment as opposed to 45% in the *voting* treatment. Even without learning effects, the propensity to choose an optimal price for the low cost type is higher in the *bidding* than in the *voting* treatment. These findings partly support Hypothesis 2a.

Result 2a. *For low cost price leaders optimal price choices p^ℓ are more frequent in the* bidding *than in the* voting *treatment. For experienced participants the same is true also for high cost price leaders.*

The price setting of low cost price leaders could be driven by fairness concerns: as they receive compensation payments from the other participants they may have a strong incentive to behave efficiently. The low cost price leader may also be inspired by reciprocity, for example, when expecting the same behavior from other participants in future rounds. Overall, the theoretical benchmark for optimal prices cannot fully explain the experimental results. Nevertheless, the qualitative prediction of Hypothesis 2b is confirmed.

The mean price choices of leaders, given their respective cost type, support Hypothesis 2b stating that lower marginal costs lead to higher prices: pooling the data from all three treatments for low cost price leaders, the mean price is 227.4, while price choices of medium cost leaders are on average 225.9, and mean prices of high cost leaders amount to 222.9. Statistical tests of the differences between price choices of low and high cost leaders and medium and high cost leaders, respectively, reveal that these differences are strongly significant (p-value < 0.001, Mann-Whitney ranksum test). Only the price choices of leaders with low and medium costs are not significantly different (p-value > 0.05).[7] Comparing the price choices of experienced players (last three rounds) for the three different types of price leaders, we find all differences to be statistically significantly different from each other (p-value < 0.01). This leads to

Result 2b. *Experienced price leaders with lower marginal costs set higher prices.*

5.3. Quantity choices

According to Hypothesis 1, followers choose optimal supply quantities given the leader's price choice. As before, to admit noise in choosing optimal quantities we allow for a 3% variation in payoff space around the optimum. For the three possible scenarios (low, medium, or high cost type is price leader), this variation has to be calculated separately. In every scenario both followers set their quantities separately, and we assume that only one of the followers possibly deviates from the optimal quantity choice. As an example take the scenario where the low cost type is price leader. The medium cost follower's optimum quantity choice (64.5) yields a profit of $4,160.25$ for him. A 3% tolerance of deviations from optimality yields a quantity range between 53 and 75 as being nearly optimal.

[7]We consider all price choices to be independent in spite of possibly many price choices of the same participant and the dependence of price choices on decision making within the matching groups.

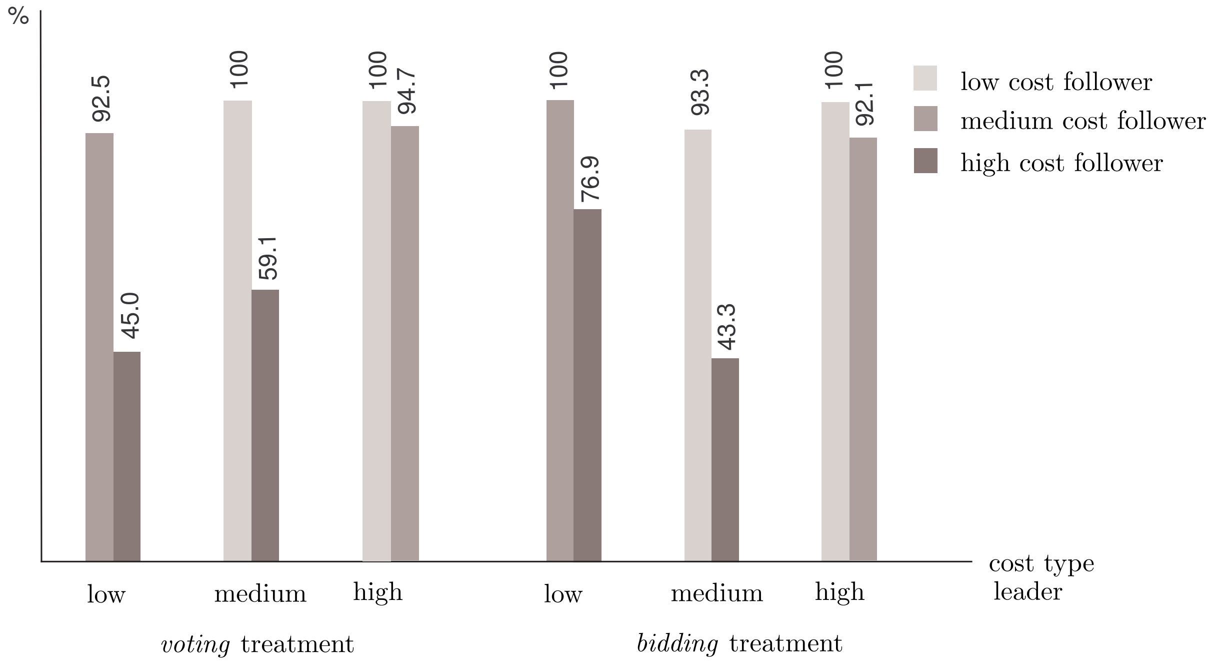

Figure 2: Percentage of followers with nearly optimal quantity choice in the last 3 rounds (with 3% tolerance for deviations from optimality)

Figure 2 displays the percentage of followers with nearly optimal quantity choices given their cost type and the cost type of the respective leader in the last three rounds. The far left columns, for example, depict the percentage of (nearly) optimal quantity choices of the medium and high cost followers in the scenario where the low cost type is price leader. In this case, 45% of the high cost followers set (nearly) optimal quantities, whereas 92.5% of the medium cost followers' choices are (nearly) optimal. Even without learning effects, we find that in both treatments over 90% of the low and medium cost followers choose (nearly) optimal quantities. This gives us

Result 3. *In the bidding and the voting treatment, more than 90% of low and medium cost type followers choose (nearly) optimal quantities.*

For the high cost followers the percentages of (nearly) optimal quantity choices are low: in the scenario with the low cost type as price leader 45% set their quantities optimally in the voting treatment as opposed to 76.9% in the bidding treatment. In the scenario with the medium cost type as price leader, 59.1% choose nearly optimally in the voting and 43.3% in the bidding treatment. The histograms in Figures 3 and 4 illustrate the variation in quantity choices.

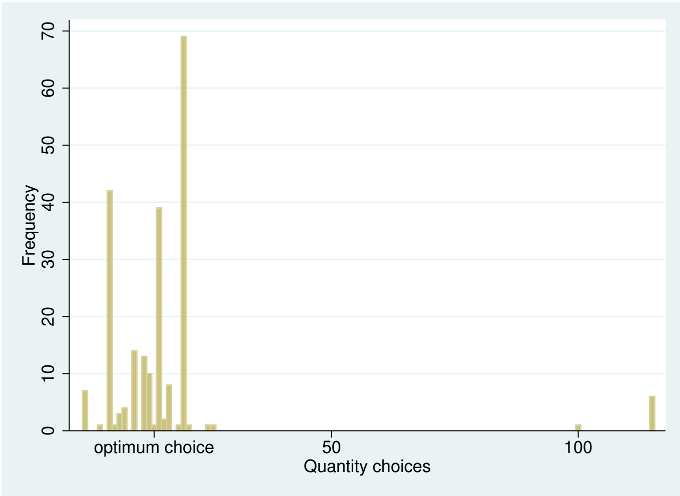

Figure 3: Quantity choices of high cost followers if the low cost type is price leader

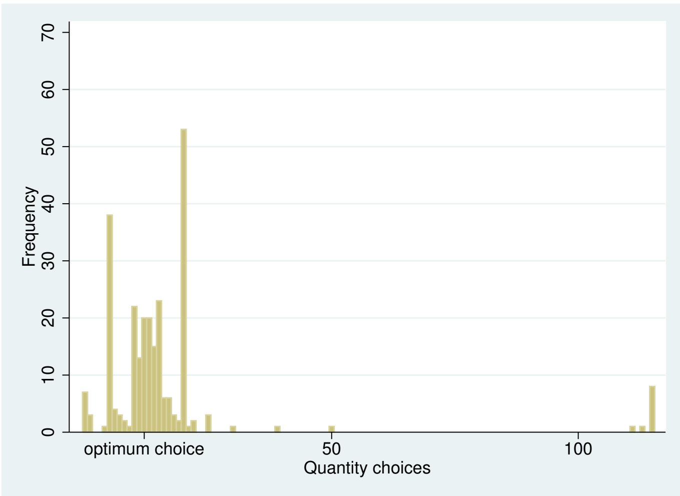

Figure 4: Quantity choices of high cost followers if the medium cost type is price leader

Possible explanations for the relatively strong deviation of the high cost followers from optimality may be that loss aversion may induce them to reduce quantities and thus their expenses. They may also want to compensate the price leader. While in the bidding treatment followers can additionally compensate the price leader, fairness attempts in the voting treatment require to sell below the optimum quantity. In both treatments, the cost type of the price leader is decisive for downward deviations from optimality. Given a low cost leader in the bidding treatment, 57.8%

(53.8%) of the high cost followers set quantities below the optimum, as compared to 29.1% (20%) in the voting treatment (numbers in parentheses are values in the last 3 rounds). The higher percentage of downward deviations in the bidding treatment could be due to an attempt to recover one's compensation payments. With a medium cost leader, the relation is reversed and lower than optimal quantities are more frequent in the voting treatment: 52.5% (63.6%) of high cost followers set lower than optimal quantities, as compared to 36.1% (33.3%) in the bidding treatment. This could be due to followers setting lower than optimal quantities in order to compensate the price leader.

The histograms also reveal that participants choices peak at the values 5 (voting: 18.7%, bidding: 14.6%), 15 (voting: 17.3%, bidding: 8.8%), and 20 (voting: 30.7%, bidding: 20.3%). This hints at the fact that participants were allowed to calculate payoffs before submitting a definite decision: participants successively tried out values in steps of 5 units and stopped when the supplied payoff seemed high enough.

6. Concluding remarks

Price leadership on oligopolistic product markets is an appealing approach to explain and justify market clearing prices in the tradition of methodological individualism according to which social phenomena are based on individual choice making. It also allows for moderate cooperation enabling firms to earn higher profits than when selling at the competitive price. By inducing a moderate price increase, price leadership may not arouse the suspicion of antitrust authorities. Even if detected, it would most certainly not be considered illegal. What should prevent one competitor from setting a price to which all other competitors adjust with the price leader serving the residual demand? To the best of our knowledge, such behavior is not illegal, and even if so, it could hardly be verified by antitrust authorities.

We have analyzed price leadership on a homogeneous market with three asymmetric competitors determining endogenously who takes on the role of the price leader. The distinction between the alternative mechanisms bidding and voting was implemented experimentally by carrying out two separate treatments. The main experimental result regarding the establishment of a price leader is that in the voting but not in the bidding treatment, firms with higher marginal costs try, and mostly succeed, to establish the lowest cost competitor as price leader. Regarding the price setting behavior, we found that optimal price choices of low and high cost sellers are more frequent in the bidding treatment. Thus, as expected, monetary compensation of the price leader crowds in efficiency concerns. Further we found that experienced price leaders with lower marginal costs choose higher prices in both treatments. Finally, considering the decisions of followers, our analysis revealed that optimal quantity choices in both treatments are close to the theoretically predicted outcome for low and medium cost followers.

Thus, although experimental outcomes partly differ from the theoretically predicted ones, the main qualitative predictions are confirmed. Most importantly, we find that lower marginal costs of price leaders indeed result in higher market prices when participants are more experienced and have learned to behave more adequately in the rather demanding experimental scenarios.

Which qualitative effects are confirmed or not depends partly on conditions such as (in)experience (see Results 2a and 2b) or the mechanism for establishing the price leader (compare Results 1a and 1b). These conditions also affect - game theoretically - unpredicted path dependence (see Result 2a).[8] Regarding the mechanism to establish the price leader, we provide, at best, some guidance as to which of the two mechanisms is better. In the field, what matters most is probably to prevent observability and verifiability by antitrust authorities. In our setup, this seems to suggest the *voting* rather than the *bidding* mechanism due to the monetary transfers of the latter.

In the real world, we cannot expect that firms will actually agree on a voting or bidding mechanism, meaning that both mechanisms are only proxies for some unknown procedures. It may be that price leadership is rather spontaneous or the result of a negotiation, whose likely outcomes are captured by the proposed voting or bidding mechanism.

[8] In industrial organization, one is more interested in the more adequate behavior of experienced participants, what implies an obligation to allow for learning.

Appendix A

INSTRUCTIONS

General Information

Thank you for participating in this experiment. You will receive 2.50 euros for showing up on time. Please remain silent and turn off your mobile phones. The instructions are identical for each participant. Please read them carefully. You are not allowed to talk to other participants during the experiment. In case you do not follow these rules, we will have to exclude you from the experiment as well as from any payment. The 2.50 euros show-up fee and any other amount of money you will earn during the experiment will be paid out to you in cash at the end of the experiment. All participants will be paid individually, i.e. no other participant will know the amount of your payment. All monetary amounts in the experiment are calculated in ECU (experimental currency units). At the end, all earned ECUs will be converted into euros using the following exchange rate: 500 ECU = 1 euro.

Experimental Procedure

The experiment consists of four control questions followed by ten experimental rounds and a final questionnaire. In each round you will interact with two other participants who will be randomly assigned each round anew. You will not be informed about the identity of these participants. It is unlikely that the same group constellation will occur twice. The interacting participants differ in a randomly assigned trait z. z can have one of three values: $z = 0$, $z = 100$ or $z = 200$. At the beginning of the experiment, you and the other participants in your group will be randomly assigned a trait z which you will keep throughout the whole experiment. In each round, three participants with the three possible traits will be randomly grouped together in such a way that each group consists of one participant with z -value 0, one participant with z-value 100 and one with z-value 200.

After each round, you will be shown the round's results. One of the rounds will be selected as relevant for the final payment which will be determined according to the rules displayed in the instructions. In case you receive a negative result in the selected round, the amount will be subtracted from your total payment. Regardless of the selected round, you will receive the amount of 2.50 euros for showing up on time. Thus your final payment cannot be negative. In addition, one of the questions from the questionnaire will be chosen as relevant to your final payment. Hence, your final payment is composed of the following parts:

Show-up fee (2.50 euros)

+ Earnings from a randomly selected round

+ Earnings from a randomly selected question from the questionnaire

Detailed Description of the Experiment

From now on, we will refer to the three different participants with their different values of z as z-value-0 participant, z-value-100 participant, and z-value-200 participant. The decisions taken by the participants will carry the z-value of their decision makers as an index. That way, every decision can be clearly associated to one z-value participant. As an example, x_0 is the value defined by the z-value 0 participant. The following three decision stages will be repeated ten times altogether, where the participants' assigned trait values $z = 0$, $z = 100$, and $z = 200$ stay the same throughout the whole experiment. Each round consists of three stages.

[next paragraph only in the voting treatment]

First Stage - Assignment of Role X

In the first stage, you will vote which one of the three z-value participants will take on role X. In the second stage, the participant in role X will decide on the value of x_z, which will have an impact on the payment of all participants in the group. During this round, the other two participants will take on role Y. In this voting procedure, all three z-value participants will cast their votes. In the event of a tie, it is randomly decided by the computer who will have role X. When voting about the assignment of role X, you can also vote for yourself. After all participants have voted, you will be informed about the voting results.

[next paragraph only in the bidding treatment]

First Stage - Assignment of Role X

In the first stage, it will be decided by placing of bids which one of the three z-value participants will take on role X. In the second stage, the participant in role X will decide on the value of x_z, which will have an impact on the payment of all participants in the group. During this round, the other two participants will take on role Y. All z-value participants will simultaneously place a bid g_z between 0 and 2000 (including the two numbers). The participant with the lowest bid will be assigned role X. The other two participants will take on role Y. We will refer to the minimal bid placed by the z-value participants with role X as $g_z^{\min}$. The z-value participant in role X will receive a payment P_z from both participants in role Y, amounting to the difference of their own bid and the bid placed by the z-value participant with role X, $P_z = g_z - g_z^{\min}$. g_z is the bid of the participant in role Y, $g_z^{\min}$ is the minimal bid of the participant in role X. In case of several identical minimal bids, the computer will randomly decide which one will take on role X. After all participants have placed their bid you will be informed about the assignment of role X.

[next paragraph only in the control treatment]

First Stage - Assignment of Role X

In the first stage, role X will be randomly assigned to one of the three z-value participants. In the second stage, the participant in role X will decide on the value of x_z, which will have an impact on the payment of all participants in the group. During this round, the other two participants will take on role Y.

[all treatments]

Second Stage - Defining the Value of x_z

The participant in role X will define the value of x_z, choosing any integer between 210 and 240 (including the two numbers). The two participants in role Y will be informed about the decision taken by the participant in role X.

Third Stage - Defining the Value of y_z

After being informed about the previously taken decision of value x_z, the two participants in role Y will independently define their value of y_z by choosing any integer between 0 and 115 (including the two numbers). This is the end of the interaction between participants in that round.

Information at the End of a Round

At the end of each round, you will receive the following information:

[only voting treatment]

The result of the vote on role X; i.e., which z-value participant will be assigned role X,

[only bidding treatment]

The result of the bid, i.e., which z-value participant will be assigned role X,

[only control treatment]

The result of the random assignment of role X to one of the z-value participants,

[all treatments]

The decision on the value of x_z by the participant in role X,
The decision on the value of y_z by both participants in role Y, and
The payment of all three z-value participants.

Payments

The payments depend on your role (X or Y), your z-value, the decision on the value of x_z by the z-value participant in role X, and the decisions on y_z by the two participants in role Y. In the following, we will refer to the z-values of the participants as za, zb, and zc. Each of the variables can take on the values 0, 100, or 200. In case the participant in role X has got the z-value za and the participants in role Y have got the z-values zb and zc, the payments can be calculated as follows:

The participant in role Y with the z-value zb and the choice y_{zb} earns:
$(x_{za} - zb - y_{zb}) \cdot y_{zb}$

The participant in role Y with the z-value zc the choice y_{zc} earns:
$(x_{za} - zc - y_{zc}) \cdot y_{zc}$

The participant in role X with the z-value za and the choice x_{za} earns:
$(x_{za} - za - R) \cdot R$
R is determined as follows: $R = 400 - x_{za} - y_{zb} - y_{zc}$

[next paragraph only in the bidding treatment]

In addition, the participant in role X receives a payment from each of the participants in role Y amounting to $P_z = g_z - g_z^{\min}$, $g_z^{\min}$ being the minimal bid by the participant in role X.

This means the amount $P_{zb} = g_{zb} - g_{za}^{\min}$ will be subtracted from the payment of the participant in role Y with the z-value zb. The participant in role Y with the z-value zc will have the amount $P_{zc} = g_{zc} - g_{za}^{\min}$ subtracted from his payment. The amount $P_{zb} + P_{zc}$ will be added to the payment of the participant in role X with the z-value za.

[all treatments]

Example:

The z-value 100 participant in role X selects $x_{100} = 223$. The z-value 200 participant in role Y selects $y_{200} = 15$. His payment is determined by $(223-200-15) \cdot 15 = 120$. The other participant in role Y has z-value 0 and selects $y_0 = 100$. His payment results from $(223 - 0 - 100) \cdot 100 = 12,300$. To determine the payment of z-value 100 participant, R has to be calculated first; $R = 400 - 223 - 15 - 100 = 62$. As a result, the z-value 100 participant's payment is $(223 - 100 - 62) \cdot 62 = 3,782$.

[only bidding treatment]

Assuming the z-value participants' bids in the first round are z-value 0: $g_0 = 1,800$

z-value 100: $g_{100} = 150$

z-value 200: $g_{200} = 200$

the z-value 100 participant would be assigned role X. In addition to the amount above, he receives payments from the participants in role Y amounting to $(1,800 - 150) + (200 - 150) = 1,700$. However, the two z-value participants in role Y each have to subtract a certain amount from their initial payment. The z-value 0 participant pays $1,800 - 150 = 1,650$ to the participant in role X. The z-value 200 participant pays $200 - 150 = 50$ to the participant in role X.

The resulting total payments are

z-value 0: $(223 - 0 - 100)100 - 1,650 = 10,650$

z-value 100: $(223 - 100 - 62) \cdot 62 + 1,700 = 5,482$

z-value 200: $(223 - 200 - 15) \cdot 15 - 50 = 70$

[all treatments]

Before the start of the experiment, we ask you to answer some control questions which are designed to improve your understanding of the rules of the experiment. If you have any questions, please raise your hand.

Appendix B

Residual demand is sometimes negative due to suboptimal behavior of the price leader (setting too high a price) or the followers (choosing too large sales quantities).[9] Actually, in 132 out of the 140 cases with negative residual demand, this outcome is caused by too high prices.

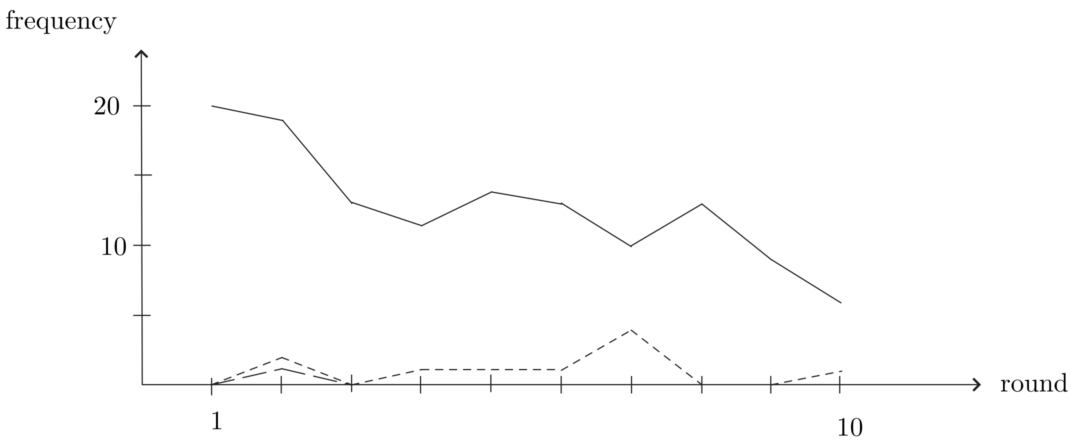

Figure 5: Frequency of negative residual demand

In Figure 5, we depict the frequencies of a negative residual demand for the respective cost types of price leaders across the 10 rounds of the experiment (the solid line representing the highest cost type, the dotted line the medium cost type, and the dashed line the lowest cost type). Thus this phenomenon mainly occurs when the highest cost type is chosen as price leader and could be explained by frustration of these high cost participants. Figure 5 additionally reveals that the frequency tends to decrease over time, meaning that learning takes place. When comparing treatments, the number of matching group outcomes with a negative residual demand is higher in the bidding treatment, confirming that this mechanism is less easily understood by our participants.

[9] In the instructions it was explained that this implies a loss for the price leader who has to buy the excess supply at his chosen price p^ℓ.

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