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Satisficing and prior-free optimality in price competition: a theoretical and experimental analysis

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Abstract

On a heterogeneous experimental oligopoly market, sellers choose a price, specify a set-valued prior-free conjecture about the others' behavior, and form their own profit-aspiration for each element of their conjecture. We formally define the concepts of satisficing and prior-free optimality and check if seller participants behave in accordance with them. We find that seller participants are satisficers, but fail to be "prior-free" optimal.

JEL classification: C92; C72; D43

Keywords: Satisficing behavior; Bounded rationality; Triopoly

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1. Introduction

The rational choice approach to market interaction investigates sales competition maintaining commonly known unbounded rationality of sellers. Undoubtedly, to explain how the reasoning of competing sellers can result in a mutually optimal constellation of sales strategies via solving a fixed-point problem is an interesting and inspiring intellectual exercise. However, this exercise needs to be supplemented with studies that do not provide only "as if"-explanations, but more realistically capture how sellers may mentally represent sales competition and generate sales choices based on such mental representation.

The basic idea of our bounded rationality approach is that sellers form profit-aspirations on the basis of what they expect from their competitors, and search for sales policies satisficing their aspirations. Although theoretical studies on aspiration based models of firm behavior were initiated some decades ago (Simon, 1947; Cyert and March, 1963; for more recent work see Dixon, 2000, and references therein), only recently experimental economists have started investigating satisficing behavior in oligopoly markets. For example, Berninghaus et al. (2006) test the absorption of satisficing in duopoly Cournot markets, and Huck et al. (2007) analyze how aspirations may lead to a failure of the merger paradox in the laboratory.

The key feature of this paper is to adopt a non-probabilistic approach to market interaction. Consider an oligopoly where each seller has to choose a *unique* price level. Each seller forms a *conjecture* about the average price charged by the remaining sellers. The conjecture of a particular seller is (potentially) a set containing all the others' average prices that the seller considers as possible. We do not require the seller to attach probabilities to the various elements in the conjecture. Therefore, we regard the conjecture as *prior-free*. Finally, we suppose that a seller forms a profit-aspiration corresponding to each element of the conjecture.

We say that a seller follows a *satisficing* mode of behavior if the unique

price he chooses is satisficing in the sense that, for each element in the seller's conjecture, the resulting profit is not lower than the corresponding aspiration. Our definition of satisficing views "optimality" as a boundary case. To explain what we mean by this, let us call the chosen price *rationalizable* if it is a best response to some price belonging to the convex combination of the minimum and maximum elements in the seller's conjecture. We shall refer to the behavior of a seller as being *prior-free optimal* if (i) his chosen price is rationalizable, and (ii) for each element of his conjecture, the corresponding profit-aspiration *equals* the profit that would be realized given his price.[1]

The experiment reported here is designed to investigate whether agents comply with our notion of prior-free optimality. More specifically, we study a multi-period triopoly market where, in every period, each seller participant must choose one price, specify a set-valued conjecture about the possible average price of his two current competitors, and form a profit-aspiration for each conjectured price. Our approach is based on systematic former studies of satisficing behavior in one-person decision problems (see Güth, 2007b, for a survey). Actually, here, we are able to capture strategic uncertainty in the same way as the uncertainty about the state of nature in (one-person) decision situations. The main difference is that, whereas the possible states of nature are exogenously given, the conjecture about the others' behavior is idiosyncratically generated by each of the competing sellers.

We are also interested in satisficing behavior *per se*, i.e., in exploring whether participants are satisficing, and how they react when being informed that their price is (not) satisficing. To this aim, in every period, we inform participants of whether or not their price is satisficing and allow them to revise any aspect of their choices (conjectures, profit-aspirations, and/or price) up to five times. By this means, we can address the following research questions. Does the likelihood of revising depend on the received satisficing feedback? If participants engage

[1] For a more general discussion of prior-free optimality see Güth (2007a).

in revisions, what do they most often revise: their conjectured prices, their profit-aspirations, or their own price?

The paper proceeds as follows. Section 2 formalizes the characteristics of the oligopoly market and of our satisficing approach. Section 3 illustrates the experimental procedures in detail. Section 4 contains the data analysis. Section 5 concludes by summarizing and commenting the results.

2. The market model and theoretical analysis

We study a multi-period heterogeneous oligopoly market with price competition. Quantity sold by individual firm i (x_i) depends negatively on the firm's own price (p_i) and positively on the average price of other firms ($\bar{p}_{-i}$) in the market. For simplicity, we assume a linear relationship and constant marginal (production) costs allowing us to equate revenues and profits by setting the price equal to the unit profit. These considerations give rise to a demand function for the ith firm of the following form:

$$x_i(\mathbf{p}) = \alpha - \beta p_i - \gamma(p_i - \bar{p}_{-i}) \tag{1}$$

where $\mathbf{p} = (p_1, \ldots, p_n)$ is the vector of all sales prices (or unit profits), n is the number of firms in the market, $\alpha, \beta, \gamma > 0$, and $\bar{p}_{-i} = \sum_{j \neq i} \frac{p_j}{n-1}$.[2] We impose non-negativity constraints on price and quantity, implying

$$0 \leq p_i \leq \frac{\alpha + \gamma \bar{p}_{-i}}{\beta + \gamma}.$$

A well-defined market game requires that the set of possible prices p_i does not depend on the others' price choices. In the case at hand, this can be

[2] Equation (1) captures the idea of monopolistic competition (Chamberlin, 1962) based on two demand curves: the so-called DD'-curve $x_i(p_i) = \alpha - \beta p_i$ when $p_i = \bar{p}_{-i}$, and the dd'-curve $x_i(\mathbf{p}) = \alpha - \beta p_i - \gamma(p_i - \bar{p}_{-i})$ allowing for $p_i \neq \bar{p}_{-i}$. Whenever firm i charges a price higher (lower) than its competitors, it loses (gains) demand, where the strength of these spillover effects depends on γ. For γ approaching 0, all sellers become monopolists; for γ tending to infinity, the dd'-curve becomes more horizontal and approaches the limit case of competitive markets.

obtained by imposing

$$0 \leq p_i \leq \frac{\alpha}{\beta + \gamma}.$$

Given the demand function specified in (1), the profits for the ith firm $(i = 1, \ldots, n)$ can be written as:

$$\pi_i(\mathbf{p}) = p_i\big(\alpha - \beta p_i - \gamma(p_i - \bar{p}_{-i})\big). \tag{2}$$

If the ith firm pursues a noncooperative profit maximizing strategy, given $\bar{p}_{-i}$, then i's reaction curve is

$$p_i(\bar{p}_{-i}) = \frac{\alpha + \gamma \bar{p}_{-i}}{2(\beta + \gamma)}.$$

The noncooperative symmetric equilibrium benchmark, assuming mutually best responses, is given by

$$p_i^* = \frac{\alpha}{2\beta + \gamma} \quad \text{for all } i, \tag{3}$$

yielding profits

$$\pi_i(\mathbf{p}^*) = \frac{\alpha^2(\beta + \gamma)}{(2\beta + \gamma)^2} \quad \text{for all } i.$$

The equilibrium benchmark assumes common knowledge of rationality. In our satisficing approach, we avoid such rationality requirement and suppose that each of the n sellers forms an idiosyncratic set-valued conjecture about his competitors' average price. For each player i, let C_i be the set of the others' average price that i considers as possible and let c_i denote an element of this set. We further suppose that i forms a profit-aspiration for each element c_i in C_i. If $A_i(c_i)$ is i's profit-aspiration when he expects c_i from his competitors, then a given sales price p_i is *satisficing* if

$$\pi_i(p_i, c_i) \geq A_i(c_i) \quad \text{for all} \quad c_i \in C_i, \tag{4}$$

where $\pi_i(p_i, c_i)$ are the profits i can attain given his price p_i and his conjecture c_i. Profit-aspirations abiding by requirement (4) will be called *achievable aspirations*.

We rely on non-probabilistic conjectures. If $c_i \in C_i$, this simply means that

seller i does not want to exclude the event $\bar{p}_{-i} = c_i$ without necessarily being able to specify how likely the event is. Notwithstanding being non-probabilistic, this approach does allow for optimality, which we qualify as "prior-free". In the following, we define the conditions needed for prior-free optimality, and discuss how to classify and measure deviations from it.

Consider seller i with a set-valued conjecture C_i and an aspiration profile $\mathbf{A}_i = \left\{A_i(c_i)\right\}_{c_i \in C_i}$. Define $\underline{c}_i = \min\{c_i : c_i \in C_i\}$ and $\bar{c}_i = \max\{c_i : c_i \in C_i\}$, where $\bar{c}_i \geq \underline{c}_i$ must hold. Take the convex hull of the elements in i's conjecture, i.e., $\text{conv}C_i = \{c_i(\lambda) = (1-\lambda)\underline{c}_i + \lambda\bar{c}_i : \lambda \in [0,1]\}$. For any $c_i(\lambda) \in \text{conv}C_i$, seller i's best response to $c_i(\lambda)$ is

$$p_i^*(\lambda) = \frac{\alpha + \gamma c_i(\lambda)}{2(\beta + \gamma)},$$

so that $p_i^*(0) = \frac{\alpha+\gamma\underline{c}_i}{2(\beta+\gamma)}$, $p_i^*(1) = \frac{\alpha+\gamma\bar{c}_i}{2(\beta+\gamma)}$, and $p_i^*(\lambda)$ increases continuously from $p_i^*(0)$ to $p_i^*(1)$ for λ increasing from 0 to 1. This delivers the first condition that seller i's choices must meet for being prior-free optimal. Let us term a price p_i *rationalizable* if it complies with $p_i \in [p_i^*(0), p_i^*(1)]$.

Condition 1 *Prior-free optimality requires seller i to specify a rationalizable price.*

Price choices that fall outside the interval $[p_i^*(0), p_i^*(1)]$ represent a failure of prior-free optimality since they cannot be rationalized by any probability distribution over C_i. We refer to this as *type 1-deviation from prior-free optimality* and measure it by the share of price choices p_i such that $p_i \notin [p_i^*(0), p_i^*(1)]$.

Requiring p_i to be rationalizable does not suffice for prior-free optimality. A second condition is that, for each c_i in C_i, the corresponding profit-aspiration $A_i(c_i)$ must be achievable and not too moderate, i.e., it must exhaust the full profit potential allowed by c_i.

Condition 2 *Prior-free optimality requires seller i to form an aspiration profile $\mathbf{A}_i = \left\{A_i(c_i)\right\}_{c_i \in C_i}$ such that $\pi_i(p_i, c_i) = A_i(c_i)$ for each c_i in C_i.*

Thus, even if $p_i \in [p_i^*(0), p_i^*(1)]$, seller i may fail to comply with prior-free optimality if he forms an aspiration profile $\mathbf{A}_i = \left\{A_i(c_i)\right\}_{c_i \in C_i}$ for which another achievable profile $\tilde{\mathbf{A}}_i = \left\{\tilde{A}_i(c_i)\right\}_{c_i \in C_i}$ exists such that $\tilde{A}_i(c_i) > A_i(c_i)$ for at least some $c_i \in C_i$, and $\tilde{A}_i(c_i) \geq A_i(c_i)$ otherwise. We refer to this as *type 2-deviation from prior-free optimality* and measure it by the share of aspiration profiles $\mathbf{A}_i$ such that $\sum_{c_i \in C_i}[\pi_i(p_i, c_i) - A_i(c_i)] > 0$.

3. Experimental protocol

The computerized experiment was conducted at the laboratory of the Max Planck Institute in Jena (Germany). The experiment was programmed using the z-Tree software (Fischbacher, 2007). Overall, we ran three sessions with a total of 81 participants, all being students from various fields at the University of Jena. Each session needed about 2 hours. The average earnings per subject were €18.50 (including a show-up fee of €2.50).

Each experimental session consisted of 9 periods. In each period, the 27 participants of a session were divided into 9 groups á three sellers (i.e., $n = 3$), so as to form 9 triopoly markets. New groups were randomly formed in each repetition (strangers design).[3] To collect more than one independent observation per session, subjects were rematched within matching groups of 9 players, guaranteeing 3 independent observations per session and 9 independent observations in total. In order to discourage repeated game effects, participants were not informed that random re-matching of the groups had been restricted in such a way.

In the instructions (see the Appendix for an English translation), subjects were told that they would act as a firm which, together with two other firms, serves one market, and that in each period all three firms were to choose, independently, a price from 0 to 12. Choices were limited to numbers up to

[3]This should isolate the effects of experience from the opportunities of tacit collusion that may occur in a repeated game. See, e.g., Abbink and Brands (2005) for an experimental study of collusive behavior in a homogeneous market with partners design.

two decimals. Participants were informed that their period-profits would be determined via function (2), where we set $\alpha = 40$, $\beta = 2$, and $\gamma = 1$. Given these parameters, from (3), the noncooperative equilibrium price is $p_i^* = 8$ and the corresponding quantity is $x_i(\mathbf{p}^*) = 24$, implying profits $\pi_i(\mathbf{p}^*) = 192$.

To check experimentally satisficing and prior-free optimality, in every period, besides choosing a sales price, each subject had to specify a set of the others' average price that he considered as possible and the profits he aimed to achieve for each conjectured price (or an aspiration profile). Participants were allowed to provide a maximum of six conjectures per period, so that their aspiration profile could contain at the most six elements. Therefore, in each period, participants had to fulfill three tasks: (*i*) choose their own price, (*ii*) predict at most six average prices that the others could charge, and (*iii*) form their profit-aspiration for each prediction.

After having completed these tasks, it was checked by the software whether satisficing requirement (4) held. Each participant was then informed of whether or not his price was satisficing. Regardless of whether the specified price was satisficing or not, a participant could either confirm it or revise some aspects of his decisions. Thus, although they could always rely on a software aided satisficing routine, participants were free to confirm any feasible sales price irrespective of its abidance by requirement (4). This allows us to investigate how people react to feedback of (non-)satisficing and, in case of revisions, what they are more willing to change: stated price, conjectured prices, or aspirations. Based on former studies (e.g., Berninghaus et al., 2006; Güth et al., 2007), we expect most subjects to modify their aspirations. To reduce the likelihood of noise in the decisions to revise, and in line with the work of Güth et al. (2007), a maximum of 5 revisions per period was warranted.

To incentivize all three tasks, in each period subjects could be paid according to realized profits, conjectures, or aspiration choices, with all three possibilities being equally likely. The three members of a group/market were paid according

to the same mode. When payments were based on conjectured prices, the payoff of a seller participant was given by

$$W_i = 180 - 10\times \mid \bar{p}_{-i} - \tilde{c}_i \mid,$$

where $\tilde{c}_i$ is i's closest conjecture to the actual $\bar{p}_{-i}$. Participants were informed about the above rule, and they were explained that the closer their best prediction to the actual average price of the others, the higher their earnings.

When payments were based on aspirations, a subject earned his highest achieved aspiration, i.e., the highest $A_i(c_i)$ complying with $\pi_i(p_i, \bar{p}_{-i}) \geq A_i(c_i)$. If all the aspirations stated by the subject exceeded his actual profits, his earnings were nil.

Seller-participants had the possibility to use a "profit calculator" to compute their period-profits. The calculator was part of the experimental software and could be started by pressing the corresponding button on the screen. When provided with data regarding the others' average price and the own price, the calculator returned the resulting period-profits. Hence, the calculator allowed participants to try out the consequences of various price strategies.

At the end of each period, participants got feedback about the average price of the others, their own period-profits, their closest prediction to the actual average price of the others, their highest achieved profit-aspiration, the mode of payment, and their resulting period experimental earnings.

4. Experimental results

We present our results in several subsections. In the first subsection, we present an overview of elicited set-valued conjectures, aspiration profiles, and prices. Then, we turn to investigate whether participants choose satisficing prices. Finally, we check if behavior is consistent with prior-free optimality.

4.1. Observed prices, conjectured prices, and aspiration profiles

As a first step, we analyze how ambiguous the elicited conjectures about the others' average price are. Let $|C_i|$ denote the cardinality of the elicited set C_i, i.e., the number of seller i's conjectured prices. In period 1, the mean and median $|C_i|$ are close to 4. From period 2 on, most subjects provide the maximum allowed number of conjectures (i.e., 6). In the last period, mean and median values are 5.30 and 6.00, respectively.

Given the increase in $|C_i|$, the distribution of conjectures and corresponding aspirations may become more disperse. Focusing on this issue appears important because subjects might have used the feature of our design that specifying more than one conjecture was costless to improve their chance of earning more when payments were based on conjectures or aspirations. Therefore, it seems worth measuring the dispersion of conjectures and aspirations. To this aim, we compute the coefficient of variation (ratio of the standard deviation to the mean) for each subject and each period. On average, the coefficient of variation of conjectures is 0.192 in the first period and 0.127 in the last period. The corresponding values for aspirations are 0.067 and 0.050. Wilcoxon signed rank tests (henceforth WSRT) comparing the coefficient of variation of conjectures as well as of aspirations in the first and the last period reveal a statistically significant difference ($p < 0.01$ in both cases).[4] Thus, the increase in the number of conjectured prices is associated with a decrease in the dispersion of conjectures and aspirations. This finding suggests that our seller participants tended to become more confident about their competitors' behavior.

The boxplots in Figure 1 provide descriptive statistics on the distributions of stated prices and average conjectured prices (i.e., $\frac{\sum_{c_i \in C_i} c_i}{|C_i|}$) over all periods. In both graphs, the $\times$ dots denote the means, and the horizontal lines indicate the theoretical equilibrium benchmarks.

[4] All reported non-parametric tests are two-sided and (unless otherwise stated) rely on the averages over players for each matching group. Due to our re-matching system, the numbers of statistically independent groups are 9 in each period.

Insert Figure 1 about here

Inspecting Figure 1a, we see that the median and the mean stated prices are both close to 7 in the first period and increase over time, with final values being, on average, significantly greater than initial ones (WSRT, $p = 0.012$). Although price choices converge to a value close to the noncooperative equilibrium benchmark (the mean price in the last period is 7.6), they are always significantly lower ($p = 0.074$ in period 8; $p = 0.055$ in periods 2 and 5; $p < 0.039$ in the remaining periods). Play was, therefore, mostly out of equilibrium with seller participants being more competitive than predicted by equilibrium theory.

Turning to average conjectured prices (cf., Figure 1b), the median and the mean values are, respectively, 6.50 and 6.69 in the first period, and 7.25 and 7.22 in the last period. The increase is statistically significant (WSRT, $p = 0.02$). A series of WSRT comparing observed average conjectured prices with the equilibrium benchmark reveal a statistically significant difference in all periods ($p < 0.01$ always). This indicates that most seller participants do not think, on average, that their competitors will behave in accordance with the equilibrium.

Although the average conjectured prices are, typically, lower than 8, are conjectures accurate? To address this question, we proceed in steps. First, we consider the convex hull of the conjectured prices, i.e., $\text{conv}C_i = \{c_i(\lambda) = (1-\lambda)\underline{c}_i + \lambda\bar{c}_i : \lambda \in [0,1]\}$, and check whether the actual average price of i's competitors ($\bar{p}_{-i}$) lies in it. By this means, we deliberately focus on subjects whose conjectures, being distributed around $\bar{p}_{-i}$, are somehow "rationalizable". Then, for those subjects complying with $\bar{p}_{-i} \in \text{conv}C_i$ we check how their best conjecture $\tilde{c}_i$ compares with the others' actual average price.

Insert Table 1 about here

Table 1 reports the percentage of subjects whose conjectured prices are such that $\bar{p}_{-i}$ lies in their convex hull. The figure starts at 62.96% and is greater than 70% from the second period on. However, the difference between the first

and the last period is only weakly statistically significant (WSRT, $p = 0.09$). With two exceptions (periods 8 and 9), we have that the best conjecture is never significantly different from the others' actual average price (WRST, $p = 0.055$ in period 8; $p = 0.027$ in period 9; $p > 0.10$ in all other periods), thereby suggesting that, overall, subjects' conjectures are rather accurate.

The boxplots in Figure 2 refer to realized profits and average aspirations ($\frac{\sum_{A_i \in \mathbf{A}_i} A_i}{|C_i|}$).[5] From Figure 2a, we see that realized profits tend to increase over time. In fact, as compared to the average initial value (176.712), average realized profits in the last period (185.951) are significantly higher ($p = 0.008$). However, due to seller participants' competitive behavior, profits stay always significantly below the theoretical benchmark (WSRT, $p < 0.05$ in each period). As to average aspirations (see Figure 2b), mean and median values increase over the first 4 periods, and are rather stable (around 180) afterwards. Overall, average aspirations are significantly lower than actual profits (WSRT, $p < 0.01$ in each period). This already suggests that aspirations are, on average, more moderate than they could actually be given the others' observed price choices.

Insert Figure 2 about here

4.2. Compliance with satisficing

The central question in this subsection is: do participants choose a satisficing price, i.e., a price complying with requirement (4)? Table 2 presents some descriptive statistics about the participants' satisficing behavior in each of the 9 experimental periods.[6]

Insert Table 2 about here

The share of participants who immediately choose a satisficing price (i.e., who achieve all their aspirations at first attempt) ranges from 83.951% in period 1

[5] The meaning of the $\times$ dots and the horizontal lines is as in Figure 1.

[6] To avoid misclassifications originating in participants' rounding, the computations assessing satisficing behavior (as well as prior-free optimality) were performed by rounding numbers to the first integer.

to 97.531% in period 9 (see row i. in Table 2). The share of those finally satisficing is above 96% in each period and is rather stable over time (see row ii. in Table 2): no significant difference is detected in the frequency of fully satisficing choices between period 1 and period 9 (WSRT, $p = 0.773$). Over all periods, the percentage of subjects undertaking at least one revision is quite low (see row iii. in Table 2). The figure starts at 28.395%, and sharply declines over time.

As to the motivations underlying revisions, rows iv. and v. in Table 2 suggest that the likelihood of revising depends on whether one chooses a satisficing price at first attempt or not. Although the figures in both rows tend to decrease over time, the propensity to revise is different depending on whether aspirations are achievable immediately or not. Taking averages over subjects and periods, the share of non-immediately satisficing subjects who revise is far above that of immediately satisficing subjects who revise (85.455% vs. 8.012%). The difference is highly significant (WSRT, $p = 0.004$).[7] Finally, row vi. shows that, on average, those who revise engage in one revision (out of 5) in each period.

Overall, 76.54% of the satisficing participants specify at least one aspiration that is lower than the profits attainable given the chosen price and the corresponding conjectured price. For each satisficing participant and each period, define the average unexhausted profit potential relative to the attainable profits as $\bar{\pi}_i^U(p_i, c_i) := \frac{\sum_{c_i \in C_i}[\pi_i(p_i,c_i) - A_i(c_i)]/\pi_i(p_i,c_i)}{|C_i|}$. Averaging over subjects and periods, $\bar{\pi}_i^U(p_i, c_i)$ is equal to 4.18%. The amount is significantly different from zero in each of the 9 periods (WSRT, $p < 0.001$ always), but it tends to decrease over time with values in the first period being, on average, significantly different from values in the last period (6.59% vs. 3.24%; WSRT, $p = 0.008$). The relative shares of unexhausted profits are rather different across participants (with an overall standard deviation of 9.11). In particular, $\bar{\pi}_i^U(p_i, c_i)$ is

[7] For each of the 9 independent matching groups, we compute the (over all periods) percentages of those who revise (a) when they immediately satisfice and (b) when they do not satisfice at first attempt. This provides us with 9 independent observations for each of the two samples. We use these two data series for performing the non-parametric test.

less than 1 percent for 32.770% of the subjects who choose a satisficing price, it ranges from 1 to 10 percent for 60.606% of them, and it exceeds 10 percent for the remaining 6.624%.

What do participants revise more often: their price, their conjectures, or their aspirations? Figure 3 displays the frequency of revisions in the three possible dimensions both within a single period and between two consecutive periods.[8] In line with the figures in row iii. of Table 2, within each period (see Figure 3a), revisions are generally very low and tend to decrease over time. Most of the within-period revisions concern aspirations. This finding is consistent with results in Berninghaus et al. (2006) and Güth et al. (2007) who report that subjects tend to revise mainly their aspirations in a repeated Cournot duopoly with point belief-elicitation and in an intertemporal allocation problem, respectively.

Insert Figure 3 about here

Since seller participants who do not immediately choose a satisficing price are more likely to revise, we focus on these participants to explain the composition of within-period revisions. We observe that 74.545% of the non-immediately satisficing subjects revise their aspiration profile, 23.636% their conjectured prices, and 12.727% their stated price.[9] The finding that conjectures are barely modified is, in retrospect, quite reasonable: if a subject considers some strategies of the rivals as plausible, his conjectures should not vary unless new information comes in (which is not the case within a period). The further finding that aspirations are revised more often than stated prices may be due to the fact that, in our framework, experimenting a new price requires a careful reconsideration (and maybe modification) of the *entire* aspiration profile. Thus, if only some of the specified aspirations are not achievable, varying

[8] A revision is a variation in a specific choice dimension. Being conjectures and aspirations (potentially) non-singleton, we take variations in their average values.

[9] These frequencies do not sum up to 100% because a few subjects revised more than one dimension simultaneously.

the price is certainly more demanding than lowering only the non-achievable aspirations. Our data show some support for this explanation: for the non-immediately satisficing subjects who engage in revisions, the overall ratio of non-achievable aspirations to provided aspirations is low and equal to 38.2%. Moreover, most of the revised aspirations (59.048%) were initially not achievable.[10]

In contrast to what is observed within each period, the percentage of revisions between two consecutive periods (see Figure 3b) is quite high throughout the experiment. For example, the share of participants changing their aspirations between the first and the second period is 96.30% and between the last two periods is 65.43%. The observation that aspirations are adjusted more frequently than conjectured and stated prices applies also to across period-revisions. Specifically, on average, from one period to the next, 78.549% of the seller participants modify their aspirations, 65.432% their conjectures, and 49.846% their stated price. The highest average rate of revisions, in all the three possible dimensions, is observed from period 1 to period 2.[11] In more details, between these two periods average conjectures are increased by 4.68%, average aspirations by 3.77%, and prices by 7.72%. In the other periods, revisions tend to be smaller but, with few exceptions, always positive in sign. This is in line with our earlier findings that stated prices, average conjectured prices, and average aspirations tend to increase over time. Since average aspirations are in each period below realized profits, it is not surprising that seller participants try more ambitious profit-aspirations in the following period.

[10] Of course, this is a hindsight-driven, ad hoc explanation. *A priori*, one could have expected seller participants to try out a new price strategy whenever some of their aspirations were not achievable.

[11] Due to some outliers, 5% of the observations were trimmed from each end of the three distributions. Results do not substantially change if we consider the entire distributions.

4.3. Compliance with prior-free optimality

Finally, we investigate whether subjects follow prior-free optimality. Table 3 presents (i) the percentage of subjects who set a price that cannot be rationalized by any probability distribution over C_i (type 1-deviation from prior-free optimality), (ii) the percentage of subjects who choose a rationalizable price, but specify too moderate aspiration profiles (type 2-deviation from prior-free optimality), (iii) the percentage of subjects who meet both conditions for prior-free optimality, and (iv) for the satisficing subjects exhibiting a type 2- (but not a type 1-) deviation, the average relative unexhausted profit potential $\bar{\pi}_i^U(p_i, c_i)$.

Insert Table 3 about here

Most seller participants fall within the type 1-deviation category in each of the 9 periods, even though the percentage of non rationalizable prices significantly decreases over time (WSRT comparing the 9 average independent shares of type 1-deviation in the first and the last period, $p = 0.022$). The percentage of type 2-deviations done by those who state a rationalizable price ranges from 22.22% in period 1 to 33.33% in period 9. According to a WSRT, the difference between the two periods is statistically significant at the conventional 5% level. At the outset of the experiment, only 3.704% of the participants meet the two conditions for prior-free optimality. Although this percentage increases over time, a WSRT does not allow rejecting the null hypothesis that the percentages (at the independent group level) in the first and the last period are the same ($p = 0.181$). Finally, the average relative unexhausted profit potential of those who choose a rationalizable price is significantly different from zero in all periods, and it is rather stable over time.[12] For 75.134% of the seller participants choosing a rationalizable price, $\bar{\pi}_i^U(p_i, c_i)$ ranges from 1 to 10 percent; for 16.822% of them, $\bar{\pi}_i^U(p_i, c_i)$ is less than 1 percent; and for the remaining 8.044%, $\bar{\pi}_i^U(p_i, c_i)$ exceeds 10 percent.

[12] A WRST comparing $\bar{\pi}_i^U(p_i, c_i)$ in the first and the last period delivers $p = 0.469$.

These findings indicate that participants do not appear to comply with prior-free optimality. Most of them fail to report a rationalizable price, and the decline in type 1-deviations does not lead to an increase in prior-free optimal choices because type 2-deviations become more frequent over time.

5. Conclusions

In this paper, we have applied the notion of satisficing to a repeated experimental triopoly market with price competition, where what one finds satisfactory depends on his conjectures about the others' average behavior. In every period, each seller participant had to choose a unique price, specify a possibly set-valued conjecture about the possible average price of his two current competitors, and form a profit-aspiration for each of his conjectured prices. In this context, a seller participant is said to follow a satisficing mode of behavior if, for each conjectured price, the corresponding aspiration does not exceed the profit realizable from this conjectured price and the stated price.

We allow conjectures to be prior-free, i.e., we do not require seller participants to specify a probability distribution over the set of conjectured prices. Thus, we can test optimality in a more basic sense than that required by expected utility maximization. More specifically, observed choices are compatible with our notion of prior-free optimality if they satisfy two testable conditions. Of these conditions, one is that the chosen price must be rationalizable, and the other is that, in case of satisficing, each specified aspiration must fully exhaust the profit potential allowed by the corresponding conjectured price and the chosen price.

In line with previous experiments on oligopoly markets (see, e.g., Dufwenberg and Gneezy, 2000; Dufwenberg et al., 2007), we find that play is mostly out of equilibrium. Our seller participants behave, on average, more competitively than predicted by equilibrium play, and anticipate that their competitors will do the same. We also observe rather few prior-free optimal choices: over-

all, 35.53% of our seller participants report a rationalizable price, and only 9.19% meet both conditions for prior-free optimality. These findings suggest that decision makers have difficulties in pursuing optimal reasoning, even when optimality does not require the specification of a prior.

A further major result of our study is that the percentage of seller participants choosing a satisficing price at the end of each period is always above 96%. However, 76.54% of these satisficing participants specify, on average, a too moderate aspiration profile: overall, they forego 4.18% of the profits they could aspire to given their chosen price and their conjectures about the others' average price. The latter finding is striking because subjects had access to a profit calculator allowing them to compute the profits corresponding to the own and the others' average price. Hence, cognitive limitations should not be held responsible for the observed moderate aspirations. One may argue that this is due to "safe" play by our participants, who wanted to guarantee themselves a positive outcome in case of payment based on aspirations. Yet, since we elicited a set-valued conjecture, we are rather confident that this argument lacks relevance in our setting. In order to improve their chance of earning money, our seller participants could report several conjectures and aspirations without having to forego profits resulting from their conjectured prices. The claim that our participants did not play "safe" is supported by the observation that the increase in the number of conjectured prices is associated with a decrease in the dispersion of conjectures and aspirations.

Finally, the experiment shows that revisions within a period are rather rare (overall, 13.85%) and are more likely to be undertaken by those who do not satisfice at first attempt. Furthermore, most of the revisions concern profit-aspirations. The latter finding is consistent with the results in Berninghaus et al. (2006) and Güth et al. (2007). In our setting, it may be due to the fact that adjusting only the non-achievable aspirations requires less cognitive effort than revising the own unique price.

To conclude, our experiment is not designed to understand why subjects, though satisficing, aspire to less than they could, given their chosen price and their conjectured prices. Our primary goal here was to document relevant experimental evidence on satisficing in market interaction. Identifying why people ask for too little could be interesting to look at in future research.

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Appendix. Experimental instructions (originally in German)

Welcome and thanks for participating in this experiment. You will receive €2.50 for having shown up on time. Please read the instructions − which are identical for all participants − carefully. From now on any communication with other participants is forbidden. If you do not follow this rule you will be excluded from the experiment and you will not receive any payment. Whenever you have a question, please raise your hand. An experimenter will then come to you and answer your question privately.

The experiment allows you to earn money. Money in the experiment will be denoted in ECU (Experimental Currency Unit). Each ECU is worth €0.01; this means that 100 ECU = €1. How many ECU you will earn depends on your decisions and on the decisions of other participants matched with you. All your decisions will be treated in an anonymous manner and they will be gathered across a computer network. At the end of the experiment, the ECU you have earned will be converted to euros and paid out to you in cash together with the show-up fee of €2.50.

Detailed information

In this experiment you will have to make decisions repeatedly. In every period you will be matched in groups of three persons. The composition of your group will randomly change after each period so that the other two members of your group will be different from one period to the next. The identity of the other participants you will interact with will not be revealed to you at any time.

In the experiment you have the role of a firm that, like two other firms (the participants you are matched with), produces and sells a certain good on a market. In each period you, as well as the other firms in your group, have to fulfill three tasks.

Task 1

Your first task is to decide *at which price you wish to sell the good*. Your price decision can be *any number between 0 and 12*. You can use up to two decimals. Thus, your choice of price can be: $0, 0.01, 0.02, \ldots, 11.98, 11.99$, or 12.

In each period, your profit is given by the price you choose multiplied by the units of the good you sell at that price:

$$\textit{Your period-profit} = (\textit{your price}) \times (\textit{number of units you sell}).$$

The "*number of units you sell*" depends on

a. your price,

b. the average price of the other two firms (where the average is obtained by adding up the prices of the two other firms and dividing the resulting sum by two).

In particular, the number of units you sell is given by:

$$\textit{Number of units you sell} \quad = \quad \Big[\textit{40} - \textit{2} \times \textit{(your price)}\Big] - \Big[\textit{your price} - \textit{average price of the others}\Big].$$

In words, two times your price is subtracted from 40; then the difference between your price and the average price of the others is

- *subtracted* from the resulting amount if the difference is positive (i.e., if your price is higher than the average price of the others),
- *added* to the resulting amount if the difference is negative (i.e., if your price is lower than the average price of the others).

Thus, the higher is your price compared to the average price of the others, the fewer units you sell. On the other hand, you sell more if the average price of the others is higher than your price.

EXAMPLE

Suppose that the prices of the other firms are 6 and 8 so that their *average price* is: $(6+8)/2 = 14/2 = \mathbf{7}$

If *your price* is **5** (< 7), then the *number of units you sell* is: $[40-2\times 5]-[5-7] = 30 + 2 = 32$. Consequently, your *period-profit* is $5 \times 32 = 160$.

If *your price* is **8** (> 7), then the *number of units you sell* is: $[40-2\times 8]-[8-7] = 24-1 = 23$. Consequently, your *period-profit* is $8 \times 23 = 184$.

If *your price* is **10** (> 7), then the *number of units you sell* is: $[40-2\times 10]-[10-7] = 20-3 = 17$. Consequently, your *period-profit* is $10 \times 17 = 170$.

Task 2

Your second task in every period is *to guess the average price of the other two firms in your current group*. In every period:

- you **must** make at least *one* guess about their average price, and
- you **can** − if you wish to − make additional guesses. The maximum number of guesses you can make is *six*.

The number of guesses you make can vary from one period to the next.

You should make as many guesses (up to a maximum of 6) as the number of possible average prices of the others you do not want to exclude. Suppose, for instance, that you do not want to exclude that: *a*) the average price of the others is 5, and *b*) the average price of the others is 6.5. Then, you should make two guesses about the others' average price: *a*) a first guess in which you expect the other two firms to choose, on average, 5; *b*) a second guess in which you expect the other two firms to choose, on average, 6.5.

Your guesses about the average price of the others must be a number from 0 to 12. You can use up to two decimals.

Task 3

Your last task in every period is *to specify the period-profit you wish to guarantee your self for each average price you guessed the others could choose.*

Suppose, for instance, that you made two guesses about the others' average price. For each of these two guesses, you need to specify the period-profit you aspire to. Similarly, if you made four guesses about the others' average price, you must specify the period-profit you aspire to for each of your four guesses.

In the following, we will refer to the period-profit you aspire to as your *profit aspiration.*

The decision aid

To help you make "satisfactory" decisions, i.e., decisions achieving your aspired period-profit for each guess you made, we provide you with a decision aid. In each period, after you have

1) chosen your price,

2) guessed the possible average prices of the others, and

3) specified your profit aspiration for each of your guesses,

the decision aid will inform you whether your stated profit aspiration(s) can be achieved or not. That is, you will learn whether, given your own price decision and your guesses about the others' average price, you can achieve the period-profit you aspire to for each of your guesses.

The decision aid will then ask you whether you want to revise your specifications in 1), 2) and/or 3).

- If you *want to revise* something, you have to click the "revise"-button. You will then move to a screen where you can modify your own price and/or your guesses about the others' average price and/or your profit aspirations.
- If you *do not want to revise* anything, you have to click the "not-revise"-button. After all participants have finished with their revisions, you will move on to the next period.

Notice that you can revise something even if your decisions were "satisfactory", i.e., they allowed you to achieve your profit aspirations.

In every period, you can make at most *five revisions*.

Period-profit calculator

Additionally, you have access to a period-profit calculator that calculates your period-profit for arbitrary price combinations. You can start the calculator by pressing the corresponding button on your screen. If you do so, a window will appear on your screen. Into this window you must enter two values: a price for yourself and an average price for the others. Given these figures, if you press the apposite button, you will know how much you would earn.

Your experimental earnings in each period

In each period, you can be paid according to your period-profit, your guesses about the others' average price, or your profit aspirations, where all the three modes of payment are equally likely. Thus, all three tasks you have to fulfill in each period can become relevant to your payment. The randomly selected mode of payment applies to all three interacting participants, which means that you *and* the other two firms in your current group will be paid according to the same procedure.

If, by random choice, your payment is based on your guesses, you will earn 180 *minus* 10 times the smallest difference between the average price you guessed the others could choose and the true average price of the others. In particular, the computer will

• consider your closest guess to the true average price of the others;

• take the numerical distance between your closest guess and the others' true average price;

• multiply this distance by 10;

• subtract the resulting amount from 180.

Hence, if your payment is based on your guesses, the closer your guesses are to the true average price of the others, the higher will be your period-payment.

EXAMPLE

Suppose that you made three guesses about the others' average price, which were 5, 6 and 6.5. If the true average price of the others is 7, your closest guess to 7 is 6.5. The numerical distance between 7 and 6.5 is 0.5 (i.e., 6.5 deviates from 7 by 0.5). Then, you will receive $180 - 10 \times 0.5 = 175$ ECU.

If, by random choice, your payment is based on your profit aspirations, you will earn your highest achieved profit aspiration, i.e., your highest aspiration that does not exceed your period-profit. In particular, the computer will check which of your profit aspirations are equal to or smaller than your period-profit.

- Among the profit aspirations that do not exceed your period-profit, you will earn the highest one.
- If all your profit aspirations exceed your period-profit, then you will earn 0 ECU.

EXAMPLE

Suppose that your period-profit is 162 ECU and you made 3 guesses about the others' average price so that you had to specify 3 profit aspirations.

- If *your profit aspirations* were 170, 160 and 150, then you earn 160 ECU because 160 is the highest aspiration that does not exceed your period-profit of 162 ECU.
- If, instead, *your profit aspirations* were 180, 172 and 170, then you earn 0 ECU because all your aspirations exceed 162 ECU.

Your experimental earnings in each period

At the end of each period, you will be told

- your price;
- the average price of the others;
- your own period-profit;
- your closest guess to the average price of the others;
- your highest achieved aspiration;
- your period experimental earnings.

Your final earnings

Your final earnings will be calculated by adding up your experimental earnings in all

periods. The resulting sum will be converted to euros and paid out to you in cash in addition to the show-up fee of €2.50.

Before the experiment starts, you will have to answer some control questions to ensure your understanding of the experiment.

Please remain quiet until the experiment starts and switch off your mobile phone. If you have any questions, please raise your hand now.

Table 1: Percentage of subjects complying with $\bar{p}_{-i} \in \text{conv}C_i$ in each period

Period	1	2	3	4	5	6	7	8	9
% Subj	62.963	71.605	79.012	70.370	80.247	76.543	72.840	79.012	75.309

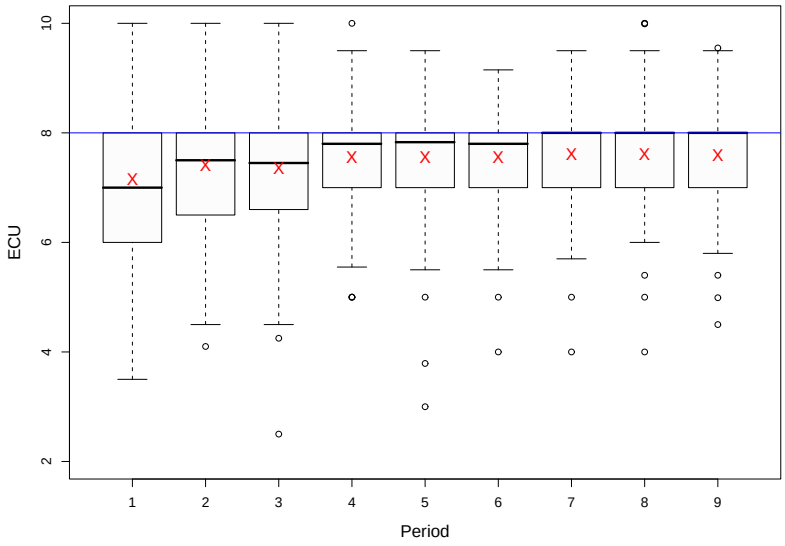
Table 2: Revisions and satisficing behavior

	Period								
	1	2	3	4	5	6	7	8	9
	Subjects fully satisficing at first attempt (%)								
i.	83.951	90.123	93.827	87.654	93.827	93.827	95.062	96.296	97.531
	Subjects fully satisficing (%)								
ii.	98.765	96.296	98.765	97.531	98.765	97.531	96.296	97.531	97.531
	Subjects revising (%)								
iii.	28.395	24.691	16.049	14.815	11.111	14.815	6.173	4.938	3.704
	Subjects revising among those not fully satisficing at first attempt (%)								
iv.	92.308	100.000	100.000	90.000	100.000	80.000	50.000	66.667	0.000
	Subjects revising among those fully satisficing at first attempt (%)								
v.	16.176	16.438	10.526	4.225	5.263	10.526	3.896	2.564	3.797
	Average number of revisions (for those who revise)								
vi.	1.217	1.250	1.385	1.250	1.444	1.083	1.600	1.250	1.000

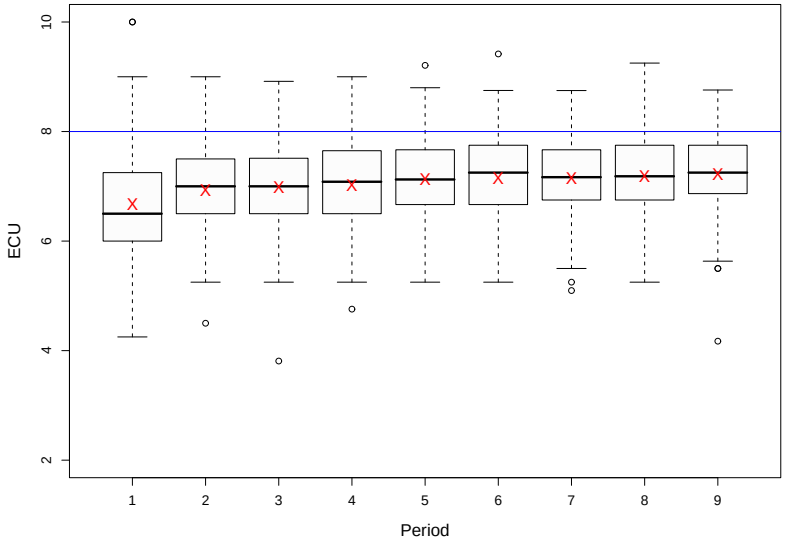
Table 3: Deviations from and compliance with prior-free optimality

	Period								
	1	2	3	4	5	6	7	8	9
	Type 1-deviation (% Subj)								
i.	72.840	62.963	69.136	64.198	61.728	61.728	56.790	56.790	53.086
	Type 2-deviation (% Subj)								
ii.	22.222	27.160	23.457	25.926	25.926	23.457	27.160	28.395	33.333
	Prior-free optimality (% Subj)								
iii.	3.704	6.173	6.173	7.407	11.111	12.346	12.346	12.346	11.111
	Average unexhausted profit potential in type 2-deviations (% Attainable profits)								
iv.	5.500	4.700	3.600	4.300	5.600	5.700	4.500	4.300	4.000

Figure 1: Distribution of stated prices and average conjectured prices

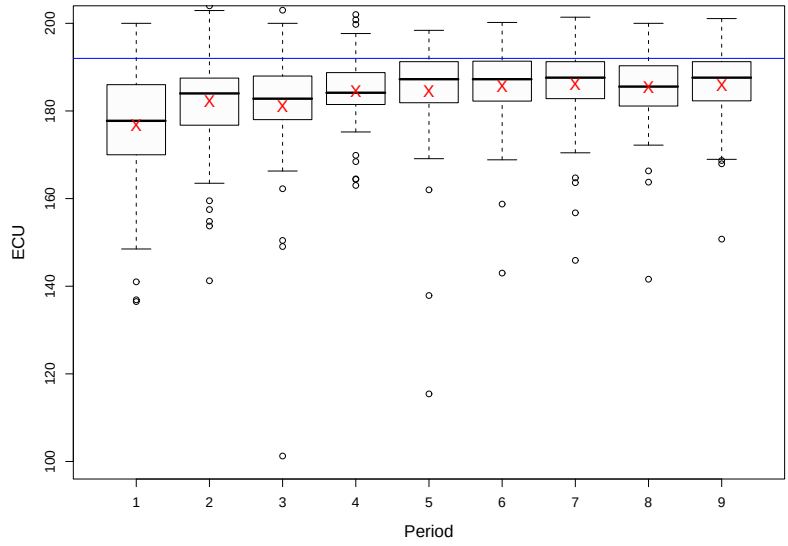


(a) Stated prices

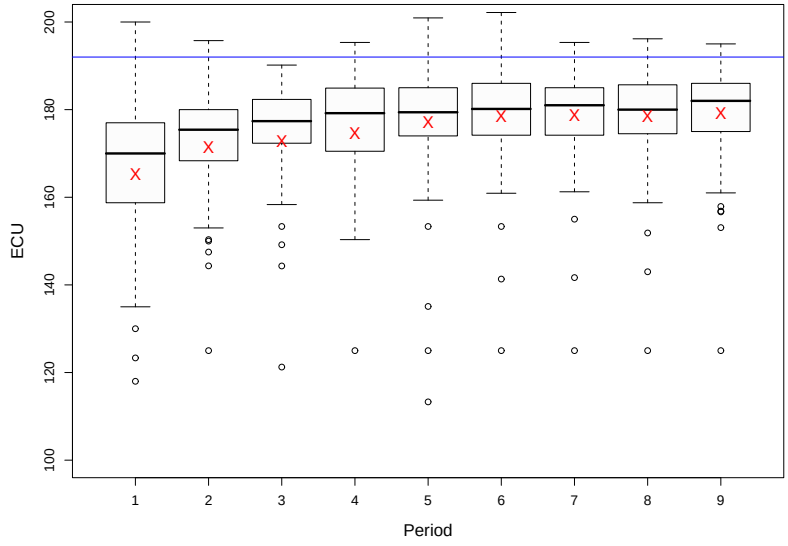


(b) Average conjectured prices

Figure 2: Distribution of realized profits and average aspirations

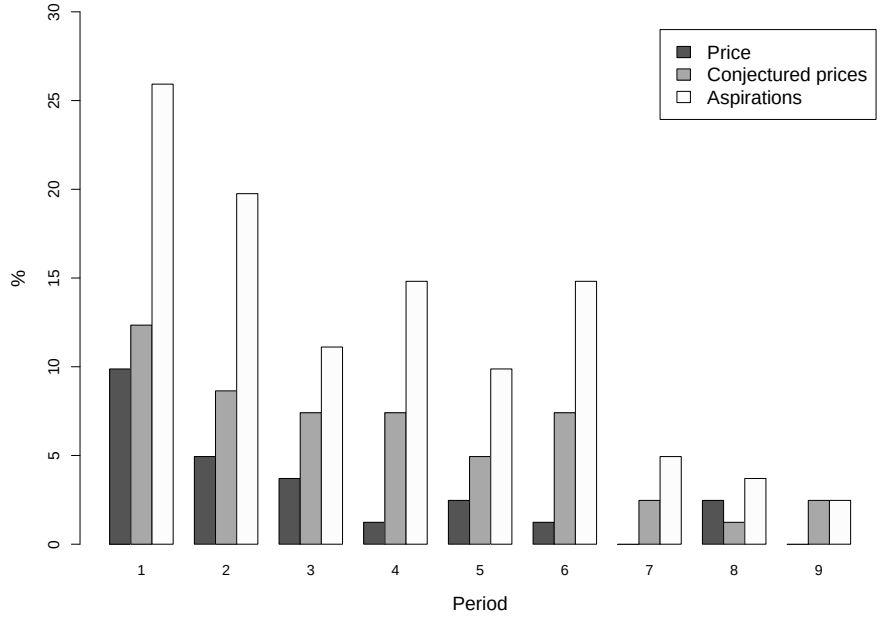


(a) Profits

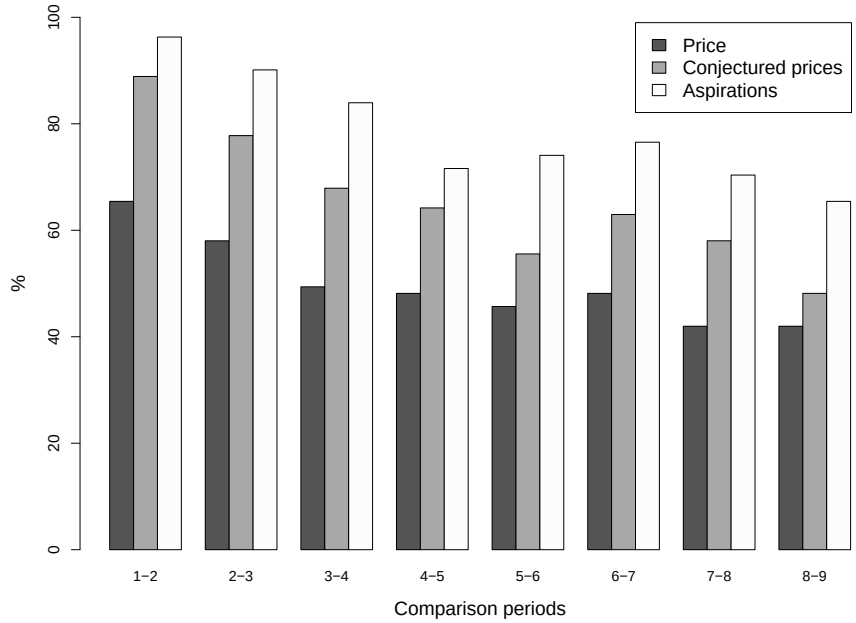


(b) Average aspirations

Figure 3: Percentage of changes in stated prices, conjectured prices, and aspirations within each single period and between two consecutive periods



(a) Within-period



(b) Across-periods