Research Article

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Number of Firms, Rationing, Matching, and Knowledge: A Comprehensive Study of Variations in Experimental Kreps–Scheinkman Markets

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Abstract: This study provides a comprehensive picture of experimental Kreps–Scheinkman markets with capacity choice in the first stage and subsequent price competition in the second. We conduct seven different treatments of such markets, varying the number of firms, demand rationing, subject matching, and subjects' knowledge about the market mechanism. We find that only the number of firms has a persistent effect on capacity choices, whereas price choices are affected by both the number of firms and the rationing scheme. From the outset, subjects in the high-knowledge condition behave in the same way as subjects with low knowledge do in later periods after gaining experience. In all treatments, conduct is more competitive than the Cournot outcome, irrespective of the Nash equilibrium prediction. Nevertheless, the Cournot model does pack some predictive power. Under efficient demand rationing where the Cournot outcome is predicted, exact Cournot choices are more likely for both capacities and prices.

Keywords: Kreps–Scheinkman, price competition, capacity commitment, demand rationing, laboratory experiment

JEL Classification: C90, D43, L11, L13

1 Introduction

In their seminal work, Kreps and Scheinkman (1983) (hereafter KS) combine the features of the classical quantity and price setting models proposed by Cournot (1838) and Bertrand (1883) with only one choice variable each. The most remarkable feature of the KS model is that, under suitable assumptions on demand

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rationing, its outcome is equivalent to the Cournot outcome. This implies that prices will decline as more firms operate in the market.

While the KS model has been subjected to experimental testing against other market institutions, and more recently variations within the KS model have also become a focus of experimental research, evidence on the latter is still both scattered and limited. The aim of this study is to provide a comprehensive analysis of how different experimental conditions affect the results within KS markets. For this purpose, we set up seven treatments mimicking the KS market environment and controlling for (i) the number of firms in a market (duopoly vs. triopoly), (ii) demand rationing (efficient vs. proportional), (iii) subject matching (random vs. fixed), and (iv) subjects' understanding of the KS market mechanism, referred to as "knowledge" (low vs. high). To the best of our knowledge, this is the first study to experimentally investigate the effect of the latter two variables in KS markets. While the impacts of both the number of firms and demand rationing have already been investigated in other studies, our results present a comprehensive picture of what drives outcomes in experimental KS markets.

As for capacity choices, we find, contrary to part of existing literature but qualitatively in line with the theory prediction, that the number of firms in the market significantly affects behavior. Notably, larger capacities are chosen in triopoly than in duopoly. In line with earlier findings, the rationing scheme does not significantly influence capacity choice. Nor does the matching procedure have any impact. Subjects with a good understanding of the KS mechanism ("high-knowledge" treatment) choose lower capacities in the early periods, but the difference vanishes in later periods as subjects in the "low-knowledge" treatments gain experience. While capacities tend to decline with the number of periods already played, they converge to levels significantly higher than the Cournot benchmark in all treatments. Exact Cournot capacity choices are rarely observed, but they occur significantly more often under efficient demand rationing when the Cournot outcome is the Nash equilibrium prediction than under proportional rationing.

With regard to the second-stage outcomes (price choices), we observe considerably lower prices than in the Cournot outcome. Once more, the number of firms has a significant effect: duopoly yields higher prices than triopoly. High knowledge again shows an effect only in the early periods, and subject matching never influences pricing in a significant way. Contrary to the first stage, the rationing scheme also has a significant effect: prices are higher with proportional than with efficient rationing.

Initially, the sensitivity of pricing to installed capacity is low and increases with the number of periods played. This implies that subjects have to learn about the effect of their capacity choices on the pricing subgame in the second

stage. Only in the high-knowledge condition do subjects exhibit a high degree of sensitivity from the beginning.

If subjects choose capacities low enough to make market-clearing pricing the pure-strategy equilibrium in the second stage, markets do not always clear. Again we find a significant effect of demand rationing on behavior. The exact market-clearing price is chosen more often under efficient rationing.

As a result of the choices in the two stages, average profits fall substantially short of the Cournot benchmark. It remains a puzzle why even after many rounds, subjects continue to install excess capacities. Explanatory approaches found in the literature do not stand up to closer scrutiny on the basis of our data.

The remainder of the study is structured as follows: In Section 2 we briefly review the theoretical and experimental literature on KS markets. Section 3 explains the design and procedures of our experiment. Section 4 sets out the equilibrium predictions. In Section 5 we present our results, and Section 6 concludes.

2 Related Literature

2.1 Theory

The KS paper referred to above explains the Cournot outcome as resulting from a two-stage process where firms choose quantities first and prices thereafter. While KS apply the efficient rationing rule, i. e. those customers with the highest willingness to pay are assumed to be served first, Davidson and Deneckere (1986) find that the KS result is sensitive to the rationing rule assumed to be operative and show that other rationing rules leaving more residual demand to the higher pricing firm may result in mixed-strategy price-setting equilibria leading to more competitive outcomes than Cournot. This matter is further clarified by Lepore (2009), who finds that, under certain conditions, the Cournot outcome *may* (but need not) survive under other than efficient rationing rules.^{1,2} Boccard and Wauthy (2000, 2004)

¹ More precisely, under the alternative assumption of proportional demand rationing, i. e. if customers are assumed to be served in random order, the Cournot outcome is still an equilibrium if the costs for installing capacity in the first stage are sufficiently high. In two further studies, Lepore (2008, 2012) is concerned with the conditions for the Cournot outcome to be an equilibrium of the KS game under either rationing rule when (a) the competitor's production costs are uncertain, or (b) market demand is uncertain when firms choose capacities.

² This strand of the literature follows the assumption made by KS that the market demand function is concave. Madden (1998) and Wu, Zhu, and Sun (2012) analyze the conditions required for the KS result to hold under different demand specifications.

generalize the KS result to the oligopoly with more than two firms. Benoît and Krishna (1987) deal with a dynamic setting in which firms play the KS game repeatedly. When capacities can be freely adjusted in each period, monopoly-level profits can be sustained in equilibrium, provided that discounting is not too severe.

2.2 Experiments

Early experiments on the KS model (Davis 1999; Muren 2000; Goodwin and Mestelman 2010) are mainly concerned with performance in comparison with theoretical benchmarks and other market institutions. The main result is that subjects in KS markets choose higher capacities and lower prices than predicted. When subjects gain experience, their behavior approaches, but usually does not reach, the Cournot-Nash equilibrium.³

Davis compares treatments of price competition with and without advance production in posted-offer triopoly markets with efficient demand rationing, finding that prices settle somewhere between the competitive (Bertrand) and the Cournot benchmark. Profits increase throughout the experiment but do not converge to the predicted Cournot level. The reported data about sold quantities indicate that capacities (not reported) are chosen above equilibrium level.

Muren investigates KS triopolies with efficient rationing and compares her outcomes both with theoretical predictions and with the experimental results on Cournot and Bertrand arrived at by Fouraker and Siegel (1963). She observes that inexperienced subjects set capacities that are considerably higher than the Cournot level, while experienced subjects' capacity choices are still somewhat higher but come close to the Cournot prediction. Goodwin and Mestelman obtain similar results, comparing KS duopolies with efficient rationing to Cournot markets and, similarly to Muren, varying the subjects' experience.

Like our study, some more recent experiments are mainly interested in the effects of variations *within* the KS framework. Considering price competition with advance production in markets with two and three firms, Brandts and Guillen (2007) find no significant difference between market capacities in duopolies and triopolies; however, in duopoly, firms choose higher prices. Cracau and Franz (2014) investigate a similar setting and, contrary to

³ Another related strand of the literature not considered here deals with sequential capacity and price choice in firms producing heterogeneous goods, see e. g. Anderhub et al. (2003).

Brandts and Guillen, also observe a difference in capacity choices: market capacities are higher in triopoly than in duopoly.⁴

The experience effect is further scrutinized by Le Coq and Sturluson (2012), who not only have inexperienced and experienced subjects play against each other in homogeneous groups but also pair inexperienced with experienced subjects. Moreover, in contrast to all studies referred to so far, their subjects do not play in fixed groups but are re-matched in every round of the experiment. Le Coq and Sturluson find that capacities (prices) decrease (increase) with both the subject's own and her competitor's experience. Furthermore, experienced subjects are more responsive in their price choices to capacities installed in the first stage. The authors conjecture that the subjects' level of rationality increases with experience and that experienced players will anticipate and respond to the lower degree of rationality displayed by their inexperienced opponents.

Finally, Lepore and Shafran (2013) study the impact of different rationing rules and the cost of installing capacity under random matching to approximate a one-shot game. In their low-cost condition with proportional demand rationing, the Cournot outcome is not a Nash equilibrium. The authors observe that Cournot capacities are frequently chosen in the high-cost condition, while higher capacities are common in the low-cost treatments. While the demand rationing rule has no impact on capacity choice, there is an effect on pricing, as in the low-cost treatments subjects set higher prices under proportional rationing. In the high-cost treatments, Cournot capacities are mostly followed by Cournot prices in the second stage.

3 Experimental Design and Procedures

Our experiment aims at drawing a comprehensive picture of the effects of different variations within the KS setting. Accordingly, our design contains four treatment variables: number of firms in the market, demand rationing, subject matching, and understanding of the KS market mechanism, referred to as “knowledge” for short.

All in all, we conducted seven treatments with different combinations of variable states. A matrix of the conducted treatments is provided in Figure 1,

⁴ The setting employed by Brandts and Guillen and by Cracau and Franz does not exactly resemble the KS model. While firms also choose both capacities and prices, there is no two-stage structure, but firms decide on their prices already when producing. Hence, they are not informed about the total amount of capacity in the market when setting prices. Moreover, Brandts and Guillen assume box demand, which does not fit the KS model either.

treatment (treatment 7) is to investigate the effect of subjects' understanding of the KS setting. For the so-called high-knowledge condition, subjects were recruited from an industrial organization class in the undergraduate economics program. They received special, more extensive instructions conducive to a more sophisticated understanding of the underlying model.⁵ As the number of subjects suitable for the high-knowledge condition was limited, we conducted only one high-knowledge treatment, namely duopolies with efficient rationing and fixed matching. Whereas the experience dimension in earlier studies considered the effect of learning-by-doing, our high-knowledge condition enhances theoretical understanding *ex ante*.

The linear total demand function in our duopoly and triopoly markets is $D(p) = 1000 - p$. In the first stage, firms choose their individual capacities k_i . Each firm can install 0 to 1,000 integer units of capacity, where each such unit costs 100 Experimental Currency Units (ECU). In the second stage, each firm decides on its price p_i . Here again, integer values between 0 and 1,000 ECU are admissible. When choosing prices, firms know their competitors' capacity choices from the first stage. Computer-simulated buyers first approach the firm that offers the good at the lowest price. If the capacity of that firm cannot fully satisfy the demand, residual demand is left for the other firms. The quantity q_i that firm i is able to sell in any period is given in eq. [1]:

$$q_i(\mathbf{p}, \mathbf{k}) = \begin{cases} \max \left\{ 0, \min \left\{ \frac{1}{m} \left(1000 - p_i - \sum_{j|p_j < p_i} k_j \right), k_i \right\} \right\} & \text{for eff. rat.} \\ \max \left\{ 0, \min \left\{ \frac{1000 - p_i}{m} \left(1 - \sum_{j|p_j < p_i} \frac{k_j}{1000 - p_j} \right), k_i \right\} \right\} & \text{for prop. rat.} \end{cases} \quad [1]$$

The quantity depends on the price vector $\mathbf{p}$, the capacity vector $\mathbf{k}$, and the effective rationing scheme, and m represents the number of firms charging the same price as firm i (including i itself). Firm i 's profit is then given by $\Pi_i(\mathbf{p}, \mathbf{k}) = p_i q_i(\mathbf{p}, \mathbf{k}) - 100k_i$.⁶ To clarify the difference between the two rationing schemes in determining residual demand, assume that firm 1 has set the lowest price $p_1 = 200$ and has produced a capacity of $k_1 = 300$. Under efficient demand rationing, those customers with the highest willingness to pay are served first. This means that, at any price higher than

⁵ The instructions are explained in greater detail below.

⁶ As is common in the literature on demand rationing, residual demand under proportional rationing is defined by the expectation of all possible customer reservation price orderings, and we do not actually model the order of such prices as a random variable. Zouhar (2016) notes that, in some cases, both this difference and the exact tie-breaking rule (when several firms set the same price) affect quantities and profits. While these effects also cause differences in the Nash equilibrium outcomes, those differences are tiny.

200 ECU, demand is reduced by 300 units. Graphically, the demand function shifts leftwards in parallel. By contrast, under proportional rationing, a random sample of those customers willing to pay at least 200 ECU is served. The fraction of demand served by the lowest-price firm 1 at p_1 is $k_1/(1000 - p_1)$, i. e. 37.5 percent in our example. Residual demand at higher prices is then 62.5 percent of the original total demand. There is still positive residual demand at all prices up to 1,000, but the demand function has become steeper. Graphically, residual demand is obtained by rotating the total demand function inward.

Fifteen sessions in all were conducted at the economics experimental lab of Kiel University. They took place in three waves during January, July, and November 2014. 170 students from all fields of study participated as subjects in the low-knowledge treatments.⁷ Due to some no-shows, the number of markets per treatment varies between 11 and 14. For the high-knowledge treatment, 32 other students were recruited from an industrial organization class in the undergraduate economics program. All these students were familiar with the standard Cournot and Bertrand oligopoly models (but not with the KS model). Each subject participated only once in the experiment.

Subjects were randomly seated in the lab on arrival. There was no way they could guess which of the other subjects they would be interacting with during the experiment. Subjects were provided with printed instructions.⁸ In the low-knowledge treatments, the settings were explained verbally and graphically, and examples illustrating demand rationing were given. The more extensive instructions for the high-knowledge treatment also contained an algebraic representation of the underlying model. Furthermore, candidates for profit-maximizing prices were proposed given capacities and the competitor's price. The experiment was computerized using z-tree (Fischbacher 2007). In all treatments, subjects could simulate the results of their decisions by using a built-in profit calculator that worked out the sales quantity and profit that would result for the subject when hypothetical capacity and price choices for all firms were entered.

When subjects finished reading the instructions, the experimenter once again highlighted the experiment's main features in a short presentation. Before subjects could proceed to the actual experiment in the z-tree computer program, they had to master a set of tasks. In the low-knowledge treatments,

⁷ For part of the sessions, the hroot software package (Bock, Baetge, and Nicklisch 2014) was used for recruitment.

⁸ The instructions for the high-knowledge treatment, exemplary instructions for one low-knowledge treatment, and the control questions to be answered by the subjects can be found in Appendices A and B.

some rather simple yes–no questions about the experimental setup and procedures had to be answered correctly. In the high-knowledge treatment, subjects were required to calculate their sales and profit for three given sets of capacity and price vectors without the profit calculator. Moreover, in three more tasks, now with the profit calculator, they had to determine the profit-maximizing price given hypothetical capacities and a hypothetical competitor price. In one of these three tasks, we asked for the profit-maximizing price when (i) Cournot capacities were installed in the first stage and (ii) the market-clearing Cournot price was set by the competitor in the second stage. The instructions and training in the high-knowledge treatment were tailored to give the Nash equilibrium prediction its best shot without actually telling the subjects what the Nash equilibrium is and thereby implementing recommended play.

After these tasks had been completed, three unpaid trial rounds and 18 paid rounds of the KS game were played. Since reading the instructions and working through the tasks was expected to take considerably more time in the high-knowledge treatment, we reduced the number of paid rounds to nine for that treatment. The number of rounds to be played was common knowledge. An average session took about 135 min for both levels of knowledge. After each round, subjects were informed about all capacity and price choices in their market and about their sales quantity and profit resulting from those choices. Subjects were not informed explicitly about their competitors' profits, but they could easily work them out for themselves using the profit calculator, if they so desired.

Subjects received a show-up fee of EUR 6 plus the sum of their earnings in the paid rounds calculated on the basis of a predefined exchange rate. Moreover, they had a starting balance to compensate for any losses in the early periods.⁹ Subjects had unlimited credit during the experiment, so if their balance became negative, they could still go on installing capacity and selling. If a subject's

⁹ The exchange rate was 40,000 ECU per Euro in the triopoly treatments and the high-knowledge duopoly treatment, and 80,000 ECU per Euro in the low-knowledge duopoly treatments, thus roughly equating per-round payoffs in the Cournot benchmark case (EUR 1.27 in the triopolies and EUR 1.13 in the low-knowledge duopolies). For the high-knowledge duopoly treatments per-round payoffs were doubled by adjusting the exchange rate as there were only half as many paid rounds. The starting balance was 240,000 ECU in the triopoly treatments, 200,000 ECU in the high-knowledge duopoly treatment, and 320,000 ECU in the low-knowledge duopoly treatments. While we first intended to provide a starting balance worth EUR 4 in all treatments (i. e. 160,000 ECU for the triopolies and the high-knowledge duopolies), we decided to increase that amount after a triopoly test session (whose data are not included in the study at hand) in order to decrease the probability of bankruptcies.

balance was negative after the last round, only the show-up fee was paid. Payments were made in private. The average payment per subject was EUR 19.70 including the show-up fee.

4 Equilibrium Predictions

The setting originally investigated by KS is most closely resembled by treatment 5, the duopoly with efficient demand rationing and random subject matching. The Nash equilibrium prediction for this treatment is the Cournot outcome with individual capacities $k_i = 300$ installed in the first stage (implying a market capacity of $K = \sum k_i = 600$) and a market-clearing price of $p = 400$ set in the second stage. The resulting equilibrium profit per firm is $\Pi_i = 90000$. In order to investigate the effect predicted by Davidson and Deneckere (1986), demand rationing is varied in treatment 6. Although Davidson and Deneckere do not provide a closed-form equilibrium solution of their modified two-stage game, they show that the KS result no longer holds and that in general there will be a unique mixed-strategy Nash equilibrium that is more competitive than the Cournot outcome. The last prediction stands in contrast to experimental evidence indicating that markets are less competitive with proportional than with efficient demand rationing (Kruse 1993; Lepore and Shafran 2013; Jacobs and Requate 2016a, 2016b).

The five remaining treatments employ fixed subject matching. They thus deviate from the original KS model but are closer to real oligopoly markets. With that matching, repeated game effects may arise. When the game is infinitely repeated and the discount factor is sufficiently high, outcomes dominating the one-shot Nash equilibrium up to full collusion can be sustained by a suitable trigger strategy (Friedman 1971). Benoît and Krishna (1987) show that in the KS framework collusion can be achieved without excess capacities if capacities can be freely adjusted in each round, as is the case in our setting. Nevertheless, we maintain the equilibrium of the one-shot game as a prediction also for the fixed matching treatments, i.e. we predict the Cournot outcome for treatments 1, 3, and 7, and a more competitive mixed-strategy equilibrium outcome for treatments 2 and 4. Altered subject matching is theoretically irrelevant since our subjects were informed in advance about the number of rounds to be played. The repeated game induced by our experiment can thus be solved via backward induction, and the equilibrium predictions for the stage game remain valid. Although in some repeated-game settings in the laboratory it has been observed that collusion could be sustained throughout most of the game and broke down

only in the last rounds (see e. g. Selten and Stoecker 1986), the results reported by Kruse (1993) indicate that the one-shot Nash equilibrium predicts behavior in price competition experiments with fixed matching, even if subjects do not know when the game will end.

The variation of knowledge in treatment 7 does not influence the theory prediction either. While subjects in the high-knowledge treatment receive more extensive instructions and training, the instructions given in the low-knowledge treatments also allow for full information. Boccard and Wauthy (2000, 2004) have extended the KS result beyond duopoly, hence our predictions for the triopoly treatments 3 and 4. In triopoly, the Cournot outcome corresponds to a market capacity of $K = 675$ in the first stage and a market price of $p = 325$ in the second; the equilibrium profit per firm is $\Pi_i = 50625$. Figure 2 summarizes the equilibrium predictions.

		<i>demand rationing</i>	
		efficient	proportional
<i>number of firms in the market</i>	$n = 2$	Treatments 1, 5, and 7: Cournot outcome: $k_i = 300, K = 600, p = 400,$ $\Pi_i = 90000.$	Treatments 2 and 6: Unique mixed-strategy NE, more competitive than Cournot outcome.
	$n = 3$	Treatment 3: Cournot outcome: $k_i = 225, K = 675, p = 325,$ $\Pi_i = 50625.$	Treatment 4: Unique mixed-strategy NE, more competitive than Cournot outcome.

Figure 2: Nash equilibrium (NE) predictions for the treatments.

Besides Nash equilibrium, two further benchmarks are provided by the fully competitive and the fully collusive state. Under full competition, the price equals marginal cost ($p=100$) and firms earn zero profits. The accompanying fully competitive market capacity is $K=900$, so that the price of 100 clears the market. The fully collusive price is $p=550$ with an accompanying market capacity of $K=450$. If one assumes capacities to be shared equally under full collusion, the induced benchmark profits per firm are $\Pi_i=101250$ in duopoly and $\Pi_i=67500$ in triopoly.

5 Results

After some brief remarks on the effect of bankruptcies, we will analyze the choices made in the two stages of the game separately. We first consider capacity choices, then price choices. Finally, we examine the profits resulting from subjects' choices in the two stages.

5.1 Bankruptcies

The bankruptcy rules set out in Section 3 are a potential source of data contamination. As subjects can go on playing when their balance is negative but cannot lose any more money, they may have an incentive to behave more adventurously so as to have a chance of re-establishing a positive balance. When designing the experiment, we considered the starting balance to be sufficiently high to prevent bankruptcies. Accordingly, we decided that the rule for dealing with the hypothetical case of a bankruptcy should be as simple as possible. However, it turned out that in the course of the experiment, six of our 202 subjects actually did go bankrupt. Four of these bankruptcies occurred in treatment 3. Here there were two markets, in each of which two of the three subjects went bankrupt. The other two bankruptcies occurred in treatments 1 and 4. However, despite the possible effect of bankruptcies on incentives, inspection of the data does not suggest that outcomes are substantially different in the markets with and without bankruptcies.¹⁰ Markets with bankruptcies are therefore included in our analyses to retain a larger data set. If we excluded the four markets where bankruptcies occurred, our results would change only slightly and all conclusions would remain the same.

5.2 Capacity choices

The left part of Table 1 and Figure 3 summarize capacity choices in the first stage. The three leftmost columns of Table 1 aggregate the data within each treatment and show the mean market capacities in each treatment across all periods as well as mean capacities in the first and the second half of the experiment. By contrast, the histograms presented in Figure 3 for each treatment display the distributions of the market capacities chosen.

¹⁰ Muren (2000) reports a similar incentive problem in her KS experiment. She also concludes that bankruptcies did not substantially affect her data.

Table 1: Market capacities and market prices: summary statistics.

Periods	Market capacities			Market prices		
	1–18	1–9	10–18	1–18	1–9	10–18
Treatment 1	926.163	992.325	860.000	248.159	224.006	272.312
<i>n</i> = 2, eff. rat.,	(296.191)	(294.493)	(283.917)	(104.638)	(97.497)	(106.322)
fixed match.	[850.000]	[1,000.000]	[800.000]	[242.857]	[205.044]	[276.188]
Treatment 2	860.940	911.102	810.778	310.254	297.457	323.052
<i>n</i> = 2, prop. rat.,	(189.428)	(197.477)	(167.406)	(90.772)	(89.703)	(90.436)
fixed match.	[825.500]	[900.000]	[800.000]	[307.689]	[292.861]	[328.204]
Treatment 3	1,083.051	1,203.750	962.352	171.095	160.864	181.327
<i>n</i> = 3, eff. rat.,	(387.863)	(455.162)	(256.321)	(86.306)	(85.707)	(86.081)
fixed match.	[950.000]	[1,200.000]	[896.000]	[148.443]	[131.391]	[160.987]
Treatment 4	1,014.991	1,063.361	966.620	214.815	201.467	228.162
<i>n</i> = 3, prop. rat.,	(256.595)	(278.391)	(223.770)	(82.141)	(78.063)	(84.284)
fixed match.	[1,000.000]	[1,010.000]	[948.000]	[204.711]	[188.537]	[216.192]
Treatment 5	932.621	967.949	897.293	239.689	231.712	247.667
<i>n</i> = 2, eff. rat.,	(202.022)	(196.472)	(202.284)	(93.422)	(83.414)	(102.264)
random match.	[919.500]	[950.000]	[900.000]	[223.333]	[218.200]	[229.772]
Treatment 6	967.324	1,029.463	905.185	296.431	263.900	328.963
<i>n</i> = 2, prop. rat.,	(289.262)	(274.644)	(291.380)	(146.042)	(127.253)	(156.608)
random match.	[950.000]	[1,002.500]	[900.000]	[266.987]	[241.120]	[307.317]
Treatment 7	n.a.	846.229	n.a.	n.a.	277.258	n.a.
<i>n</i> = 2, eff. rat.,		(191.890)			(80.407)	
fixed match.,		[829.000]			[270.272]	
high knowledge						

Note: Standard errors in parentheses. Medians in square brackets.

The most conspicuous result from Table 1 is that mean market capacities in all treatments are considerably higher than Cournot capacities. The mean capacities observed are mostly 40 to 60 percent above Cournot levels. This holds true for all treatments, no matter whether the Cournot outcome corresponds to the theoretical prediction or not. Although the mean capacities in Table 1 are mostly somewhat higher than the corresponding medians, the latter are still well above Cournot levels. Accordingly, the results are not driven by a few outliers, a fact that is also confirmed by the capacity distributions in Figure 3.

A comparison of the second to the third column in Table 1 indicates that mean capacities decline in all treatments as the experiment proceeds. We do not find any indication of markets becoming more competitive in the last few

Figure 3: Distributions of market capacities.

periods due to endgame effects.¹¹ The highest capacities are observed in the triopoly treatments (3 and 4), which is qualitatively in accordance with the equilibrium prediction.

To investigate the evolution of capacities formally, we set up a regression taken from Noussair, Plott, and Riezman (1995) that has been applied to KS experiments by Davis (1999), Le Coq and Sturluson (2012), and Lepore and Shafran (2013). It has the following form:

$$K_{ht} = \sum_{j=1}^7 \left(\beta_j TD_j \frac{1}{t} + \gamma_j TD_j \frac{t-1}{t} \right) + \varepsilon_{ht}. \quad [2]$$

The dependent variable in the regression is the market capacity K in market h and period t . We use TD_j , $j=1, \dots, 7$, to denote the set of treatment dummy variables, where TD_j equals one in treatment j and zero otherwise. Interacted with two different period weights, each treatment dummy appears twice on the right hand side of the equation. The first period weight, $1/t$, equals one in the first period and then declines, whereas the second weight, $(t-1)/t$, equals zero in the first period and then increases, approaching one as t goes to infinity. The two weights sum up to one in each period. Consequently, the β_j coefficients are estimates of market capacities in the first period (starting points) and the γ_j coefficients are estimates of the long-term market capacity convergence levels in treatment j . The regression thus allows for different convergence patterns in each treatment.¹²

We ran a GLS regression that corrected the standard errors for autocorrelation and heteroskedasticity within markets across periods. Regression results are presented in Panel A of Table 2. In all treatments, market capacities converge to levels significantly higher than the respective Cournot capacity (all p 's < 0.01 , t -tests).¹³ Convergence levels are fairly close to the competitive

¹¹ To test for endgame effects, we compared for each treatment market capacities in the last period to capacities in the second to last period. We do not find any significant differences in capacities (all p 's > 0.5 , Mann-Whitney tests). The same holds true if capacities in the last two periods are compared to those in the third and forth to last periods. Moreover, if we add to regression [2] dummy variables $TD_j \times end$, $j = 1, \dots, 7$, where end equals one in either (i) the last or (ii) the last two periods, the hypothesis that the coefficients of all added variables are zero cannot be refuted ($p = 0.88$ in case (i) and $p = 0.36$ in case (ii), F -tests).

¹² Unlike other specifications in the literature, we do not allow for different starting levels for each session or market within the same treatment.

¹³ All p -values refer to two-tailed tests.

Table 2: Market capacities: regression results and treatment effects.

Panel A: Estimated Starting Points (β 's) and Convergence Levels (γ 's) of Market Capacities		
	β_j	γ_j
Treatment 1	1,063.578	866.707
$n = 2$, eff. rat., fixed match.	(67.474)	(36.111)
Treatment 2	984.21	841.501
$n = 2$, prop. rat., fixed match.	(72.880)	(39.004)
Treatment 3	1,536.977	976.892
$n = 3$, eff. rat., fixed match.	(72.880)	(39.004)
Treatment 4	1,208.245	935.012
$n = 3$, prop. rat., fixed match.	(72.880)	(39.004)
Treatment 5	981.549	911.532
$n = 2$, eff. rat., random match.	(76.121)	(40.739)
Treatment 6	1,073.534	929.163
$n = 2$, prop. rat., random match.	(72.880)	(39.004)
Treatment 7	864.64	813.966
$n = 2$, eff. rat., fixed match., high knowledge	(61.661)	(40.883)
Observations	1,458	
Adjusted R^2	0.064	
Panel B: Treatment effects		
<i>Demand rationing</i>	$\beta_1 = \beta_2$ $\beta_3 > ***\beta_4$ $\beta_5 = \beta_6$	$\gamma_1 = \gamma_2$ $\gamma_3 = \gamma_4$ $\gamma_5 = \gamma_6$
<i>Number of firms in the market</i>	$\beta_1 < ***\beta_3$ $\beta_2 < **\beta_4$	$\gamma_1 < **\gamma_3$ $\gamma_2 < *\gamma_4$
<i>Subject matching</i>	$\beta_1 = \beta_5$ $\beta_2 = \beta_6$	$\gamma_1 = \gamma_5$ $\gamma_2 = \gamma_6$
<i>Knowledge</i>	$\beta_1 > **\beta_7$	$\gamma_1 = \gamma_7$

Notes: Panel A: GLS regression with clustered errors at market level. Clustered standard errors in parentheses.

Panel B: Results of two-tailed t -tests on equality of coefficients from Panel A. “>” (“<”) indicate that the first coefficient is significantly larger (smaller) than the second, where ***, **, and * denote the 1, 5, and 10 percent significance levels. “=” indicates that equality of the two coefficients cannot be rejected at the 10 percent significance level.

quantity of 900. Indeed, in five of the seven treatments, the convergence level is not significantly different from 900 at the ten-percent level. Only in the high-knowledge treatment 7 do market capacities converge to a level significantly lower than the competitive quantity ($p < 0.05$). The convergence level in treatment 3 is significantly higher than 900, but this result hinges on the inclusion

of markets with bankruptcies. The low R^2 of the regression indicates that there is a lot of variance in the capacity choice data that cannot be captured by treatment-specific convergence processes.¹⁴

In order to elicit treatment effects, we compare the coefficients of two treatments that differ only with respect to one treatment variable. Recall the treatment matrix in Figure 1 to see that there are three pairwise comparisons for investigating the effect of demand rationing (treatment 1 vs. treatments 2, 3 vs. 4, and 5 vs. 6), two for the number of firms in the market (1 vs. 3 and 2 vs. 4), two for the subject matching rule (1 vs. 5 and 2 vs. 6), and one for the knowledge condition (1 vs. 7). We consider effects both in the starting points and in the convergence levels. The significance-test results are presented in Panel B of Table 2. As for demand rationing and subject matching, the test results show no valid treatment effects. In only one of three pairwise comparisons is there a significant effect of demand rationing on starting point capacities and never is there any significant effect on capacity convergence levels. Subject matching never produces any significant effect. The high-knowledge treatment yields significantly lower market capacities than the control treatment at the start, but the two convergence levels do not significantly differ from each other. The number of firms in the market is the only treatment variable in our setting that produces a uniform and persistent significant effect on capacities. In both pairwise comparisons and for both starting points and convergence levels, market capacities are significantly higher in triopoly than in duopoly.¹⁵ Recall from Section 4 that this effect qualitatively accords with the theory prediction. According to the Cournot benchmarks, market capacity in triopoly is expected to be 12.5 percent above capacity in duopoly (675 vs. 600 units). Comparing the estimated convergence levels in treatments 1 and 3 – which differ only with respect to the number of firms in the market and for both of which the Cournot outcome is predicted – we find that this ratio holds almost perfectly: γ_3 is by 12.7 percent higher than γ_1 . That is, while market capacities are

¹⁴ Alternative specifications we tried yielded identical implications and even lower R^2 's.

¹⁵ As an alternative approach to investigating treatment effects, we also applied non-parametric significance tests on market capacity data from different treatments. In the treatments with fixed subject matching, mean capacities in a market over all periods are taken as observations, while in the treatments with random subject matching the data from single periods are pooled. In the pairwise comparison of market capacities in two treatments as described above, Mann-Whitney tests yield results largely identical to those in Panel B of Table 2. Demand rationing and subject matching never affect capacity choices significantly. Capacities are significantly higher in triopoly than in duopoly ($p < 0.05$ for treatment 2 vs. treatment 4 and $p < 0.1$ for treatment 1 vs. treatment 3). High knowledge does not significantly lower mean market capacities over all periods (1–9), although there is a significant difference in four single periods (periods 2–5, all p 's < 0.1).

considerably higher than the theory prediction in both treatments, they exceed the prediction by roughly the same percentage, namely by 42 to 45 percent.¹⁶

Capacities substantially above the Cournot prediction are in line with what has been observed in the majority of KS experiments. The results of earlier studies indicate that some features of our setting, i. e. inexperienced subjects (Muren 2000; Goodwin and Mestelman 2010; Le Coq and Sturluson 2012) and low costs for installing capacity (Lepore and Shafran 2013), are conducive to high capacity choices. So the high capacity levels observed in our experiment do not come as a big surprise. As for the treatment effects, only two of our four treatment variables have been varied in earlier related studies. Our conclusion that demand rationing does not significantly affect capacity choices is in line with the outcome in Lepore and Shafran (2013). The significantly higher capacities observed in triopolies stand in contrast to the results produced by Brandts and Guillen (2007), who do not find such an effect, and reinforce the findings by Cracau and Franz (2014).

We furthermore investigated the instances in which the exact Cournot capacity was installed in a market. Such instances are rare; their average frequency across all treatments is 1.8 percent.¹⁷ While the overall level of Cournot capacity choices is very low, Cournot capacities occur significantly more frequently in those treatments where the Cournot outcome is the Nash equilibrium (treatments 1, 3, 5, and 7: treatments with efficient demand rationing) than in those where it is not (treatments 2, 4, and 6: treatments with proportional demand rationing). In the four treatments where the Cournot outcome is the theoretical prediction, the relative frequency of exact Cournot market capacities is 2.6 percent, whereas in the other treatments it is 0.8 percent. The hypothesis that frequency is independent of the equilibrium prediction is refuted by a chi-squared test at the one-percent significance level.¹⁸ Remarkably, this effect is so pronounced only if *exact*

¹⁶ We are grateful to a referee for pointing this out.

¹⁷ Lepore and Shafran (2013) also find that Cournot capacities are relatively rare in their low-cost duopoly treatments. They observe frequencies of *individual* Cournot capacities between 7 and 9 percent. However, those frequencies cannot be readily compared to ours. Lepore and Shafran count instances where individuals choose the individual Cournot capacity, while we count instances where the sum of all individual capacity choices in a market equals the Cournot market capacity. Moreover, they employ a much coarser capacity grid than we do, which renders observations of the precise Cournot capacity more likely in their setting.

¹⁸ One might argue that it is the high-knowledge treatment condition rather than demand rationing that influences the frequency of Cournot capacities. The sample for the test is then biased because there is no counterpart to treatment 7 with proportional rationing. However, when the data from treatment 7 are excluded from the sample, the test result is still significant at the five-percent level.

Cournot capacities are considered. By contrast, if one counts all capacities within a five- or ten-percent range around the benchmark as Cournot capacities, the difference between rationing schemes is diminished and no longer significant.¹⁹

5.3 Price choices

We now look at price choices in the second stage. As a measure for the market price we take the average price in a given market and period weighted by sales quantities, i.e. total sales revenue divided by total sales quantity. The three rightmost columns of Table 1 show the development of market prices across periods within each treatment. As in the first stage, we observe much more competitive conduct than predicted by the Cournot benchmark, i.e. prices are substantially lower than the Cournot prices of 400 ECU (in duopoly) or 325 ECU (in triopoly).

In order to analyze the impact of the treatment conditions on market prices, we pursue a regression approach analogous to the one discussed in Section 5.2. Besides replacing the endogenous variable from regression [2], we furthermore have to include capacity choices from the first stage as an important additional explanatory factor. The relationship between the market capacity determined in the first stage and the market price determined in the second is illustrated by a scatter plot in Figure 4. Each circle shows the market capacity and the average market price in one specific market and period. As one would expect, higher capacities involve lower prices. The plot also illustrates that, irrespective of the capacity installed, subjects are very reluctant to set a price below 100 ECU in the second stage, presumably to avoid certain losses.

The regressions presented in Panel A of Table 3 include all exogenous variables known from the capacity regression and consider additional variables to control for the capacity installed in the first stage. Specification [1] includes a set of six capacity dummies. A capacity dummy equals one if the market capacity installed lies in the interval referred to in its caption.²⁰ Capacities up to 600 units

¹⁹ We owe the idea to consider also ranges around the exact Cournot benchmark to a referee. Using a five-percent range, we find that the relative frequency of a market capacity within that range is 6.3 percent under efficient 4.5 percent under proportional rationing ($p = 0.13$). With a ten-percent range, the respective frequencies are 11.0 and 8.8 percent ($p = 0.17$). The numbers of instances of capacities equal or close to the Cournot benchmark are contained in Table 6 in Appendix C.

²⁰ Interval boundaries were chosen such that there are at least 20 observations in every capacity category. Variations in this respect leave the implications of the results unchanged.

Figure 4: Scatter plot of market capacities and market prices with kernel fit.

are the omitted category, i. e. the β and γ coefficient estimates pertain to markets with a capacity of no more than 600 units, and the dummy coefficients show the change in market price relative to that capacity interval. The estimates for the dummy coefficients are all negative and increase in absolute value, signifying a monotonic negative relationship between capacity and price. The only exception is the sixth dummy coefficient for capacities larger than 1,600 units, which is smaller in absolute value than the fifth dummy coefficient. This, however, accords with the kernel fit line in Figure 4, indicating that the negative relationship between capacity and price ends when capacities become very high.²¹

Specification [2] builds on the insight from Figure 4 indicating a convex relationship between capacity and price. It includes capacity as an exogenous factor with both a linear and a quadratic term. The regression yields a significant negative coefficient for the linear term and a significant positive coefficient for the quadratic term, thus confirming the convex link posited. The magnitude of the coefficient estimates suggests that the first unit of installed capacity decreases the market price by approximately 0.65 ECU. If there are already

²¹ All kernel fits in this study were generated with a Gaussian kernel and a bandwidth of 15 percent of the respective capacity range.

Table 3: Market prices: regression results and treatment effects.

Panel A: Estimated Starting Points (β 's) and Convergence Levels (γ 's) of Market Prices				
	(1)		(2)	
	β_j	γ_j	β_j	γ_j
Treatment 1	389.191	394.011	663.495	670.772
$n=2$, eff. rat., fixed match.	(17.486)	(8.159)	(21.904)	(15.502)
Treatment 2	449.882	445.892	712.719	723.044
$n=2$, prop. rat., fixed match.	(18.654)	(8.743)	(22.689)	(15.924)
Treatment 3	402.973	323.999	695.264	600.183
$n=3$, eff. rat., fixed match.	(19.430)	(8.846)	(22.012)	(15.869)
Treatment 4	392.318	386.299	673.652	663.031
$n=3$, prop. rat., fixed match.	(18.732)	(8.953)	(22.650)	(16.550)
Treatment 5	411.669	385.860	686.126	664.511
$n=2$, eff. rat., random match.	(19.283)	(8.953)	(23.228)	(16.534)
Treatment 6	435.323	456.654	719.704	731.143
$n=2$, prop. rat., random match.	(18.651)	(8.448)	(22.782)	(15.868)
Treatment 7	411.885	400.823	691.094	677.005
$n=2$, eff. rat., fixed match., high knowledge	(15.742)	(11.731)	(20.343)	(17.593)
cap(600,800]	-97.359			
	(6.722)			
cap(800, 1,000]	-154.071			
	(6.591)			
cap(1,000, 1,200]	-212.236			
	(7.106)			
cap(1,200, 1,400]	-236.052			
	(8.110)			
cap(1,400, 1,600]	-265.027			
	(10.454)			
cap(1,600, ...]	-235.971			
	(13.266)			
Capacity			-0.653	
			(0.028)	
Capacity ²			$1.95 \cdot 10^{-4}$	
			$(1.29 \cdot 10^{-5})$	
Observations	1,458		1,458	
Adjusted R^2	0.561		0.577	
Panel B: Treatment effects				
	(1)		(2)	
	$\beta_1 < ** \beta_2$	$\gamma_1 < *** \gamma_2$	$\beta_1 < ** \beta_2$	$\gamma_1 < *** \gamma_2$
Demand rationing	$\beta_3 = \beta_4$	$\gamma_3 < *** \gamma_4$	$\beta_3 = \beta_4$	$\gamma_3 < *** \gamma_4$
	$\beta_5 = \beta_6$	$\gamma_5 < *** \gamma_6$	$\beta_5 = \beta_6$	$\gamma_5 < *** \gamma_6$

(continued)

Table 3: (continued)

Number of firms in the market	$\beta_1 = \beta_3$	$\gamma_1 >^{***} \gamma_3$	$\beta_1 = \beta_3$	$\gamma_1 >^{***} \gamma_3$
	$\beta_2 >^{**} \beta_4$	$\gamma_2 >^{***} \gamma_4$	$\beta_2 = \beta_4$	$\gamma_2 >^{***} \gamma_4$
Subject matching	$\beta_1 = \beta_5$	$\gamma_1 = \gamma_5$	$\beta_1 = \beta_5$	$\gamma_1 = \gamma_5$
	$\beta_2 = \beta_6$	$\gamma_2 = \gamma_6$	$\beta_2 = \beta_6$	$\gamma_2 = \gamma_6$
Knowledge	$\beta_1 = \beta_7$	$\gamma_1 = \gamma_7$	$\beta_1 = \beta_7$	$\gamma_1 = \gamma_7$

Notes: Panel A: GLS regressions with clustered errors at market level. Clustered standard errors in parentheses.

Panel B: Results of two-tailed *t*-tests on equality of coefficients from Panel A. “>” (“<”) indicate that the first coefficient is significantly larger (smaller) than the second, where ***, **, and * denote the 1, 5, and 10 percent significance levels. “=” indicates that equality of the two coefficients cannot be rejected at the 10 percent significance level.

500 (1,000) units of capacity installed, one further unit will lead to a price decrease of about 0.46 (0.26) ECU.^{22,23}

Both specifications exhibit an R^2 many times higher than that of the capacity regression, the prime reason being the large explanatory power of first-stage capacities. Specification [2] has a slightly better fit than specification [1]. As for the treatment effects, concentrating ourselves on the price convergence levels (the γ coefficients), we find two significant effects. Prices are significantly higher with proportional than with efficient demand rationing and also higher in duopoly than in triopoly. By contrast, neither subject matching nor the knowledge condition has any significant effect. Again, whereas the absolute price levels are lower than predicted by the theory, the relative effect of the number of firms on prices conforms to the prediction. Moreover, both significant effects on pricing are in line with the experimental results reported by Lepore and Shafran (2013), Brandts and Guillen (2007), and Cracau and Franz (2014).

The high capacities observed in the early periods of the experiment suggest that initially some subjects fail to appreciate the impact of their capacity choice on the pricing subgame in the second stage. Le Coq and Sturluson (2012) find that the sensitivity of pricing decisions to installed capacity is higher in later

²² As an artifact of the regression, a price-increasing effect of increasing capacity occurs if capacity exceeds 1,673 units. However, this result is of little relevance since capacities only exceed this level in under two percent of our observations.

²³ As the regression contains no general constant but a full set of treatment dummies without an omitted category, the β and γ coefficients function as treatment-specific constants and indicate the starting point and long-term price levels in the respective treatment when all other variables take values of zero. Hence, in specification [2] the estimates of the β and γ coefficients pertain to price levels in the respective treatment in a hypothetical state with zero capacity.

periods. To investigate this issue in our setting, we set up two further regressions. The first, specification [3], has the form

$$P_{ht} = \sum_{j=1}^7 \left(\beta_j TD_j \frac{1}{t} + \gamma_j TD_j \frac{t-1}{t} \right) + \delta K_{ht} \frac{1}{t} + \zeta K_{ht} \frac{t-1}{t} + \varepsilon_{ht}.$$

[3]

The dependent variable is market price P in market h and period t . The term in brackets estimates treatment-specific price starting points and convergence levels, as known from the above regressions. Two additional terms capture the interaction between installed market capacity K_{ht} and period weights. The δ coefficient estimates the sensitivity of pricing to capacity in the first period, while the ζ coefficient estimates this sensitivity in the long term (when t goes to infinity). We expect capacity to have a price-decreasing effect in all periods, i. e. both δ and ζ should be negative. Moreover, the sensitivity should increase over periods as more subjects learn about the effect of their choices in the first stage, i. e. ζ should be smaller (larger in absolute value) than δ . The results presented in Table 4 confirm

Table 4: Sensitivity of pricing to capacity: regression results.

	(3)		(4)	
	δ	ζ	δ_j	ζ_j
	−0.109*** (0.022)	−0.280*** (0.009)		
Treatment 1			−0.087 (0.055)	−0.286*** (0.020)
$n=2$, eff. rat., fixed match.			0.021 (0.065)	−0.284*** (0.032)
Treatment 2			−0.023 (0.038)	−0.085*** (0.016)
$n=2$, prop. rat., fixed match.			−0.114** (0.045)	−0.260*** (0.024)
Treatment 3			−0.028 (0.076)	−0.419*** (0.028)
$n=3$, eff. rat., fixed match.			−0.165*** (0.057)	−0.430*** (0.017)
Treatment 4			−0.369*** (0.059)	−0.329*** (0.037)
$n=3$, prop. rat., fixed match.				
Treatment 5				
$n=2$, eff. rat., random match.				
Treatment 6				
$n=2$, prop. rat., random match.				
Treatment 7				
$n=2$, eff. rat., fixed match., high knowledge				
Observations	1,458		1,458	
Adjusted R^2	0.512		0.607	

Notes: GLS regressions with clustered errors at market level. Clustered standard errors in parentheses. ***, **, and * denote significance at the 1, 5, and 10 percent level.

these suppositions.²⁴ Both δ and ζ are significantly negative, and ζ is significantly smaller than δ at the one-percent level (t -test).

In specification [4], capacity is interacted with both period weights and treatment dummies TD_j . We can thus consider the sensitivity of pricing to capacity at the treatment level. The regression equation is

$$P_{ht} = \sum_{j=1}^7 \left(\beta_j TD_j \frac{1}{t} + \gamma_j TD_j \frac{t-1}{t} + \delta_j K_{ht} TD_j \frac{1}{t} + \zeta_j K_{ht} TD_j \frac{t-1}{t} \right) + \varepsilon_{ht}. \quad [4]$$

The regression results in Table 4 show that the δ coefficient is not significantly different from zero in four of the seven treatments (treatments 1, 2, 3, and 5). That is, we cannot reject the null hypothesis that subjects choose prices while completely ignoring installed capacities in the first period of these treatments. In treatments 4 and 6, installed capacity significantly decreases prices, but the effect is rather small. Only in treatment 7 do we find a significant and sizable negative effect. By contrast, in the long term, higher capacities lead to lower prices in all treatments, as all ζ coefficients are negative and significant. The sensitivity of pricing to capacity significantly increases from early to later periods in five treatments (null hypothesis $\zeta_j = \delta_j$ rejected in favor of $\zeta_j < \delta_j$, $p < 0.01$, t -tests). The two exceptions are treatment 3, where sensitivity is still small in the long term, and treatment 7, where sensitivity is large from the beginning. It appears that the extensive instructions provided for the high-knowledge treatment were successful in enlightening the subjects on the connection between capacity and price choices *ex ante*, while many subjects in the other treatments had to learn about that connection from experience.

We now compare our pricing data to the Nash equilibrium prediction in the pricing subgame given capacity choices. A testable theoretic prediction is only available if individual capacities k_i are so small that market-clearing pricing is the pure-strategy equilibrium of the second-stage subgame. If, by contrast, chosen capacities at the first stage are too large, the equilibrium strategies involve randomization over prices. The conditions for market-clearing pricing to be the equilibrium of the second-stage subgame depend on both the demand rationing scheme and the number of firms in the market. Under efficient rationing, in a market with n firms, there are n conditions which must simultaneously hold. In our setting, those conditions are

$$k_i \leq 500 - \sum_{j \neq i} k_j / 2, i = 1, \dots, n. \quad [5]$$

²⁴ As they are not in the focus of our interest in these regressions, the estimates for the β and γ coefficients are omitted in Table 4.

Under proportional rationing, the condition is that the sum of individual capacities must not be greater than 500,²⁵

$$\sum_i k_i \leq 500.$$

[6]

It is immediately obvious that the condition under proportional rationing is more restrictive, i. e., the region of capacity vectors for which market-clearing pricing is the equilibrium under proportional rationing is a proper subset of the respective region under efficient rationing.²⁶

The data in the first column of Table 5 show how often in the first stage subjects choose capacities that entail market-clearing pricing as the equilibrium

Table 5: Market clearing in the pricing subgame.

	Market-clearing pricing is Nash equilibrium	Market cleared	Exact market-clearing price chosen...	
			...At individual level	...By all subjects in the market
Treatment 1	0.159	0.625	0.400	0.075
<i>n</i> = 2, eff. rat., fixed match.	(40/252)	(25/40)	(32/80)	(3/40)
Treatment 2	0.019	0.750	0.250	0.000
<i>n</i> = 2, prop. rat., fixed match.	(4/216)	(3/4)	(2/8)	(0/4)
Treatment 3	0.093	0.300	0.233	0.000
<i>n</i> = 3, eff. rat., fixed match.	(20/216)	(6/20)	(14/60)	(0/20)
Treatment 4	0.009	1.000	0.167	0.000
<i>n</i> = 3, prop. rat., fixed match.	(2/216)	(2/2)	(1/6)	(0/2)
Treatment 5	0.085	0.294	0.559	0.294
<i>n</i> = 2, eff. rat., random match.	(17/198)	(5/17)	(19/34)	(5/17)
Treatment 6	0.069	0.333	0.100	0.000
<i>n</i> = 2, prop. rat., random match.	(15/216)	(5/15)	(3/30)	(0/15)
Treatment 7	0.146	0.429	0.524	0.333
<i>n</i> = 2, eff. rat., fixed match., high knowledge	(21/144)	(9/21)	(22/42)	(7/21)
Treatments 1–7	0.082	0.462	0.358	0.126
	(119/1,458)	(55/119)	(93/260)	(15/119)

25 See Lepore (2009) for an extensive discussion of these conditions.

26 Iskakov and Iskakov (2014) apply their concept of equilibrium in secure strategies to capacity-constrained price competition. Equilibrium in secure strategies is a broad pure-strategy equilibrium concept that contains Nash equilibrium in pure strategies as a special case, i. e. every pure-strategy Nash equilibrium is also an equilibrium in secure strategies. The conditions for a strategy bundle to be an equilibrium in secure strategies are that (i) no player *i* can

of the second-stage subgame. Averaged over all treatments, such capacity vectors are chosen in only 8.2 percent of all instances. Pricing subgames with a pure-strategy equilibrium are especially rare in the treatments with proportional rationing (3.2 percent).

In the further analysis, we consider only those subgames where market-clearing pricing is the pure-strategy equilibrium and investigate whether markets actually clear in the second stage and whether subjects choose the exact market-clearing Cournot price of $1000 - \sum_i k_i$. The results are displayed in the remaining columns of Table 5. We observe that market clearing occurs only in somewhat less than half of the instances where it is predicted. Nevertheless, the theoretical equilibrium has some predictive power, since market clearing occurs in less than five percent of those cases where it is not predicted by first-stage capacities (data not reported). Our result stands in contrast to Lepore and Shafran (2013), who find that their KS markets clear in roughly 90 percent of the cases where it is predicted. However, most of their observations stem from their high-cost treatments, and the few observations from their low-cost treatments that are comparable to ours show substantially lower rates. Muren's (2000) KS markets clear in 50 to 60 percent of the cases where it is predicted, which is reasonably close to our rate of 46.2 percent. As regards exact market-clearing pricing, we find that the respective price of $1000 - \sum_i k_i$ is set by a subject in 35.8 percent of the cases where this price is the pure strategy equilibrium.^{27,28} Considering this issue at the market level,

represent a threat to another player j , i. e. i cannot change her strategy such that i 's payoff increases and j 's payoff decreases, and (ii) no player can profitably and securely deviate from the given strategy bundle, where a deviation is secure if the execution of any threats the deviating player exposes herself to by her deviation cannot reduce her payoff below her initial payoff level. Using this equilibrium concept, Iskakov and Iskakov show that under proportional rationing an equilibrium in secure strategies exists if capacities fulfill the conditions given above for *efficient* rationing and the equilibrium implies market-clearing pricing. While they consider only proportional rationing, their arguments also apply in the case of efficient rationing. Hence, interestingly, they provide an equilibrium concept where the conditions for existence of a pure-strategy equilibrium do not depend on demand rationing.

27 Here decisions at the individual level are analyzed. The number of analyzed cases is therefore given by the number of markets where market clearing is the equilibrium multiplied by the number of firms in each market.

28 Davis (1999) finds that in the initial periods of his KS treatment, subjects choose the market-clearing price in about 20 percent of those cases where market-clearing pricing is the equilibrium. This share increases throughout the experiment, fluctuating around the 85-percent mark in the final periods. However, Davis' results are not directly comparable to ours for several reasons. The price grid Davis employs is coarser than ours. The maximum capacity each firm can install is smaller relative to market demand than in our setting, which renders capacity choices where market

we find that the exact market-clearing price is set by all firms in the market in 12.6 percent of the cases.

Examining the data in the third column of Table 5, we note that subjects in the treatments with efficient rationing have a higher propensity for choosing the exact market-clearing Cournot price than subjects in the treatments with proportional rationing. The relative frequencies are 40.3 percent under efficient rationing and 13.6 percent under proportional rationing. A chi-squared test refutes independence of frequencies from the rationing scheme at the one-percent significance level.²⁹ This result parallels the finding from Section 5.2 saying that under efficient rationing, exact Cournot capacities are more likely to be installed in the first stage. Yet, whereas the influence of the rationing scheme in the first stage corresponds to the equilibrium prediction, in the second stage we find an unpredicted significant effect of the rationing scheme. Since we are considering only those markets with a pure-strategy equilibrium in the pricing subgame, the equilibrium predictions are now identical under both rationing schemes. We propose a somewhat speculative explanation for our finding in the second stage. Since capacities entailing market-clearing pricing as an equilibrium in the second stage are chosen more rarely under proportional rationing, subjects in those treatments had less opportunity for observing market-clearing pricing to be optimal when capacities are sufficiently small. If one assumes that experience is needed to understand optimal pricing, this would explain the observed difference in pricing behavior. This is a plausible assumption in the rather complex KS framework and is also corroborated by our finding referred to earlier: that subjects need experience to appreciate the link between their decisions in the first and second stages.

5.4 Profits

After examining capacity and price choices separately, we now look at how those choices interact and which profit levels they bring about. We observe that in all treatments profits are substantially lower than predicted by the respective

clearing is the equilibrium of the pricing subgame more likely. Subjects in Davis' study may therefore have more opportunities to learn optimal pricing strategy in such a situation. Moreover, prices that are no more than two cents below the exact market-clearing price are considered by Davis to be unsubstantial deviations from the equilibrium and are included in the above shares.

²⁹ This result remains valid if we exclude the data from treatment 7 following the argument advanced in fn. 18.

Cournot outcomes.³⁰ Moreover, profits are somewhat higher under proportional than under efficient demand rationing. This contrasts with the theory prediction but is in line with the results for the low-cost treatments reported by Lepore and Shafran (2013).

It is common in KS experiments for subjects to earn considerably less than the theoretical equilibrium profits. This is apparently due to excessive capacity installation at the first stage, which on the one hand entails costs for units that cannot be sold, and on the other induces low sales prices in the second stage. Since subjects continue to choose such high capacities many rounds later, when the experience they have gained might be expected to prevent this, the question that arises is whether they derive some latent utility from their behavior.

Davis (1999) suggests that subjects may strategically set high capacities in order to bully the other players in their market so that their competitors will install less capacity and leave a large share of the market to the bully. He argues that such attempts are often successful, referring to the strong positive correlation between capacity shares and profit shares within markets in his KS treatment data. While we find a similar correlation in our data,³¹ we do not consider this to provide sufficient evidence for the strategic success of bullying. After all, a larger capacity share leads to more market power, so it is likely to induce a higher profit share within a market. To judge success, however, performance across markets also needs to be considered. Davis acknowledges that average profits are lowest in the markets with the highest capacities.

The relationship between absolute individual capacities and absolute individual profits is suitable for investigating whether choosing high capacities is a successful strategy. The results are clearly negative. Spearman's rank correlation coefficient between the mean individual capacity and the mean individual profit per period is -0.47 in duopolies and -0.39 in triopolies. The scatter plots in Figure 5 allow for a more precise analysis. The kernel fits show that there exists an interior profit-maximizing capacity. According to the kernel regressions, the profit-maximizing capacity is 312 in duopoly and 274 in triopoly. The profit-maximizing capacity in duopoly is remarkably close to the Cournot capacity,

30 Summary statistics of profits per firm can be found in Table 7 in Appendix C. Considering only the raw individual profit data in that table, we see that due to high variances the mean individual profits in the treatments are not significantly different from their respective Nash prediction. However, putting up a regression similar to the one in Section 5.2 with individual profit as the endogenous variable, we find that in all treatments profit convergence levels are significantly smaller than the Nash equilibrium profit (all p 's < 0.01 , t -tests).

31 Spearman's rank correlation coefficient between the capacity share and the profit share of a subject in her market, both averaged over all periods, is 0.56. The data of 14 subjects are disregarded in the calculation because in those cases the average market profit is negative.

Figure 5: Scatter plots of individual capacities and individual profits with kernel fits.

whereas in triopoly it is roughly 20 percent above Cournot. The corresponding profit is about 56,300 in duopoly and about 17,400 in triopoly. In other words, the average profit that can be attained with an empirically optimal capacity choice is still considerably lower than the equilibrium profit. Furthermore, subjects on average set substantially higher capacities than optimal *ex post*. We therefore do not share Davis' view of excess capacities as successful bully behavior.

From a different vantage, Lepore and Shafran (2013) argue that when the cost for installing capacity is low, subjects stand to lose little by choosing too high a capacity that is not fully utilized in the second stage. However, high capacities may generate large gains if the other players happen to install low capacities. High capacity choices may thus be considered gambling behavior. The kernel fits in Figure 5 illustrate that, on average, subjects lose by gambling. Moreover, we find that high profits in one period do not correlate with high capacity choices. Categorizing individual capacity choices in single periods by profit, we see that the highest individual profits are actually realized at below-average individual capacities.³² High profits are apparently more likely to be triggered by implicit collusion with low capacities than by exploiting opportunities induced by high individual capacities.

To some extent, our analysis questions the explanations for excess capacities in the literature since it shows that choosing high capacities is rarely fruitful, no matter whether one assumes a strategic or an opportunistic rationale behind such decisions. It is thus an unresolved question why even in the long term the futility of such tactics fails to register with the subjects.

³² The data can be found in Table 8 in Appendix C.

6 Conclusion

This study adds to the scant literature on experimental Kreps–Scheinkman oligopoly markets by providing a comprehensive analysis on how different experimental conditions impact on market outcomes. Seven treatments are conducted with different combinations of the following four treatment variables: number of firms in a market, demand rationing, subject matching, and subjects' understanding of KS markets (referred to as “knowledge”). Theory predicts the Cournot outcome under efficient demand rationing and a more competitive outcome driven by mixed strategies under proportional rationing.

We find that in all treatments both capacity choice and pricing is considerably more competitive than the Cournot outcome. Larger market capacities are chosen in triopoly than in duopoly, which is qualitatively in accordance with the predicted effect. Subjects with high knowledge first set lower capacities, but the effect vanishes when low-knowledge subjects reduce their capacities after the initial rounds. Neither demand rationing nor subject matching affects capacity choice. At the pricing stage, both the number of firms and demand rationing have persistent effects. Prices are higher in duopoly than in triopoly and with proportional than with efficient rationing. Again, knowledge makes a difference only in the initial rounds. Investigating the sensitivity of price choices to installed capacity, it appears that subjects in the low-knowledge condition have to learn by experience about the relationship between capacity and price choices. Both exact Cournot capacities and exact market-clearing pricing are more likely to occur under efficient than under proportional demand rationing. Subjects' earnings fall substantially short of equilibrium profits due to excessive capacity installation. It still remains a puzzle why even after many rounds, subjects do not reduce capacities.

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Appendix A

Translation (from German) of the written instructions in treatments 3 and 7

Treatment 3

Welcome to the Laboratory for Economic Experiments at Kiel University.

You are about to participate in an economic experiment where you will have to make some decisions. You can also earn some money. The amount of money

will depend both on your own decisions and the decisions of the other participants in the experiment.

Please read these instructions carefully. If you have any questions, please raise your hand. An experimenter will come over and answer your questions personally. Please do not communicate with other participants during the experiment.

All participants receive the same instructions.

In this experiment you represent a **firm** producing and selling a single good. In a given market, you **compete with two other firms** represented by two of the other participants. All firms produce and sell the same good.

For your participation you will receive a fee of EUR 6, but you can earn more money in the course of the experiment. The amount will depend both on your own decisions and the decisions of the other participants in the experiment.

Throughout the experiment, all financial transactions are expressed in **Experimental Currency Units (ECU)**. Your **start balance** at the beginning of the experiment is **240,000 ECU**. You will be paid your final balance at the end of the experiment at an **exchange rate of 40,000 ECU/Euro**, i. e. for each 40,000 ECU of your final balance you will receive 1 Euro. Additionally, you will receive your participation fee.

The experiment consists of **18 periods**. At the beginning of the experiment, the participants will be randomly divided into groups of three. The other members of your group will be your competitors. The group constellation will remain fixed throughout the experiment.

Each period of the experiment consists of two stages:

First stage: In the first stage, you and the other firms must simultaneously and independently **decide on your production quantity** of the good. All **integers from 0 to 1,000 are admissible** quantities.

Production incurs **costs of 100 ECU per unit produced**. Your production costs will be subtracted from your balance.

After the first stage, all firms will be informed about the production quantities of the other firms in their group.

Second stage: In the second stage, you and the other firms must simultaneously and independently **decide on your asking price** for the good on the market. All **integers from 0 up to 1,000 are admissible** prices.

Your sales revenue will be added to your balance. Your sales revenue is equal to the price you choose multiplied by your sales quantity. Your sales quantity depends both on the production quantities and the prices chosen by

you and the other firms. In the following paragraphs you will find a precise description of the way sales quantities are determined.

Market demand describes the maximum quantity of the good that can be sold in each period at a given price. Demand will be simulated by the computer and will be identical in all periods. There are many different potential customers with different amounts of willingness to pay for the good. A sale will come about if the offering price is no higher than a customer's maximum willingness to pay. At a price of 0 ECU, there will be a total demand for 1,000 units on the market. A price increase of 1 ECU will reduce demand by 1 unit. For example, a price of 500 ECU will correspond to a demand for 500 units. At a price of 1,000 ECU no one will be prepared to buy the good. Here is a graphic representation of this relationship:

In each period, firms can sell no more units of the good in the second stage than they have produced in the first stage.

Customers will first try to purchase the good from the firm offering the lowest price. The customers with the highest willingness to pay will be served first. If several firms choose the same price, demand will be divided equally among them.

If a firm has not chosen the lowest price in its group, residual demand may or may not occur. This is illustrated by the following two examples: For both examples assume that firms 1 and 2 have chosen prices of 300 ECU and 400 ECU, respectively. Let the production quantity of firm 1 be 700 units in the first example and 200 units in the second and the production quantity of firm 2 100 units in both cases.

We are interested in the remaining demand for firm 3 if it asks a different price. In the figures below, the remaining demand for firm 3 is represented by the bold line.

If firm 3 chooses a price below 300 ECU, its price will be the lowest, and the entire market demand will fall to it.

If firm 3 chooses a price above 300 ECU, firm 1 will sell its units first. In the first example (upper figure), the production quantity of firm 1 satisfies the entire demand at this price, so the other firms are unable to sell any units at prices above 300 ECU. In the second example (lower figure), however, the production quantity of firm 1 is not enough to satisfy all market demand. Accordingly, a residual demand is left over at prices above 300 ECU. If firm 3 then chooses a price above 400 ECU, firm 2 will also sell its units previous to firm 3. In the example, firm 2 again cannot satisfy all remaining demand at a price of 400 ECU, so there is some residual demand left for firm 3 even at prices higher than 400 ECU.

If a firm cannot sell its entire first-stage production in the second stage, the units left will be forfeited, i. e. they cannot be transferred to the next period. However, production costs are incurred for all units produced, whether they can be sold or not.

Your **profit** or loss (in ECU) in a period is equal to your **sales revenue** (= the price you choose multiplied by your sales quantity) in **the second stage minus** your **production costs** (= the production quantity you choose multiplied by 100 ECU) in **the first stage**.

Your balance in each period is increased or decreased by your profit or loss in that period. If your balance should become negative during the experiment, you can still go on producing and selling, i. e. your firm has unlimited credit in the experiment. If your final balance at the end of the experiment should be negative, you will only be paid your participation fee. Your participation fee will not be used to offset any losses.

To get a general idea of the sales quantities and profits resulting from different price and quantity combinations, use the “**profit calculator**”. Simply enter a hypothetical production quantity and a hypothetical asking price for each firm and click on “Calculate”. Your resulting sales quantity and profit will be displayed. You can use the profit calculator throughout the experiment.

After each period, a “**history**” screen will inform you about the outcomes so far. For all previous periods, it shows the production quantities and prices chosen by the firms, your resulting sales quantity, your sales revenue, your production costs, and your profit. Your current money balance will also be displayed.

The following two screenshots illustrate the use of the profit calculator and the history screen:

Here you can enter three hypothetical production quantities and asking prices and have the results calculated.

Profit calculator

My production quantity: 220

Other production quantity 1: 100

Other production quantity 2: 100

My price: 300

Other price 1: 220

Other price 2: 200

Calculate

My production quantity	Other production quantity 1	Other production quantity 2	My price	Other price 1	Other price 2	My sales quantity	My profit
220	100	100	300	220	100	220	22000
220	100	100	300	220	100	100	10000
220	100	100	300	220	100	0	-22000
220	100	100	300	220	100	0	-22000

Here you can enter and submit your choice for the current period (production quantity in the first stage, asking price in the second stage).

First stage:
Choice of production quantities

My production quantity:

Submit

The results of the profit calculator are displayed here.

For practice purposes, there will be **three trial periods** before the actual periods start. The procedures in the trial periods are the same as in the actual periods described above, but the outcomes of the trial periods will not add to your payoff. Your start balance for the trial periods is 100,000 ECU. After the trial periods your balance will be set at 240,000 ECU – your start balance for the actual periods – independently of your profits or losses in the trial periods. After the trial periods, the participants will be randomly re-divided into new groups. The new groups will stay as they are throughout all actual periods of the experiment. The profit calculator will be available to you during the trial periods and the actual periods. The history, however, will not be displayed after the trial periods and will only contain data pertaining to the actual periods.

After the experiment, your **final balance** will be **paid out to you** at the exchange rate referred to earlier. Additionally, you will receive your participation fee. None of the other participants will know how much you get, nor will you know how much they get. In addition, no participant has any way of finding out who he/she was interacting with during the experiment.

Clicking on the “Continue” button on your screen will show you statements designed to check whether all participants have understood the instructions. Please decide whether those statements are right or wrong. As soon as all participants have evaluated the statements correctly, the first trial period will start.

If you have any questions concerning the experiment, please raise your hand. Good luck and have fun!

Treatment 7

Welcome to the Laboratory for Economic Experiments at Kiel University.

You are about to participate in an economic experiment where you will have to make some decisions. You can also earn some money. The amount of money will depend both on your own decisions and the decisions of the other participants in the experiment.

Please read these instructions carefully. If you have any questions, please raise your hand. An experimenter will come over and answer your questions personally. Please do not communicate with other participants during the experiment.

All participants receive the same instructions.

In this experiment you represent a **firm** producing and selling a single good. In a given market, you **compete with one other firm** represented by one of the other participants. All firms produce and sell the same good.

For your participation you will receive a fee of EUR 6, but you can earn more money in the course of the experiment. The amount will depend both on your own decisions and the decisions of the other participants in the experiment.

Throughout the experiment, all financial transactions are expressed in **Experimental Currency Units (ECU)**. Your **start balance** at the beginning of the experiment is **200,000 ECU**. You will be paid your final balance at the end of the experiment at an **exchange rate of 40,000 ECU/Euro**, i.e. for each 40,000 ECU of your final balance you will receive 1 Euro. Additionally, you will receive your participation fee.

The experiment consists of **9 periods**. At the beginning of the experiment, the participants will be randomly divided into groups of two. The other member of your group will be your competitor. The group constellation will remain fixed throughout the experiment.

Each period of the experiment consists of two stages:

First stage: In the first stage, you and the other firm must simultaneously and independently **decide on your production quantity** of the good. All **integers from 0 up to 1,000 are admissible** quantities.

Production incurs **costs of 100 ECU per unit produced**. Your production costs will be subtracted from your balance.

After the first stage, all firms will be informed about the production quantity of the other firm in their group.

Second stage: In the second stage, you and the other firm must simultaneously and independently **decide on your asking price** for the good on the market. All **integers from 0 up to 1,000 are admissible** prices.

Your sales revenue will be added to your balance. Your sales revenue is equal to the price you choose multiplied by your sales quantity. In the following paragraphs you will find a precise description of the way sales quantities are determined.

Market demand describes the maximum quantity of the good that can be sold in each period at a given price. Demand will be simulated by the computer and will be identical in all periods. The market demand function $MD(p)$ is given by

$$MD(p) = 1000 - p.$$

At a price of 0 ECU, there will be a total demand for 1,000 units on the market. A price increase of 1 ECU will reduce demand by 1 unit. At a price of 1,000 ECU no one will be prepared to buy the good. Here is a graphic representation of this relationship:

Customers will first try to purchase the good from the firm offering the lowest price. The customers with the highest willingness to pay will be served first. If both firms choose the same price, demand will be divided equally among them.

Your sales quantity depends both on the production quantities and the prices you choose and those chosen by the other firm. Three cases are to be distinguished: **1.** You choose the lower price. The entire market demand falls to you. **2.** Both firms choose the same price. Market demand is divided equally. **3.** You choose the higher price. First the other firm will sell up to its capacity. There may or may not be some residual demand left for you.

This is illustrated by the following two examples. For both examples assume that the other firm has chosen a price of 300 ECU. Let the production quantity of the other firm be 200 units in the first example and 700 units in the second.

In the figures above, the remaining demand for your firm is represented by the bold line.

If your price is lower than 300 ECU, your price is the lowest and the entire market demand falls to you. If your price is higher than 300 ECU, the other firm will sell its units first. The bold line in the figures is shifted leftwards by this quantity. In the first example (upper figure), the production quantity of the other firm is not enough to satisfy all market demand. Accordingly, residual demand is left over for you at prices above 300 ECU. In the second example (lower figure), however, the production quantity of the other firm satisfies the entire demand at this price, so you will be unable to sell any units at prices above 300 ECU.

Formally, the demand that falls to a firm can be expressed as follows: Let q be your production quantity, $\tilde{q}$ the production quantity of the other firm, and p

and $\tilde{p}$ the prices chosen by you and the other firm, respectively. The demand falling to you is given by

$$D = \begin{cases} 1000 - p & p < \tilde{p} \\ 500 - p/2 & p = \tilde{p} \\ \max\{0, 1000 - p - \tilde{q}\} & p > \tilde{p} \end{cases}$$

D cannot be negative. If you have chosen the higher price and $1000 - p - \tilde{q}$ yields a negative value, your residual demand is zero.

In the second stage, you can sell at most as many units as are demanded. Moreover, you can sell no more than you have produced in the first stage. That is, your sales quantity V is given by the minimum of these two values:

$$V = \min\{D, q\}.$$

Look at the following two examples to see how your sales quantity is determined.

Example 1	Production quantity (units)	Price (ECU)
My firm	300	400
Other firm	200	300

You have chosen the higher price. Your residual demand is $D = 1000 - p - \tilde{q} = 1000 - 400 - 200 = 400$. As you have produced no more than 300 units, that is the highest number of units you can sell: $V = \min\{400, 300\} = 300$.

Example 2	Production quantity (units)	Price (ECU)
My firm	300	350
Other firm	700	250

You have again chosen the higher price. $1000 - p - \tilde{q} = 1000 - 350 - 700 = -50$ yields a negative value. Your residual demand is $D = \max\{0, -50\} = 0$. You therefore cannot sell any units, $V = \min\{0, 300\} = 0$.

If a firm cannot sell its entire first-stage production in the second stage, the units left will be forfeited, i. e. they cannot be transferred to the next period. However, production costs are incurred for all units produced, whether they can be sold or not.

Your **profit** or loss Π (in ECU) in a period is equal to your **sales revenue** (= the price you choose multiplied by your sales quantity) in **the second stage** **minus** your **production costs** (= production quantity you choose multiplied by 100 ECU) in **the first stage**:

$$\Pi = Vp - 100q.$$

This profit function due to the case discriminations in determining sales quantity is a piecewise function. Given the production quantities q and $\tilde{q}$ and the price chosen by the other firm $\tilde{p}$, the following prices are possible candidates for the price that maximizes your profit:

- (I) $p = 1000 - q$,
- (II) $p = 1000 - q - \tilde{q}$,
- (III) $p = 500$
- (IV) $p = 500 - \tilde{q}/2$, round to next integer if applicable,
- (V) $p = \tilde{p}$,
- (VI) $p = \tilde{p} - 1$.

When you make your price choice in the experiment, you will know about q and $\tilde{q}$, but not about $\tilde{p}$. However, you can interpret $\tilde{p}$ as the price you expect the other firm to choose.

The following example illustrates how to find your profit-maximizing price given q , $\tilde{q}$, and $\tilde{p}$.

Example 3	Production quantity (units)	Price (ECU)
My firm	400	?
Other firm	400	300

The candidates for your profit-maximizing price are (I) 600, (II) 200, (III) 500, (IV) and (V) 300, and (VI) 299.

The price candidates yield the following sales quantities and profits:

(I)	$V = 1000 - 600 - 400 = 0$	$\Pi = 0 \cdot 600 - 100 \cdot 400 = -40000$.
(II)	$V = \min\{1000 - 200, 400\} = 400$	$\Pi = 400 \cdot 200 - 100 \cdot 400 = 40000$.
(III)	$V = 1000 - 500 - 400 = 100$	$\Pi = 100 \cdot 500 - 100 \cdot 400 = 10000$.
(IV) and (V)	$V = 500 - 300/2 = 350$	$\Pi = 350 \cdot 300 - 100 \cdot 400 = 65000$.
(VI)	$V = \min\{1000 - 299, 400\} = 400$	$\Pi = 400 \cdot 299 - 100 \cdot 400 = 79600$.

A comparison of the profits reveals that 299 is your profit-maximizing price choice in this example.

Your balance in each period is increased or decreased by your profit or loss in that period. If your balance should become negative during the experiment, you can still go on producing and selling, i. e. your firm has unlimited credit in the experiment. If your final balance at the end of the experiment should be negative, you will only be paid your participation fee. Your participation fee will not be used to offset any losses.

To get a general idea of the sales quantities and profits resulting from different price and quantity combinations, use the “**profit calculator**”. Simply enter a hypothetical production quantity and a hypothetical asking price for

each firm and click on “Calculate”. Your resulting sales quantity and profit will be displayed. You can use the profit calculator throughout the experiment.

After each period, a “**history**” screen will inform you about the outcomes so far. For all previous periods, it shows the production quantities and prices chosen by the firms, your resulting sales quantity, your sales revenue, your production costs, and your profit. Your current money balance will also be displayed.

The following two screenshots illustrate the use of the profit calculator and the history screen:

Here you can enter two hypothetical production quantities and asking prices and have the results calculated.

Here you can enter and submit your choice for the current period (production quantity in the first stage, asking price in the second stage).

Profit calculator

My production quantity: 500

Other production quantity: 400

My price: 300

Other price: 200

Calculate

First stage: Choice of production quantities

My production quantity:

Submit

My production quantity	Other production quantity	My price	Other price	My sales quantity	My profit
240	500	400	400	0	-24000
240	500	400	400	0	-8700
240	500	400	400	240	9000
250	400	500	200	16	23000
300	400	300	200	240	10000

The results of the profit calculator are displayed here.

Results in this period

Your current balance is: 20100

My production quantity: 500

Other production quantity: 400

My price: 600

Other price: 400

My sales quantity: 0

My revenue: 0

My cost: 50000

My profit: -50000

Period	My production quantity	Other production quantity	My price	Other price	My sales quantity	My revenue	My cost	My profit
-2	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0	0
1	400	500	300	500	400	120000	40000	120000
2	500	400	400	200	0	0	50000	-50000
3	500	400	600	400	0	0	50000	-50000

Go to next period

This is the history showing the outcomes of all previous periods. Zeros are displayed for trial periods.

For practice purposes, there will be **three trial periods** before the actual periods start. The procedures in the trial periods are the same as in the actual

periods described above, but the outcomes of the trial periods will not add to your payoff. Your start balance for the trial periods is 100,000 ECU. After the trial periods your balance will be set at 200,000 ECU – your start balance for the actual periods – independently of your profits or losses in the trial periods. After the trial periods, the participants will be randomly re-divided into new groups. The new groups will stay as they are throughout all actual periods of the experiment. The profit calculator will be available to you during the trial periods and the actual periods. The history, however, will not be displayed after the trial periods and will only contain data pertaining to the actual periods.

After the experiment, your **final balance** will be **paid out to you** at the exchange rate referred to earlier. Additionally, you will receive your participation fee. None of the other participants will know how much you get, nor will you know how much they get. In addition, no participant has any way of finding out who he/she was interacting with during the experiment.

Clicking on the “Continue” button on your screen will show you tasks designed to check whether all participants have understood the instructions. As soon as all participants have solved the tasks, the first trial period will start.

If you have any questions concerning the experiment, please raise your hand. Good luck and have fun!

Appendix B

Translation of the control questions

Control questions in treatments 1–6

Binary choice: correct or incorrect.

1. The participants will be re-divided into new groups before each period of the experiment. – Correct if random matching condition; incorrect if fixed matching condition.
2. In each period each firm first chooses its production quantity. Firms are informed about all production quantities in their group. Then each firm chooses its asking price. – Correct.
3. Production costs per unit are equally large for every unit. – Correct.
4. A firm that has not chosen the lowest price in its group can never sell any units in the respective period. – Incorrect.
5. If a firm is unable to sell its whole production in one period, it can re-offer the unsold units in the next period. – Incorrect.

Control tasks in treatment 7

Task 1	Production quantity (units)	Price (ECU)
My firm	500	300
Other firm	500	350

My sales quantity: ____ (correct answer: 500)

My profit: ____ (correct answer: 100,000)

Task 2	Production quantity (units)	Price (ECU)
My firm	700	400
Other firm	400	500

My sales quantity: ____ (correct answer: 600)

My profit: ____ (correct answer: 170,000)

Task 3	Production quantity (units)	Price (ECU)
My firm	400	450
Other firm	500	400

My sales quantity: ____ (correct answer: 50)

My profit: ____ (correct answer: -17,500)

Task 4	Production quantity (units)	Price (ECU)
My firm	300	?
Other firm	300	400

My profit-maximizing price: ____ (correct answer: 400)

My maximum profit: ____ (correct answer: 90,000)

Task 5	Production quantity (units)	Price (ECU)
My firm	250	?
Other firm	200	200

My profit-maximizing price: ____ (correct answer: 550)
My maximum profit: ____ (correct answer: 112,500)

Task 6	Production quantity (units)	Price (ECU)
My firm	400	?
Other firm	400	500

My profit-maximizing price: ____ (correct answer: 499)
My maximum profit: ____ (correct answer: 159,600)

Appendix C

Table 6: Frequencies of Cournot capacities.

	<i>Exact</i>	<i>± 5 percent</i>	<i>± 10 percent</i>
Treatment 1	0.032	0.052	0.131
<i>n</i> = 2, eff. rat., fixed match.	(8/252)	(13/252)	(33/252)
Treatment 2	0.009	0.032	0.116
<i>n</i> = 2, prop. rat., fixed match.	(2/216)	(7/216)	(25/216)
Treatment 3	0.000	0.051	0.079
<i>n</i> = 3, eff. rat., fixed match.	(0/216)	(11/216)	(17/216)
Treatment 4	0.000	0.065	0.083
<i>n</i> = 3, prop. rat., fixed match.	(0/216)	(14/216)	(18/216)
Treatment 5	0.030	0.056	0.076
<i>n</i> = 2, eff. rat., random match.	(6/198)	(11/198)	(15/198)
Treatment 6	0.014	0.037	0.065
<i>n</i> = 2, prop. rat., random match.	(3/216)	(8/216)	(14/216)
Treatment 7	0.049	0.111	0.167
<i>n</i> = 2, eff. rat., fixed match., high knowledge	(7/144)	(16/144)	(24/144)
Treatments 1–7	0.018	0.055	0.100
	(26/1,458)	(80/1,458)	(146/1,458)

Table 7: Profits per firm: summary statistics.

Periods	1–18	1–9	10–18
Treatment 1 $n=2$, eff. rat., fixed match.	35,819.797 (43,860.007) [40,000.000]	26,553.708 (44,606.965) [25,100.000]	45,085.885 (41,144.603) [53,625.000]
Treatment 2 $n=2$, prop. rat., fixed match.	60,001.518 (37,421.334) [61,953.100]	53,699.266 (39,506.239) [55,980.550]	66,303.770 (34,156.647) [67,556.500]
Treatment 3 $n=3$, eff. rat., fixed match.	5,384.717 (29,451.782) [5,617.500]	–1,973.653 (31,908.973) [850.000]	12,743.088 (24,712.170) [12,000.000]
Treatment 4 $n=3$, prop. rat., fixed match.	18,823.696 (30,791.982) [17,525.000]	14,784.639 (31,241.118) [14,623.050]	22,862.752 (29,841.103) [19,775.000]
Treatment 5 $n=2$, eff. rat., random match.	34,128.109 (35,494.925) [35,070.500]	30,721.520 (36,747.108) [29,600.000]	37,534.697 (33,948.457) [38,557.500]
Treatment 6 $n=2$, prop. rat., random match.	42,031.159 (51,634.314) [34,855.350]	34,501.973 (49,213.397) [32,242.300]	49,560.345 (52,997.567) [42,914.000]
Treatment 7 $n=2$, eff. rat., fixed match., high knowledge	n.a.	49,834.674 (31,995.914) [52,399.500]	n.a.

Note: Standard errors in parentheses. Medians in square brackets.

Table 8: Individual capacities categorized by individual profits.

	$n=2$	$n=3$
All	455.562 (166.869) [431.000]	349.674 (168.973) [310.000]
Top profit decile	438.000 (134.388) [400.000]	324.566 (99.762) [300.000]
Bottom profit decile	579.483 (195.877) [600.000]	551.369 (201.295) [500.000]

Note: Standard errors in parentheses. Medians in square brackets.

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