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number of firms, rationing, matching, and knowledge: a comprehensive study of variations in experimental kreps-scheinkman markets

by Martin Jacobs

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

Martin Jacobs[§]

Abstract. This study provides a comprehensive picture of experimental Kreps-Scheinkman markets with capacity choice in the first stage and subsequent price competition at the second. We conduct seven different treatments of such markets, varying the number of firms, the demand rationing scheme, the subject matching, and subjects' knowledge about the market mechanism. We find that only the number of firms entails a persistent effect on capacity choices. Price choices are affected by both the number of firms and the rationing scheme. Subjects in the high-knowledge condition behave in the same manner from the first periods as subjects with low knowledge do in later periods after having gained experience. In all treatments conduct is generally more competitive than the Cournot outcome, irrespective of whether the Cournot outcome is the Nash equilibrium or not. Nevertheless, the Cournot model entails some predictive power. Exact Cournot choices are more likely to occur for both capacities and prices under efficient demand rationing, where the Cournot outcome is the equilibrium, than under proportional rationing.

JEL classification: C90, D43, L11, L13.

Key words: Kreps-Scheinkman, Cournot, price competition, capacity choice, demand rationing, oligopoly, laboratory experiment.

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1 Introduction

In their seminal work, Kreps and Scheinkman (1983) (hereafter KS) combine the features of the classical quantity and price setting models suggested 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 rationing, its outcome is equivalent to the Cournot outcome. This implies prices decline as more firms operate in the market.

While the KS model has been put to experimental tests against other market institutions, and more recently also variations within the KS model have come into the focus of experimental research, the evidence about the latter is still scattered and limited. The aim of this study is to provide a comprehensive analysis on how different experimental conditions affect the results within KS markets. For this purpose, we set up seven treatments mimicking the KS market environment while 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 about 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 number of firms and demand rationing have been investigated in one study already, our results present a comprehensive picture of what drives outcomes in experimental KS markets.

As to capacity choices, we find, contrary to existing literature, 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. The matching procedure does not have an impact either. Subjects with good understanding of the KS mechanism (“high-knowledge” treatment) choose lower capacities in the early periods, but the difference vanishes in later periods when subjects in the “low-knowledge” treatments gain experience. While capacities tend to decline as the number of periods already played increases, they converge to levels significantly higher than the Cournot benchmark in all treatments. Exact Cournot capacity choices are rarely observed, but occur significantly more often under efficient demand rationing, when the Cournot outcome is the Nash equilibrium prediction, than under proportional rationing

As to the second-stage outcomes (price choices), we observe considerably lower prices than in the Cournot outcome. Once more, the number of firms entails 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, also the rationing scheme has a significant effect: prices are higher with proportional than with efficient rationing. All effects remain valid if we control for the capacities chosen at the first stage.

The sensitivity of pricing to installed capacity is first low and increases with the number of periods played. That is, subjects have to learn about the effect of their capacity choices on the pricing subgame at the second stage. Only in the high-knowledge condition do subjects exhibit a large sensitivity from the beginning.

If subjects choose capacities sufficiently low such that market-clearing pricing is the pure-strategy equilibrium at the second stage, markets do not always clear. Again there is 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 at the two stages, average profits substantially fall short of the Cournot benchmark. It remains a puzzle why subjects continue to install excess capacities even after many rounds. Explanatory approaches from the literature do not withstand a closer scrutiny of our data.

The remainder of this 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 provides the equilibrium predictions. In section 5 we present our results while section 6 concludes.

2 Related literature

2.1 Theory

As to the theoretical literature, the abovementioned KS paper 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, Davidson and Deneckere (1986) find that the KS result is sensitive to which rationing rule is assumed, and show that other rationing rules leaving more residual demand to the higher pricing firm may result in mixed-strategy price setting equilibria rendering more competitive outcomes than Cournot. This matter is further clarified by Lepore (2009) who finds that, under certain conditions, the Cournot outcome *can* (but need not) survive under other than efficient rationing rules.^{1,2} Boccard and Wauthy

¹ More precisely, under the alternative assumption of proportional demand rationing the Cournot outcome is still an equilibrium if the costs for installing capacity at 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

(2000; 2004) 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 compared to theoretical benchmarks and to 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 mostly 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 prices to 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 being reported) are chosen above equilibrium level.

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

Some more recent experiments are, like our study, 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

game under either rationing rule when the competitor's production costs are uncertain or, respectively, market demand is uncertain when firms choose capacities.

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

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

between market capacities in duopolies and triopolies; however, in duopoly firms choose higher prices at the second stage.⁴

The experience effect is further scrutinized by Le Coq and Sturluson (2012) who not only let inexperienced and experienced subjects play against each other in homogeneous groups, but also pair inexperienced with experienced subjects. Moreover, in contrast to all aforementioned studies, 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 at the first stage. The authors conjecture that the subjects' level of rationality increases with experience and that experienced players anticipate and respond to the lesser rationality of their inexperienced opponents.

Finally, Lepore and Shafran (2013) study the impact of different rationing rules and 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 chosen frequently in the high-cost condition while higher capacities are common in the low-cost treatments. While the demand rationing rule does not impact on capacity choice, pricing is affected 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 at the second stage.

3 Experimental design and procedures

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

- Figure 1 about here -

All in all, we conducted seven treatments with different combinations of variable states. A matrix of the conducted treatments is provided in Figure 1 where the seven black numbered squares in the figure stand for the seven treatment conditions. Treatments which differ with respect to only one of the four treatment variables are connected with a line. The core treatment structure is made up of the treatment variables “number of firms” (duopoly and

⁴ Brandts and Guillen assume box demand which, strictly speaking, does not fit the KS model.

triopoly) and “demand rationing” (efficient and proportional) which are varied in a 2x2-design (treatments 1-4). In those four treatments, subjects interact within fixed groups throughout all rounds. Additionally, we also conducted two duopoly treatments with random subject matching and different rationing rules (treatments 5 and 6). While fixed matching is the prevailing condition in related experiments, and certainly the most realistic assumption with respect to real oligopoly markets, the original KS model pertains to a one-shot game. Treatments with random matching resembling a one-shot game are therefore needed to rigorously test the predictive power of the KS Cournot outcome and its sensitivity to the employed rationing scheme. Due to financial constraints and because the results of a study by Kruse (1993) suggest that one-shot Nash equilibria can predict behavior also in fixed matching treatments, we abstained from conducting random matching treatments in the triopoly. The remaining treatment number 7 has the purpose 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 in order to allow for a distinguished 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 $D(p) = 1000 - p$. At the first stage, firms choose their individual capacities k_i . Each firm can install 0 to 1000 integer units of capacity where each such unit costs 100 Experimental currency units (ECU). At the second stage, each firm decides about its price p_i , where integer values from 0 and 1000 ECU are admissible prices. 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 that firm cannot satisfy all the demand with its capacity, residual demand is left for the other firms. The quantity q_i firm i is able to sell in any period depends on the price vector \mathbf{p} , the capacity vector \mathbf{k} , and the effective rationing scheme,

⁵ The instructions are explained in greater detail below.

$q_i(\mathbf{p}, \mathbf{k})$

$$= \begin{cases} \max \left\{ 0, \min \left\{ \frac{1}{m} \left(1000 - p_i - \sum_{j|p_j < p_i} k_j \right), k_i \right\} \right\} & \text{for efficient rationing} \\ \max \left\{ 0, \min \left\{ \frac{1000 - p_i}{m} \left(1 - \sum_{j|p_j < p_i} \frac{k_j}{1000 - p_j} \right), k_i \right\} \right\} & \text{for proportional rationing} \end{cases}$$

where 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

In total 15 sessions were conducted in the economics experimental lab at Kiel University 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 of the undergraduate economics program. All those 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 upon their arrival. They could not infer with whom of the other subjects they would interact 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 the 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 which returned a subject's resulting sales quantity and profit when hypothetical capacity and price choices for all firms were entered.

When subjects finished reading the instructions, the experimenter 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-

⁶ As it 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 (2015) notes that this difference as well as the exact tie-breaking rule (when several firms set the same price) affects quantities and profits in some cases. While those effects also cause differences concerning the Nash equilibrium outcomes, the differences are tiny.

⁷ For part of the sessions, the hroot software package (Bock et al., 2014) was used for recruitment.

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

knowledge treatments, 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 aid of 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 price of the competitor's. In one of those three tasks, we asked for the profit maximizing price given (i) Cournot capacities were installed at the first stage and (ii) the market clearing Cournot price was set by the competitor at the second stage. The instructions and training in the high-knowledge treatment were tailored in a way 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 the tasks had been finished, three unpaid trial rounds and 18 paid rounds of the KS game were played. Since reading the instructions and working through the tasks would 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 minutes in both knowledge conditions. 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 about their competitors' profits explicitly, but could easily inquire them using the profit calculator if they wanted to.

Subjects received a show-up fee of 6 Euro plus the sum of their earnings in the paid rounds at a predefined exchange rate. Moreover, they had a starting balance to compensate for losses in early periods.⁹ Subjects had an unlimited credit during the experiment; if their balance became negative, they could nevertheless go on installing capacity and selling. In case a subject's 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 19.7 Euro, including the show-up fee.

⁹ The exchange rate was 40,000 ECU per Euro in the triopoly treatments and in the high-knowledge duopoly treatment, and 80,000 ECU per Euro in the low-knowledge duopoly treatments. 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.

4 Equilibrium predictions

The setting originally investigated by KS is most closely resembled in 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 at the first stage (implying a market capacity of $K = \sum_i k_i = 600$) and a market-clearing price of $p = 400$ set at 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 does no longer hold and that in general there will be a unique mixed-strategy Nash equilibrium that, given the low production costs in our setting, 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 possibly arise. In case of infinite repetition and a sufficiently high discount factor, all outcomes dominating the one-shot Nash equilibrium can be sustained by a suitable trigger strategy (Friedman, 1971). Benoît and Krishna (1987) show that in the KS framework this 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 also as a prediction 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. The 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. Moreover, the results by Kruse (1993) indicate that the one-shot Nash equilibrium predicts the 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, also the instructions given in the low-knowledge treatments allow for full information. Bocard 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 $K = 675$ at the first stage, and a market price of $p = 325$ at the second stage; the equilibrium profit per firm is $\Pi_i = 50625$. Figure 2 summarizes the equilibrium predictions.

- Figure 2 about here -

5 Results

After a short remark on the effect of bankruptcies, we will analyze the choices at the two stages of the game separately. We first consider capacity choices and then proceed to analyze price choices. Finally, we examine the profits resulting from subjects' choices at the two stages.

5.1 Bankruptcies

Our bankruptcy rules exposed in section 3 are a potential source of contaminating our data. As subjects can go on playing, but cannot lose further money when their balance is negative, they may have an incentive to behave more adventurous in order to have a chance to return to a positive balance. When designing the experiment, we considered the starting balance to be sufficiently high to prevent bankruptcies. We therefore chose a rule as simple as possible to deal with the hypothetical case of a bankruptcy. However, it turned out that in fact six of our 202 subjects went bankrupt in the course of the experiment. Four of such bankruptcies occurred in treatment 3, where 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. When looking at the data, however, despite the possible effect of bankruptcies on incentives, we do not find outcomes to be 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. Our results would change only slightly and all conclusions will remain the same if we exclude those six markets where bankruptcies occurred.

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

5.2 Capacity choices

Figures 3 and 4 summarize capacity choices at the first stage. Figure 3 aggregates the data within each treatment and period and shows the development of the mean market capacities in each treatment across periods. Combining the data from several periods, Table 1 numerically presents the information visualized in Figure 3. By contrast, the histograms presented in Figure 4 for each treatment display the distributions of chosen market capacities.

- Figure 3 about here -

- Table 1 about here -

- Figure 4 about here -

The first obvious result from Figure 3 is that mean market capacities in all treatments are considerably higher than Cournot capacities. Comparing the mean capacities across all periods in Table 1 to the respective Cournot benchmark, we find that the observed mean capacities are largely 40 to 60 percent above Cournot levels. This holds true for all treatments, no matter whether the Cournot outcome is the theoretical prediction or not. Although the mean capacities in Table 1 are mostly somewhat higher than the corresponding medians, the latter are still substantially above Cournot levels. The results thus are not driven by a few outliers, which is also confirmed by the capacity distributions in Figure 4.

Figure 3 indicates that mean capacities across treatments diverge in the first periods. The highest capacities are observed in the triopoly treatments (3 and 4),¹¹ the lowest in the high-knowledge treatment (7). Mean capacities then decline over periods. An exception is the high-knowledge treatment which features no visible time trend. By period nine, the last period for which observations from the high-knowledge treatment are available, the mean capacities in the six other treatments have roughly approached that in the high-knowledge treatment. Towards the last periods, mean capacities appear to reach constant levels. Those hypothesized convergence levels are close to each other for all treatments. Capacities in the triopolies still are the highest, but there is no big difference to the capacities in duopoly markets. In the last few periods, capacities in the triopoly treatments are largely between 900 and 1000, while those in the duopoly treatments are mostly between 800 and 900 (see also the rightmost column of Table 1).

¹¹ The very large mean capacities observed in the first periods in treatment 3 are partly due to markets in which bankruptcies occurred. However, even if one disregards those markets, treatment 3 still has the highest mean capacities among all treatments in the first periods.

To investigate those observations formally, we set up a regression that originates from Noussair et al. (1995) and has been applied to KS experiments by Davis (1999), Le Coq and Sturluson (2012), and Lepore and Shafran (2013). This has the following form:

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

The dependent variable in the regression is the market capacity K in market h and period t . By TD_j , $j = 1, \dots, 7$, we denote the set of treatment dummy variables, where TD_j equals one in treatment j and zero else. 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 of each treatment 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 estimate market capacities in the first period (starting points) and the γ_j coefficients estimate the long-run market capacity convergence levels in treatment j . The regression thus allows for different convergence patterns in each treatment.¹²

- Table 2 about here -

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 larger than the respective Cournot capacity (all p 's < 0.01 , t -tests).¹³ Convergence levels are rather close to 900, which represents the competitive quantity. 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 larger than 900, but this result hinges upon 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 which 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 to investigate the effect of demand rationing (treatment 1

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.

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

vs. treatment 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 in both the starting points and in the convergence levels. The significance test results are presented in Panel B of Table 2. As to demand rationing and subject matching, the test results show no valid treatment effects. There is a significant effect of demand rationing on starting point capacities in only one of three pairwise comparisons, and no significant effect on capacity convergence levels. Subject matching never entails a significant effect. With respect to the knowledge condition, the visual impression from Figure 3 is confirmed by the test results. 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 which entails a uniform and persistent significant effect on capacities. Market capacities are significantly larger in triopoly than in duopoly in both pairwise comparisons and for both starting points and convergence levels.¹⁵

Our finding of capacities substantially above the Cournot prediction is 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, namely 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. Thus the high capacity levels observed in our experiment do not come out as a big surprise. As to the treatment effects, only two of our four treatment variables have already been varied in related studies. Our finding on demand rationing not significantly affecting capacity choices is in line with the result by Lepore and Shafran (2013). Yet, the significantly higher capacities observed in triopolies stand in contrast to the result by Brandts and Guillen (2007) who do not find such an effect.

- Table 3 about here -

Figure 4 already indicates that in all treatments capacities are higher than the Cournot benchmark in the vast majority of markets. Table 3 shows the number of instances in which

¹⁵ As an alternative approach to investigate treatment effects we also applied nonparametric 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. Pairwise comparing 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 larger 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 decrease 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).

the exact Cournot capacity was installed. Such instances are rare; their average frequency across all treatments is 1.8 percent.¹⁶ In the two triopoly treatments there is not a single instance in which the market capacity equals the Cournot benchmark. Apart from the fact that coordination on the Nash equilibrium becomes more difficult with more players, another important reason for this may be a prominent number effect. The Cournot market capacity in duopoly is 600 and requires each player to set a capacity of 300 if capacities are shared equally. In triopoly, by contrast, each player has to choose a capacity of 225, a less prominent number than 300, to bring about the Cournot market capacity of 675. Indeed, if we consider individual capacity choices, we do not observe any choices of 225 in the triopoly treatments either. The modal individual capacity choice is 400 in all duopoly treatments with an average frequency of 17.0 percent and 300 in the two triopoly treatments with an average frequency of 13.6 percent. Hence, subjects do not only choose higher than Cournot capacities, but also concentrate their choices on prominent numbers.

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; those treatments with efficient demand rationing) than in those where it is not (treatments 2, 4, and 6; those treatments with proportional demand rationing). In the four treatments where the Cournot outcome is the theoretical prediction, the frequency of exact Cournot market capacities is 2.6 percent whereas in the other treatments it is 0.8 percent. The hypothesis that the frequency is independent of the equilibrium prediction is rejected by a chi-squared test at the one percent significance level.¹⁷

5.3 *Price choices*

We now look at price choices at the second stage. As 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. Both Table 4 and Figure 5 show the development of market prices across periods within each treatment. As at the first stage, we observe a much

¹⁶ 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 readily be 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 exact Cournot capacity more likely in their setting.

¹⁷ One may argue that the high knowledge treatment condition rather than demand rationing influences the frequency of Cournot capacities. The sample for the test is then biased because there is no counterpart treatment of 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.

more competitive conduct than predicted by the Cournot benchmark, i.e. prices are substantially lower than the Cournot price of 400 (in duopoly) or, respectively, 325 (in triopoly). Prices are lowest in the triopoly treatments (3 and 4) and highest in the duopoly treatments with proportional rationing (2 and 6) as well as in the high-knowledge treatment (7). Prices increase somewhat throughout the experiment in most treatments.

- Table 4 about here-

- Figure 5 about here -

In a first step we analyze the impact of the treatment conditions on market prices without taking into account the influence of chosen capacities on pricing decisions. We perform a regression analogous to that explained in section 5.2 (the only change being the replacement of the endogenous variable), and we again inquire the effect of the treatment variables by comparing treatments pairwise. The results are presented in column (1) of Panel B of Table 5. Concentrating our attention on how treatment conditions impact on the estimated convergence levels (the γ coefficients), we obtain clear-cut results. The convergence price level is significantly lower under efficient than under proportional demand rationing, and lower in triopoly than in duopoly. Subject matching does not entail a significant effect on prices. The high-knowledge condition yields higher prices in the first periods, but fails to produce a significant effect on the convergence price level.

- Table 5 about here -

- Figure 6 about here -

In a second step, we add market capacity as explanatory factor to the model. The scatter plot in Figure 6 illustrates the relationship between market capacity determined at the first stage and market price determined at the second. Each circle shows the market capacity and the average market price in one specific market and period. As one expects, higher capacities involve lower prices. The plot also illustrates that subjects are very reluctant to set a price below 100 at the second stage irrespective of the installed capacity, presumably in order to avoid a sure loss. Regressions (2) and (3) in Panel A of Table 5 amend regression (1) by including terms for the installed capacity at the first stage. Specification (2) includes a set of six capacity dummies. A capacity dummy equals one if the installed market capacity lies in the interval mentioned in its caption.¹⁸ Capacities up to 600 units 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.

¹⁸ 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.

The estimates for the dummy coefficients are all negative and increase in absolute value, signifying a monotone negative relationship between capacity and price. The only exception is the sixth dummy coefficient for capacities larger than 1600 units which is smaller in absolute value than the fifth dummy coefficient. This, however, accords with the kernel fit line in Figure 6 indicating that the negative relationship between capacity and price is broken when capacities become very high.¹⁹

Specification (3) builds on the insight from Figure 6 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 supposed convex link. 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 500 (1000) units of capacity installed, one further unit leads to a price decrease of about 0.46 (0.26) ECU.^{20,21}

The inclusion of capacity as explaining factor increases the share of explained variance in the regression more than sixfold; specification (3) has a slightly better fit than specification (2). Nevertheless, the inclusion of capacity does not change the implications with respect to treatment effects, as the significance test results in Panel B of Table 5 reveal. If one controls for installed capacity levels at the first stage, price convergence levels still 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 entails a significant effect. The two significant effects on pricing are in line with the results by Lepore and Shafran (2013) and Brandts and Guillen (2007).

The high capacities observed in the early periods of the experiment suggest that some subjects in the beginning fail to appreciate the impact of their capacity choice on the pricing subgame at the second stage. Le Coq and Sturluson (2012) find that the sensitivity of pricing decisions to installed capacity is higher in later periods. In order to investigate this matter in our setting, we set up two further regressions. The first, specification (4), has the form

¹⁹ All kernel fits in this study were generated with a Gaussian kernel and a bandwidth of 15 percent of the respective capacity range.

²⁰ As an artifact of the regression, a price-increasing effect of increasing capacity occurs if capacity exceeds 1673 units. However, this result is of little relevance since capacities are larger than this level in less than two percent of our observations.

²¹ 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-run price levels in the respective treatment when all other variables take values of zero. Hence, in regression (3) the estimates of the β and γ coefficients pertain to price levels in the respective treatment in a hypothetical state with zero capacity.

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

The dependent variable is the market price P in market h and period t . The term in the 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 estimates this sensitivity in the long run (when t goes to infinity). We expect capacity to have a price-decreasing effect in any period, i.e. both δ and ζ should be negative. Moreover, the sensitivity should increase over periods when more subjects learn about the effect of their choices at the first stage, i.e. ζ should be smaller (larger in absolute value) than δ . The results presented in Table 6 confirm these suppositions.²² Both δ and ζ are significantly negative and ζ is significantly smaller than δ at the one percent level (t -test).

- Table 6 about here -

In specification (5) capacity is interacted with both period weights and treatment dummies TD_j . We thus can consider the sensitivity of pricing to capacity on the treatment level. The regression equation is

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

The regression results in Table 6 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 those 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 run 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 the sensitivity is still small in the long run, and treatment 7, where the sensitivity is large from the beginning. It appears that the extensive instructions in the high-knowledge treatment have been successful in teaching the subjects the connection between capacity and

²² 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 6.

price choices *ex ante*, while many subjects in the other treatments had to learn about that connection by experience.

We now compare our pricing data to the Nash equilibrium prediction in the pricing subgame given capacity choices. A testable theory prediction is available only 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

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

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

$$\sum_i k_i \leq 500.^{23}$$

It is immediate that the condition under proportional rationing is more restrictive, that is, the region of capacity vectors for which market-clearing pricing is the equilibrium under proportional rationing is a real subset of the respective region under efficient rationing.²⁴

The data in the first column of Table 7 show how often subjects at the first stage choose capacities that entail market-clearing pricing as the equilibrium 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).

- Table 7 about here -

²³ See Lepore (2009) for an extensive discussion of these conditions.

²⁴ 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 which 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 impose 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 that the equilibrium implies market-clearing pricing. While they consider only proportional rationing, their arguments go through also 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.

In the further analysis we consider only those subgames where market-clearing pricing is the pure-strategy equilibrium and investigate whether markets actually clear at 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 7. 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 those 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 comparable to ours show substantially lower rates. Muren's (2000) KS markets clear in 50 to 60 percent of those 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 those cases where this price is the pure strategy equilibrium.^{25,26} Considering this issue on the market level, it occurs in 12.6 percent of the cases that the exact market-clearing price is set by all firms in the market. Examining the data in the third column of Table 7, we notice that subjects in the treatments with efficient rationing have a higher propensity to choose 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 rejects the independence of frequencies from the rationing scheme at the one percent significance level.²⁷ This result parallels the finding from section 5.2 that under efficient rationing exact Cournot capacities are more likely to be installed at the first stage. Yet, whereas the influence of the rationing scheme at the first stage corresponds to the equilibrium prediction, at the second stage we find an unpredicted significant effect of the rationing scheme. Since we consider only those markets with a pure-strategy equilibrium in the pricing subgame, the equilibrium predictions are now identical under both rationing

²⁵ Here decisions on 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.

²⁶ Davis (1999) finds that subjects in the initial periods of his KS treatment 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 and circulates around 85 percent in the last 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 clearing is the equilibrium of the pricing subgame more likely. Subjects in Davis' study may therefore have more chances to learn the optimal pricing strategy in such a situation. Moreover, prices which are no more than two cents below the exact market-clearing price are considered by Davis as unsizable deviations from equilibrium and are included in the above shares.

²⁷ This result remains valid if we exclude the data from treatment 7 following the argument given in fn. 17.

schemes. We can provide a somewhat speculative explanation for our finding at the second stage. Since capacities which entail market-clearing pricing as equilibrium at the second stage are chosen more rarely under proportional rationing, subjects in those treatments had less opportunity to experience market-clearing pricing to be optimal when capacities are sufficiently small. This explains the observed difference in pricing behavior if one assumes that experience is needed to understand how to price optimally. This is a plausible assumption in the rather complex KS framework and is also corroborated by our above finding that subjects need experience to appreciate the link between their decisions at the first and second stage.

5.4 Profits

After examining capacity and price choices separately, we now analyze how those choices interact and which profit levels they bring about. Table 8 provides summary statistics of profits per firm in each treatment. Although the individual profit data exhibit very high variances, it becomes clear that in all treatments profits are substantially lower than predicted by the respective Cournot outcomes.²⁸ Moreover, profits are somewhat greater under proportional than under efficient demand rationing. This contrasts with the theory prediction, but is in line with the results from the low-cost treatments by Lepore and Shafran (2013).

- Table 8 about here -

It is a common finding in KS experiments that subjects 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 hand, triggers low sales prices at the second stage. Since subjects choose such high capacities even after many rounds when they have gained experience, the question arises whether they draw some latent utility from that 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 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

²⁸ Considering only the raw individual profit data in Table 8, due to the 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 that in section 5.2 with individual profit as 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).

KS treatment data. While we find a similar correlation in our data,²⁹ we do not consider this to provide sufficient evidence for bullying to be strategically successful. After all, a larger capacity share leads to more market power and therefore is likely to induce a higher profit share within a market. To judge success, however, also performance across markets is to be considered. Davis acknowledges that average profits are lowest in those markets with the highest capacities.

The relationship between absolute individual capacities and absolute individual profits is suitable to investigate whether choosing high capacities is eventually 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 7 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 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 profit that can be attained on average 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.

- Figure 7 about here -

Differently, Lepore and Shafran (2013) argue that when the cost for installing capacity is low subjects lose little by choosing a too high capacity that is not fully utilized at the second stage. However, high capacities bring about the chance of a large gain if the other players happen to install low capacities. High capacity choices may thus be considered gambling behavior. The kernel fits in Figure 7 illustrate that on average subjects lose by gambling. Moreover, we find that high profits in one period do not correlate with high capacity choices. Table 9 categorizes individual capacity choices in single periods by profit. We see that the highest individual profits are actually realized at below-average individual capacities. High profits are apparently more triggered by implicit collusion with low capacities than by exploiting opportunities induced by a high individual capacity.

- Table 9 about here -

²⁹ 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 that calculation because the average market profit is negative in those cases.

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 then an unresolved question why subjects do not realize the failure of their tactics even in the long run.

6 Conclusion

This study adds to the so far limited literature of 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 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 both capacity choice and pricing is considerably more competitive than the Cournot outcome in all treatments. Larger market capacities are chosen in triopoly than in duopoly. 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 entail 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 on installed capacity, it appears that subjects in the low-knowledge condition have to learn by experience about the relationship between capacity and price choices. Exact Cournot capacities as well as exact market-clearing pricing are more likely to occur under efficient than under proportional demand rationing. Subjects' earnings substantially fall short of equilibrium profits due to excessive capacity installation. It still remains a puzzle why subjects do not reduce capacities even after many rounds of experience.

Appendix A

English translation 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 on both your own decisions and the decisions of the other participants in the experiment.

Please read these instructions carefully. If after reading there are any questions, please raise your hand. An experimenter will approach you and answer your questions in private. 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. On a market you **compete with two other firms** being represented by two of the other participants. All firms produce and sell the same good.

For your participation you will receive a fee of 6 Euro. You can earn further money during the experiment. The amount will depend on both your own decisions and the decisions of the other participants in the experiment.

Throughout the experiment, all money amounts will be accounted in **Experimental Currency Units (ECU)**. Your **start balance** at the beginning of the experiment is **240,000 ECU**. Your final balance at the end of the experiment will be paid off to you 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 matched into groups of three. The other members of your group will be your competitors. The grouping will be fixed throughout the experiment.

Each **period** of the experiment **consists of two stages**:

First stage: On the first stage you and the other firms must simultaneously and independently **decide on your production quantity** of the good. All **integers from 0 up to 1000 are admissible** quantities.

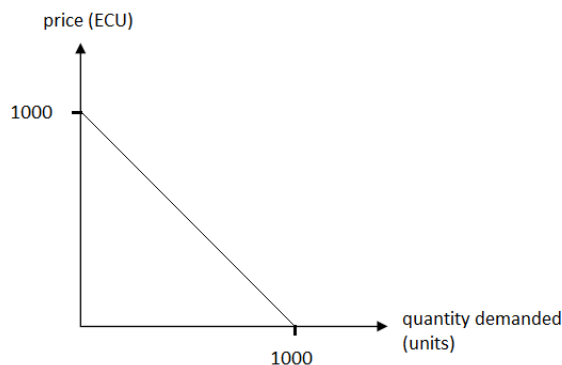
Production incurs **costs of 100 ECU per unit produced**. Your production costs will be subtracted from your balance.

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

Second stage: On the second stage you and the other firms must simultaneously and independently **decide on the price** at which to offer the good on the market. All **integers from 0 up to 1000 are admissible** prices.

Your sales revenue will be added to your balance. Your sales revenue is equal to the price chosen by you multiplied by your sales quantity. Your sales quantity depends on both the production quantities and the prices chosen by you and the other firms. In the following paragraphs you can find a precise description of how sales quantities are determined.

The market demand describes the quantity of the good that can at most 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 costumers with different willingnesses to pay for the good. A sale will come about if the offer price is no higher than a costumers maximum willingness to pay. At a price of 0 ECU there will be a total demand for 1000 units on the market. With a price increase by 1 ECU, demand is reduced by 1 unit. So, for example, at a price of 500 ECU, 500 units will be demanded. At a price of 1000 ECU no one will be ready to buy the good. Here is a graphical representation of this relationship:



Each firm in each period can sell at most as many units of the good at the second stage as it has produced at the first stage.

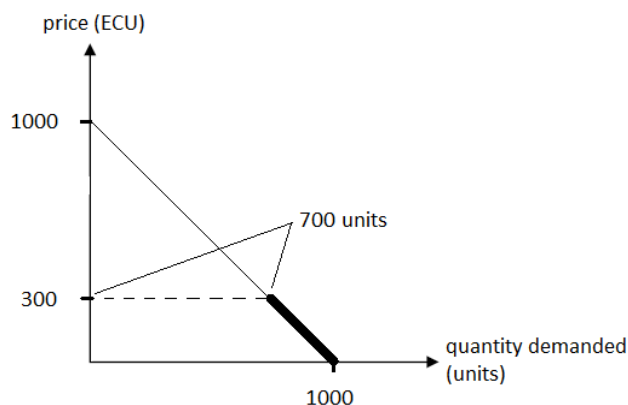
Customers will first try to purchase the good from the firm offering at the lowest price. Those customers with the highest willingness to pay will be served first. In case several firms choose the same price, demand will be divided equally among them.

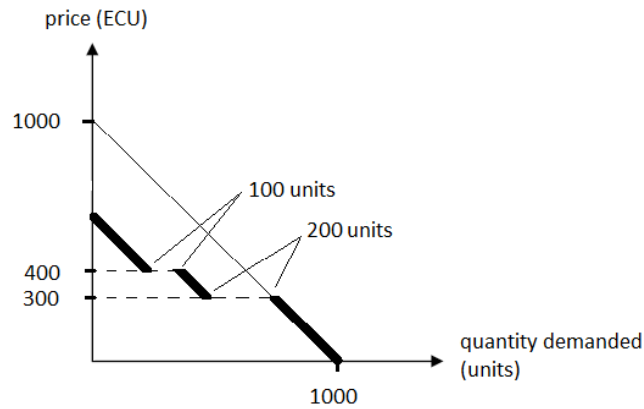
If a firm has not chosen the lowest price within its group, there may be some residual demand left over for it or not. This is illustrated by the following two examples. For both examples assume that firms 1 and 2 have chosen prices of 300 ECU and 400 ECU respectively. The production quantity of firm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

We are interested in the remaining demand for firm 3 at different price choices of firm 3. 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 is the lowest and it is confronted with the entire market demand.

If firm 3 chooses a price above 300 ECU, firm 1 sells its units first. In the first example (upper figure), the production quantity of firm 1 satisfies the whole 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. Therefore, a residual demand is left over at prices above 300 ECU. If firm 3 then chooses a price above 400 ECU, also firm 2 will 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.





In case a firm cannot sell its entire production from the first stage at the second stage, the units that could not be sold will forfeit and cannot be transferred to the next period. However, production costs are incurred for all units produced, no matter whether they can be sold or not.

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

Your balance in each period is increased or decreased by your profit or loss respectively in this period. If your balance should become negative during the experiment, you can nevertheless go on producing and selling, i.e. your firm has a credit without limit 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 charged against any losses.

To get a general idea of your sales quantities and profits resulting from different price and quantity combinations, you may use the "**profit calculator**". Simply enter a hypothetical production quantity and a hypothetical offer price for each firm and click on "Calculate". Then your resulting sales quantity and profit will be displayed. You may use the profit calculator throughout the whole experiment.

Moreover, after each period a screen with a "**history**" will inform you about the outcomes so far. For all past periods the "history" shows the production quantities and prices chosen by the firms, your resulting sales quantity, your sales revenue, your production cost and your profit. Moreover, your current money balance will be displayed.

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

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

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

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	120	500	250	220	500	220	33000
220	120	500	400	220	500	500	66000
220	120	500	500	220	500	190	73000
220	120	500	550	220	500	0	-22000
220	305	500	300	220	299	0	-22000

The results of the profit calculator are displayed here.

Your total profit so far is displayed here.

The results of the last period are displayed here.

Periods 2 Remaining time [sec] 31

Results

Your current balance is: 302461

My production quantity: 450
 Other production quantity 1: 500
 Other production quantity 2: 250
 My price: 333
 Other price 1: 412
 Other price 2: 154
 My sales quantity: 417
 My sales revenue: 138861
 My cost: 45000
 My profit: 93861

Go to next period

Period	My production quantity	Other production quantity 1	Other production quantity 2	My price	Other price 1	Other price 2	My sales quantity	My sales revenue	My cost	My profit
-2	0	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
1	450	158	542	450	455	145	8	3600	45000	-41400
2	450	500	250	333	412	154	417	138861	45000	93861

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

To practice 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 to 240,000 ECU - your start balance for the actual periods - independent of your profits or losses in the trial periods. After the trial periods, the participants will be randomly re-matched into new groups. The new groups will stay fixed throughout all actual periods of the experiment. The profit calculator will be available to you during both trial and actual periods. The history, however, will not be displayed after trial periods and will only contain the data of the actual periods.

Your **final balance** will be **paid to you** after the experiment at the above-mentioned exchange rate. Additionally, you will receive your participation fee. None of the other participants will come to know your payoff, and neither will you come to know the payoff of any other participant. Furthermore, no participant will come to know with whom he or she interacted during the experiment.

If you click on the "Continue" button on your screen, some statements will appear to check whether all participants have understood the instructions. Please decide whether those statements are right or wrong. As soon as all participants will have evaluated the statements correctly, the first trial period will start.

If there are any questions concerning the experiment, please raise your hand. Enjoy the experiment!

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

Please read these instructions carefully. If after reading there are any questions, please raise your hand. An experimenter will approach you and answer your questions in private. 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. On a market you **compete with one other firm** being represented by one of the other participants. All firms produce and sell the same good.

For your participation you will receive a fee of 6 Euro. You can earn further money during the experiment. The amount will depend on both your own decisions and the decisions of the other participants in the experiment.

Throughout the experiment, all money amounts will be accounted in **Experimental Currency Units (ECU)**. Your **start balance** at the beginning of the experiment is **200,000 ECU**. Your final balance at the end of the experiment will be paid off to you 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 matched into groups of two. The other member of your group will be your competitor. The grouping will be fixed throughout the experiment.

Each **period** of the experiment **consists of two stages**:

First stage: On 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 1000 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 within their group.

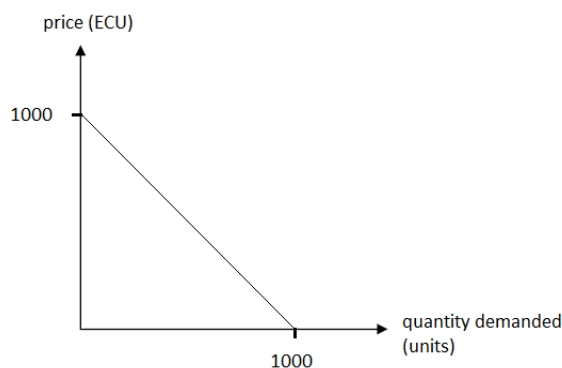
Second stage: On the second stage you and the other firm must simultaneously and independently **decide on the price** at which to offer the good on the market. All **integers from 0 up to 1000 are admissible** prices.

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

The market demand describes the quantity of the good that can at most 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

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

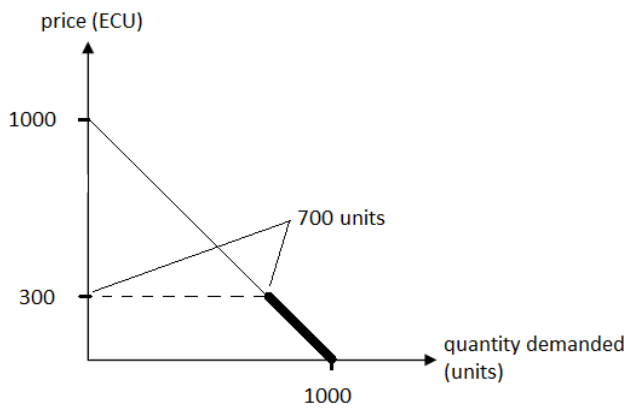
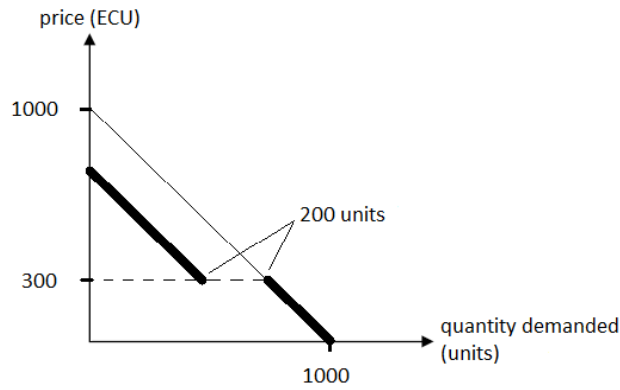
At a price of 0 ECU, there will be a total demand for 1000 units on the market. With a price increase by 1 ECU, demand is reduced by 1 unit. At a price of 1000 ECU no one will be ready to buy the good. Here is a graphical representation of this relationship:



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

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

This is illustrated by the following two examples. For both examples assume that the other firm has chosen a price of 300 ECU. 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 you are confronted with the entire market demand. If your price is higher than 300 ECU, the other firm sells 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. Therefore, a 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 whole demand at this price, so you are unable to sell any units at prices above 300 ECU.

Formally, the demand a firm is confronted with 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 you are confronted with 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. In case you have chosen the higher price and $1000 - p - \tilde{q}$ yields a negative value, your residual demand is zero.

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

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

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

<i>Example 1</i>	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, you can sell no more than those units: $V = \min\{400, 300\} = 300$.

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

You again have 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, $V = \min\{0, 300\} = 0$.

In case a firm cannot sell its entire production from the first stage at the second stage, the units that could not be sold will forfeit and cannot be transferred to the next period. However, production costs are incurred for all units produced, no matter whether they can be sold or not.

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

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

This profit function due to the case discriminations in determining the sales quantity is a piecewise function. Given the production quantities q and \tilde{q} and the price of the other firm \tilde{p} , the following prices are possible candidates for the price which 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 will make your price choice in the experiment, you will know about q and \tilde{q} , but not about \tilde{p} . However, you may interpret \tilde{p} as the price which 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} .

<i>Example 3</i>	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) $V = 1000 - 600 - 400 = 0$ $\Pi = 0 * 600 - 100 * 400 = -40000$.
- (II) $V = \min\{1000 - 200, 400\} = 400$ $\Pi = 400 * 200 - 100 * 400 = 40000$.
- (III) $V = 1000 - 500 - 400 = 100$ $\Pi = 100 * 500 - 100 * 400 = 10000$.
- (IV) and (V) $V = 500 - 300/2 = 350$ $\Pi = 350 * 300 - 100 * 400 = 65000$.
- (VI) $V = \min\{1000 - 299, 400\} = 400$ $\Pi = 400 * 299 - 100 * 400 = 79600$.

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 respectively in this period. If your balance should become negative during the experiment, you can nevertheless go on producing and selling, i.e. your firm has a credit without limit 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 charged against any losses.

To get a general idea of your sales quantities and profits resulting from different price and quantity combinations, you may use the "**profit calculator**". Simply enter a hypothetical production quantity and a hypothetical offer price for each firm and click on "Calculate". Then your resulting sales quantity and profit will be displayed. You may use the profit calculator throughout the whole experiment.

Moreover, after each period a screen with a "**history**" will inform you about the outcomes so far. For all past periods the "history" shows the production quantities and prices chosen by the firms, your resulting sales quantity, your sales revenue, your production cost and your profit. Moreover, your current money balance will be displayed.

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

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

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

My production quantity	Other production quantity	My price	Other price	My sales quantity	My profit
240	500	500	489	0	-24000
240	500	499	489	240	95750
240	500	498	489	240	95520
325	452	532	222	16	23388
325	452	333	222	215	19095

The results of the profit calculator are displayed here.

Your total profit so far is displayed here.

The results of the last period are displayed here.

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
0	0	0	0	0	0	0	0	0
1	425	530	389	500	425	169575	42500	127075
2	295	432	488	397	90	44550	20500	19050
3	555	400	666	488	0	0	55500	-55500

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

To practice 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 to 200,000 ECU - your start balance for the actual periods - independent of your profits or losses in the trial periods. After the trial periods, the participants will be randomly re-matched into new groups. The new groups will stay fixed throughout all actual periods of the experiment. The profit calculator will be available to you during both trial and actual periods. The history, however, will not be displayed after trial periods and will only contain the data of the actual periods.

Your **final balance** will be **paid to you** after the experiment at the above-mentioned exchange rate. Additionally, you will receive your participation fee. None of the other participants will come to know your payoff, and neither will you come to know the payoff of any other participant. Furthermore, no participant will come to know with whom he or she interacted during the experiment.

If you click on the "Continue" button on your screen, some tasks will appear to check whether all participants have understood the instructions. As soon as all participants will have solved the statements, the first trial period will start.

If there are any questions concerning the experiment, please raise your hand. Enjoy the experiment!

Appendix B

Translation of the control questions.

Control questions in treatments 1-6

Binary choice: correct or wrong.

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

Control tasks in treatment 7

<i>Task 1</i>	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)

<i>Task 2</i>	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)

<i>Task 3</i>	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)

<i>Task 4</i>	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)

<i>Task 5</i>	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)

<i>Task 6</i>	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)

References

- Anderhub, V., Güth, W., Kamecke, U., and Normann, H.-T. (2003), Capacity Choices and Price Competition in Experimental Markets, *Experimental Economics* 6: 27-52.
- Benoît, J.-P. and Krishna, V. (1987), Dynamic Duopoly: Prices and Quantities, *The Review of Economic Studies* 54: 23-35.
- Bertrand, J. (1883), Théorie des richesses, *Le journal des sçavans* 1883: 499-508.
- Boccard, N. and Wauthy, X. (2000), Bertrand Competition and Cournot Outcomes: Further Results, *Economics Letters* 68: 279-285.
- Boccard, N. and Wauthy, X. (2004), Bertrand Competition and Cournot Outcomes: A Correction, *Economics Letters* 84: 163-166.
- Bock, O., Baetge, I., and Nicklisch, A. (2014), hroot - Hamburg Registration and Organization Online Tool, *European Economic Review* 71: 117-120.
- Brandts, J. and Guillen, P. (2007), Collusion and Fights in an Experiment with Price-Setting Firms and Advance Production, *Journal of Industrial Economics* 55: 453-473.
- Cournot, A. A. (1838), *Recherches sur les principes mathématiques de la théorie des richesses*, Hachette, Paris.
- Davidson, C. and Deneckere, R. (1986), Long-Run Competition in Capacity, Short-Run Competition in Price, and the Cournot Model, *The RAND Journal of Economics* 17: 404-415.
- Davis, D. D. (1999), Advance Production and Cournot Outcomes: An Experimental Investigation, *Journal of Economic Behavior and Organization* 40: 59-79.
- Fischbacher, U. (2007), z-Tree: Zurich Toolbox for Ready-Made Economic Experiments, *Experimental Economics* 10: 171-178.
- Fouraker, L. E. and Siegel, S. (1963), *Bargaining Behavior*, McGraw-Hill, New York et al.
- Friedman, J. W. (1971), A Non-Cooperative Equilibrium for Supergames, *The Review of Economic Studies* 38: 1-12.
- Goodwin, D. and Mestelman, S. (2010), A Note Comparing the Capacity Setting Performance of the Kreps-Scheinkman Duopoly Model with the Cournot Duopoly Model in a Laboratory Setting, *International Journal of Industrial Organization* 28: 522-525.
- Iskakov, A. B. and Iskakov, M. B. (2014), Ravnovesiya v bezopasnykh strategiyakh v tsenovoy duopolii Bertrana-Edzhvorta (Equilibrium in Secure Strategies in the Bertrand-Edgeworth Duopoly), *Matematicheskaya Teoriya Igr i eë Prilozheniya* 6: 42-59.
- Jacobs, M. and Requate, T. (2016a), *Bertrand-Edgeworth Markets with Increasing Marginal Costs and Voluntary Trading: Experimental Evidence*, Economics Working Paper 2016-01, University of Kiel.

- Jacobs, M. and Requate, T. (2016b), *Demand Rationing in Bertrand-Edgeworth Markets with Fixed Capacities: An Experiment*, Economics Working Paper 2016-03, University of Kiel.
- Kreps, D. M. and Scheinkam, J. A. (1983), Quantity Precommitment and Bertrand Competition Yield Cournot Outcomes, *The Bell Journal of Economics* 14: 326-337.
- Kruse, J. B. (1993), Nash Equilibrium and Buyer Rationing Rules: Experimental Evidence, *Economic Inquiry* 31: 631-646.
- Le Coq, C. and Sturluson, J. T. (2012), Does Opponents' Experience Matter? Experimental Evidence from a Quantity Precommitment Game, *Journal of Economic Behavior and Organization* 84: 265-277.
- Lepore, J. J. (2008), Cournot and Bertrand-Edgeworth Competition When Rivals' Costs Are Unknown, *Economics Letters* 101: 237-240.
- Lepore, J. J. (2009), Consumer Rationing and the Cournot Outcome, *The B.E. Journal of Theoretical Economics* 9, Issue 1, Article 28.
- Lepore, J. J. (2012), Cournot Outcomes under Bertrand-Edgeworth Competition with Demand Uncertainty, *Journal of Mathematical Economics* 48: 177-186.
- Lepore, J. J. and Shafran, A. P. (2013), Consumer Rationing and Cournot Outcomes: Experimental Evidence, *Southern Economic Journal* 79: 727-746.
- Madden, P. (1998), Elastic Demand, Sunk Costs and the Kreps-Scheinkman Extension of the Cournot Model, *Economic Theory* 12: 199-212.
- Muren, A. (2000) Quantity Precommitment in an Experimental Oligopoly Market, *Journal of Economic Behavior and Organization* 41: 147-157.
- Noussair, C. N., Plott, C. R., and Riezman, R. G. (1995), An Experimental Investigation of the Patterns of International Trade, *The American Economic Review* 85: 462-491.
- Wu, X., Zhu, Q., and Sun, L. (2012), On Equivalence between Cournot Competition and the Kreps-Scheinkman Game, *International Journal of Industrial Organization* 30: 116-125.
- Zouhar, J. (2015), PQ Oligopoly, Proportional Rationing, and Randomly Ordered Consumers, *Central European Journal of Operations Research*, doi: 10.1007/s10100-015-0400-0.

Tables and figures

Market Capacities				
	<i>periods</i>	<i>1-18</i>	<i>1-9</i>	<i>10-18</i>
Treatment 1		926.163	992.325	860.000
<i>n</i> = 2, eff. rat., fixed match.		(296.191)	(294.493)	(283.917)
		[850.000]	[1000.000]	[800.000]
Treatment 2		860.940	911.102	810.778
<i>n</i> = 2, prop. rat., fixed match.		(189.428)	(197.477)	(167.406)
		[825.500]	[900.000]	[800.000]
Treatment 3		1083.051	1203.750	962.352
<i>n</i> = 3, eff. rat., fixed match.		(387.863)	(455.162)	(256.321)
		[950.000]	[1200.000]	[896.000]
Treatment 4		1014.991	1063.361	966.620
<i>n</i> = 3, prop. rat., fixed match.		(256.595)	(278.391)	(223.770)
		[1000.000]	[1010.000]	[948.000]
Treatment 5		932.621	967.949	897.293
<i>n</i> = 2, eff. rat., random match.		(202.022)	(196.472)	(202.284)
		[919.500]	[950.000]	[900.000]
Treatment 6		967.324	1029.463	905.185
<i>n</i> = 2, prop. rat., random match.		(289.262)	(274.644)	(291.380)
		[950.000]	[1002.500]	[900.000]
Treatment 7		n.a.	846.229	n.a.
<i>n</i> = 2, eff. rat., fixed match., high knowledge			(191.890)	
			[829.000]	
Standard errors in parentheses. Medians in square brackets.				

Table 1: Market capacities: Summary statistics.

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
<i>n</i> = 2, eff. rat., fixed match.	(67.474)	(36.111)
Treatment 2	984.21	841.501
<i>n</i> = 2, prop. rat., fixed match.	(72.880)	(39.004)
Treatment 3	1,536.977	976.892
<i>n</i> = 3, eff. rat., fixed match.	(72.880)	(39.004)
Treatment 4	1,208.245	935.012
<i>n</i> = 3, prop. rat., fixed match.	(72.880)	(39.004)
Treatment 5	981.549	911.532
<i>n</i> = 2, eff. rat., random match.	(76.121)	(40.739)
Treatment 6	1,073.534	929.163
<i>n</i> = 2, prop. rat., random match.	(72.880)	(39.004)
Treatment 7	864.64	813.966
<i>n</i> = 2, eff. rat., fixed match., high knowledge	(61.661)	(40.883)
Observations	1,458	
Adjusted R ²	0.064	

GLS regression with clustered errors on the market level. Clustered standard errors in parentheses.

Panel B: Treatment Effects

<i>demand rationing</i>	$\beta_1 = \beta_2$	$\gamma_1 = \gamma_2$
	$\beta_3 >^{***} \beta_4$	$\gamma_3 = \gamma_4$
	$\beta_5 = \beta_6$	$\gamma_5 = \gamma_6$
<i>number of firms in the market</i>	$\beta_1 <^{***} \beta_3$	$\gamma_1 <^{**} \gamma_3$
	$\beta_2 <^{**} \beta_4$	$\gamma_2 <^* \gamma_4$
<i>subject matching</i>	$\beta_1 = \beta_5$	$\gamma_1 = \gamma_5$
	$\beta_2 = \beta_6$	$\gamma_2 = \gamma_6$
<i>knowledge</i>	$\beta_1 >^{**} \beta_7$	$\gamma_1 = \gamma_7$

Results of two-tailed *t*-tests on equality of coefficients from Panel A. ">" ("<<") indicates 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.

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

**Frequencies of Exact Cournot Market Capacities
by Treatment**

Treatment 1	0.032
$n = 2$, eff. rat., fixed match.	(8/252)
Treatment 2	0.009
$n = 2$, prop. rat., fixed match.	(2/216)
Treatment 3	0.000
$n = 3$, eff. rat., fixed match.	(0/216)
Treatment 4	0.000
$n = 3$, prop. rat., fixed match.	(0/216)
Treatment 5	0.030
$n = 2$, eff. rat., random match.	(6/198)
Treatment 6	0.014
$n = 2$, prop. rat., random match.	(3/216)
Treatment 7	0.049
$n = 2$, eff. rat., fixed match., high knowledge	(7/144)
Treatments 1-7	0.018
	(26/1458)

Table 3: Frequencies of Cournot capacities.

Market Prices				
	<i>periods</i>	<i>1-18</i>	<i>1-9</i>	<i>10-18</i>
Treatment 1		248.159	224.006	272.312
<i>n</i> = 2, eff. rat., fixed match.		(104.638)	(97.497)	(106.322)
		[242.857]	[205.044]	[276.188]
Treatment 2		310.254	297.457	323.052
<i>n</i> = 2, prop. rat., fixed match.		(90.772)	(89.703)	(90.436)
		[307.689]	[292.861]	[328.204]
Treatment 3		171.095	160.864	181.327
<i>n</i> = 3, eff. rat., fixed match.		(86.306)	(85.707)	(86.081)
		[148.443]	[131.391]	[160.987]
Treatment 4		214.815	201.467	228.162
<i>n</i> = 3, prop. rat., fixed match.		(82.141)	(78.063)	(84.284)
		[204.711]	[188.537]	[216.192]
Treatment 5		239.689	231.712	247.667
<i>n</i> = 2, eff. rat., random match.		(93.422)	(83.414)	(102.264)
		[223.333]	[218.200]	[229.772]
Treatment 6		296.431	263.900	328.963
<i>n</i> = 2, prop. rat., random match.		(146.042)	(127.253)	(156.608)
		[266.987]	[241.120]	[307.317]
Treatment 7		n.a.	277.258	n.a.
<i>n</i> = 2, eff. rat., fixed match., high knowledge			(80.407)	
			[270.272]	

Standard errors in parentheses. Medians in square brackets.

Table 4: Market prices: Summary statistics.

Panel A: Estimated Starting Points (β 's) and Convergence Levels (γ 's) of Market Prices

	(1)		(2)		(3)	
	β_j	γ_j	β_j	γ_j	β_j	γ_j
Treatment 1	203.122	247.597	389.191	394.011	663.495	670.772
<i>n</i> = 2, eff. rat., fixed match.	(19.844)	(12.353)	(17.486)	(8.159)	(21.904)	(15.502)
Treatment 2	281.190	321.223	449.882	445.892	712.719	723.044
<i>n</i> = 2, prop. rat., fixed match.	(21.434)	(13.343)	(18.654)	(8.743)	(22.689)	(15.924)
Treatment 3	177.785	157.158	402.973	323.999	695.264	600.183
<i>n</i> = 3, eff. rat., fixed match.	(21.434)	(13.343)	(19.430)	(8.846)	(22.012)	(15.869)
Treatment 4	192.367	219.178	392.318	386.299	673.652	663.031
<i>n</i> = 3, prop. rat., fixed match.	(21.434)	(13.343)	(18.732)	(8.953)	(22.650)	(16.550)
Treatment 5	237.739	234.718	411.669	385.860	686.126	664.511
<i>n</i> = 2, eff. rat., random match.	(22.388)	(13.936)	(19.283)	(8.953)	(23.228)	(16.534)
Treatment 6	250.775	298.103	435.323	456.654	719.704	731.143
<i>n</i> = 2, prop. rat., random match.	(21.434)	(13.343)	(18.651)	(8.448)	(22.782)	(15.868)
Treatment 7	279.638	277.809	411.885	400.823	691.094	677.005
<i>n</i> = 2, eff. rat., fixed match., high knowledge	(18.718)	(15.389)	(15.742)	(11.731)	(20.343)	(17.593)
cap(600,800]			-97.359			
			(6.722)			
cap(800,1000]			-154.071			
			(6.591)			
cap(1000,1200]			-212.236			
			(7.106)			
cap(1200,1400]			-236.052			
			(8.110)			
cap(1400,1600]			-265.027			
			(10.454)			
cap(1600,...]			-235.971			
			(13.266)			
cap					-0.653	
					(0.028)	
cap ²					1.95*10 ⁻⁴	
					(1.29*10 ⁻⁵)	
Observations	1,458		1,458		1,458	
Adjusted R ²	0.086		0.561		0.577	

GLS regressions with clustered errors on the market level. Clustered standard errors in parentheses.

...

Panel B: Treatment Effects

	(1)		(2)		(3)	
<i>demand rationing</i>	$\beta_1 <^{***} \beta_2$	$\gamma_1 <^{***} \gamma_2$	$\beta_1 <^{**} \beta_2$	$\gamma_1 <^{***} \gamma_2$	$\beta_1 <^{**} \beta_2$	$\gamma_1 <^{***} \gamma_2$
	$\beta_3 = \beta_4$	$\gamma_3 <^{***} \gamma_4$	$\beta_3 = \beta_4$	$\gamma_3 <^{***} \gamma_4$	$\beta_3 = \beta_4$	$\gamma_3 <^{***} \gamma_4$
	$\beta_5 = \beta_6$	$\gamma_5 <^{***} \gamma_6$	$\beta_5 = \beta_6$	$\gamma_5 <^{***} \gamma_6$	$\beta_5 = \beta_6$	$\gamma_5 <^{***} \gamma_6$
<i>number of firms in the market</i>	$\beta_1 = \beta_3$	$\gamma_1 >^{***} \gamma_3$	$\beta_1 = \beta_3$	$\gamma_1 >^{***} \gamma_3$	$\beta_1 = \beta_3$	$\gamma_1 >^{***} \gamma_3$
	$\beta_2 >^{***} \beta_4$	$\gamma_2 >^{***} \gamma_4$	$\beta_2 >^{**} \beta_4$	$\gamma_2 >^{***} \gamma_4$	$\beta_2 = \beta_4$	$\gamma_2 >^{***} \gamma_4$
<i>subject matching</i>	$\beta_1 = \beta_5$	$\gamma_1 = \gamma_5$	$\beta_1 = \beta_5$	$\gamma_1 = \gamma_5$	$\beta_1 = \beta_5$	$\gamma_1 = \gamma_5$
	$\beta_2 = \beta_6$	$\gamma_2 = \gamma_6$	$\beta_2 = \beta_6$	$\gamma_2 = \gamma_6$	$\beta_2 = \beta_6$	$\gamma_2 = \gamma_6$
<i>knowledge</i>	$\beta_1 <^{***} \beta_7$	$\gamma_1 = \gamma_7$	$\beta_1 = \beta_7$	$\gamma_1 = \gamma_7$	$\beta_1 = \beta_7$	$\gamma_1 = \gamma_7$

Results of two-tailed t-tests on equality of coefficients from Panel A. ">" ("<") indicates 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.

Table 5: Market prices: Regression results and treatment effects.

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

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

Table 6: Sensitivity of pricing to capacity: Regression results.

Market Clearing in the Pricing Subgame

	<i>market-clearing pricing is Nash equilibrium</i>	<i>market cleared</i>	<i>exact market-clearing price chosen...</i>	
			<i>...on individual level</i>	<i>...by all subjects in the market</i>
Treatment 1	0.156	0.625	0.400	0.075
<i>n</i> = 2, eff. rat., fixed match.	(40/256)	(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	0.079	0.294	0.559	0.294
<i>n</i> = 2, eff. rat., random match.	(17/216)	(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
	(119/1458)	(55/119)	(93/260)	(15/119)

Table 7: Market clearing in the pricing subgame.

Profits per Firm				
	<i>periods</i>	<i>1-18</i>	<i>1-9</i>	<i>10-18</i>
Treatment 1		35,819.797	26,553.708	45,085.89
<i>n</i> = 2, eff. rat., fixed match.		(43,860.007)	(44,606.965)	(41,144.603)
		[40,000.000]	[25,100.000]	[53,625.000]
Treatment 2		60,001.518	53,699.266	66,303.77
<i>n</i> = 2, prop. rat., fixed match.		(37,421.334)	(39,506.239)	(34,156.647)
		[61,953.100]	[55,980.550]	[67,556.500]
Treatment 3		5,384.717	-1,973.653	12,743.09
<i>n</i> = 3, eff. rat., fixed match.		(29,451.782)	(31,908.973)	(24,712.170)
		[5,617.500]	[850.000]	[12,000.000]
Treatment 4		18,823.696	14,784.639	22,862.75
<i>n</i> = 3, prop. rat., fixed match.		(30,791.982)	(31,241.118)	(29,841.103)
		[17,525.000]	[14,623.050]	[19,775.000]
Treatment 5		34,128.109	30,721.520	37,534.70
<i>n</i> = 2, eff. rat., random match.		(35,494.925)	(36,747.108)	(33,948.457)
		[35,070.500]	[29,600.000]	[38,557.500]
Treatment 6		42,031.159	34,501.973	49,560.35
<i>n</i> = 2, prop. rat., random match.		(51,634.314)	(49,213.397)	(52,997.567)
		[34,855.350]	[32,242.300]	[42,914.000]
Treatment 7		n.a.	49,834.674	n.a.
<i>n</i> = 2, eff. rat., fixed match., high knowledge			(31,995.914)	
			[52,399.500]	

Standard errors in parentheses. Medians in square brackets.

Table 8: Profits per firm: Summary statistics.

Individual Capacities Categorized by Individual Profits		
	<i>n</i> = 2	<i>n</i> = 3
All	455.562	349.674
	(166.869)	(168.973)
	[431.000]	[310.000]
Top profit decile	438.000	324.566
	(134.388)	(99.762)
	[400.000]	[300.000]
Bottom profit decile	579.483	551.369
	(195.877)	(201.295)
	[600.000]	[500.000]

Standard errors in parentheses. Medians in square brackets.

Table 9: Individual capacities categorized by individual profits.

				<i>demand rationing</i>		
				efficient	proportional	
				<i>knowledge</i>		
				high	low	
<i>number of firms in the market</i>	$n = 3$	<i>subject matching</i>				
	$n = 2$					
		fixed				
		random				

Figure 1: The treatment matrix.

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

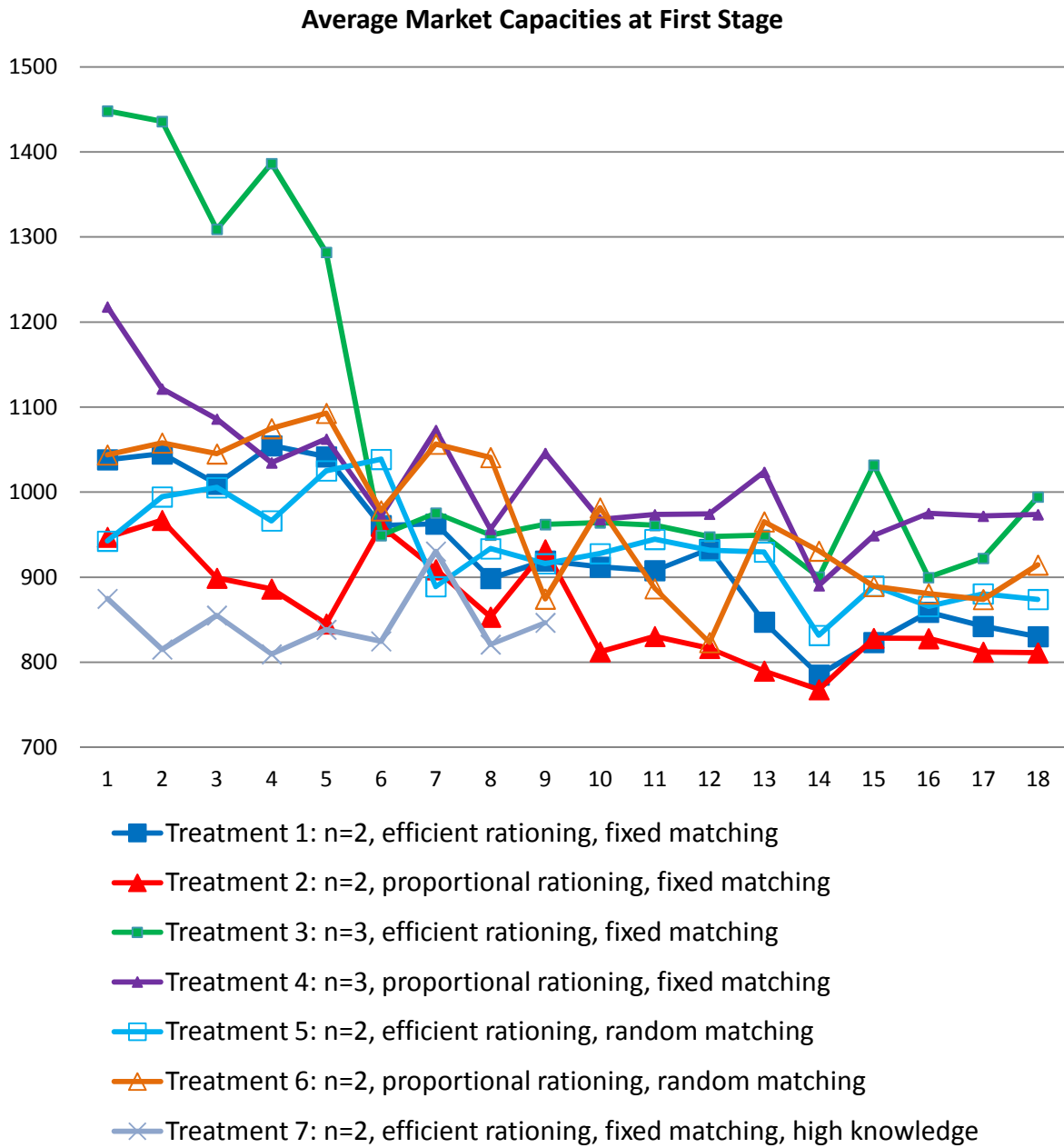


Figure 3: Series of market capacities.

MARKET CAPACITIES BY TREATMENT

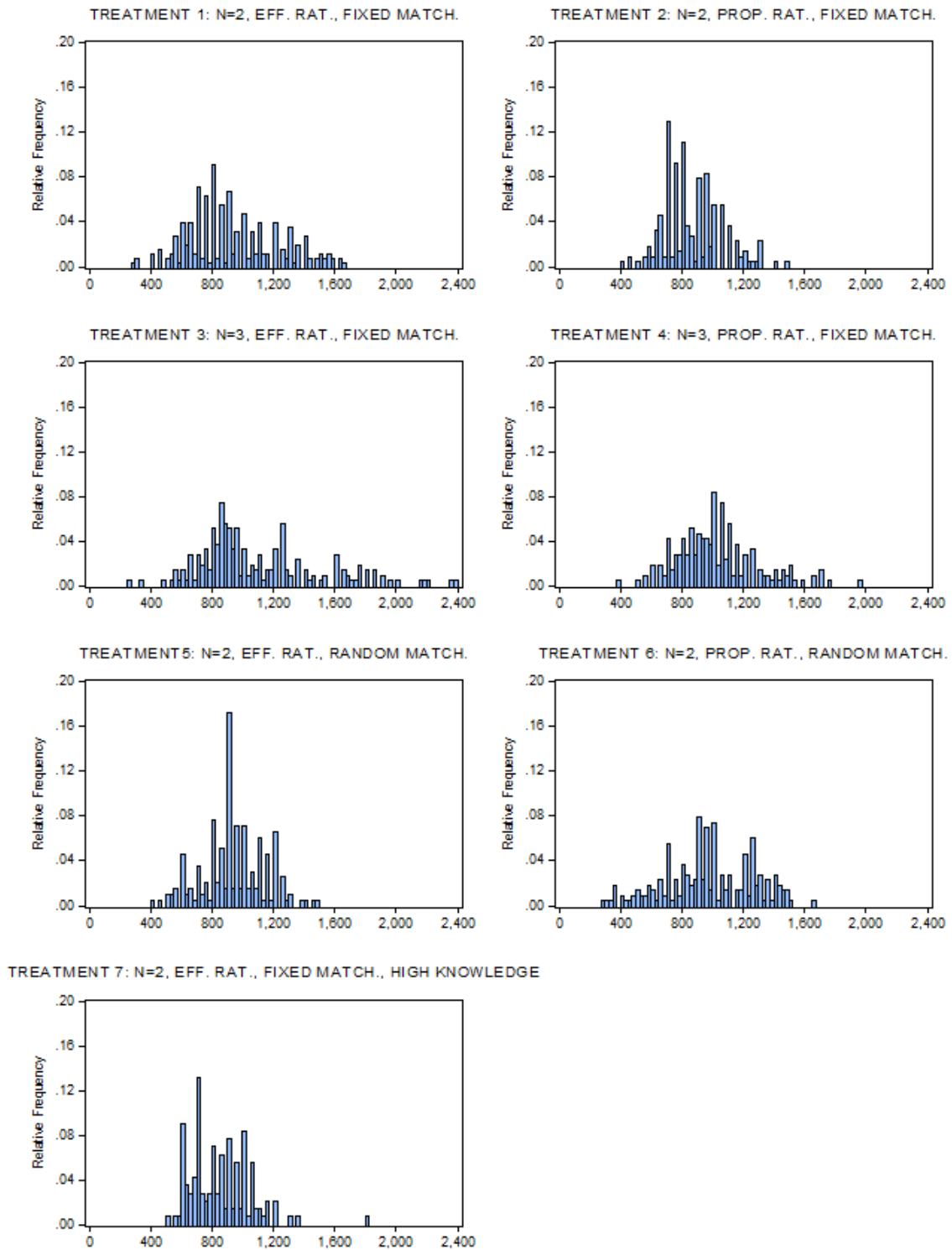


Figure 4: Distributions of market capacities.

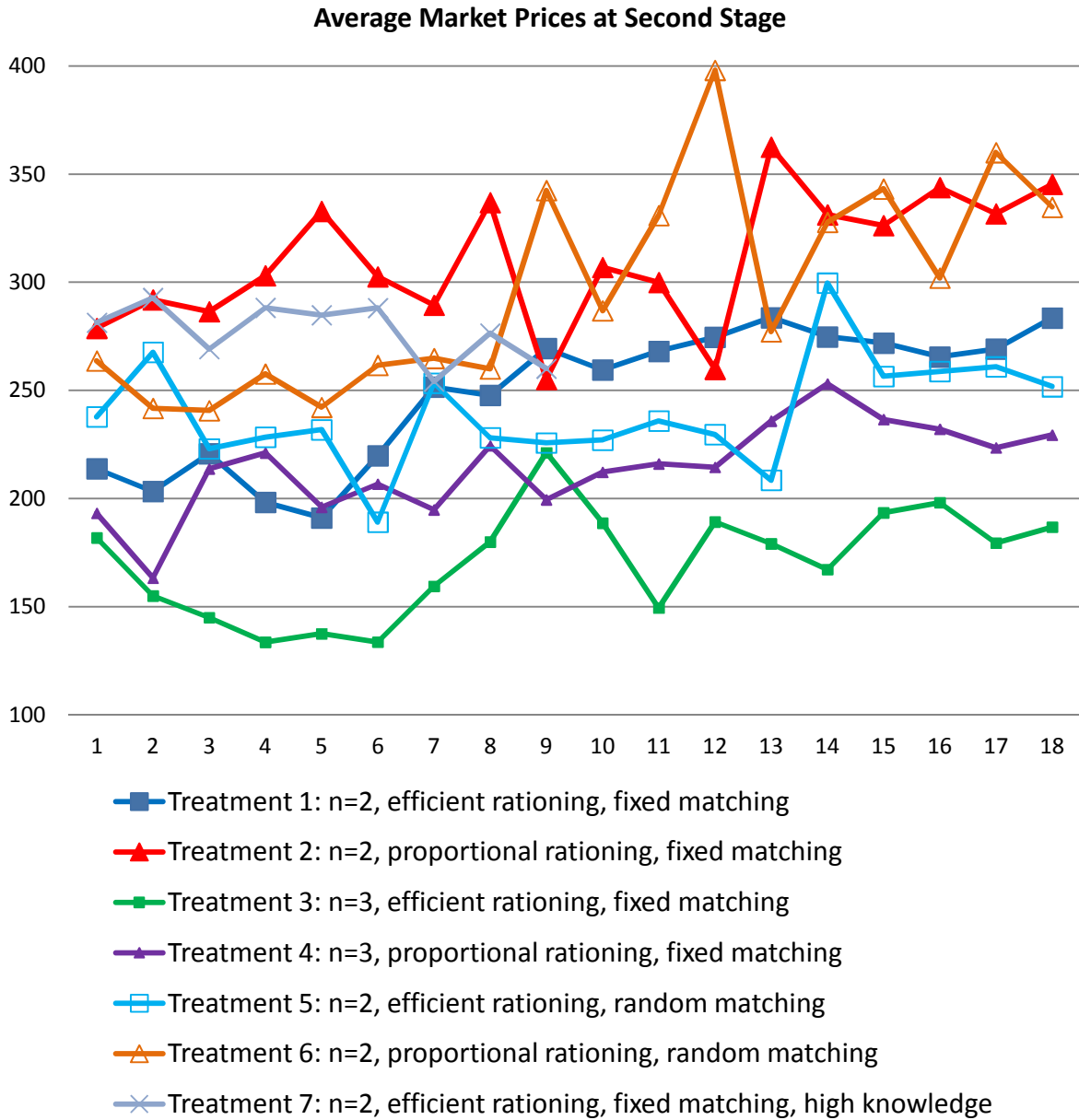


Figure 5: Series of market prices.

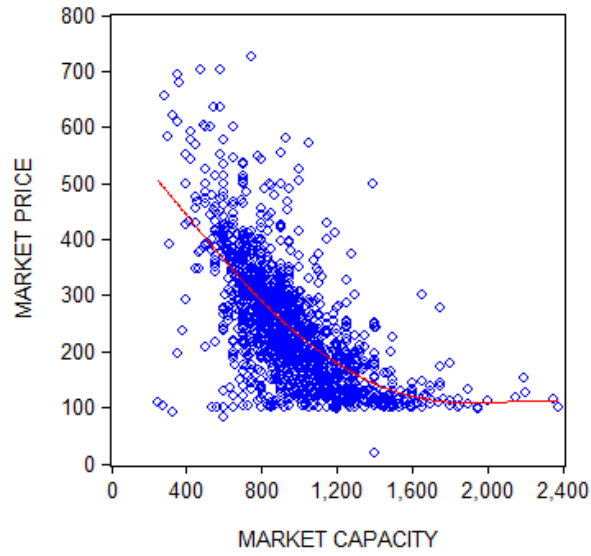


Figure 6: Scatter plot of market capacities and market prices with kernel fit.

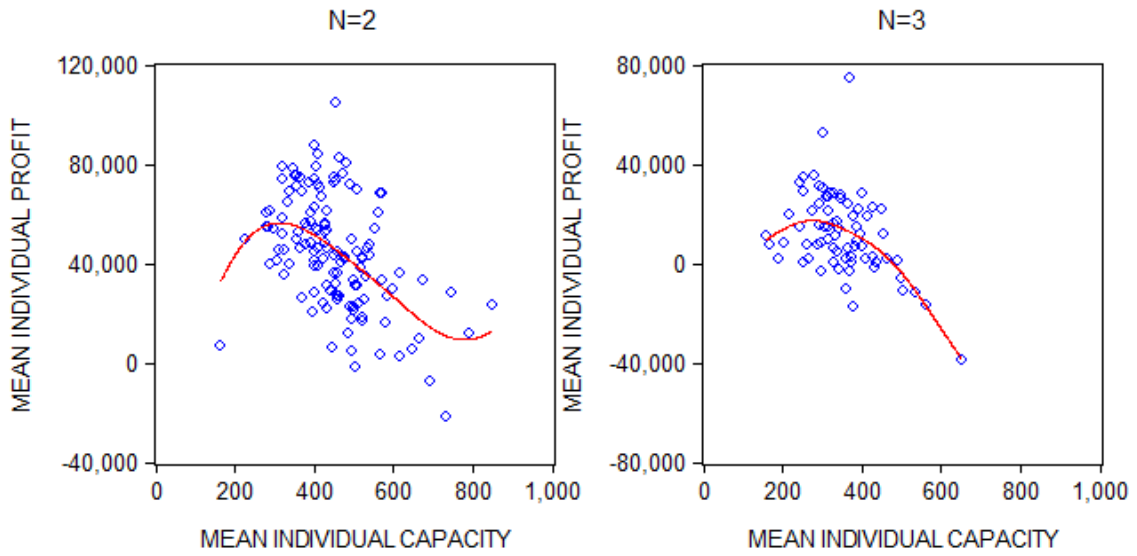


Figure 7: Scatter plots of individual capacities and individual profits with kernel fits.