

# Excess Capacity and Pricing in Bertrand-Edgeworth Markets: Experimental Evidence\*

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## Abstract

We conduct experiments testing the relationship between excess capacity and pricing in Bertrand-Edgeworth duopolies and triopolies. We systematically vary the experimental markets between small amount of excess capacity (suggesting monopoly) and no capacity constraints (suggesting perfect competition). Controlling for the number of firms, higher production capacity leads to lower prices. However, the decline in prices as industry capacity rises is less pronounced than predicted by Nash equilibrium, and a model of myopic price adjustments has greater predictive power. With higher capacities, Edgeworth-cycle behavior becomes less pronounced, causing lower prices. Evidence for collusion is limited and restricted to low-capacity duopolies.

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# 1 Introduction

The Bertrand-Edgeworth model of price-setting firms which operate under capacity constraints (Edgeworth, 1925) is one of the core oligopoly theories. It addresses the intermediate range between uncontested monopoly and perfect competition which is crucial for research in theoretical industrial organization by varying firms' capacities. If capacities are sufficiently small, competition is ineffective and firms charge the monopoly price; whereas, if capacities are not binding, perfect competition emerges. In this way, the model generates market outcomes between monopoly and marginal-cost pricing thought to be intuitive for oligopoly. This is Edgeworth's (1925) main competitive advantage to Bertrand's (1883) approach which is often dismissed as a paradox.

A central feature of Bertrand-Edgeworth oligopoly is that there is no static Nash equilibrium in pure strategies. Instead, there is a mixed-strategy equilibrium which predicts that firms charge prices above marginal cost but below the monopoly level, and averages prices are predicted to decline with capacity. (See, for example, the early references by Beckmann, 1965, and Levitan and Shubik, 1972). At its boundaries, the model exhibits discontinuities in that the nature of equilibrium changes. Once capacities are not binding any more, the Nash equilibrium is in pure strategies and prices are equal to marginal cost. Similarly, if there is no excess capacity at all, pure-strategy pricing at the monopoly level is the equilibrium.

In this paper, we provide a comparative-statics analysis of excess capacity in experimental Bertrand-Edgeworth markets. We run experiments with several levels of capacities, addressing the whole range of capacities between monopoly and perfect competition. Our experiments are thus suitable to shed light on the discontinuities just mentioned. We run two series of treatments as we consider both duopoly and triopoly markets.

The seminal reference analyzing experimental Bertrand-Edgeworth markets is Brown-Kruse

et al. (1994).<sup>1</sup> They analyze four-firm markets and vary both the information available to the participants and the level of industry capacity. Our setup differs from the one in Brown-Kruse et al. (1994) in several dimensions. They analyze three levels of industry capacity, but even for the largest level of capacity, marginal cost pricing is not a Nash equilibrium in their experiments. We run many capacity levels and we also include treatments where the (pure strategy) Bertrand outcome is the Nash equilibrium. Capacity levels in Brown-Kruse et al. (1994) are relatively high, and monopoly pricing is presumably difficult to achieve for participants: there are four sellers, but tacit collusion is known to occur in experiments usually only with two or three firms (Isaac and Reynolds, 2002; Huck et al., 2004). Only 9 to 13 percent of industry capacity are utilized at the monopoly price, and a relatively high discount factors of 0.78 would be required to sustain collusion in the infinitely repeated game. We consider fewer firms, the monopoly price is presumably more focal and we also employ treatments where excess capacity is relatively small (86 percent of capacity is used at the monopoly price, the minimum discount factor is one half or less). While differences in the demand schedule prevent a direct comparison of our results to those of Brown-Kruse et al. (1994), our analysis should complement theirs in that we consider a richer set of capacities and vary the number of firms.<sup>2</sup>

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<sup>1</sup>Following Dufwenberg and Gneezy's (2001) introduction of a simplified Bertrand-Edgeworth setting (which boils down to a Bertrand-Edgeworth setting with inelastic demand and one buyer), there has been a growing number of Bertrand-Edgeworth experiments. See, for example, Dufwenberg et al. (2007); Apesteguia et al. (2007); Abbink and Brandts (2007); Hinlopen and Soetevent (2008); Brandts and Guillén (2004) study homogenous goods markets in which firms specify capacity and then select a price.

<sup>2</sup>Related to Bertrand-Edgeworth oligopoly are posted-offer markets (see e.g., Plott and Smith, 1978, or Ketcham, Smith and Williams, 1984). Posted-offer markets differ to Bertrand-Edgeworth markets in that, first, information is incomplete (sellers know only their own cost schedule) and, second, sellers have to choose a maximum number of units they wish to sell. As noted by Brown-Kruse et al. (1994, p. 344), most posted-offer markets do not address the excess capacity issue.

Brown-Kruse et al. (1994) test the predictive power of various theories of price competition: Competitive pricing, mixed-strategy pricing, tacit collusion and Edgeworth cycle behavior. Their main finding is that all of these theories help to explain the data. However, if a single theory were to be chosen to rationalize the data, Edgeworth-cycle theory would perform best. Edgeworth (1925, p. 116) had already argued that firms will engage in cyclic behavior. Firms will undercut each other's prices but undercutting a rival's price is only worthwhile up to a certain price level. Once this level has been reached, firms prefer jumping back to the monopoly price. Eventually, firms will arrive at the prices vector from which they started and have thus completed an (Edgeworth) cycle. Brown-Kruse et al. (1994) find strong evidence for such cyclical behavior, as do some posted-offer experiments (see, for example, Plott and Smith, 1978; Ketcham, Smith and Williams, 1984; Davis, Holt and Villamil, 2002).<sup>3</sup>

Our basic results confirm those in Brown-Kruse et al. (1994). We find that average prices decrease as excess capacity goes up. While this is consistent with the static Nash equilibrium, the data are better explained by Edgeworth-cycle behavior. Not only are average weighted prices closer to the predicted Edgeworth cycle prices, but we cannot reject the hypothesis that firms are engaging in some form of myopic price adjustment. There is little tacit collusion.

The additional insights from our study are that the significance and the strength of these results depend on the capacity levels. First, we find that the predictive power of the static Nash equilibrium varies with industry capacities. Specifically, the gap between Nash predictions and observed average prices significantly increases alongside the level of excess capacity. Second, also the explanatory power of the model of myopic price adjustments depends on the capacity level. The Edgeworth price adjustment process is *stronger* for treatments with *lower* production capac-

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<sup>3</sup>See also the recent related studies on price dispersion by Morgan et al. 2006 and Orzen (2008) where the equilibrium is also in mixed strategies.

ities. As capacities become bigger and eventually not binding, the intensity of Edgeworth-cycle behavior diminishes substantially. Regarding monopoly pricing, we observe that it is significantly and negatively correlated with industry capacity. When capacities are “small” and approach the monopoly level, a share of prices is indeed at the monopoly level.

Our data are also suitable to illuminate the discontinuities of the Bertrand-Edgeworth model to perfect competition and monopoly. While the intensity of Edgeworth cycles decreases with capacity, even in the case where capacities are such that marginal cost pricing is the pure-strategy equilibrium, Edgeworth-cycle theory still describes pricing behavior rather accurately. That is, even though in theory the Nash equilibrium regime changes from mixed to pure-strategy, we find no corresponding discontinuity in behavior in the experiment. A similar point applies to monopoly pricing. Even for the lowest level of capacity we study, the share of monopoly prices does not exceed 31 percent and, again, much of the data still exhibits cyclical patterns.

Finally, our results add to the existing literature concerned with the effect of the number of competitors on market outcomes. Three findings merit note; firstly and consistent with the existing literature, increasing the number of firms keeping production capacity constant leads to lower market prices. Secondly, the extent to which prices are autocorrelated diminishes with triopolies vis-à-vis duopolies. Furthermore, the extent to which firms engage in Edgeworth cycles is lower in markets with three firms than in markets with two firms. Finally, we observe a drop in the frequency of monopoly pricing when we move from duopolies to triopolies. While there is some evidence of attempts at collusive behavior in two-firm markets, we find no such evidence in markets with three competitors.

The following section describes the model under scrutiny. Section 3 describes the experimental design and methodology; section 4 analyzes the results and section 5 concludes the paper.

## 2 The Model

We consider a symmetric Bertrand-Edgeworth oligopoly with  $n$  firms. Denote by  $k$  a firm's capacity such that  $nk$  is industry capacity and  $(n - 1)k$  is the capacity of a firm's competitors. Firms' production costs up to capacity are assumed to be zero for simplicity.

There are  $m$  buyers, each of whom buys one unit of the good as long as the price does not exceed  $\bar{p}$ . Buyers buy from the firm with the lowest price first. If this firm's capacity is exhausted, they move on to the second lowest price and so on. If two or more firms charge the same price and if their joint capacity exceeds the (remaining) number of customers, demand is split equally among firms.

We assume

$$nk > m > (n - 1)k. \tag{1}$$

These assumptions imply that there is competition, but it is not perfect and static Nash equilibrium profits will be positive. If  $m > nk$ , all firms would charge the maximum price of  $\bar{p}$  and there would not be any competition at all. If  $(n - 1)k > m$ , any subset of  $n - 1$  firms can serve the entire market so there would be perfect Bertrand competition where price equals marginal cost in equilibrium. Since  $m > (n - 1)k$ , equation (1) ensures the static Nash equilibrium is in mixed strategies. Due to the assumption, only two relevant contingencies exist for each firm. If a firm does not charge the highest price, it sells  $k$  units. If a firm does charge the highest price, it sells  $m - (n - 1)k$  units.

### 2.1 Equilibrium Analysis

In this section, we derive the static Nash equilibrium, the minimum discount factor required for collusion in the repeated game and a prediction for markets characterized by myopic Edgeworth-cycle behavior. The proofs of the following three propositions can be found in the appendix.

**Proposition 1.** *The unique static Nash equilibrium is in mixed strategies with support  $[\underline{p}, \bar{p}]$  where  $\underline{p} = \bar{p}(m - (n - 1)k)/k$ . In equilibrium, the probability that a firm charges a price of no more than  $p$  is*

$$\left( \frac{\bar{p}(m - (n - 1)k) - pk}{p(m - nk)} \right)^{1/(n-1)} \quad (2)$$

*Equilibrium profits are  $\pi^N = \underline{p}k = \bar{p}(m - (n - 1)k)$  and the expected capacity-weighted Nash equilibrium price is  $p^N = \underline{p}kn/m$ .*

This is the standard result for Bertrand-Edgeworth oligopolies with inelastic demand. Firms randomize in equilibrium and choose prices between the reservation price and some lower bound that depends on the excess capacity. Nash equilibrium profits and average prices vary between the monopoly level (for  $nk = m$ ) and the perfectly competitive level (for  $k = m$ ).

We now turn to the infinitely repeated game. Time is indexed from  $t = 0, \dots, \infty$  and firms discount future profits with a factor  $\delta$ , where  $0 \leq \delta < 1$ . We will look for subgame perfect collusive equilibria with profits higher than those of the static Nash equilibrium. When analyzing the repeated game, denote by  $\pi_i^c$  the profit firm  $i$  earns when all firms adhere to collusion. Let  $\pi_i^d$  denote the profit when a firm defects, and  $\pi_i^p$  is the profit per period when a punishment path is triggered. We assume that firms revert to the static Nash equilibrium after a defection, thus we have  $\pi_i^p = \pi_i^N$ .<sup>4</sup>

**Proposition 2.** *The minimum discount factor required for collusion in the infinitely repeated game is  $\underline{\delta} = 1/n$ .*

The proposition shows that the minimum discount factor depends only on the number of firms but not on  $k$ . This is due to the symmetry of the model. Indeed, it is our aim to control

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<sup>4</sup>Note that the static Nash equilibrium payoff is equal to the minimax payoff here. Thus, harsher punishments do not exist.

for  $\underline{\delta}$  given industry capacity,  $kn$ , because otherwise, we would change both capacities and  $\underline{\delta}$  in the experiments.

The proof of the proposition shows that colluding at the reservation price  $\bar{p}$  requires the lowest discount factor. Thus, while the folk theorem says that infinitely many outcomes can be a subgame perfect equilibrium of this game, both payoff dominance and the minimum discount factor suggest that players may coordinate on  $\bar{p}$ .

Finally, we consider Edgeworth-cycle behavior. The idea is that, in multi-period Bertrand-Edgeworth markets, firms may dynamically adjust their prices by best responding, assuming that the other firms keep their prices constant. Firms keep undercutting their rivals' prices until they reach a price level (which coincides with the lower bound of the support of the mixed-strategy equilibrium,  $\underline{p}$ ) where they are better off charging the reservation price even if they do not sell their capacity at that price. In other words, in an Edgeworth cycle firms play the myopic best reply, holding naive price expectations.

As all firms which do not charge the highest price in the market sell  $k$ , the myopic best reply is to undercut by the smallest amount (one here for illustration) the rival firm that charged the highest price in the previous period. Formally

$$p_i^{t+1} = \begin{cases} \max\{p_{j \neq i}^t\} - 1, & \text{if } \max\{p_{j \neq i}^t\} - 1 \geq \underline{p} \\ \bar{p} & \text{else} \end{cases} . \quad (3)$$

These kind of myopic price choices suggest the following proposition.

**Proposition 3.** *Edgeworth-cycle pricing behavior implies an average price of  $(\bar{p} + \underline{p})/2$ .*

Proposition 3 is intuitive. If firms play a complete Edgeworth cycle, they charge each of the prices in  $[\bar{p} - \underline{p}]$  exactly once. Thus the average price is the mean of  $\bar{p}$  and  $\underline{p}$  where  $\underline{p}$  is an in Proposition 1.



Neither Proposition 1 nor Proposition 3 do apply when  $m < (n - 1)k$  (see (1)). In that case, capacity constraints are not binding any more and the pure strategy Nash equilibrium is where price equals marginal cost. As firms do not strictly gain when price equals marginal cost, starting a new Edgeworth cycle does not improve profits either. However, we note already here that, since firms make zero profits when price equals marginal cost, charging  $\bar{p}$  does not reduce profits either. For that reason (and this is supported by the data), we will apply the prediction in Proposition 3 also in the treatments where  $m < (n - 1)k$ .

### 3 Experimental Design and Procedures

In order to tackle our research question, we ran a series of experimental Bertrand-Edgeworth markets. In all treatments, there were  $m = 300$  computer simulated consumers, who demanded one unit of a good at the lowest price, as long as that price did not exceed  $\bar{p} = 100$ . The main treatment variable is industry production capacity, which was always symmetrically distributed, and the number of firms in the market (two or three). The choice of capacity distributions was made such that we had treatments in which the static prediction was perfect competition, all the way to a distribution close to point where firms had monopoly power. Table 1 summarizes the treatments. We also ran as an extra control treatment a variant of treatment 250-250, where firms had a fixed production cost. We elaborate more on this treatment in the analysis section.

|         |           |             |             |             |         |         |
|---------|-----------|-------------|-------------|-------------|---------|---------|
| $n = 2$ | treatment | 175-175     | 201-201     | 225-225     | 250-250 | 300-300 |
|         | $K$       | 350         | 402         | 450         | 500     | 600     |
| $n = 3$ | treatment | 116-116-116 | 134-134-134 | 150-150-150 |         |         |
|         | $K$       | 348         | 402         | 450         |         |         |

Table 1: Treatments

We implemented the treatments with a fixed-matching scheme, and generated six markets (or groups) for each treatment. Subjects were told they were representing a firm in a market where

they would meet with one (or two) other firms. Subjects participated in one treatment only and the capacity distribution was held fixed in each market, meaning that each subject dealt with one capacity only. Subjects were informed about all features of the market in the trading rules (instructions are reproduced in the Appendix).

Sessions lasted for at least 30 periods. From the 31<sup>st</sup> period on, a random stopping rule was imposed with a continuation probability of 5/6. Subjects were fully informed about the minimum number of periods and the details of the termination rule. In each period, subjects were asked to enter their price in a computer terminal. Once all subjects had made their decisions, the round ended and a screen displayed the prices chosen by all firms in the market, as well as the profit of each individual firm. Finally subjects were told their accumulated profit up to that point.

Payments consisted of a show-up fee of £5 plus the sum of the profits over the course of the experiment. For payments, we used an “Experimental Currency Unit (ECU)”. In all treatments, 25,000 ECU were worth £1.

The sessions were run in the F.E.E.L.E. lab at the University of Exeter during the Spring of 2008. The experiment was programmed in z-Tree (Fischbacher, 2007). Sessions lasted for about 60 minutes and average payment was £17 (roughly \$31). We conducted two experimental sessions with nine participants for each of the three-firm markets and one session with twelve participants for each of the duopoly markets. The data for treatments 201-201 and 134-134-134 are taken from Fonseca and Normann (2008). These sessions were run by the same experimenter and using the same protocol at the Economics Experiments Laboratory of Royal Holloway College (University of London) during the Fall of 2004 and 2005. We have a total of 96 subjects participating in the Exeter sessions plus 30 subjects who participated in the 201-201 and 134-134-134 treatments at Royal Holloway College.

| Treatment   | $K$ | Prediction           |          |       |                  |
|-------------|-----|----------------------|----------|-------|------------------|
|             |     | $\underline{\delta}$ | $p^{EC}$ | $p^N$ | $p$              |
| 175-175     | 350 | 0.5                  | 85.71    | 83.33 | 84.96<br>(9.70)  |
| 201-201     | 402 | 0.5                  | 75.63    | 66.00 | 78.44<br>(11.93) |
| 225-225     | 450 | 0.5                  | 66.67    | 50.00 | 60.50<br>(19.57) |
| 250-250     | 500 | 0.5                  | 60.00    | 33.00 | 54.04<br>(23.62) |
| 250-250-FC  | 500 | 0.5                  | 60.00    | 33.00 | 47.62<br>(21.79) |
| 300-300     | 600 | 0.5                  | 50.00    | 0.00  | 40.48<br>(22.20) |
| 116-116-116 | 348 | 0.33                 | 79.63    | 68.00 | 73.51<br>(9.46)  |
| 134-134-134 | 402 | 0.33                 | 61.94    | 32.00 | 64.69<br>(20.19) |
| 150-150-150 | 450 | 0.33                 | 50.00    | 0.00  | 41.73<br>(18.10) |

Table 2: Predicted and observed average weighted prices.

## 4 The Results

### 4.1 Overview

Throughout, we consider data from period 11 onwards to allow for learning effects. Using the full data set would not alter the qualitative results. Table 2 displays weighted average price for each treatment. The average prices of the treatments clearly differ. Counting each group average as one observation, a non-parametric Kruskal-Wallis test on the duopoly data (excluding the 250-250-FC data) is highly significant ( $\chi^2 = 20.97$ ,  $d.f. = 5$ ,  $p = 0.0008$ ), as is the same test on the three-firm markets ( $\chi^2 = 8.84$ ,  $d.f. = 2$ ,  $p = 0.0120$ ).

Table 2 suggests that industry capacity and prices are negatively correlated. The Spearman correlation coefficient is quantitatively substantial and significant for both the duopolies ( $\rho = -0.75$ ,  $p < 0.0001$ ) and the three-firm markets ( $\rho = -0.71$ ,  $p = 0.0010$ ). If we compare treatments pairwise, we find that a rise in capacity almost always results in significantly lower prices – the

exceptions being the comparisons between treatments 175-175 and 201-201, as well as 116-116-116 and 134-134-134 (two-tailed Mann-Whitney U test,  $p < 0.05$ ).

## 4.2 Analysis of the Nash equilibrium prediction

The negative correlation of average prices is predicted by the static Nash equilibrium. So, qualitatively, the Nash prediction is consistent with this trend. It is, however, clear that the Nash equilibrium does not do well in terms of the quantitative prediction. The rate of decrease in prices is less pronounced compared to what the mixed-strategy equilibrium predicts. It seems that, as excess capacity increases, the difference between predicted Nash prices and average weighted prices also goes up. Figure 1 shows the average market price for each capacity, as well as the predicted Nash price and Edgeworth cycle price. Indeed, a rank-sum test using the difference between the average price for each market and the Nash prediction confirms that this gap significantly increases with industry capacity for both duopolies (J-T statistic 4.017,  $p < 0.001$ ) and three-firm markets (J-T statistic 3.719,  $p < 0.001$ ).

Since the static Nash equilibrium of this game is in mixed strategies, it is desirable to look at the distribution of posted prices in each treatment and compare it to the predicted mixed strategy distribution. Figures 2 and 3 display the predicted and observed price distributions for the duopoly and triopoly markets, respectively. As is readily observable from the figures, all the observed data distributions significantly differ from their theoretical counterparts at the 1% level using Kolgomorov-Smirnov tests. This is consistent with evidence from Brown-Kruse et al. (1994) and Fonseca and Normann (2008), who reported significant differences between predicted mixed strategy distributions and observed price distributions.

An alternative interpretation of Nash behavior in this context is that subjects make in every period an independent draw with replacement from the mixed strategy equilibrium distribution of

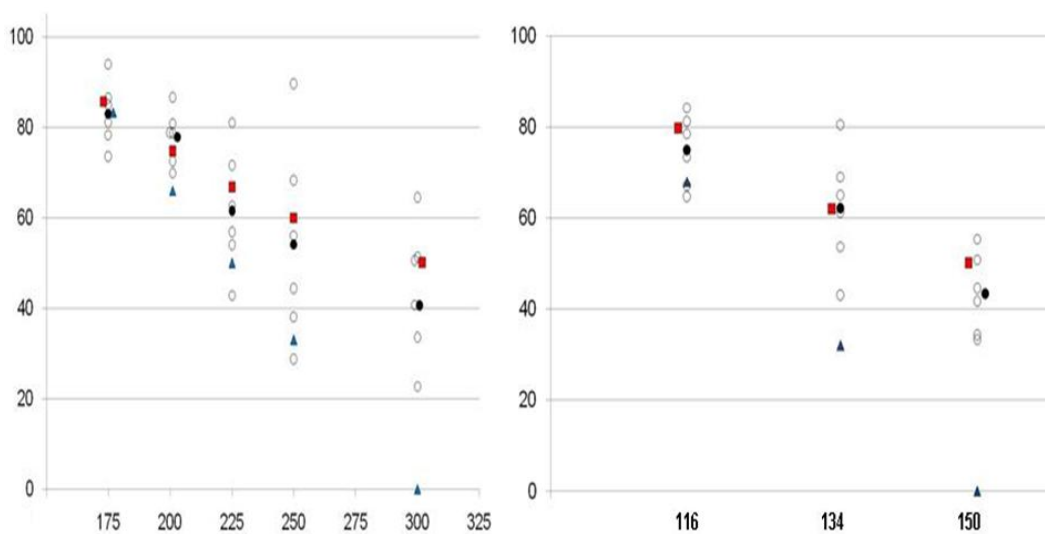


Figure 1: Group average prices for the duopolies (left) and triopolies (right). The squares are the Edgeworth-cycle prediction, the triangles are the Nash equilibrium prediction and the solid dots are the treatment average.

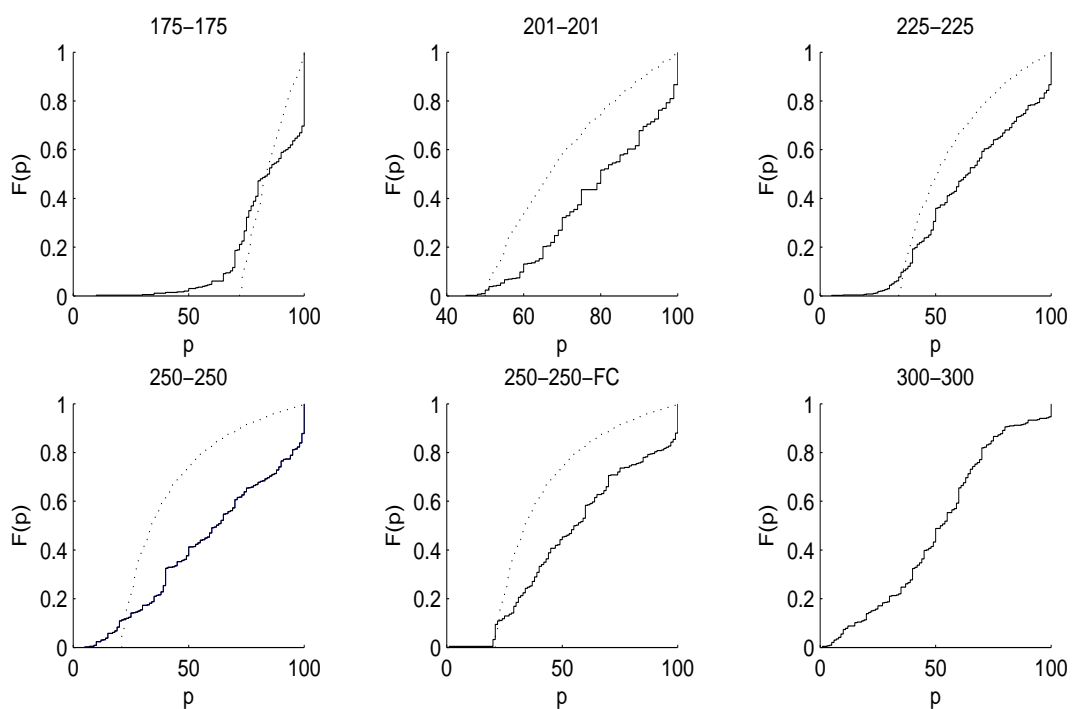


Figure 2: Predicted (dotted line) and observed cumulative price distributions, duopoly treatments

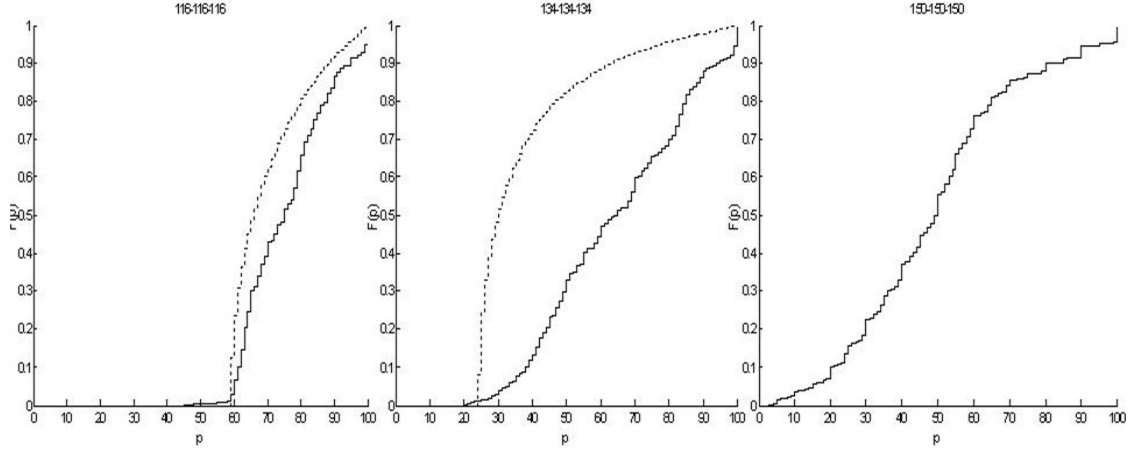


Figure 3: Predicted (dotted line) and observed cumulative price distributions, triopoly treatments

|                       | (175-175) | (201-201) | (225-225) | (250-250) | (300-300) | All      |
|-----------------------|-----------|-----------|-----------|-----------|-----------|----------|
| $(P_t - P_{t-1})$     | -0.571**  | -0.560**  | -0.431**  | -0.384**  | -0.289**  | -0.418** |
| $(P_{t-1} - P_{t-2})$ | (0.039)   | (0.073)   | (0.038)   | (0.037)   | (0.061)   | (0.035)  |
| Perinv                | -5.416    | 35.535    | -10.575   | 6.059     | -95.486   | -13.697  |
|                       | (28.311)  | (14.642)  | (28.130)  | (50.526)  | (41.069)  | (16.444) |
| Const                 | 0.747     | -1.929*   | 0.400     | 0.122     | 4.293     | 0.693    |
|                       | (1.420)   | (0.508)   | (0.951)   | (2.012)   | (1.905)   | (0.716)  |
| N                     | 240       | 396       | 384       | 348       | 312       | 1584     |
| R-squared             | 0.33      | 0.31      | 0.18      | 0.14      | 0.09      | 0.17     |

Table 3: Autocorrelation of prices: duopolies

prices,  $F(p)$ . As such, one would expect there to be no correlation between current and previous prices. To test this hypothesis, we regressed the difference between the price posted by firm  $i$  at time  $t$  and the price posted by the same firm at time  $t - 1$  on its lag plus a variable equal to the inverse of the period (*Perinv*) number to allow for time trends. We find that the coefficient on the lag of the regressor gets smaller as total capacity increases. This effect is significant for the duopolies (J-T statistic = 3.505,  $p < 0.001$ ) but not significantly for triopolies (J-T statistic = 0.970,  $p = 0.166$ ). This indicates that the degree to which prices are autocorrelated diminishes with excess capacity and with the number of firms.

To conclude, the static mixed-strategy equilibrium captures the negative correlation between average prices and industry capacity well. On the other hand, it is obvious that subjects do not

| $(P_t - P_{t-1})$     | (116-116-116) | (134-134-134) | (150-150-150) | All      |
|-----------------------|---------------|---------------|---------------|----------|
| $(P_{t-1} - P_{t-2})$ | -0.348**      | -0.213**      | -0.223**      | -0.237** |
|                       | (0.063)       | (0.065)       | (0.038)       | (0.031)  |
| Perinv                | -7.614        | 51.805        | -30.729       | -3.329   |
|                       | (28.669)      | (43.757)      | (44.318)      | (22.809) |
| Const                 | 0.254         | -2.554        | 1.860         | -0.057   |
|                       | (1.538)       | (2.259)       | (2.536)       | (1.233)  |
| N                     | 414           | 360           | 396           | 1170     |
| R-squared             | 0.12          | 0.05          | 0.05          | 0.06     |

Table 4: Autocorrelation of prices: triopolies

randomize in the way the theory stipulates. Central for our research question is the finding that, with higher capacities, the gap between the Nash prediction and average prices gets bigger.

### 4.3 Tacit Collusion

We now address the issue of collusion. As one can see in Figures 2 and 3, there is some mass on the reservation price in all treatments. As discussed in the theory section, while many possible prices may sustain collusion in equilibrium, the maximum price,  $\bar{p}$  is the natural candidate, both because it is payoff dominant and also because it requires the smallest discount factor.<sup>5</sup> When looking at the aggregate data across treatments we find some limited evidence of collusion. 13% of posted prices are equal to 100 in the duopoly treatments and 5% in the triopoly condition. When we look at the proportion of cases where all subjects posted  $p = 100$  in a given period, the percentage drops to 3% in the duopoly conditions and 0% in the triopoly conditions.

However, these averages mask the variation that exists across different capacity configurations. We find that in the duopoly case, the share of  $p = 100$  prices goes significantly up as total capacity goes down. Using each market as one independent observation, the Spearman correlation between share of  $p = 100$  and capacity is high and significant ( $\rho = -0.51$ ,  $p = 0.004$ ); using a

<sup>5</sup>It is worth noting that neither the static mixed strategy Nash equilibrium nor the Edgeworth cycle predict price distributions with any mass at  $p = 100$ .

| Treatment   | $p = 100$ | all firms $p_t = 100$ |
|-------------|-----------|-----------------------|
| 175-175     | 0.31      | 0.16                  |
| 201-201     | 0.10      | 0.01                  |
| 225-225     | 0.13      | 0.02                  |
| 250-250     | 0.12      | 0.02                  |
| 300-300     | 0.04      | 0.01                  |
| Total       | 0.13      | 0.03                  |
| 116-116-116 | 0.05      | 0.00                  |
| 134-134-134 | 0.05      | 0.00                  |
| 150-150-150 | 0.05      | 0.00                  |
| Total       | 0.05      | 0.00                  |

Table 5: Relative frequency of collusion

Jonckheere-Terpstra test we can reject the hypothesis that shares of  $p = 100$  is constant across treatments in favor of the alternative that it rises as total capacity drops (J-T statistic = -2.85,  $p = 0.004$ ).

When we turn to the triopoly data, we find very little evidence of collusion. The relative frequency of  $p = 100$  is constant at 5% across all treatments, and the relative frequency of three firms simultaneously posting prices equal to 100 is zero. We can reject therefore any relationship between capacity and share of  $p = 100$  prices using either test Spearman's  $\rho = 0.01$ ,  $p = 0.958$ ; J-T statistic = 0,  $p = 0.999$ ). Previous studies of Bertrand markets (Dufwenberg and Gneezy, 2001) found that the degree of competition increased dramatically when the number of firms went from two to three (and four). In their paper, firms were able to serve the entire market. Our evidence suggests that even when capacities are binding, such that no firm is able to serve all consumers, cooperation is too difficult to sustain as one moves beyond a simple duopoly. Table 5 summarizes the results.

A possible explanation for the high frequency of  $p = 100$  observations is that subjects may have attempted to signal the intention to collude by repeatedly posting the maximum price over a number of periods, even when such actions are not corresponded by the other subjects. We found that about half of all  $p = 100$  observations are consistent with (failed) attempts to signal collusion



intentions.

#### 4.4 Analysis of the EC prediction

Brown-Kruse et al. (1994) suggest that subjects' behavior may be consistent with Edgeworth cycles. Table 2 confirms this. Figure 1 suggests that, at least at the aggregate level, Edgeworth cycles are a much better predictor of behavior than the Nash equilibrium in both the duopoly and triopoly conditions.

In order to construct a formal test of Edgeworth cycle pricing, we follow Brown-Kruse et al. (1994) in running OLS estimations of individual price adjustments across periods in all treatments. We estimated the following equation:  $P_{i,t} - P_{i,t-1} = \beta_0 + \beta_1(P_{i,t}^E - P_{i,t-1}) + \beta_2(P_{i,t-1}^E - P_{i,t-2}) + \epsilon_{i,t}$ . The dependent variable is the change in prices from period  $t$  to  $t - 1$ ; the independent variables are the predicted Edgeworth adjustment and its lag.

Based on this estimation, we are able to formulate a number of hypotheses. The first hypothesis is that there is no price adjustment process; that is,  $\beta_1 = \beta_2 = 0$ . The second hypothesis is that firms make an immediate and perfect Edgeworth adjustment, which implies  $\beta_0 = 0$ ,  $\beta_1 = 1$  and  $\beta_2 = 0$ . The third hypothesis,  $\beta_1 = 0$  is that any adjustment is not immediate; finally, the fourth test is that there is no lag in the adjustment process,  $\beta_2 = 0$ .

Estimating the Edgeworth price adjustment equation at the subject level and performing the aforementioned tests broadly lead us to reject the hypothesis that the observed price adjustments are either immediate or perfect. This is consistent across duopolies and triopolies and it is qualitatively similar to the evidence presented by Brown-Kruse et al. (1994); the noticeable discrepancy is that we report a higher rejection rate for the third hypothesis, which may indicate a worse performance of Edgeworth cycle behavior in our data set. This evidence is summarized in table 6.

Tables 7 and 8 show the results from estimating the equation treatment by treatment in

| Treatment   | (1)                        | (2)                                     | (3)           | (4)           |
|-------------|----------------------------|---|---------------|---------------|
|             | $\beta_1 = 0, \beta_2 = 0$ | $\beta_0 = 0, \beta_1 = 1, \beta_2 = 0$ | $\beta_1 = 0$ | $\beta_2 = 0$ |
| 175-175     | 0.58                       | 0.42                                    | 0.58          | 0.00          |
| 201-201     | 0.75                       | 0.75                                    | 0.75          | 0.17          |
| 225-225     | 0.67                       | 0.67                                    | 0.83          | 0.08          |
| 250-250     | 0.67                       | 0.92                                    | 0.75          | 0.17          |
| 300-300     | 0.67                       | 0.92                                    | 0.83          | 0.08          |
| Duopolies   | 0.83                       | 0.82                                    | 0.88          | 0.08          |
| 116-116-116 | 0.61                       | 0.94                                    | 0.78          | 0.11          |
| 134-134-134 | 0.67                       | 0.61                                    | 0.67          | 0.06          |
| 150-150-150 | 0.72                       | 0.72                                    | 0.72          | 0.17          |
| Triopolies  | 0.78                       | 0.80                                    | 0.80          | 0.09          |

Table 6: Fraction of rejection of null hypothesis at the 5% level by treatment

|           | (175-175)          | (201-201)          | (225-225)          | (250-250)          | (300-300)          | All                |
|-----------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| $\beta_1$ | 0.521**<br>(0.088) | 0.499**<br>(0.046) | 0.485**<br>(0.052) | 0.454**<br>(0.034) | 0.465**<br>(0.024) | 0.465**<br>(0.020) |
| $\beta_2$ | -0.248*<br>(0.090) | -0.043<br>(0.069)  | -0.0892<br>(0.053) | -0.105*<br>(0.040) | 0.041<br>(0.042)   | -0.079<br>(0.029)  |
| $\beta_0$ | -0.829<br>(0.558)  | 0.074<br>(0.124)   | -1.422<br>(1.068)  | -1.908<br>(1.851)  | 0.154<br>(0.246)   | -0.994<br>(0.503)  |
| Obs.      | 240                | 300                | 384                | 348                | 312                | 1584               |
| R-squared | 0.29               | 0.23               | 0.22               | 0.25               | 0.29               | 0.24               |

Table 7: Edgeworth-cycle estimates at treatment level: duopolies

|           | (116-116-116)      | (134-134-134)      | (150-150-150)       | All                 |
|-----------|--------------------|--------------------|---------------------|---------------------|
| $\beta_1$ | 0.467**<br>(0.024) | 0.412**<br>(0.076) | 0.388**<br>(0.095)  | 0.398**<br>(0.064)  |
| $\beta_2$ | 0.014<br>(0.052)   | -0.046<br>(0.035)  | -0.131**<br>(0.031) | -0.093*<br>(0.033)  |
| $\beta_0$ | -1.342*<br>(0.417) | -1.241<br>(0.559)  | -1.481<br>(0.775)   | -1.224**<br>(0.393) |
| Obs.      | 414                | 360                | 396                 | 1170                |
| R-squared | 0.31               | 0.17               | 0.24                | 0.22                |

Table 8: Edgeworth-cycle estimates at treatment level: triopolies

both the duopoly and triopoly conditions. Table 7 quantifies the extent to which duopolists make myopic adjustments to their rival's actions in the previous period. The coefficient of  $\beta_1$  is positive and significant in all treatments, as well as in the aggregate. The coefficient of  $\beta_2$  is close to zero and negative (except for treatment 300-300). However,  $\beta_2$  is only significant for treatments 175-175 and 225-225, as well as in the pooled case. The same findings are repeated for the triopoly conditions. The coefficient on  $\beta_1$  is positive and significant, while the coefficient on  $\beta_2$  is close to zero and not always significant. This indicates that firms are indeed making immediate, if only partial, adjustments to rivals' previous period prices. Regression (2) confirms the same findings with respect to the triopoly treatments, albeit with a weaker relationship.

These results give a much less conclusive view than the evidence from the aggregate level data. A closer look at the price distributions in figure 2 may help understand why. On one hand, we see in a number of treatments there is mass at  $p = 100$  (this is clearest in the case of 175-175), which may be indicative of collusion. On the other hand, in almost all treatments, we also see that the lower bound of the pricing distribution is below the theoretical lower bound (which is the same value in the Edgeworth cycle). So, while on the aggregate level, subjects appear to be behaving in accordance to Edgeworth cycles, the individual level data does not always support this claim.

One alternative hypothesis is that a noisy Edgeworth process is occurring. The previous section provided some tentative support for this hypothesis using aggregate level data.<sup>6</sup> We now turn our attention at how treatment effects impact Edgeworth cycles. Going back to table 6, we

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<sup>6</sup>Feedback from post-experimental questionnaires reinforces this belief. We transcribe a representative description by a subject of her behavior in the experiment: "Initially, I tried to set a price that would undercut the price set by company A by a small amount so as to maximise profit. However, when the price set by company A got around 30, I predicted that the next round it would be lower, something like 20-25 and so I set my price at 100. By forgetting about setting the lowest price and selling 75 units at 100 I was guaranteed a profit of 7500. If instead I had tried to undercut company A by setting my price at, say 20, I would only have made 5550 profit and this was less than 7500."

can also see the frequency with which our null hypotheses are rejected treatment by treatment.

The first thing to notice is that the percentage of rejections of hypothesis (1) (no Edgeworth adjustment) is quite high across all treatments. Furthermore, the fraction of rejections of hypothesis (4) is quite low across all treatments. This suggests that while there is in fact some type of Edgeworth price adjustment ongoing, it is imperfect.

Focusing our attention to hypothesis (2), we see a rise in the rejection frequency as the aggregate production capacity goes up (it would be perfectly monotonic if not for treatment 201-201). This indicates that the higher total capacity is, the less likely it is that firms are making perfect Edgeworth adjustments. The rejection rates of treatments 250-250 and 300-300 are already close to 100%, meaning that almost no subject in that treatment is doing perfect Edgeworth price adjustments. This is consistent with the evidence presented in table 2. The difference between the average expected Edgeworth cycle prices and the observed prices increases as we move from the low excess capacity treatment (175-175) to the the high excess capacity treatment (300-300). The same pattern is not apparent from the triopoly data. This may be because subjects have difficulty in tracking pricing behavior of more than one competitor.

The results also suggest a high level of heterogeneity in behavior across markets within the same treatment. Figure 5 displays price histograms for treatment 175-175, which was the treatment in which Edgeworth price adjustments were most salient. We see a high level of heterogeneity across different groups; group 3 appears to be quite collusive, with a very high frequency of observations close to or including  $p = 100$ , while group 6 has a distribution of prices which includes price levels significantly below the lowest predicted price (75) in either mixed strategy equilibrium or Edgeworth cycles. A similar conclusion is drawn from looking at the behavior in other treatments. The complete set of histograms for all treatments is available in the Appendix. In short, Edgeworth cycles predict of aggregate level behavior well, but not individual behavior.

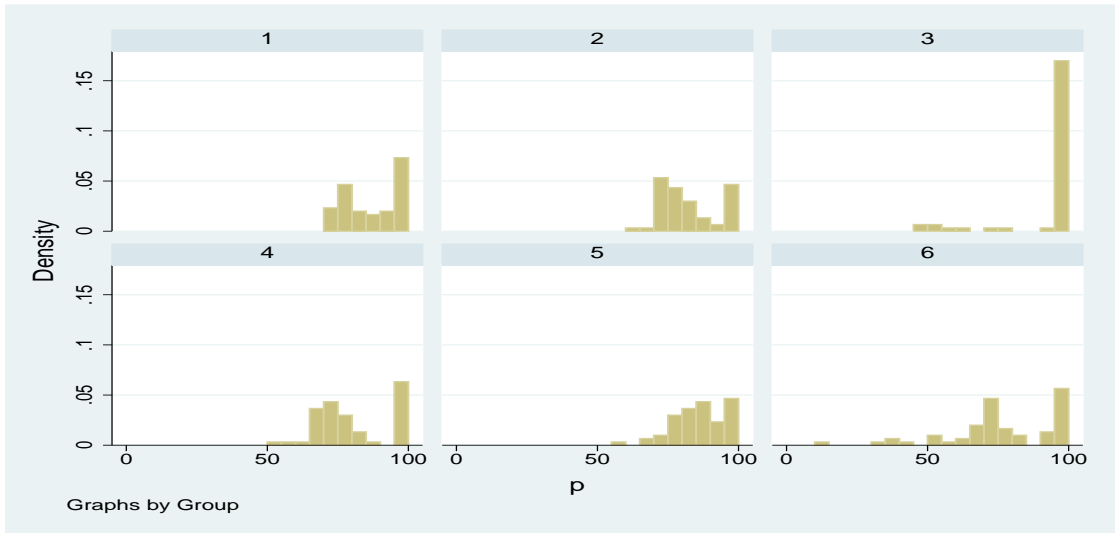


Figure 4: *Histogram of pricing decisions by group, treatment 175-175*

#### 4.5 Aspiration Levels

Could loss aversion be a cause for the higher prices observed in the experiment? As noted above, as excess capacity increases, the difference between predicted Nash prices and average weighted prices also goes up. It seems plausible that, for high levels of excess capacity, subjects' earnings might fall below some (unobserved) aspiration level and thus causes subjects to charge higher prices. Such an effect has been found in price-setting oligopolies where subjects incurred fixed cost for participating in the market (Offerman and Potters, 2006) and in Cournot oligopolies where a merger caused one firm to fall behind its pre-merger profit (Huck et al., 2007).

In order to test for aspiration levels, we ran a variant of the 250-250 treatment in which we introduced a fixed cost of 5000 ECU in every period. This is the maximum fixed cost which does not alter the mixed strategy equilibrium. As one can see from table 2, there are no significant differences in weighted prices. If anything, price are even lower with the fixed cost. We cannot reject the hypothesis that prices generated from the two treatments come from different distributions using a Kolmogorov-Smirnov test, nor the hypothesis that the means are equal (Mann-Whitney U test).

As such, we can conclude that aspiration levels does not play a significant role in behavior in the experiments.<sup>7</sup>

## 4.6 Discussion

Our main research question is how variations in industry capacity affect pricing behavior in Bertrand-Edgeworth oligopolies. Essentially, we found the following effects: firstly, the larger capacities, the bigger the gap between average static Nash equilibrium prices and observed prices. Secondly, with larger capacities the monopoly price is charged less frequently. Thirdly, the larger industry capacity, the less predictive power myopic Edgeworth cycles have.

These findings constitute two puzzles. The first puzzle is that lower capacities are associated with both more pronounced Edgeworth-cycle behavior and more monopoly pricing. After all, Edgeworth-cycle behavior is based on playing a (myopic) best-reply (which is non-cooperative behavior), whereas setting the monopoly price should be considered as tacit collusion. The second puzzle is that the first result suggests there is *relatively* more collusion with higher capacities in the sense that prices are increasingly above the Nash level. While the absolute price level is decreasing with capacities, collusion defined relatively to Nash is increasing with capacities. But, if there is more “collusion” with higher capacities, how does this fit with less monopoly pricing?

Our view is as follows. Suppose there is no excess capacity. Then firms participants would surely charge the monopoly price almost all the time. All our predictions (static Nash, tacit collusion and Edgeworth cycles) predict the monopoly prices. As excess capacity gets positive, subjects play Edgeworth cycles. Note that, with smaller capacities, the monopoly price will be played more frequently because the numbers of periods required for a complete cycle is smaller. While this cannot fully explain the frequencies we observe, it may be part of the story explaining

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<sup>7</sup>We will not include the data from 250-250-FC in the other parts of the analysis. Including them does not affect the results presented in the paper.

puzzle number one.

As capacities get bigger, the high-price firm earns relatively less money. The more “expensive” it becomes to be the high-price firm, the more random subjects’ price choices become. By contrast, with small capacities, the payoff gap between high and low-price firm is smaller. What this reasoning boils down to is that playing the Edgeworth cycle is an (imperfect) form of tacit collusion. Subjects do not always charge the monopoly price, nor do they take regular turns in being the high-price firm. However, subjects can afford to play relatively predictable pricing patterns when excess capacity is low. Thus, with higher capacities Edgeworth cycles lose some of their predictive power. Thus, puzzle number two remains but it is clear from the data that subjects play more aggressively. Subjects still do play the static Nash but they do fall further below the Edgeworth-cycle level with higher capacities. Their behavior becomes more, not less, competitive.

The notion that subjects play more collusively when excess capacity is high can also resolve the issue that tacit collusion should be easier with three firms, not in duopoly. (Recall the minimum discount factor in the repeated game is  $1/n$ .) Controlling for industry capacity, average prices are lower with three firms but they are actually “more collusive” in that the distance to Nash gets bigger.

Finally, we discuss our findings regarding the discontinuities of the Bertrand-Edgeworth model when capacities become non-binding or when there is no excess capacity at all such that pure-strategy equilibria emerge. We found no comparable discontinuity in the data. Indeed, our treatments “large” excess capacity suggesting perfect competition exhibited, to a large extent, cyclical behavior even though capacities were not binding at all. The perhaps provocative conclusion from this is that Bertrand experiments (or at least those Bertrand experiments with inelastic demand like Dufwenberg and Gneezy, 2000; Brandts and Guillén (2004); Abbink and Brandts, 2007) should consider the Bertrand-Edgeworth outcome as a plausible prediction. At marginal cost pric-

ing, profits are zero and apparently players then choose to switch back to the maximum price. This also gives them zero profit but it starts a new cycle. This is clearly boundedly rational behavior. With “small” levels of excess capacity, we also found evidence for cyclical behavior. Here, however, behavior seems more in line with the theory. Average Nash equilibrium prices and the support of the mixed strategy converge to the monopoly price when excess capacities are small. This is what is occurring in the data.

## 5 Conclusion

This paper examines pricing behavior in Bertrand-Edgeworth markets. In particular, we are interested in studying the effect on prices of increasing total production capacity. The game theoretical analysis of this class of games predicts that a unique Nash equilibrium in pure strategies does not exist if the total production capacity in the market is higher than demand, but any subset of firms cannot serve the market by themselves. The only Nash equilibrium is in mixed strategies, where firms randomly select from a unique distribution. In a previous analysis of this class of games, Edgeworth (1925) proposed an alternative approach: he claimed that firms would engage in successive price adjustments relative to their rivals’ prices in the previous period. Firms would undercut each other up to the point where it would be more profitable to charge the monopoly price, thus creating a cycle.

When considering data at the aggregate level, our findings confirm the results of the original Bertrand-Edgeworth experiments by Brown-Kruse et al. (1994). In other words, Nash theory predicts the subjects’ pricing behavior only partially and only qualitatively well. Observed weighted average prices move in the direction predicted by static Nash equilibrium: the higher the total production capacity is, the lower prices are. This occurs in both duopoly and triopoly conditions. However, the rate of decrease in prices is much lower than predicted. When we focus our attention



to pricing distributions, we find significant differences between predicted Nash price distributions and the observed price distributions. We also find some evidence of attempts at collusive behavior. The proportion of posted prices equal to 100 is negatively correlated with total capacity. However, with the exception of one group, those attempts are largely unsuccessful.

By contrast, a model of myopic price adjustments provides a better fit of the data. Not only are average weighted prices closer to the predicted Edgeworth cycle prices, but we cannot reject the hypothesis that firms are engaging in some form of myopic price adjustment. Crucially, (and perhaps counter-intuitively) the Edgeworth price adjustment process is stronger for treatments with lower production capacities. As we move closer to the perfectly competitive case, the intensity of Edgeworth cycle behavior diminishes dramatically. As a result the difference between expected Edgeworth-cycle prices and average weighted prices also increases. Nevertheless, average weighted prices are significantly above predicted Nash prices. This is quite clear for the case where Nash equilibrium prices are zero.

## Appendix A: Proofs

**Proof of Proposition 1.** The probability that firm  $i$  is the firm with the highest price is  $(G(p))^{n-1}$ , and  $1 - (G(p))^{n-1}$  is the probability that firm  $i$  does not charge the highest price. In equilibrium, the expected profit of all prices contained in the support must be the one given in the Proposition,  $\bar{p}(m - (n - 1)k)$ , that is,

$$p [(G(p))^{n-1}(m - (n - 1)k) + (1 - (G(p))^{n-1})k] = \bar{p}(m - (n - 1)k). \quad (4)$$

Manipulating (4) yields

$$p [(G(p))^{n-1}(m - nk) + k] = \bar{p}(m - (n - 1)k) \quad (5)$$

$$(G(p))^{n-1} = \frac{\bar{p}(m - (n - 1)k) - pk}{p(m - nk)} \quad (6)$$

Note that  $G(\bar{p}(m - (n - 1)k)/k) = 0$  and  $G(\bar{p}) = 1$ . This verifies that a firm earns  $\pi^N$  for any price in the support provided the other firms randomize according to  $G(p)$ .

The capacity-weighted average Nash price is derived as follows. If  $q_i$  denotes the number of units sold by firm  $i$ , the weighted average price is  $\sum_{i=1}^n p_i q_i / \sum_{i=1}^n q_i$ . From  $\sum_{i=1}^n q_i = m$  and since  $\sum_{i=1}^n p_i q_i = \sum_{i=1}^n \pi_i^N$  in Nash equilibrium, we obtain  $p^N = \sum_{i=1}^n \pi_i^N / m = \bar{p}(m - (n - 1)k)n/m$  as claimed. Note that the weighted average price differs from the unweighted mean since the high-price firms sell less than its capacity.

Finally, uniqueness of the equilibrium is simply implied by the observations that (i) there cannot be a pure-strategy equilibrium; (ii) there cannot be a mixed-strategy equilibrium which puts positive weights on prices outside the support since prices  $p < \underline{p}$  are strictly dominated by  $\bar{p}$ ; (iii) there cannot be a mixed-strategy equilibrium on  $[\underline{p}, \bar{p}]$  with different randomization weights because, as can be seen from the derivation of the equilibrium  $G(p)$  above, if firm  $i$  chooses any price  $p$  more frequently than  $G(p)$ , firm  $j$  would best respond by charging the pure strategy  $p - \epsilon$ —which

cannot be an equilibrium.  $\square$

**Proof of Proposition 2.** Suppose first that firms successfully collude by tacitly agreeing to charge a price of  $p \leq \bar{p}$ . Then collusive profits are  $\pi_i^c = pmk/K = pm/n$  (that is, each firm gets its symmetric share of industry profit). Defecting with a price marginally smaller than  $p$ , firm  $i$  can get  $\pi^d = pk > \pi_i^c$ . Finally,  $\pi_i^p = \bar{p}(m - (n - 1)k)$ . Collusion is a subgame perfect Nash equilibrium only if  $\pi^c/(1 - \delta) \geq \pi^d + \pi^p\delta/(1 - \delta)$  or

$$\delta \geq \frac{\pi^d - \pi^c}{\pi^d - \pi^p} = \frac{p - pm/(nk)}{p - \bar{p}(m - (n - 1)k)/k} \quad (7)$$

From  $\partial\delta/\partial p < 0$ , colluding with a price smaller than  $\bar{p}$  not only decreases profits but also requires a higher discount factor. Therefore, we analyze perfect collusion where firms charge the reservation price  $\bar{p}$  when colluding. With  $p = \bar{p}$ , (7) simplifies to  $\delta \geq 1/n$ .  $\square$

**Proof of Proposition 3.** The best response characterized by (3) implies that prices are chosen from the interval  $[p, \bar{p}]$  (which coincides with the support of the mixed-strategy equilibrium). To prove the proposition, we need to show that prices are uniformly distributed over the interval.

Suppose first that there are  $n = 2$  firms and let  $p_1 \geq p_2$  denote the two (weakly) highest prices charged in  $t = 0$ . If  $p_1 > p_2$  strictly, the high-price firm will charge  $p_2 - 1$  in  $t = 1$  and all other firms will set  $p_1 - 1$  in  $t = 1$ . Then  $\max\{p_{j \neq i}^{t=1}\} = p_1 - 1$  for *all* firms and thus *all* firms will charge  $p_1 - 2$  in  $t = 2$ . But then all firms will charge  $p_1 - 3$  in  $t = 3$ ,  $p_1 - 4$  in  $t = 4$  and so on until the firms switch to  $\bar{p}$  and eventually charge  $p_1 - 2$  to begin a new Edgeworth cycle. Hence, all prices in  $[p, \bar{p}]$  are chosen exactly once by all firms in a cycle (except for the first two periods) and thus prices are uniformly distributed. The same holds if  $p_1 = p_2$  in  $t = 0$ . All firms set the same price already from period  $t = 1$  on and then play the Edgeworth cycle.

With  $n = 2$  firms, the pattern is different. As there is only one rival for each firm,  $\max\{p_{j \neq i}^t\}$  is always the price of the other firm. This trivially leads to Edgeworth cycles where all prices are

played and are thus uniformly distributed. To see this, suppose that in  $t = 0$  firm 1 chooses  $\hat{p}$  and firm 2 chooses  $\tilde{p}$ . Then the following pattern in Table ? emerges (where  $\hat{p} - 6 = \underline{p}$  is merely chosen as an illustration). Prices  $\hat{p}, \hat{p} - 1, \hat{p} - 2, \dots, \hat{p} - 6 = \underline{p}, \bar{p}, \bar{p} - 1, \dots, \hat{p} + 1$  are played exactly once over an Edgeworth cycle and prices are thus uniformly distributed.

|        | $t = 0$     | $t = 1$         | $t = 2$         | $t = 3$         |     | $t = 6$                       | $t = 7$         | $t = 8$         | $t = 9$         |
|--------|-------------|-----------------|-----------------|-----------------|-----|-------------------------------|-----------------|-----------------|-----------------|
| firm 1 | $\hat{p}$   | $\tilde{p} - 1$ | $\hat{p} - 2$   | $\tilde{p} - 3$ | ... | $\hat{p} - 6 = \underline{p}$ | $\tilde{p} - 7$ | $\bar{p} - 1$   | $\tilde{p} - 5$ |
| firm 2 | $\tilde{p}$ | $\hat{p} - 1$   | $\tilde{p} - 2$ | $\hat{p} - 3$   | ... | $\tilde{p} - 6$               | $\bar{p}$       | $\tilde{p} - 4$ | $\bar{p} - 2$   |

## Appendix B: Sample Duopoly Instructions

### Instructions

Hello and welcome to our experiment. Please read this instruction set very carefully, since through your decisions and the decisions of other participants, you may stand to gain a significant amount of money. We ask you to remain silent during the entire experiment; if at any point in time you require assistance, please raise your hand.

In this experiment you will be in the role of a firm, which is in a market with another firm. The firms produce some good and there are no costs of producing this good.

This market is made up of 300 identical consumers, each of whom wants to purchase one unit of the good at the lowest price. The consumers will pay as much as 100 Experimental Currency Units (ECU) for a unit of the good.

In each market there will be 2 firms, A and B. You can find your type written on the top right-hand corner of this instruction set. Each firm will be able to supply 300 consumers.

The market will operate as follows. In the beginning of each period, all firms will set their selling prices. Then the firm who set the lowest price will sell its capacity at the selected price. The firm who set the second lowest price will not have any customers left to supply.

If more than one firm set the same price and if the number of consumers firms can supply is higher than the number of consumers who haven't bought the good, then they will split the available consumers proportionally to their capacity. In order to fix ideas, let us go over a couple of illustrative examples:

#### Example A:

Suppose that the two firms choose the following prices: Firm A sets a price of 85 and firm B chooses a price of 75. Firm B set the lowest price and therefore sells its 300 units first at a price of 75, making a profit of 22,500 ECU. Firm A set the highest price and therefore will not supply any

customers, therefore making 0 ECU.

Example B: Suppose that the two firms choose the following prices: Firm A and firm B both set a price of 70. Given that they set the same price and also given that their combined capacity (600 units) is larger than the number of customers, they will have to share the available customers. Since their capacities are equal, so will their share of the sales. Hence, both firms will sell 150 units at a price of 70 each unit, therefore making a profit of 10,500 ECU.

At the end of each period, all the firms are informed of the chosen prices by all firms and their own profits. There will be at least 30 periods in this experiment once the 30th period is over, the computer will throw a "virtual" dice that will determine whether the experiment continues. If a value of 6 is shown, the experiment is over. If any other value is shown, the experiment continues.

You will be matched with the same participants in every period.

At the end of the experiment, you will be told of the sum of profits made during the experiment, which will be your payment. You will receive £1 for every 25,000 ECU you earn during the experiment. Additionally you will receive £5 for participating.

## Appendix C: Sample Triopoly Instructions

### Instructions

Hello and welcome to our experiment. Please read this instruction set very carefully, since through your decisions and the decisions of other participants, you may stand to gain a significant amount of money. We ask you to remain silent during the entire experiment; if at any point in time you require assistance, please raise your hand.

In this experiment you will be in the role of a firm, which is in a market with two other firms. The firms produce some good and there are no costs of producing this good.

This market is made up of 300 identical consumers, each of whom wants to purchase one unit of the good at the lowest price. The consumers will pay as much as 100 Experimental Currency Units (ECU) for a unit of the good.

In each market there will be 3 firms, A, B and C. You can find your type written on the top right-hand corner of this instruction set. Each firm will only be able to supply a fraction of the 300 consumers. Firms A, B and C will each be able to supply 116 consumers.

The market will operate as follows. In the beginning of each period, all firms will set their selling prices. Then the firm who set the lowest price will sell its capacity at the selected price. Then, the firm who set the second lowest price will supply either its capacity or whatever is left of the market at the chosen price and so on.

If more than one firm set the same price and if the number of consumers firms can supply is higher than the number of consumers who haven't bought the good, then they will split the available consumers proportionally to their capacity. In order to fix ideas, let us go over a couple of illustrative examples:

#### Example A:

Suppose that the three firms choose the following prices. Firm A sets a price of 85, firm B sets a price of 76 and firm C chooses a price of 63. Firm C sets the lowest price and sells 116 units first, making a profit of  $63 \times 116 = 7308$  ECU. Firm B set the second lowest price and has a remaining 184 customers to sell to. Therefore it will sell 116 units at price of 76, thus generating profits of  $116 \times 76 = 8816$ . Firm A set the highest price. Because firms B and C have already sold their output, there are 68 customers left. Firm A will then sell 68 units at a price of 85, generating 5780 units of profit.

#### Example B:

Suppose that the three firms choose the following prices. Firm A sets a price of 50, firm B chooses a price of 45 and firm C chooses a price of 50. This means that firm B will sell all its output first to 116 customers and make 5220 ECU profit ( $116 \times 45$ ). This leaves 184 customers left to supply. Given that both firm A and C have set the same price and the fact that they can sell a combined total of 232 units, this means they will have to share whatever customers are left. Given that both firm A and C can sell 116 units each, this means they will share the 184 consumers equally. So firm A and C will sell 92 units at a price of 50, making 4150 ECU profit.

At the end of each period, all the firms are informed of the chosen prices by all firms and

their own profits. There will be at least 30 periods in this experiment; once the 30th period is over, the computer will throw a "virtual" dice that will determine whether the experiment continues. If a value of 6 is shown, the experiment is over. If any other value is shown, the experiment continues.

You will be matched with the same participants in every period.

At the end of the experiment, you will be told of the sum of profits made during the experiment, which will be your payment. You will receive £1 for every 15,000 ECU you earn during the experiment. Additionally you will receive £5 for participating.



## Appendix D: Graphs

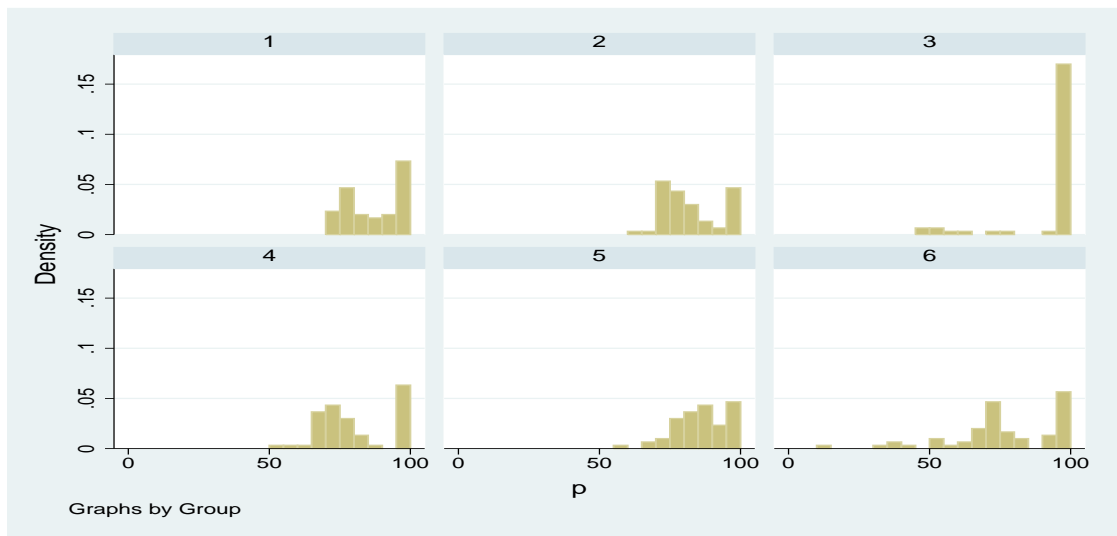


Figure 5: *Histogram of pricing decisions by group, treatment 175-175*

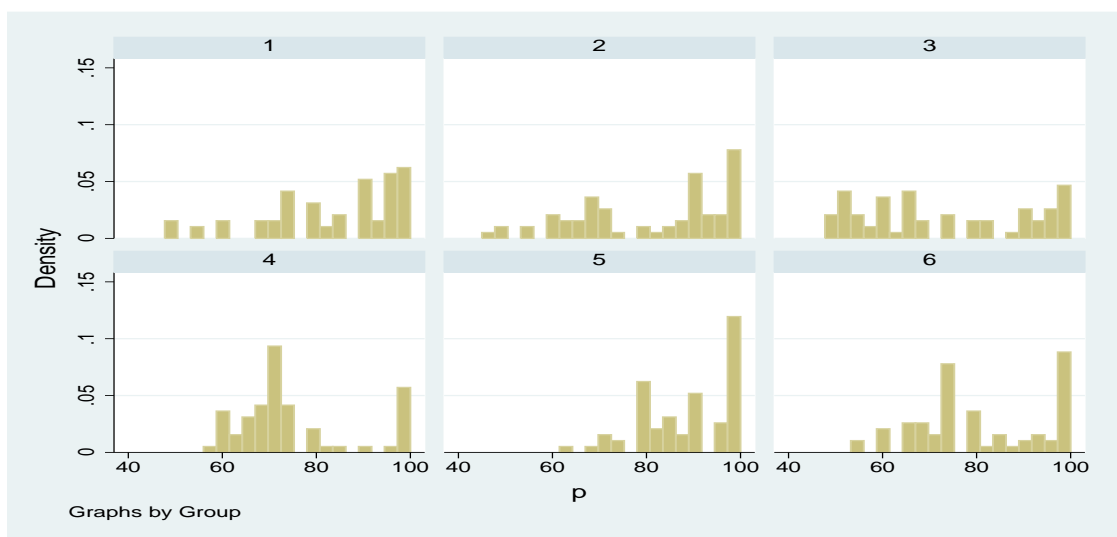


Figure 6: *Histogram of pricing decisions by group, treatment 201-201*

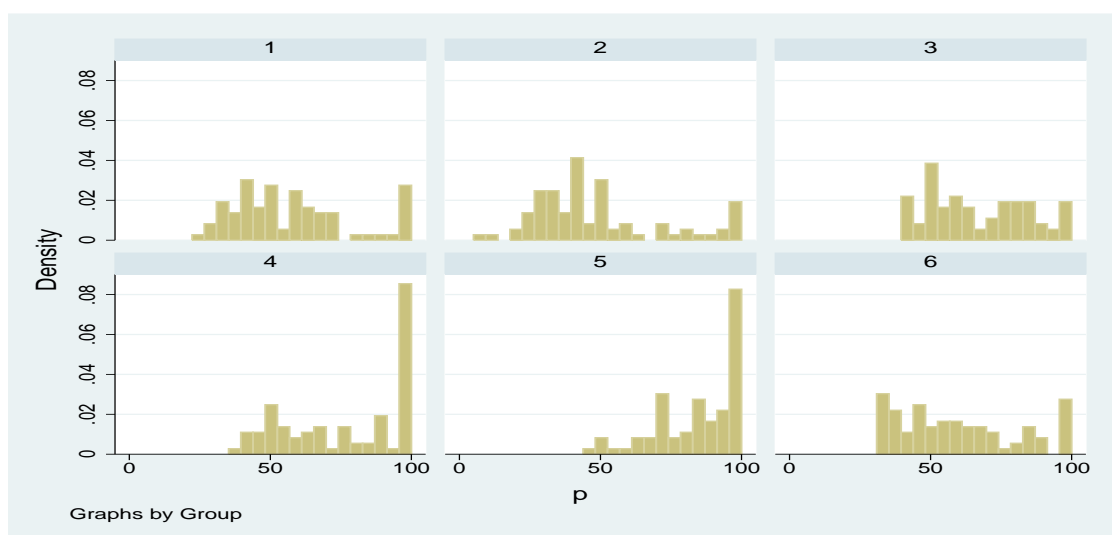


Figure 7: *Histogram of pricing decisions by group, treatment 225-225*

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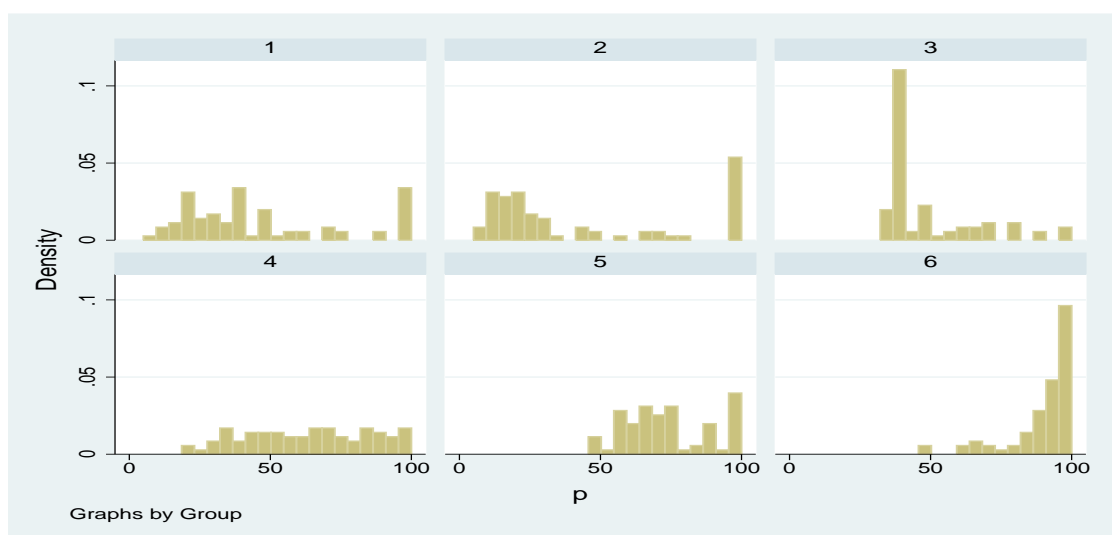


Figure 8: *Histogram of pricing decisions by group, treatment 250-250*

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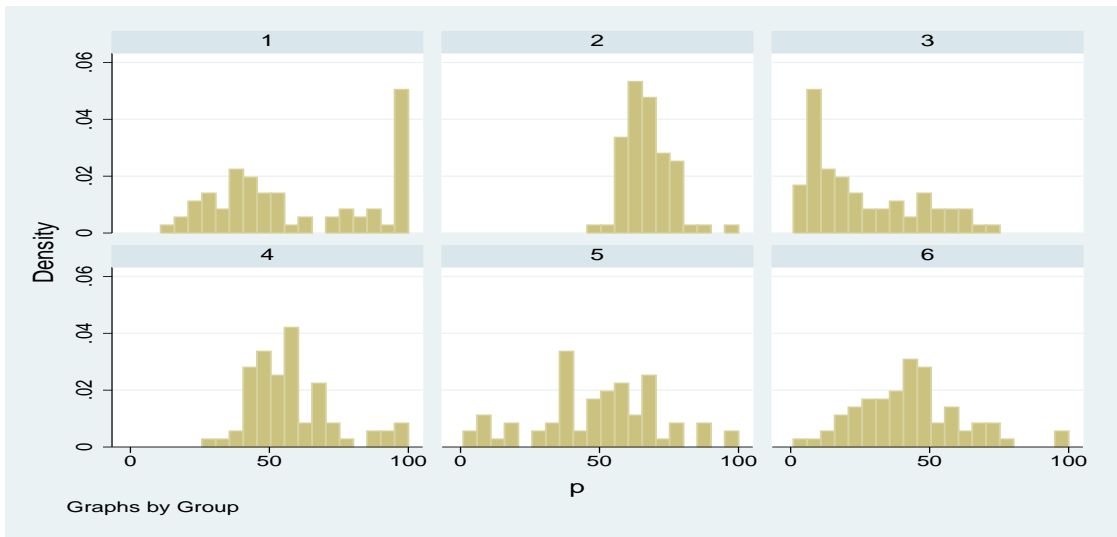


Figure 9: *Histogram of pricing decisions by group, treatment 300-300*

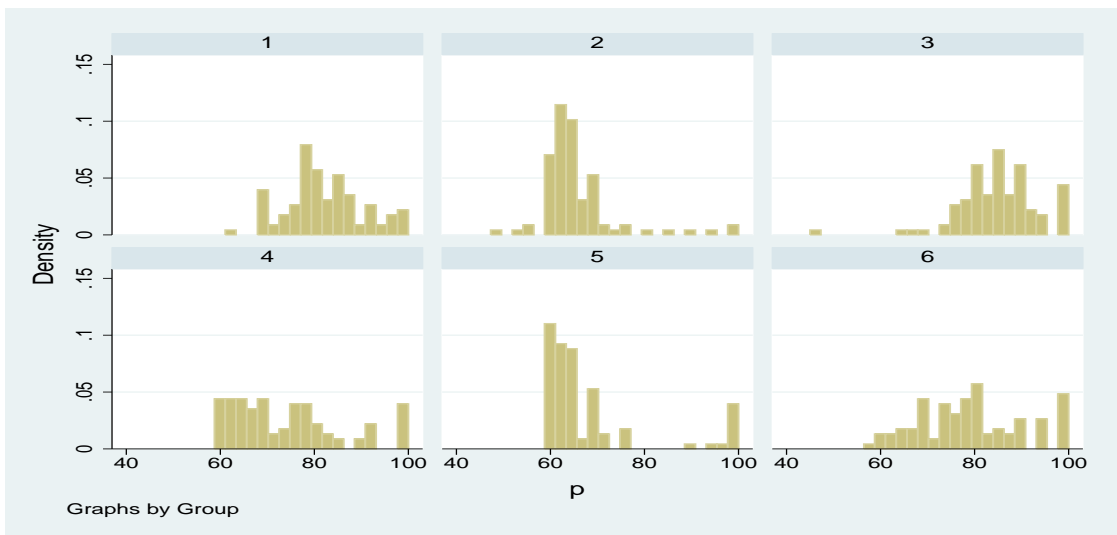


Figure 10: *Histogram of pricing decisions by group, treatment 116-116-116*

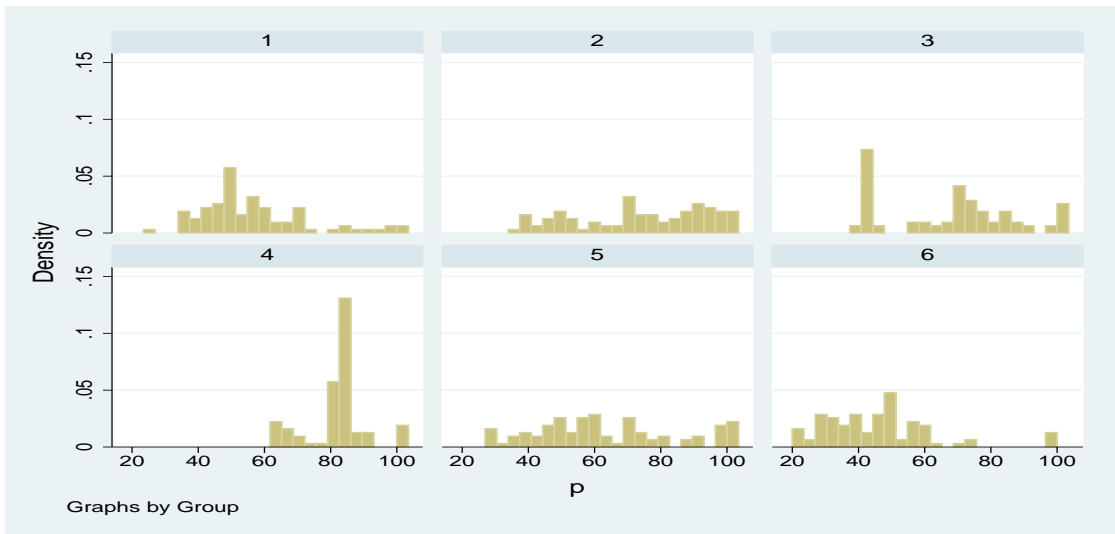


Figure 11: *Histogram of pricing decisions by group, treatment 134-134-134*

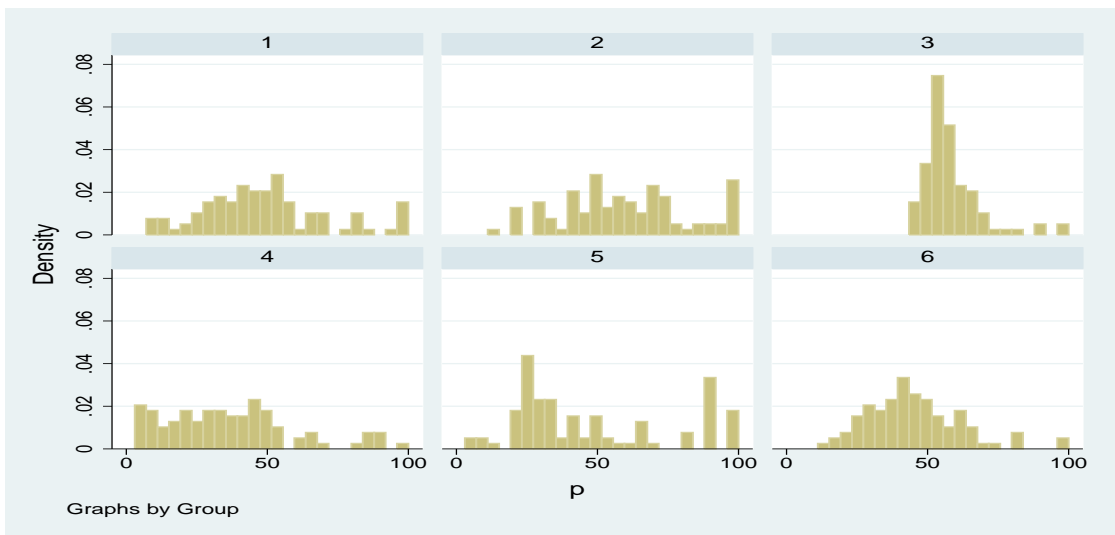


Figure 12: *Histogram of pricing decisions by group, treatment 150-150-150*