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MERGERS, ASYMMETRIES AND COLLUSION: EXPERIMENTAL EVIDENCE*

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We analyse the impact of mergers in experimental Bertrand-Edgeworth oligopolies. Treatment variables are the number of firms (two, three) and the distribution of industry capacity (symmetric, asymmetric). Consistent with a dynamic collusion model, we find that, even though they are more concentrated, asymmetric markets exhibit lower prices than symmetric markets with the same number of firms. Consistent with the static Nash prediction, duopolies charge higher prices than triopolies when we control for (a)symmetry. The overall impact of a merger (which comprises both fewer firms and an asymmetry) is anti-competitive but the price increase is not significant.

Merger policy is primarily concerned with firm consolidations that create or strengthen a dominant player in the market. By examining proposed mergers, competition policy aims at preventing negative effects on competition and welfare. Central to this approach are static measures of market concentration such as the Herfindahl-Hirschman index. The concentration measures help to identify which of the proposed mergers are likely to impede competition.

Recent theoretical work (Compte *et al.*, 2002; Kühn, 2004; Vasconcelos, 2005) on collusion has, however, shown that concentration measures can be misleading. A merger is more than the exit of a firm. The merged firm comprises the assets (e.g. capacities, product lines, capital stock, patents) of the two previously unmerged firms. A merger involving the largest firm in the market will therefore not only reduce the number of firms but also create a more asymmetric market structure than the pre-merger industry. Although the merger does increase concentration, the authors show that the resulting asymmetries actually hinder collusion.

The research of Compte *et al.* (2002), Kühn (2004) and Vasconcelos (2005) contributes to the analytical foundations of a second route in merger policy. This route tries to identify the coordinated effects of mergers, and it has recently been receiving a lot of attention in both the EU and the US (Kolasky, 2002; Dick, 2003). Merger analysis based on static concentration measures is usually referred to as unilateral-effects analysis (Motta, 2004). Unilateral effects occur if the merged firm is able to charge higher prices and still increase its profits. With coordinated effects (or 'collective dominance'), the merged firm cannot raise the price on its own but the merger enhances the scope for collusive pricing in the market. What the theory papers highlight is that the unilateral effects of a merger may be at odds with the coordinated effects.[1]

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[1] Such a scenario is more than a mere theoretical possibility. See the discussion of the Nestlé-Perrier case (Commission Decision of 22 July 1992, Case N3IV/M190) in Compte *et al.* (2002) or Motta (2004).

In this article, we report experimental evidence on the effects of asymmetric markets structures, such as those resulting from mergers and other capacity consolidations. Asymmetries are a central issue in the current debate on coordinated effects of mergers (Dick, 2003).[2] Following Compte *et al.* (2002), the model underlying our experiments is a price-setting oligopoly where firms face capacity constraints. We analyse the effects of mergers and capacity consolidations using two experimental treatment variables, the number of firms (two, three) and the distribution of the industry capacity (symmetric, asymmetric). In all four treatments, industry capacity and demand are held constant. This design allows us to compare symmetric markets with asymmetric markets (holding the number of firms constant) and we can also compare two- to three-firm markets (controlling for the symmetry of the capacity distribution). Such comparisons are useful because mergers involving the largest firm in the industry imply both a reduction of the number of firms and a more asymmetric capacity distribution. Our design is suitable for disentangling the two effects.

Equilibrium analysis shows that concentration has an ambiguous impact in this model. On the one hand, increasing the size of the largest firm increases average static (mixed-strategy) Nash equilibrium prices but, on the other hand, it also increases the minimum-discount factor required for collusion in the repeated game.

The main motivation for using experimental methods in this area is that it is difficult to gain insights into our research question with field data. There is a significant number of intervening factors surrounding a merger which directly affect post-merger pricing decisions on both the merged firm and its competitors. These include economic conditions, cost gains derived from the merger, barriers to entry or industry maturity. However, the theory under scrutiny does not take these elements into account. By employing experimental methods, we can abstract from the aforementioned factors and solely focus on the strategic aspects of mergers on pricing behaviour. For example, our experimental design excludes efficiency gains from the mergers. Whereas efficiency gains no doubt exist in many mergers in the field, it seems useful to exclude them in the experiment in order to focus on the anti-competitive effects of the merger only. Furthermore, we can also set up suitable experimental market parameters in order to test the central hypotheses discussed in the theoretical literature.

Our results indicate that, even though they are more concentrated, asymmetric markets exhibit lower prices than symmetric markets with the same number of firms. This is consistent with the dynamic collusion analysis of Compte *et al.* (2002). In contrast to predictions derived from the dynamic model but consistent with the static Nash equilibrium, duopolies charge higher prices than three-firm oligopolies when we control for (a)symmetry. The overall impact of a merger (which comprises both a reduction in the number of firms and a more asymmetric market structure) is anti-competitive but the price increase is not significant.

[2] See also the Merger Guidelines of the Office of Fair Trading which regard 'symmetry (of size and cost) of the relevant firms' (Office of Fair Trading (2003) section 4.14, p.26)) as one of the 'key elements in giving the firms the ability to align on terms of coordination.'

1. The Model

Consider a Bertrand-Edgeworth oligopoly with n firms. Denote by k_i firm i's capacity and label firms without loss of generality such that $k_1 \leq k_2 \leq \cdots \leq k_n$. Further, let $K := \sum_{i=1}^{n} k_i$ denote aggregate industry capacity, and let $K_{-i} := \sum_{j \neq i} k_j$ denote aggregate capacity of firm i'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 firm with 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, we follow Compte *et al.* (2002) by assuming that demand is allocated proportionally to capacity; see also Allen and Hellwig (1993) who use proportional rationing in a static game.

We assume

$$K > M > K_{-1}. \tag{1}$$

The two inequalities imply that there is competition but it is not perfect and static Nash equilibrium profits will be positive. If $M > K$, competition is not effective and all firms charge the monopoly price, $\bar{p}$. If $K_{-n} > M$, 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 $M > K_{-1} > K_{-n}$, (1) ensures the static Nash equilibrium is in mixed strategies. The second inequality in (1) is not necessary for the equilibrium to be in mixed strategies ($M > K_{-n}$ suffices) but $M > K_{-1}$ simplifies the analysis substantially. It implies that even the smallest firm sells a positive amount when it charges the highest price. Therefore, only two relevant contingencies exist for each firm. Either a firm is the high price firm (in which case it sells $M - K_{-i}$ units) or it is not (in which case it sells k_i units).

2. Equilibrium Analysis

Consider the static (one shot) Nash equilibrium first. We provide a complete derivation of the mixed-strategy equilibrium distributions of prices in the Appendix but the basics of the analysis are rather simple. By charging $p_n = \bar{p}$, the largest firm can ensure that it gets a profit of at least $\bar{p}(M - K_{-n}) > 0$. Thus, the largest firm will never set a price below

$$\underline{p} = \bar{p}\frac{M - K_{-n}}{k_n}. \tag{2}$$

This implies that the smaller firms $i < n$ can sell their full capacity by charging a price slightly below $\underline{p}$ and obtain a profit of $\bar{p}(M - K_{-n})k_i/k_n$. Consequently, this is also the mixed-strategy Nash equilibrium profit for all firms $i = 1,\ldots,n$

$$\pi_i^N = \bar{p}(M - K_{-n})\frac{k_i}{k_n}. \tag{3}$$

The lower bound of the support of the mixed-strategy Nash equilibrium is $\underline{p}$.

Because we have asymmetric capacity distributions, prices have to be weighted with the number of units sold when average prices are calculated. It is easy to see that[3]

$$p^N = \bar{p}(M - K_{-n})\frac{K}{Mk_n}. \tag{4}$$

is the prediction for expected weighted Nash equilibrium prices.

As for the infinitely repeated game, we present a simplified version of the analysis in Compte *et al.* (2002). Time is indexed from $t = 0, \ldots, \infty$ and firms discount future profits with a factor δ, where $0 \leq \delta < 1$. The static Nash equilibrium is also a Nash equilibrium of the infinitely repeated game. We will look for subgame perfect collusive equilibria with profits higher than those of the static Nash equilibrium. When analysing the repeated game, denote by π_i^c the profit firm i earns when all firms adhere to collusion. Let π_i^d denote the profit when a firm defects, and π_i^p is the profit per period when a punishment path is triggered.

Consider collusion first and assume that all firms tacitly agree to charge a price of $p \leq \bar{p}$. Then collusive profits are $\pi_i^c = pMk_i/K$. When it defects with a price marginally smaller than p, firm i can get $\pi_i^d = pk_i > \pi_i^c$. Finally, after a deviation, we assume that firms revert to the static Nash equilibrium. Static Nash equilibrium profits here coincide with the α^* punishments of Compte *et al.* (2002). Moreover, assuming more severe punishments would not change our results (see footnote 3). We have $\pi_i^p = \pi_i^N$ as in (3).

Collusion is a subgame perfect Nash equilibrium only if $\pi_i^c/(1-\delta) \geq \pi_i^d + \pi_i^p\delta/(1-\delta)$ or

$$\delta \geq \frac{\pi_i^d - \pi_i^c}{\pi_i^d - \pi_i^p} := \delta_i, i = 1, \ldots, n, \tag{5}$$

where δ_i denotes the minimum-discount factor required for firm i to adhere to collusion. Substituting π_i^c, π_i^d and π_i^p into (5) and simplifying, we obtain

$$\delta_i = \frac{p - pM/K}{p - \bar{p}(M - K_{-n})/k_n}. \tag{6}$$

From $\partial\delta_i/\partial p < 0$, colluding with a price smaller than $\bar{p}$ not only decreases profits but also requires a higher discount factor. Therefore, we restrict the analysis to perfect collusion where firms charge the reservation price $\bar{p}$ when colluding. With $p = \bar{p}$, (6) simplifies to

$$\delta_i = \frac{k_n}{K}. \tag{7}$$

The incentives to adhere to collusion are the same for all firms as δ_i does not depend on k_i. Hence, $\max\{\delta_1, \delta_2, \ldots, \delta_n\} = k_n/K := \underline{\delta}$ is the minimum discount factor required for successful collusion.[4]

[3] 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 $p^N = \sum_{i=1}^n \pi_i^N / M$ as in (4).

[4] Punishments more severe than Nash reversions would reduce $\delta_1 \ldots \delta_{n-1}$ but not δ_n since π_n^N is also firm n's maximin profit. Thus, $\max\{\delta_1, \delta_2, \ldots, \delta_n\} = k_n/K$ as with Nash reversions.

We conclude the analysis by explicitly stating the effects of mergers and capacity reallocation policies. Simple calculations show that average Nash prices as in (4) increase in k_n. In the repeated game, $\underline{\delta} = k_n/K$ as in (7) increases in k_n. Thus, the policy message for mergers is ambiguous. The static analysis suggests that competition is weaker when k_n increases but the dynamic analysis says that collusion becomes more difficult.[5] Higher k_n can be due to some asymmetry but note that k_n is also higher for symmetric markets with fewer firms. Thus one prediction from the collusion model is that more fragmented symmetric markets will be more prone to collusion (Kühn, 2006). We summarise

PROPOSITION. *Holding industry capacity constant, a merger or capacity reallocation policy that increases the capacity of the largest firm, k_n, increases average weighted static Nash equilibrium prices but reduces the minimum discount factor required for collusion. The opposite is true if k_n is reduced.*

What is the intuition behind the proposition? When k_n increases, the largest firm can unilaterally obtain a profit higher than the previous static mixed-strategy Nash profit by charging the reservation price $\bar{p}$. In other words, its best-response function changes due to the merger. Accordingly, not only firm n, but also all other firms $i \neq n$ in the market (which anticipate firm n's changed behaviour), charge higher prices and earn a higher profit in the new Nash equilibrium. The impact of an increase of k_n on $\underline{\delta}$ is also straightforward. In (5), only $\pi_i^p = \pi_i^N$ depends on k_n. As just seen, an increase of k_n will push up π_i^N for all i. Intuitively, when the punishment becomes less severe, collusion gets more difficult in the repeated game. Of course, an increase of k_n will also reduce at least one $k_{i \neq n}$ as we keep K constant. However, this effect cancels out as all terms in (5) (i.e., π_i^d, π_i^c and π_i^p) are proportional to k_i.

Our view of the theory is that it provides qualitative predictions for the data analysis. We interpret (4) and (7) as opposing rankings of competitiveness of markets, both based on k_n. This approach is standard (Davis *et al.*, 2002) but it is arguably only a rough interpretation of the theories; see the discussion in Kühn (forthcoming). The question of whether subjects actually collude or play the mixed Nash equilibrium is discussed in Section 5.

3. Experimental Design

We analyse four different treatments. In all treatments, industry capacity is $K = 402$ and there are always $M = 300$ (simulated) consumers, each demanding one unit of a good as long as the price does not exceed $\bar{p} = 100$.

Our treatment variables are the number of firms (two or three) and the distribution of industry capacity (symmetric, asymmetric). Successful collusion rarely occurs when there are more than three firms in experiments (Huck *et al.*, 2004). Hence, we focus on

[5] The effect of mergers is, however, unambiguous if we condition the analysis on δ. If $k_n/K > \delta$ both before and after merger, the static Nash equilibrium is relevant and an increase of k_n should raise prices. If $k_n/K \leq \delta$ before the merger but $k_n/K > \delta$ afterwards, prices should fall from collusive to static Nash levels. Finally, if $k_n/K < \delta$ both before and after merger, the merger has no impact as the industry should be collusive either way.

Table 1

Treatments

		Capacity distribution	
		Symmetric	Asymmetric
Firms	Two	201-201	268-134
	Three	134-134-134	160-134-108

two and three firms. We label treatments according to capacity allocation; k_2-k_1 for duopolies and $k_3-k_2-k_1$ for three-firm oligopolies. The assumptions on K, M, and k_i satisfy (1). Table 1 summarises the two-by-two design.

The logic of our treatment design is as follows. If two firms merge in treatment 134-134-134, the resulting capacity allocation is as in treatment 268-134. Now, 268-134 is both asymmetric and has fewer firms compared to 134-134-134. We therefore need a symmetric control treatment (201-201) and an asymmetric three-firm treatment (160-134-108).[6] A merger of the large and the small firm in 160-134-108 also implies a capacity distribution as in 268-134. Furthermore, faced with a merger that would lead to 268-134, a competition authority might consider a merger remedy where capacity is reallocated from the large firm to the small firm. If so, the capacity distribution that minimises (static) concentration measures is the same as in our symmetric 201-201 treatment.

We implemented the four 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 including the trading rules; instructions are reproduced in Fonseca and Normann (2007).

Sessions lasted for at least 30 periods. From the 31st 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)'. The exchange rate varied between treatments because of the large profit differences we expected between two and three-firm markets and between small and large firms. In 134-134-134 and 160-134-108, 15,000 ECU were worth £1. In 201-201, 35,000 ECU were worth £1. Finally, in 268-134 £1 was earned for each 45,000 ECU accumulated.

The sessions were run in the Economics Experiments Laboratory of Royal Holloway College (University of London) during the autumn of 2004 and 2005. The experiment

[6] There is some leeway regarding the capacity distribution of the asymmetric three-firm markets; capacities have to satisfy $134 > k_1 > 102$, $k_1 + k_3 = 268$ and $k_2 = 134$. Note that it is not possible to control for the *degree* of asymmetry across the two asymmetric treatments.

was programmed in z-Tree (Fischbacher, 2007). Sessions lasted for about 60 minutes and average payment was £16.34 (roughly \$30). We conducted two experimental sessions with nine participants for each of the three-firm treatments and one session with twelve participants for each of the duopoly treatments. This makes a total of 60 participants who were recruited from all over the campus.

4. Main Results

Table 2 summarises the data. The column on the right reports the observed weighted average price for each treatment. The predicted weighted Nash price, p^N, and the minimum discount factor required for collusion, $\underline{\delta}$, are taken from (4) and (7). In the Table, we order the treatments by the size of the largest firm, k_n. In order to take learning effects into account, we use data from period 11 on only throughout the results sections.[7] The results in Table 2 suggest that duopolies are less competitive than three-firm markets but that asymmetric treatments are more competitive than symmetric ones. Whereas while prices in the asymmetric industries are at or even below the static Nash level, they are above that level in the symmetric markets. Thus, asymmetries seem to hinder collusion.

We elaborate on these effects using the two least-squares regressions reported in Table 3. In both regressions, price is the dependent variable. We account for possible dependence among observations within each market (or group) by reporting robust standard errors with market-level clusters (Wooldridge, 2003).

Regression (*a*) in Table 3 quantifies the price differences between treatments. In this regression, the dummy variables denote the treatment conditions and the baseline treatment 134-134-134 is omitted to avoid collinearity. The coefficient of 160-134-108 is negative and significant, that is, prices are lower than in 134-134-134. By contrast, prices in 201-201 and 268-134 are higher than the baseline treatment, although significantly

Table 2
Summary Statistics

	Predictions		data
Treatment	p^N	$\underline{\delta}$	p
134-134-134	32.00	0.33	64.69 (20.19)
160-134-108	47.91	0.40	43.56 (19.44)
201-201	66.00	0.50	78.44 (11.93)
268-134	83.00	0.67	73.39 (11.76)

Notes. The predictions are the expected weighted Nash price, p^N and the minimum discout factor, $\underline{\delta}$; from the data, we report the average wieghted price p, (standard deviation in parenthesis)

[7] Our results do not change qualitatively when we include data from all periods. While there is no time trend in the data, there is nevertheless evidence for learning in that in some treatments the distributions of prices change somewhat over time.

Table 3
Results of the Regressions

(*a*)		(*b*)	
160-134-108	−18.20**		
	(8.48)		
201-201	13.56**	*duopoly*	20.40***
	(6.56)		(4.79)
268-134	7.27	*asymmetry*	−12.19**
	(6.92)		(4.74)
constant	67.32***	constant	64.21***
	(6.27)		(5.08)
N	1,563	N	1,563
R^2	0.25	R^2	0.24

Notes. Linear regressions with market-level clustering; standard errors in parenthesis; *** and ** indicate significance of the 1% and 5% levels, respectively.

so only in the former case. The difference between the coefficients of 201-201 and 268-134 is statistically significant (F test, p value $= 0.085$).[8]

Regression (*b*) analyses the data according to our treatment variables (number of firms, symmetry of the capacity distribution). The dummy variable *duopoly* is equal to one in 201-201 and 268-134, and the asymmetry dummy is equal to one 160-134-108 and 268-134. Across all treatments, duopolies charge about 20.40 more than three-firm oligopolies. Firms in the asymmetric treatments charge lower prices by about 12.19 points. Both variables are significantly different from zero.

What are the implications of these results? In our data, a merger in 134-134-134 resulting in 268-134 would (insignificantly) raise prices. When disentangling the impacts of asymmetry and of changes of n due to the merger, we find that increasing k_n through a reduction of n causes price increases, given an (a)symmetric capacity distribution. Increasing k_n while keeping n constant does, by contrast, lead to lower prices.

From the point of view of the theory, the 'number effect' that duopolies charge higher prices is consistent with the static Nash equilibrium prediction whereas the repeated-game analysis wrongly predicts that the three-firm markets are more collusive. Regarding the effect of asymmetries, the static Nash equilibrium gives the wrong prediction in this case as asymmetries coincide with a higher concentration and, hence, should lead to higher prices. It is the repeated-game argument that correctly predicts the direction of the price change. We summarise:

RESULT. *Controlling for the number of firms, asymmetric capacity distributions imply lower prices. This is consistent with the repeated-game analysis. Controlling for the (a)symmetry of the capacity distribution, a reduction in the number of firms leads to higher prices. This is consistent with the static Nash-equilibrium analysis.*

In terms of the above Proposition, both static and repeated-game arguments predict some aspects of the data correctly but neither can fully account for all the effects we observe either. Increases in concentration due to a reduction of the number of firms

[8] If we use non-parametric tests instead (where one average price per group serves as the unit of observation), we obtain the same results in terms of the significance of treatment effects.

affect prices differently from increases in concentration due to an asymmetry. Given these opponent forces, it is perhaps not surprising that the overall impact of a merger (which comprises both a reduction of the number of firms and a more asymmetric industry) does not significantly raise prices in our experiment.

5. Further Results and Discussion

So far, we have interpreted the theory qualitatively in the sense that (4) and (7) imply opposite rankings of competitiveness, and we have tested for consistency with these rankings using average prices. The results suggested (in)consistencies with the theories in this broad sense. We now turn to the question of whether the data correspond to (or refute) the mixed-strategy equilibrium or some notion of collusion in a more narrow sense. This issue is discussed extensively in Brown-Kruse *et al.* (1994) for symmetric markets. We report only a few central findings.

Figure 1 displays predicted and actual price distributions (see the Appendix for the derivations). As expected from the results in Table 2, the distributions of prices in the data are rather different from those in the static prediction. Kolmogorov-Smirnov (one-sample) tests indicate that the predicted and the observed distributions differ significantly in all treatments at the 1% level.[9]

In the asymmetric treatments, the distribution of static Nash prices is type-dependent (see Appendix). What we find in the data of those treatments is that the pricing behaviour of the different types is more similar than static theory suggests. For example, predicted medians in 268-134 are 100 and 76.50 for the large and the small firm, respectively, whereas observed medians are 74.00 and 70.00. In 160-134-108, observed medians are virtually identical (49.00, 50.00, 50.00) but the predicted values read 50.48 (large firm), 45.19 (medium firm), and 41.59 (small firm). A similar point can be made

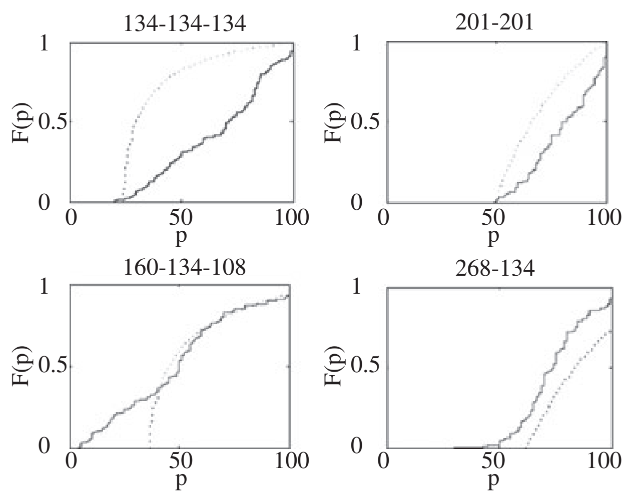

Fig. 1. *Predicted* (dotted line) *and Observed Cumulative Price Distributions*

[9] The KS test statistics are: $D = 0.561$ in 134-134-134, $D = 0.322$ in 160-134-108, $D = 0.310$ in 201-201, and $D = 0.278$ in 268-134, where the cut-off values for 1% significance are all not higher than 0.060.

regarding observations of $\bar{p}$. The large firm in 268-134 has 11.4% of the observations on $\bar{p}$ (where it should have 50% mass) compared to 3.7% of the observations for the small firm (which should have no mass on $\bar{p}$). In 160-134-108, the large firm only should have mass on $\bar{p}$ (16.25%) but we find that, at least to some extent, the three types of firms charge $\bar{p}$ (9.1%, large; 6.1%, medium; 5.1%, small). Finally, conducting (two-sample) Kolgomorov-Smirnov tests on the equality of the distributions shows that we cannot reject the hypothesis that price distributions are the same in 160-134-108.[10]

As the static Nash equilibrium is in mixed strategies, it might be difficult for participants in experiments to learn to play the correct distribution of prices. Surely, this is much more intricate than learning to play some unique pure-strategy equilibrium. If we cannot expect the equilibrium price distribution to be played correctly, do subjects at least play rationalisable strategies? In general, all prices in the support of the mixed-strategy Nash distributions, $[\underline{p}, \bar{p}]$, are rationalisable, where $\underline{p}$ is as in (2) (in Figure 1, this is the intersection of the dotted line with the horizontal axis) and where $\bar{p} = 100$. In the symmetric treatments, prices are virtually never below $\underline{p}$. In 201-201 there is only one (of 300) prices below $\underline{p}$ and in 134-134-134 there are only 5 (of 360) such observations. By contrast, there are quite a few observations of prices outside the interval $[\underline{p}, \bar{p}]$. In 268-134 there are 90 (of 516) prices below $\underline{p}$ and in 160-134-108 there are 203 (of 567) prices outside the support. Hence, rationalisability fails in the asymmetric treatments whereas almost all prices are rationalisable in the symmetric treatments.[11]

The result that virtually all prices are rationalisable in the symmetric treatments may have implications for the interpretation of our results (as pointed out by a referee). If prices are rationalisable, the data may well be consistent with one-shot behaviour and do not necessarily indicate collusion – even though in the symmetric treatments average prices are higher than in the static Nash equilibrium. A similar point concerns observations where firms charge the monopoly price, $\bar{p} = 100$ (see Figure 1). In our experiment $\bar{p}$ is focal and also yields the highest collusive profits at the lowest discount factor, but it is also true that this price is in the set of rationalisable prices. Thus, interpreting observations of $\bar{p}$ in the symmetric treatments as evidence for collusion may not be appropriate.

The following observations also suggest caution when interpreting the price data in the symmetric treatments as collusive. We see surprisingly few instances of collusion where all firms charge the same price (only 12 of 480 cases). There are only two cases where all firms charge $\bar{p}$ and we never observe uniform pricing in two consecutive periods. More generally, if tacit collusion were developing over time, one would expect prices in a given round of the experiment to be positively correlated with prices in the previous periods. We find limited supporting evidence for this hypothesis. In the 134-134-134 treatment, the correlation of prices in round t with rounds $t-1$ and $t-2$ is

[10] The KS test statistics are: large vs. medium $D = 0.081$, large vs. small $D = 0.101$, medium vs. small $D = 0.071$ where the cut-off value for 10% significance is 0.107.

[11] Another implication of rationalisability is that the lower bound of the support, $\underline{p}$, should increase in k_n. In the asymmetric markets, $\underline{p}$ should be higher than in the symmetric markets but we note that $\underline{p}$ decreases (Figure 1). In markets with fewer firms and given (a)symmetry, we should also observe an increased $\underline{p}$ and it is apparent in Figure 1 that this is the case. These findings confirm our above results obtained from the analysis of average prices.

0.64 and 0.46, while in the 201-201 treatment, the same correlation is equal to 0.17 and 0.23, respectively.

To conclude, as in previous experiments (Brown-Kruse *et al.*, 1994), the data show little evidence in favour of the static Nash equilibrium; strategies are rationalisable only in the symmetric treatments; and stable collusion in which all firms charge the same price over multiple periods does not occur. While we believe that more research should be dedicated towards the behavioural forces in Bertrand-Edgeworth experiments,[12] we maintain that our data can be interpreted 'as if' consistent with either the static Nash prediction or the collusion model, as is done in our main result.

6. Related Literature

In this Section, we briefly review some related experimental papers; see Engel (2007), Huck *et al.* (2004) and Huck *et al.* (2007) for further references. Among others, Davis and Holt (1994), Davis *et al.* (2002) and Huck *et al.* (2007) have studied mergers in experiments but, in contrast to this study, these papers deal with essentially symmetric markets. Davis and Holt (1994) study unilateral merger effects in posted-offer markets. They change industry concentration by capacity reallocations and through mergers. Consistent with our findings, their data suggest that the main impact of mergers on prices is well captured by the static Nash prediction. While there are firms of different sizes in Davis and Holt (1994), their treatments are symmetric in that the firms with market power have the same cost functions. The smaller firms do not affect the Nash equilibrium. Davis *et al.* (2002) analyse symmetric two and three-firm posted-offer markets, keeping dynamic incentives constant. They find that introducing market power (reflected in higher Nash prices) affects prices only in the three-firm markets and not in the duopolies. Huck *et al.* (2007) is about mergers in Cournot oligopoly. In their experiments, the firms of two players actually consolidate in the middle of the experiment. Theoretically, the post-merger market should be symmetric but Huck *et al.* (2007) show that merged firms produce significantly more output than their competitors.

One of our main results is that asymmetric industries find it more difficult to collude. Mason *et al.* (1992) have obtained a related result. In Cournot duopoly experiments, they find that, when firms differ in their marginal cost parameters, markets are more competitive than in the symmetry case. While similar in spirit, note that their result does not relate to the theoretical research of the Compte *et al.* (2002), Kühn (2004) and Vasconcelos (2005) papers (where it should be added that these experiments were not designed to analyse the dynamic collusion problem studied in the papers). When duopolistic firms have different (constant) marginal costs, coordinating on a point on the Pareto frontier is more intricate than in the symmetric case. In the absence of side payments, the joint-profit maximum is an unlikely candidate for collusion as it requires the inefficient firm to shut down. There are no focal points either. What is more, the incentives for collusion will depend on which point on the Pareto frontier is arbitrarily selected in the model with asymmetric marginal costs. The results in Mason *et al.* (1992)

[12] Brown-Kruse *et al.* (1994) find 'Edgeworth cycles' have some explanatory power in their symmetric Bertrand-Edgeworth experiments. In an Edgeworth cycle, firms play the myopic best reply, holding naive price expectations, such that prices are in $[\underline{p}, \bar{p}]$.

show that subjects in experiments find it hard to collude in this setup. The problem analysed in this article and in the aforementioned theory papers is rather different. Here, there is a unique and focal price that maximises industry profits and so colluding is probably not much of a coordination problem. (Even in the cases of imperfect collusion studied in Vasconcelos (2005), firms do not have conflicting interests regarding the price to charge.) Nevertheless, the asymmetries studied here reduce prices when we control for the number of firms.

The theoretical model underlying the recent experiments in Morgan *et al.* (2006) shares some similarities with the model of this article. In their Bertrand model, as in our markets, a firm that is not charging the lowest price still sells a positive amount. However, in their case, this is due to brand-loyal consumers. Morgan *et al.* (2006) analyse how the comparative statics predictions for changes in the degree of consumer loyalty are borne out in the data in symmetric settings.

7. Conclusion

In this article, we analyse the impact of mergers and capacity consolidations on prices in Bertrand-Edgeworth laboratory markets. Our data suggest that increases in concentration due to a reduction of the number of firms affect prices differently from increases in concentration due to an asymmetry. While neither the static Nash equilibrium nor the dynamic collusion model can fully account for the treatment effects we observe, our results confirm the main hypotheses in Compte *et al.* (2002), Kühn (2004) and Vasconcelos (2005) in that asymmetries appear to hinder collusion. The policy conclusions from this is that concentration measures can be misleading, and merger remedies that aim at post-merger symmetry can backfire.

Appendix: Mixed-strategy Nash Equilibrium

Here, we derive the static Nash mixed-strategy equilibrium. Recall $K > M > K_{-1}$. This implies that there are only two contingencies for each firm. If firm i is the firm with the highest price, it earns $p(M - K_{-i})$. If firm i is not the firm with the highest price, it earns pk_i. In the main text, we derive the lower bound of the support of the mixed-strategy (2) and argue that mixed-strategy Nash equilibrium profits are as in (3) for all firms $i = 1,\ldots,n$. For a complete characterisation of the mixed-strategy Nash equilibrium, let $G_i(p)$ denote the probability that firm i's charges a price less than or equal to p.

We claim that the mixed-strategy equilibrium distribution functions are

$$G_i(p) = \left[\frac{\bar{p}(M - K_{-n}) - pk_n}{p(M - K)k_n}\prod_{j=1}^{n} k_j\right]^{1/(n-1)} k_i^{-1}. \tag{8}$$

To verify the equilibrium profits and the mixed-strategy distributions, note that the probability that firm i is the firm with the highest price is $\Pi_{j\neq i}G_j(p)$, and $1 - \Pi_{j\neq i}G_j(p)$ is the probability that firm i does not charge the highest price (where Π denotes product). In equilibrium, the expected profit of all prices in the support must be the same. Hence, firm i has got the following expected profit

$$p\left\{\Pi_{j\neq i}G_j(p)(M - K_{-i}) + \left[1 - \Pi_{j\neq i}G_j(p)\right]k_i\right\} = \frac{\bar{p}(M - K_{-n})}{k_n}k_i \tag{9}$$

from charging p.

Manipulating (9) yields

$$p\left[\Pi_{j\neq i}G_j(p)(M-K)+k_i\right]=\frac{\bar{p}(M-K_{-n})}{k_n}k_i \tag{10}$$

$$\Pi_{j\neq i}G_j=\frac{\bar{p}(M-K_{-n})-pk_n}{p(M-K)k_n}k_i \tag{11}$$

$$\Pi_j G_j=\frac{\bar{p}(M-K_{-n})-pk_n}{p(M-K)k_n}k_iG_i. \tag{12}$$

In order to show that $G_i(p)$ is correct, we substitute $G_i(p)$ as in (8) into the left-hand side of (12) and obtain

$$\prod_{l=1}^{n}\left\{\left[\frac{\bar{p}(M-K_{-n})-pk_n}{p(M-K)k_n}\prod_{j=1}^{n}k_j\right]^{1/(n-1)}k_l^{-1}\right\} \tag{13}$$

$$=\left[\frac{\bar{p}(M-K_{-n})-pk_n}{p(M-K)k_n}\prod_{j=1}^{n}k_j\right]^{n/(n-1)}\prod_{l=1}^{n}k_l^{-1} \tag{14}$$

$$=\frac{\bar{p}(M-K_{-n})-pk_n}{p(M-K)k_n}\left[\frac{\bar{p}(M-K_{-n})-pk_n}{p(M-K)k_n}\right]^{1/(n-1)}\left(\prod_{j=1}^{n}k_j\right)^{1/(n-1)} \tag{15}$$

$$=\frac{\bar{p}(M-K_{-n})-pk_n}{p(M-K)k_n}k_i\left[\frac{\bar{p}(M-K_{-n})-pk_n}{p(M-K)k_n}\prod_{j=1}^{n}k_j\right]^{1/(n-1)}k_i^{-1}. \tag{16}$$

The last expression is equal to the right-hand side of (12) – and thus verifies both the distribution functions (8) and the profits in (3).

Manipulating (8), we obtain $G_i(\bar{p})\leq 1$ if and only if $k_i^{n-1}/\Pi_{j\neq n}k_j\geq 1$. This implies two things. Firstly, if $k_i^{n-1}/\Pi_{j\neq n}k_j>1$, we get $G_i(\bar{p})<1$ strictly. In that case, firm i puts mass $1-G_i(\bar{p})$ on $\bar{p}$. Note that $k_i^{n-1}/\Pi_{j\neq n}k_j>1$ never holds under symmetry and is always true for the largest firm in asymmetric markets with $k_n>k_{n-1}$. Secondly, when $k_i^{n-1}/\Pi_{j\neq n}k_j<1$, firm i will not randomise over $[\underline{p},\bar{p}]$ but over $[\underline{p},\hat{p}]$ where $\hat{p}$ is implicitly defined by $G_i(\hat{p})=1$. The remaining firms play with the $G_i(p)$ accordingly changed for $n-1$ (or fewer) firms over $[\hat{p},\bar{p}]$ (or over another interval below $\bar{p}$ determined by the point at which the next firm 'drops out' and so on). The condition $k_i^{n-1}/\Pi_{j\neq n}k_j<1$ never holds in duopoly nor in symmetric markets. For three firms, it always holds for the smallest firm whenever we have $k_1<k_2$ strictly.

For the 134-134-134 treatment, we get

$$G_i(p)=\left(\frac{134p-3200}{102p}\right)^{1/2}, i=1,2,3 \tag{17}$$

and $\underline{p}=3200/134=23.88$. For 201-201, we obtain

$$G_i(p)=\frac{201p-9900}{102p}, i=1,2 \tag{18}$$

and $\underline{p}=9900/201=49.25$. In 268-134, mixed equilibrium distributions are

$$G_i(p)=\left(\frac{268p-16600}{102p}\right)\frac{134}{k_i}, i=1,2 \tag{19}$$

where $G_2(p = 100) = 1/2 < 1$ and $\underline{p} = 16600/268 = 61.94$. In 160-134-108, we have

$$G_i(p) = \begin{cases} \left(\frac{160p - 5800}{102p}\right)^{1/2} \frac{(134 \cdot 108)^{1/2}}{k_i}, i = 1, 2, 3; & \text{if } \underline{p} \leq p \leq 74.6 \\ \left(\frac{160p - 5800}{102p}\right) \frac{134}{k_i}, i = 2, 3; & \text{if } 74.6 < p \leq 100, \end{cases} \quad (20)$$

where $G_1(p = 74.6) = 1$, $G_2(p = 100) = 1, G_3(p = 100) = 0.8375$ and $\underline{p} = 5800/160 = 36.25$.

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