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Industry Structure and Collusion with Uniform Yardstick Competition: Theory and Experments*

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Abstract

We study cartel stability in an industry that is subject to uniform yardstick regulation. In a theoretical model, we show that the number of symmetric firms does not affect collusion. In a laboratory experiment, however, we do find an effect. If anything, increasing the number of firms facilitates collusion. Our theory suggests that an increase in heterogeneity increases the regulated price if firms do not collude, but also makes collusion harder, rendering the net effect ambiguous. Our experiment suggests that the effect of collusion is stronger.

JEL Classification Codes: C73, C92, L13, L41.

Keywords: Collusion, Industry Structure, Yardstick Competition, Experiment.

1 Introduction

It is well known that in unregulated markets, an increase in the number of firms hinders collusion. The higher the number of firms, the higher the potential benefits of deviating from a cartel agreement (see e.g. Motta, 2004). The same holds for firm heterogeneity. The more firms differ, for example in terms of size, the harder it becomes to form a cartel. Smaller firms have stronger incentives to deviate from collusive agreements (see

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e.g. Ivaldi et al., 2003). Experimental studies, such as Abbink and Brandts (2005) or Fonseca and Normann (2008), confirm these insights.

Yet, much less is known about the incentives to collude in an industry that is subject to yardstick competition. With yardstick competition, prices for regional monopolies are set by a regulator on the basis of actual costs of similar firms. This gives such firms an incentive to try to agree to keep their costs high, or at least to report that costs are high (Tangerås, 2002). Many industries are subject to yardstick regulation. Most notably, in the US Medicare's payment to a hospital for a treatment depends on the average cost of similar treatments in other hospitals (Shleifer, 1985). But yardstick competition is also used in industries as diverse as water supply and sewerage[1], electricity networks[2], railways[3] and bus transport services[4], to name but a few.

More often than not, industries with yardstick competition are subject to consolidation. Regulators and antitrust authorities then face an extra challenge: to decide whether to allow such consolidation. To be able to do so, it is essential to have a thorough understanding of how industry structure affects the incentives to collude. Insights from unregulated markets do not necessarily carry over to these environments. This paper aims to contribute to that understanding.

One example of the issues involved is the Dutch energy-distribution industry. In that industry, the number of network operators has halved during the past decade. At the same time, firm-size heterogeneity has increased. The industry now consists of a few large players, and some small ones (see Haffner et al., 2010) These changes influence the effectiveness of yardstick competition if they affect the incentives for firms to collude. Understanding the relationship between industry structure and collusion is thus essential for understanding the effectiveness of regulation through yardstick competition.

In this paper, we study to what extent the number of firms and firm-size heterogeneity in an industry subject to uniform yardstick competition affects collusion. We first do

[1] Dassler, Parker and Saal (2006).

[2] Haffner, Delmer and Van Til (2010); Blázques-Gómez and Grifell-Tatje (2009); Jamasb and Pollitt (2007).

[3] Mizutani, Kozumi and Matsushima (2009).

[4] Dalen and Gomez-Lobo (2002).

so in a theoretical framework. A theoretical model is an important tool in helping to understand the fundamental mechanisms that are at play, and the tradeoffs that are involved. However, repeated game models of the type we study do suffer from a multiplicity of equilibria, and remain silent on how, and to what extent players in the real world may be able to coordinate on one of those equilibria. Therefore, we also test our model in a laboratory experiment.

Ever since Shleifer (1985) it is well known that yardstick competition is most effective with a discriminatory yardstick. The price that one firm can charge then depends on the cost levels of all *other* firms. Still, in our analysis, we focus on a uniform yardstick, where the price that one firm can charge depends on the weighted average cost levels of all firms involved. Despite the superior theoretical properties of a discriminatory yardstick, a uniform yardstick is more often used in practice.[5]

We use a simple model, loosely based on Shleifer (1985), where firms have to exert costly effort to lower their costs. For simplicity, managerial benefits are a concave and quadratic function of a firm's marginal costs. Managers aim to maximize the sum of profits and managerial benefits, and do so in a repeated game. In our theoretical analysis we find that, with symmetric firms, the number of firms has no effect on cartel stability. However, firm-size heterogeneity hinders collusion. The effect of mergers on cartel stability is ambiguous. Mergers that lead to symmetric market shares facilitate collusion. Mergers that do not involve the smallest firm in the industry, hinder collusion as they improve the competitive outcome for the smallest firm, making it more attractive for the manager of that firm to defect from a cartel agreement. If two small firms merge, then such a merger usually facilitates collusion.

Our experimental implementation is loosely based on Potters et al. (2004). To facilitate coordination, we allow subjects to communicate in each period, before setting their cost level. We look at five treatments that differ in the number of firms (2 or 3) and the extent of firm-size heterogeneity. In each treatment, we study how successful experimental subjects are in establishing collusion. To do so, we look at three measures

[5] One example being the Dutch energy-distribution industry discussed above (Haffner et al., 2010)

of collusion: the incidence of full collusion, a collusion index, and the resulting market price.

Most surprisingly, we find that in our experiment an increase in the number of symmetric firms facilitates collusion. We do find that firm-size heterogeneity hinders collusion, but only in the case of 3 firms. Two firms with different sizes in fact find it easier to cooperate than our theory predicts - but still harder than 2 symmetric firms. Also, we find evidence that mergers that lead to symmetric firms indeed facilitate collusion. The theoretical effects of an increase in heterogeneity are ambiguous. On the one hand, such an increase raises prices if firms do not collude; on the other hand, it makes collusion harder. Our experiment suggests that the net effect for consumers is positive. Summing up, we find that a heterogeneous industry structure is of key importance for having relatively little collusion under yardstick competition.

The remainder of this paper is organized as follows. Section 2.1 provides more background on yardstick competition, while Section 2.2 discuss other experiments studying the impact of industry structure on the incidence of collusion. Section 3 describes our theoretical model. Section 4 presents the experimental design, while Section 5 describes the results of our experiment. Section 6 concludes.

2 Background

2.1 Yardstick competition

The last decades saw the liberalization of several network industries that used to be state-owned vertically-integrated monopolies. Examples include telecommunications, electricity, gas, water and sewerage. Parts of these industries are natural monopolies characterized by subadditivity of costs, which calls for regulatory supervision (Viscusi et al., 2005). A key component of such supervision is the regulation of tariffs. Historically, regulated tariffs were either based on actual costs or an allowed rate of return. However, such schemes give little incentive to increase productive efficiency, as lower costs directly translate to lower revenues. Hence, the incentive power is low, as a change in costs hardly affect firms' profits. Introducing price-cap regulation solves this problem, but also implies the risk of significant rents or losses for regulated firms. To overcome both problems, Shleifer (1985) proposed to use tariffs based on the actual costs of a group of similar (benchmark) firms. This type of tariff regulation is called yardstick regulation. As tariffs are based on the relative performance of a firm, yardstick regulation is generally seen as a powerful tool both for giving incentives for productive efficiency as well as for rent extraction (Tangerås, 2002; Burns, Jenkins, and Riechmann, 2005).

The incentive power of a yardstick partly depends on the exact manner in which costs of the benchmark firms determine tariffs. Essentially, there are two types of yardsticks. With a *uniform yardstick* every firm faces the same cap on the tariffs it may charge, based on cost information of all firms in the benchmark group. With a *discriminatory yardstick*, every firm faces a specific cap based on the costs of all *other* firms in the benchmark group. The latter scheme gives a stronger incentive to improve efficiency. For both schemes, numerous methods exist to determine the yardstick, including the (weighted) average costs, the median costs, the 25th percentile of costs or just the best practice of all benchmark firms (Yatchew, 2001). In the Dutch regulation of electricity distribution networks, for instance, the yardstick is based on weighted average costs.

Experiences with yardstick regulation exist in several industries, including the water supply and sewerage industry in the United Kingdom (Dassler, Parker and Saal, 2006), electricity networks in the Netherlands (Haffner, Delmer and Van Til, 2010), Spain (Blázques-Gómez and Grifell-Tatje, 2009) and the United Kingdom (Jamasb and Pollitt, 2007), railways in Japan (Mizutani, Kozumi and Matsushima, 2009) and bus transport services in Norway (Dalen and Gomez-Lobo, 2002). In several cases, the introduction of yardstick regulation improved productive efficiency or resulted in lower consumer prices.[6] In other cases, however, the experience appeared to be less successful.[7]

[6]Mizutani et al. (2009), for instance, find that the efficiency of Japanese railway companies, measured by the variable costs per unit of output, improved significantly after the introduction of yardstick regulation. Jamasb et al. (2004) report that the British model of incentive regulation in the electricity distribution industry has brought significant price reductions to consumers. Haffner et al. (2010) find that yardstick regulation of the Dutch electricity and gas networks resulted in lower network tariffs without adversely affecting network investments.

[7]Dalen et al. (2002) for instance do not find an effect on the cost efficiency of Norwegian bus companies, for which the authors blame the bargaining power of the regulated firms to reduce the incentive power of the regulatory scheme. For the incentive regulation in the Spanish electricity-distribution

What these experiences teach us are that a number of conditions have to be met before yardstick regulation can be effective. First, there should be a sufficiently large number of comparable firms using similar techniques operating within a similar environment. That is, a large group of homogeneous benchmark firms should exist. Second, revenues of regulated firms should be fully based on the yardstick. They should not take other concerns into account, such as the impact yardstick regulation may have on the risk of bankruptcy. Finally, firms should operate independently from each other. Any cooperation would reduce the effectiveness of yardstick competition (Jamasb, Nillesen and Pollitt, 2004).

In this paper we therefore assess the risk of collusion with yardstick regulation under different industry structures. Tangerås (2002) observes that yardstick competition is near useless if firms are able to collude. In his model, collusion takes place through joint manipulation of productivity reports that the regulator uses to determine tariffs. In our paper, firms that collude jointly refrain from exerting effort to lower actual costs. In Tangerås (2002), collusion becomes less likely if the number of firms increases, which is in line with the literature on collusion in unregulated markets.

In unregulated markets, the feasibility of collusion also depends on the heterogeneity of firms. The more firms differ, the harder it is to reach an agreement (see e.g. Motta, 2004). In empirical work this is found for the US airline industry, where the extent of competition appears to be positively related to firm-size heterogeneity (Barla, 2000). In our paper, we study whether the same holds for industries with yardstick regulation.

2.2 Experiments on collusion

Several economic experiments have analysed the impact of industry structure on collusion in unregulated markets. Most studies focus on the effect of the number of firms. Huck et al. (2004) study homogeneous-product quantity-setting oligopolies. They find some collusion in markets with 2 firms, little collusion in markets with 3 firms, and no collusion

industry, negative effects on consumer welfare were found by Blázques-Gómez et al. (2011), which resulted from the fact that inefficient firms received financial compensations afterwards in order to prevent bankruptcies.

in markets with 4 or 5 firms. Other studies look at homogeneous-product price-setting oligopolies. Abbink and Brandts (2005) find that collusion decreases with the number of firms when costs are private information. Abbink and Brandts (2008) find the same result with increasing marginal costs, and Fonseca and Normann (2008) with capacity constraints. Fonseca and Normann (2012) also find more collusion with fewer firms. Moreover, they find that the ability to communicate facilitates collusion, the effect being strongest for industries with an intermediate number of firms.

Other experiments focus on asymmetries between firms. With quantity setting, Mason et al. (1992) find more collusion if firms have equal rather than different marginal costs. Phillips et al. (2011) confirm this result. With price competition, Fonseca and Normann (2008) find more collusion if firms have identical capacity constraints, and Dugar and Mitra (2009) find more collusion if the range of possible firm-specific marginal costs is smaller. Dugar and Mitra (2013) confirm the latter result in a slightly different context. Argenton and Müller (2012) however, find that collusion is unaffected if firms have different rather than identical cost structures. Still, overwhelmingly, experiments on unregulated markets find that asymmetries do hinder collusion.

To the best of our knowledge, the only economic experiment that also deals with yardstick regulation is Potters et al. (2004), on which our experiment is loosely based. Potters et al. (2004) study the effect of yardstick design on collusion in a duopoly with symmetric firms. They compare a uniform yardstick to a discriminatory one. When firms behave non-cooperatively, the discriminatory yardstick yields lower prices and lower profits, making it more prone to collusion. In their experiment, the authors indeed find higher cost levels with a discriminatory yardstick. Of course, our research question is very different from that addressed in Potters et al. (2004). Another difference is that the experiment in that paper also includes a stage in which firms set prices, while we simply impose prices to equal the price cap imposed by the regulator.

3 The model

3.1 Setup

There are n firms that play an infinitely repeated game. Each firm acts as a local monopolist. For simplicity, we assume that firm i faces demand that is completely inelastic, with mass $\alpha_i \in (0,1)$. We normalize total demand, so $\sum_{i=1}^{n} \alpha_i = 1$ and α_i reflects firm i's share of total demand. For ease of exposition, we will refer to α_i as the market share of firm i. In each period, i decides on its constant marginal cost c_i for that period. Firm i's profits then equal $\pi_i(c_i, \mathbf{c}_{-i}) = (p_i - c_i)\alpha_i$, where p_i is determined through regulation. The vector $\mathbf{c}_{-i}$ consists of the cost levels chosen by other firms, that affects π_i through the regulated price p_i.

We assume that the manager of firm i maximizes

$$u_i(c_i) = \pi_i(c_i, \mathbf{c}_{-i}) + R_i(c_i), \tag{1}$$

with R_i a managerial benefit that is non-negative and concave: $R_i \geq 0, R_i'' < 0$, and $R_i(0) = 0$. Note that this specification is equivalent to Shleifer (1985), where managers invest in a cost-reducing technology. For simplicity, we use the following quadratic specification:

$$R_i(c_i) = \left(bc_i - ac_i^2\right)\alpha_i, \tag{2}$$

where $a, b \in \mathcal{R}^+$ are parameters and $c_i \in [0, b/a]$. Throughout, we assume that a and b are such that all expressions we derive are well defined. The assumption that managerial benefit is proportional to market share is for consistency: if the market is shared among more firms, we do not want total managerial benefit to exogenously increase as a result. Note that we allow R_i to be decreasing in c_i for large enough c_i. In electricity networks for example, high marginal costs are often associated with a lack of maintenance. Such networks are prone to outages, compensation claims and political pressure, all factors that do not exactly contribute to a quiet life for the manager.[8] Also,

[8]Moreover, note that in our set-up demand is inelastic. In the more realistic set-up of elastic demand it can be shown that a concave and strictly increasing managerial benefit implies a total utility function that is indeed strictly decreasing for high enough c_i.

this choice simplifies the experimental implementation of our model. Note that for all firms, managerial benefit is maxizimed by

$$c^m = \frac{b}{2a} \tag{3}$$

The regulator uses a uniform weighted yardstick, where the price a firm is allowed to charge equals the weighted average of all cost levels in the industry:

$$p_i(c_i, \mathbf{c}_{-i}) = \sum_{j=1}^{n} \alpha_j c_j, \tag{4}$$

which implies that all firms get to charge the same price. For simplicity, we assume that all firms choose to charge this price, rather than any lower price. This is also what we usually see in practice. Total utility to manager i is thus given by

$$u_i(c_i, \mathbf{c}_{-i}) = \left(\sum_{j=1}^{n} \alpha_j c_j - c_i \right) \alpha_i + \left(bc_i - ac_i^2 \right) \alpha_i. \tag{5}$$

3.2 Firm-size heterogeneity

We are interested in how the extent of firm-size heterogeneity affects collusion. For that, we need a measure of firm-size heterogeneity of our industry. Naturally, the most homogenous industry structure is one in which all firms have the same size. With two firms, an industry arguably becomes more heterogenous if the (weakly) larger firm gains market share relative to the (weakly) smaller firm. For example, industry structure B with $(\alpha_1^B, \alpha_2^B) = (0.7, 0.3)$ is more heterogeneous than industry structure A with $(\alpha_1^A, \alpha_2^A) = (0.6, 0.4)$. If we extend this definition to more than two firms, we have the following

Definition 1. *Suppose we move from industry structure A to industry structure B. Then B is more heterogenous than A if that move consists of a transfer of market share from some firm i to some firm k, with i the weakly smaller firm in industry structure A. Hence, B is more heterogeneous than A if $\exists i, k$ with $\alpha_i^A \leq \alpha_k^A$ such that $\alpha_i^B < \alpha_i^A$ and $\alpha_k^B > \alpha_k^A$ whereas $\alpha_j^A = \alpha_j^B$ for all $j \neq i, k$.*

From this definition, we immediately have

Lemma 1. *An increase in heterogeneity implies an increase in the Herfindahl index.*

Proof. Consider a move from industry structure A to industry structure B, where B is more heterogeneous. Without loss of generality, $\alpha_i^B = \alpha_i^A - \Delta$ and $\alpha_k^B = \alpha_k^A + \Delta$ for some $\Delta > 0$ and $\alpha_i^A \leq \alpha_k^A$, whereas $\alpha_j^A = \alpha_j^B$ for all $j \neq i, k$. The Herfindahl index in industry structure B then equals

$$H_B = \left(\alpha_i^A - \Delta\right)^2 + \left(\alpha_k^A + \Delta\right)^2 + \sum_{j \notin \{i,k\}} \left(\alpha_j^A\right)^2 \tag{6}$$

$$= 2\Delta\left(\Delta + \alpha_k^A - \alpha_i^A\right) + H_A. \tag{7}$$

With $\alpha_k^A \geq \alpha_i^A$ and $\Delta > 0$, this implies that $H_B > H_A$. □

3.3 Competition

Consider the case where managers unilaterally maximize their utility. For ease of exposition, we will refer to this as the competitive outcome. For given $\mathbf{c}_{-i}$, maximizing (5) with respect to c_i yields

$$c_i^* = \frac{b - 1 + \alpha_i}{2a}. \tag{8}$$

Note that this is a dominant strategy, as it does *not* depend on the cost level of other firms. Also note that c_i^* is increasing in market share α_i : the higher α_i, the stronger the influence this firm has on the regulated price, and the more attractive it is to choose a higher cost level. Finally, note that c_i^* is strictly lower than the cost level that maximizes managerial benefits (given by (3)). Lower costs increase profits, giving managers an incentive to be more efficient.

Note that, if consumers value the product at v, total welfare equals

$$W = (v - p) + \left(p - \sum_i \alpha_i c_i\right) + \sum_i \left(bc_i - ac_i^2\right)\alpha_i, \tag{9}$$

where the first term is consumer surplus, and the other two terms reflect total managerial utility. Maximizing with respect to c_i yields that at the social optimum all firms charge the same cost level:

$$c^W = \frac{b - 1}{2a}. \tag{10}$$

From (8), the social optimum is reached if all firms are vanishingly small, so $\alpha_i = 0 \ \forall i$.

In terms of comparative statics, we can now establish

Theorem 1. *In the competitive outcome, we have the following:*

(a) An increase in firm-size heterogeneity implies an increase in the regulated price.

(b) With symmetric firms, an increase in the number of firms implies a decrease in the regulated price.

Proof. From Lemma 1, an increase in firm-size heterogeneity implies an increase in the Herfindahl index. Using (8) and (4) the regulated price with competition is given by

$$p_i^* = \sum_{j=1}^{n} \alpha_j c_j^* = \sum_{j=1}^{n} \frac{b-1+\alpha_j}{2a} \alpha_j = \frac{b-1}{2a} + \frac{H}{2a}, \tag{11}$$

with H the Herfindahl index. This establishes (a). As an increase in the number of symmetric firms lowers H, it also implies (b). □

3.4 Collusion

As usual, a cartel is stable if the short-run benefits of defection are outweighed by the long-term losses due to cartel breakdown. In other words, following e.g. Friedman (1971) we assume grim trigger strategies and look for the critical discount factor $\hat{\delta}$ such that all managers have an incentive to stick to the cartel agreement. With the usual arguments manager i does not defect from a cartel if

$$\frac{u_i^k}{1-\delta} > u_i^D + \frac{\delta}{1-\delta} u_i^*, \tag{12}$$

with u_i^D the utility of manager i when she defects, u_i^K her utility in a cartel, and u_i^* her utility in the competitive outcome. This implies that we require

$$\delta > \hat{\delta}_i(\alpha_i) \equiv \frac{u_i^D - u_i^K}{u_i^D - u_i^*}. \tag{13}$$

For cartel stability, we need that this condition is satisfied for all managers:

$$\delta > \hat{\delta} \equiv \max \left\{ \hat{\delta}_i(\alpha_1), \ldots, \hat{\delta}_i(\alpha_n) \right\}. \tag{14}$$

We will focus on the cartel agreement in which all managers set the same cost level c_k, that maximizes the sum of their utilities. Arguably, this is the most obvious and focal agreement. We will refer to it as the perfect symmetric collusive agreement. Of course, if this would not yield a stable cartel, managers could still try to coordinate on a different agreement, either symmetric or asymmetric. In our theoretical analysis, however, we rule out this option as we feel that it would be much harder to coordinate on such an alternative. Of course, in the experimental implementation of our model, firms are free to try to coordinate on whatever they can agree upon.

If firms coordinate on a common cost level c_k, we immediately have $p = c_k$, so all profits are zero and the cartel simply maximizes joint managerial benefit $U = bc_k - ac_k^2$, so

$$c_k^* = c^m = \frac{b}{2a}. \tag{15}$$

We now have:

Theorem 2. *The perfect symmetric collusive agreement yields a stable cartel if, for all $i = 1, \ldots, n$,*

$$\delta > \hat{\delta}_i(\alpha_i) \equiv \frac{1}{2} \frac{(1 - \alpha_i)^2}{1 - \alpha_i + \alpha_i^2 - H}, \tag{16}$$

with $H \equiv \sum_{j=1}^n \alpha_j^2$ the Herfindahl index.

Proof. For the cartel to be stable, we need that (13) is satisfied for all i. To evaluate the values for u_i^*, u_i^K, and u_i^D, we proceed as follows. First, plugging (8) into (5), we have

$$u_i^* = u_i(c_i^*, \mathbf{c}_{-i}^*) = \frac{\alpha_i}{4a} \left(b^2 - 1 + 2 \sum_{j=1}^n \alpha_j^2 - \alpha_i^2 \right) \tag{17}$$

with $\mathbf{c}_{-i}^* \equiv (c_1^*, \ldots, c_{i-1}^*, c_{i+1}^*, \ldots, c_n^*)$. Second, plugging (15) into (5), we have

$$u_i^K = u_i(c_k^*, \mathbf{c}_{-k}^*) = \frac{\alpha_i b^2}{4a}, \tag{18}$$

with $\mathbf{c}_{-k}^* \equiv (c_k^*, \ldots, c_k^*)$. Third, as it is a dominant strategy for a manager to set c_i^* given by (8), c_i^* is also the optimal deviation. Hence

$$u_i^D = u_i(c_i^*, \mathbf{c}_{-k}^*) = \frac{\alpha_i}{4a} \left(b^2 + 1 + \alpha_i^2 - 2\alpha_i \right). \tag{19}$$

Plugging (17)–(19) into (13) gives the result. □

From the proof of the theorem, we have that for manager i, her utility in a cartel is only higher than her utility in the competitive outcome if $u_i^K > u_i^*$, or

$$\frac{\alpha_i b^2}{4a} > \frac{\alpha_i}{4a}\left(b^2 - 1 + 2H - \alpha_i^2\right), \tag{20}$$

which requires

$$\alpha_i^2 > 2H - 1. \tag{21}$$

If this condition is not satisfied, manager i earns more in the competitive outcome than in the perfect symmetric collusive agreement; her managerial benefits are lower, but the increase in profits more than makes up for this. Hence (21) is a necessary condition for cartel stability.

To analyze how exogenous factors affect cartel stability, we need to know how these affect the manager with the highest critical discount factor. We can establish:

Lemma 2. *If the perfect symmetric collusive agreement is stable, then the critical discount factor $\hat{\delta}_i(\alpha_i)$ is the highest for the smallest firm.*

Proof. Note that we compare different α_i's within the same industry structure, hence $H \equiv \sum_{j=1}^n \alpha_j^2$ is fixed. In that case

$$\frac{\partial \hat{\delta}_i\left(\alpha_i|H\right)}{\partial \alpha_i} = -\frac{1}{2}\frac{\left(1-\alpha_i\right)\left(1+\alpha_i-2H\right)}{\left(1-\alpha_i+\alpha_i^2-\sum_{j=1}^n \alpha_j^2\right)^2}. \tag{22}$$

For the cartel to be stable we need from (21) that $\alpha_i^2 > 2H-1$ for all i, which implies that the numerator is positive. With the denominator clearly positive as well, this implies $\frac{\partial \hat{\delta}_i(\alpha_i|H)}{\partial \alpha_i} < 0$, which establishes the result. □

Lemma 2 immediately implies that a cartel is stable if and only if the smallest firm has no incentive to defect.

3.5 Factors that facilitate collusion

We now study which factors facilitate collusion. First, and somewhat surprising, we find

Theorem 3. *With symmetric firms, an increase in the number of firms has no effect on the stability of collusion.*

Proof. With symmetric firms, $\alpha_i = 1/n$ for all firms so from Theorem 2 the critical discount factor simplifies to

$$\hat{\delta}(1/n) = \frac{1}{2} \frac{\left(1 - \frac{1}{n}\right)^2}{1 - \frac{1}{n} + \left(\frac{1}{n}\right)^2 - n\left(\frac{1}{n}\right)^2} = \frac{1}{2} \frac{\left(1 - \frac{1}{n}\right)^2}{\left(1 - \frac{1}{n}\right)^2} = \frac{1}{2}, \tag{23}$$

which does not depend on n. □

This result can be understood as follows. Different from the situation in an unregulated market, defection utility in a cartel with uniform yardstick competition is *decreasing* in the number of firms. Here, the utility a manager obtains when defecting from a cartel agreement is mainly driven by her market share, which is exogenously given. That market share is decreasing in the number of firms. Competition profits and cartel profits also decrease in the number of firms. From (13), the net effect on cartel stability is ambiguous. In our simple quadratic framework, the lower utility from defecting and the lower utility from staying in the cartel exactly cancel out, yielding no effect on cartel stability.

For the effect of firm-size heterogeneity, we find the following:

Theorem 4. *An increase in firm-size heterogeneity increases the critical discount factor and hence makes a cartel less likely to be stable.*

Proof. In Appendix A. □

Comparing this result to Theorem 1, we thus have an interesting trade-off. On the one hand, a more homogeneous industry structure implies a lower price – provided that firms behave competitively. At the same time, however, it makes collusion more likely.

We now study the effect of a merger in our framework. First, it is straightforward to establish the following

Theorem 5. *Suppose we are in industry structure A. A merger leads to industry structure B. Such a merger facilitates collusion if and only if*

$$\frac{1}{2}\frac{\left(1-\underline{\alpha}^B\right)^2}{1-\underline{\alpha}^B+\left(\underline{\alpha}^B\right)^2-H^B}<\frac{1}{2}\frac{\left(1-\underline{\alpha}^A\right)^2}{1-\underline{\alpha}^A+\left(\underline{\alpha}^A\right)^2-H^A}, \tag{24}$$

with $\underline{\alpha}^\kappa$ *the market share of the smallest firm in industry structure* κ*, and* H^κ *the Herfindahl index in industry structure* κ*,* $\kappa \in \{A, B\}$*.*

Proof. Follows directly from Theorem 2 and Lemma 2. □

Using this theorem, we can derive a number of scenarios in which a merger either always facilitates, or always hinders collusion:

Corollary 1. *A merger affects cartel stability in the following manner:*

(a) If the merger does not affect the market share of the smallest firm, then it hinders collusion.

(b) Suppose that after the merger, there is no firm with a smaller market share than the merged firm. Then a sufficient condition for the merger to facilitate collusion is that the pre-merger industry structure has $H \leq 7/16$*.*

(c) If the merger leads to symmetric firms, then it facilitates collusion.

Proof. In Appendix A. □

Result (a) is particularly strong: whenever the smallest firm (or one of the smallest firms) is not part of the merger, then the merger necessarily hinders collusion. The intuition is as follows. As the market share of the smallest firm is unaffected, the merger also has no effect on either the collusion utility or the defection utility of the manager of that firm. However, it does affect her utility in the competitive outcome. From the proof of Theorem 1 a more concentrated industry implies higher competitive prices, and hence higher competitive utilities. Thus, defection from a cartel becomes less costly in the long run, making it more attractive to defect.

Broadly speaking, the results suggest that most mergers that lead to a more homogeneous market structure (such as the scenarios described in (b) and (c) of the Corollary) facilitate collusion, while most mergers that lead to a less homogeneous market structure (such as the scenario described in scenario (a)) hinder collusion. In our experiment, it is not feasible to study many of the scenarios described in the Corollary in depth. We will therefore focus on part (c).

4 Experiment

4.1 Design

In our experiment, subjects play the game described above for at least 20 rounds. From round 20 onwards, the experiment ends with a probability of 20% in each round, to avoid possible end game effects (see also Normann and Wallace, 2012). We use fixed matching: every subject plays with the same group members in all rounds.

Every round consists of three steps. First, subjects can communicate using a chat screen. This chat is completely anonymous. Second, subjects unilaterally choose cost levels c_i. Third, prices are determined using (4). After each round, subjects learn the profits and managerial benefits they have realized, and the cost levels that each subject has set. Although not very common in a cartel experiment, we feel that the unrestricted communication we allow for creates circumstances that are closest to the real world. Also, without communication, it is hard to sustain collusion in a cartel experiment with more than two players, see e.g. Haan et al. (2009).

We set $a = 1/24$ and $b = 1$. These choices assure that the competitive and collusive cost levels derived in (8) and (15) are integers. We run 5 treatments that differ in the number of firms and the extent of firm-size heterogeneity. In our exposition, we normalize the total size of the market to 12 rather than 1, which allows us to represent market sizes of all firms in all treatments as integer numbers.[9] The first 3 treatments have 3 firms and are denoted TrioXYZ, with X, Y and Z the size of firms 1, 2 and 3,

[9]Note that in the actual experiment, we always normalized the size of the smallest firm to 1, which makes it easier to explain the experiment to the subjects. See the instruction in Appendix B for an example.

respectively. The other treatments have 2 firms and are denoted DuoXY, with X and Y the sizes of firms 1 and 2.

Table 1: Overview of treatments.

Treatment	Market shares				Competition				Cartel	
	α_1	α_2	α_3	HHI	c_1^*	c_2^*	c_3^*	p^*	$c_k^* = p_k$	$\hat{\delta}$
Trio444	33%	33%	33%	0.333	4	4	4	4.00	12	0.50
Trio633	50%	25%	25%	0.375	6	3	3	4.50	12	0.64
Trio642	50%	33%	17%	0.389	6	4	2	4.67	12	0.71
Duo66	50%	50%		0.500	6	6		6.00	12	0.50
Duo84	67%	33%		0.556	8	4		6.67	12	1.00

Market shares give the markest shares that we impose for each experimental firm in that treatment, HHI is the resulting Hirschman Herfindahl Index. c_i is the competive cost level of firm i that our theory predicts, p^* the resulting regulated price, c^k and p^k are the collusive cost levels and prices predicted by our theory, $\hat{\delta}$ the critical discount factor for the cartel to be stable.

Table 1 provides information for each treatment. The first panel gives the market share for each firm and the resulting Herfindahl index. The second panel provides competitive cost levels and the resulting price. The third panel gives collusive cost levels and the critical discount factor $\hat{\delta}$ of the cartel. From (15), collusive cost levels do not depend on industry structure; in all treatments, the perfect symmetric collusive cost level equals 12.

The 5 treatments allow us to evaluate the effect of the number of firms and firm-size heterogeneity on market performance in terms of cost levels and regulated prices. They also allow us to evaluate the effect of a merger. In our evaluation of the experimental results we do not interpret the critical discount factors as a strict prediction of the outcome of the experiment. Thus, we do not expect that there will *always* be collusion whenever the δ we impose is larger than the $\hat{\delta}$ we derived. Neither do we expect that there will *never* be collusion whenever the δ we impose is smaller than the $\hat{\delta}$ we derived. Rather, we interpret a higher value of $\hat{\delta}$ as making a cartel less likely to occur, or more successful if it occurs. This is in line with other work (see e.g. Bigoni et al, 2012).

From Theorem 3 we expect that, with symmetric firms, the number of firms does not affect collusion:

Hypothesis 1 (Number of firms)**.** *The amount of collusion in Duo66 is the same as that in Trio444.*

From Theorem 4 we expect that more heterogeneity implies less collusion:

Hypothesis 2 (Heterogeneity)**.** *(a) There is more collusion in Duo66 than in Duo84; (b) There is more collusion in Trio444 than in Trio633, and more collusion in Trio633 than in Trio642.*

Finally, from Corollary 1(c) we expect that mergers that lead to symmetric firms, facilitate collusion:

Hypothesis 3 (Merger to symmetry)**.** *(a) There is more collusion in Duo66 than in Trio633; (b) There is more collusion in Duo66 than in Trio642.*

4.2 Implementation

The experiment was conducted at the Groningen Experimental Economics Laboratory (GrEELab) at the University of Groningen in February and March 2013. A total of 214 subjects participated, all students from the University of Groningen (80.4%) or the Hanze University of Applied Sciences (19.6%), most of them in the fields of economics and business (59.3%). Every session consisted of one treatment and lasted between 80 and 115 minutes. Subjects signed in for sessions, while treatments were randomly assigned to sessions.

Every treatment with 2 subjects was played in two sessions while every treatment with 3 subjects was played in three sessions. Between 14 and 18 subjects participated in a session, resulting in 16 to 17 groups per treatment. This is similar to other cartel experiments, see e.g. Bigoni et al. (2012), Dijkstra et al. (2011) and Hinloopen and Soetevent (2008). The experiment was programmed in z-Tree (Fischbacher, 2007). Printed instructions were provided and read aloud.[10] On their computer, subjects first had to answer a number of questions correctly to ensure understanding of the experiment. Participants were paid their cumulative earnings in euros. Since firm size differed

[10]Instructions for Trio633 are reproduced in Appendix B. Instructions for other treatments are similar and available upon request.

between treatments, exchange rates were varied such that participants would receive identical amounts with full collusion. Furthermore, they received an initial endowment of €4. Average earnings were €16.80 and ranged from €7.75 to €24.00.

5 Results

5.1 Three measures of collusion

For comparison, we only include the first 20 rounds of each group in our analysis. In this section, we introduce three measures to evaluate the extent of collusion: the incidence of full collusion; a collusion index; and price. We explain these measures in more detail below. For each measure, we give its development over time in each treatment, and compare averages between all treatments. In the next section, we confront our hypotheses with the results of the experiment.

We use non-parametric tests to determine whether there are significant differences between treatments. We use the Mann-Whitney U Test (MWU) to compare two populations, and the Jonckheere-Terpstra Test to test for ordered effects in multiple populations.[11] All significance levels reported are for the no-treatment effect versus the one-sided alternative.

First, we look at the **incidence of full collusion**. In all treatments, the perfect symmetric collusive agreement is for all firms to set a cost level of 12. For ease of exposition we refer to this as full collusion. The incidence of full collusion is thus defined as the percentage of markets with full collusion. Figure 1 shows how the incidence of full collusion develops over time, in all treatments.[12] The number of markets with full collusion is substantial. There are no clear time trends. From the Figure, Trio444 seems to be the most collusive, while the least collusion is found in Trio642.

Table 2 gives the average incidence of full collusion for all treatments, and reports on pairwise comparisons between treatments. The entries in the right-hand panel indicate whether the row treatment has an incidence of collusion that is significantly higher (>)

[11] The Jonckheere-Terpstra test compares multiple populations under the null that these are from the same distribution, and an ordered alternative hypothesis. See Jonckheere (1954) or Terpstra (1952).

[12] The development of costs over time for each individual market are given in the Appendix B.

Figure 1: Incidence of full collusion (across all groups).

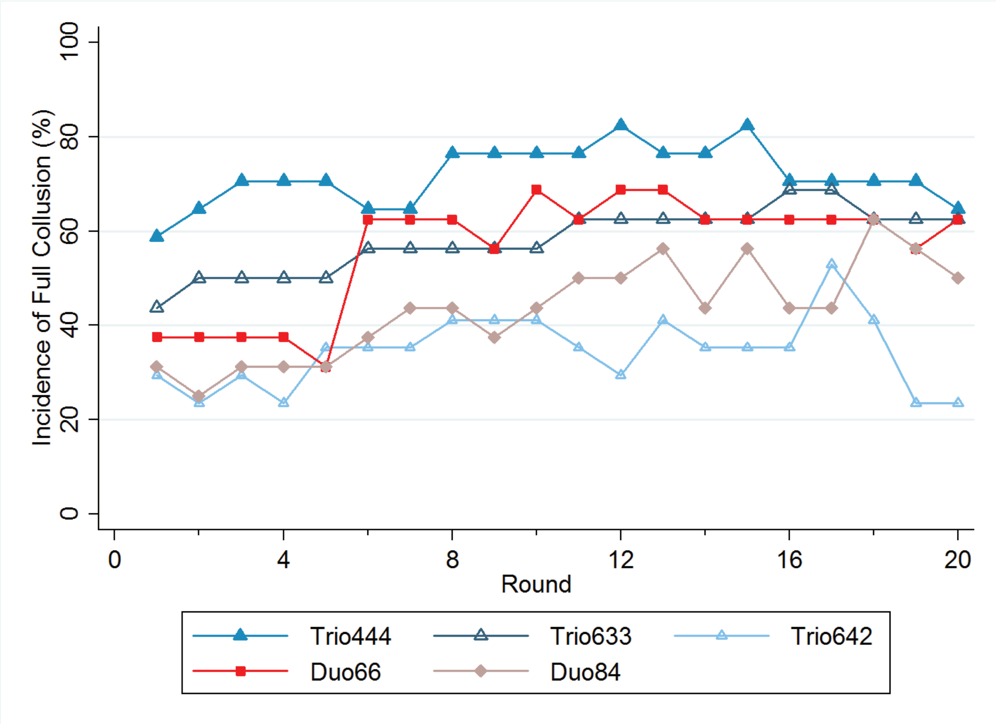


Table 2: Incidence of full collusion (across all rounds and groups).

Treatment	Average	Trio633	Trio642	Duo66	Duo84
Trio444	71.8%	$\approx$	$>^{**}$	$>^{+}$	$>^{*}$
Trio633	58.1%		$>^{+}$	$\approx$	$\approx$
Trio642	34.4%			$<^{*}$	$\approx$
Duo66	56.3%				$\approx$
Duo84	43.4%				

Entries in the right-hand panel indicate whether the row treatment yields rates of full collusion that are significantly lower (<), significantly higher (>), or that do not differ significantly (≈) from the rates in the column treatment. Differences between treatments are tested using the MWU test for equality. $^{+}$: significant at 10% level; * at 5%; ** at 1%.

or significantly lower (<) than the column treatment, or whether the difference is not significant (≈). We use this convention throughout the remainder of this paper. From the Table, we thus have for example that Trio444 leads to significantly more collusion than Trio642, Duo66, and Duo84. The difference with Trio633 is not significant.

One drawback of this measure is that it only considers markets to be collusive if market participants succeed in achieving full collusion. Arguably, any market with prices higher than those in the competitive outcome is collusive to at least some extent. Also, the closer prices are to the fully collusive outcome, the more collusive that market is. We therefore study the **collusion index**, which is the relative premium that firms are able to achieve over and above the competitive outcome:

$$\text{collusion index} \equiv \frac{\text{price} - p^*}{12 - p^*}, \tag{25}$$

with p^* the competitive price. Note that this measure allows for the fact that the competitive price level differs across industry structures (see Table 1). If the competitive outcome is achieved, the collusion index equals 0. If the collusive outcome of 12 is achieved, it equals 1. The higher the index, the more successful firms are in colluding.

Figure 2: Average collusion index per round (across all groups).

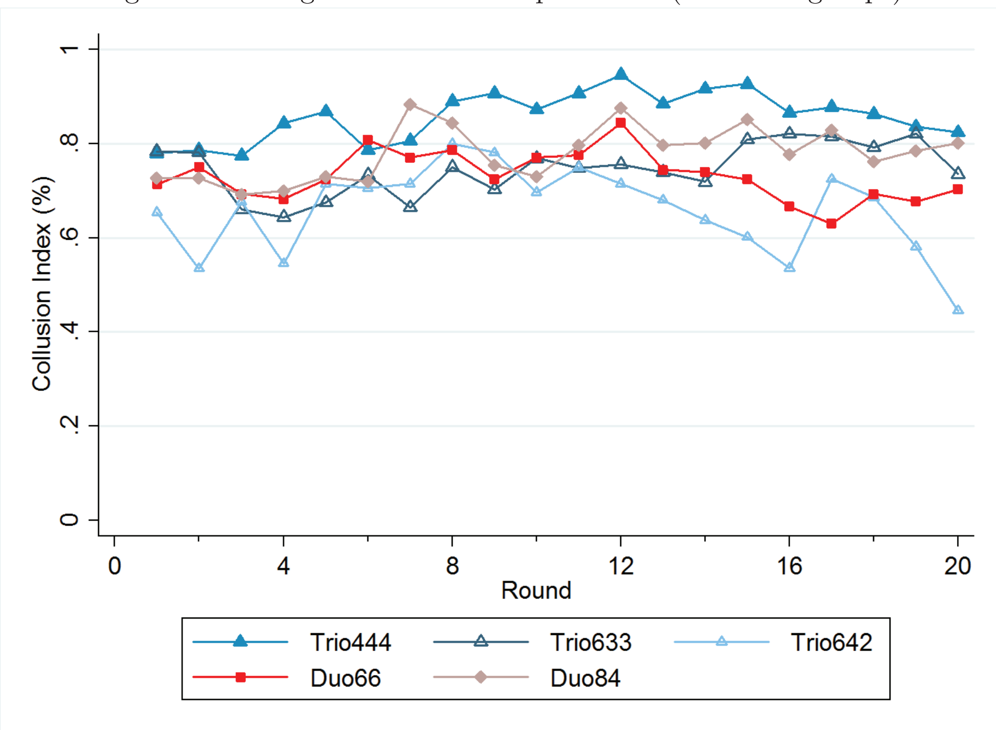


Figure 2 shows how the collusion index develops over time, in all treatments. Qualitatively, the picture looks very similar to that for the incidence of full collusion. Trio444 seems the most collusive, and Trio642 the least collusive treatment. Table 3 gives treat-

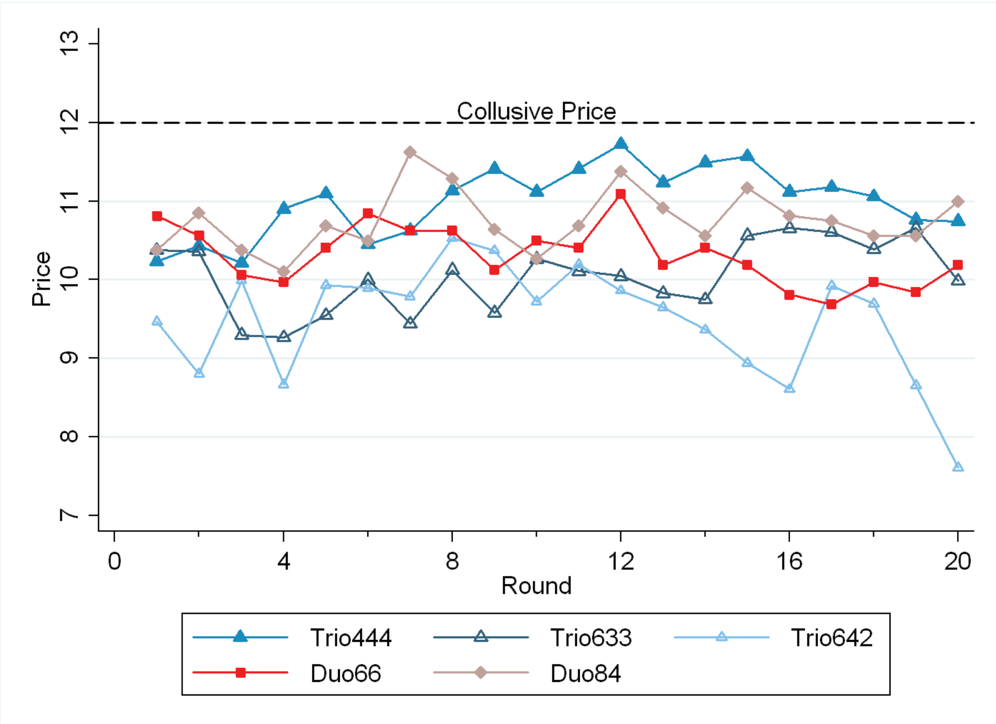
Table 3: Collusion index (across all rounds and groups).

Treatment	Average	Trio633	Trio642	Duo66	Duo84
Trio444	99.6%	$\approx$	$>^{**}$	$>^{*}$	$>^{*}$
Trio633	74.6%		$\approx$	$\approx$	$\approx$
Trio642	65.9%			$\approx$	$<^{+}$
Duo66	73.1%				$\approx$
Duo84	77.9%				

Entries in the right-hand panel indicate whether the row treatment yields a collusion index that is significantly lower (<), significantly higher (>), or that does not differ significantly ($\approx$) from the index in the column treatment. Differences between treatments are tested using the MWU test for equality. $^{+}$: significant at 10%; * at 5%; ** at 1%.

ment averages and pairwise comparisons.

Figure 3: Average market price per round (across all groups).



Of course, a regulator is most interested in the price for consumers that ultimately prevails. Despite a slightly higher incidence of collusion, for example, an industry structure may still be preferable if it leads to lower competitive prices that more than outweigh the adverse effects of the occasional cartel. For that reason, we also look at **prices**. Aver-

Table 4: Market price (across all rounds and groups).

Treatment	Average	Trio633	Trio642	Duo66	Duo84
Trio444	11.00	$\approx$	$>^*$	$\approx$	$\approx$
Trio633	10.04		$\approx$	$\approx$	$\approx$
Trio642	9.48			$\approx$	$<^*$
Duo66	10.32				$\approx$
Duo84	10.76				

Entries in the right-hand panel indicate whether the row treatment yields prices that are significantly lower ($<$), significantly higher ($>$), or that do not differ significantly ($\approx$) from the column treatment. Differences between treatments are tested using the MWU test for equality. *: significant at 5%.

age prices over time are given in Figure 3. Consistent with our earlier measures, average prices are high, and come closest to the collusive outcome in Trio444. From Table 4, most pairwise comparisons are no longer significant.

5.2 Test of hypotheses

In the previous subsection, we gave an overview of the experimental results. We now discuss to what extent those results confirm our hypotheses.

Table 5: Comparison of treatments with symmetric firms (across all rounds and groups).

Measure	Trio444		Duo66
Incidence of full collusion	71.8%	$>^+$	56.3%
Collusion index	85.8%	$>^*$	73.1%
Price	11.0	$\approx$	10.3

Entries between values indicate whether the value to the left is significantly higher ($>$), or does not differ significantly ($\approx$) from the value to the right. Differences between treatments are tested using the MWU test for equality. $^+$ denotes significance at the 10% level; * at 5%.

Hypothesis 1 is concerned with the number of (symmetric) firms. From Table 5, however, this hypothesis is clearly rejected by our data. Both the incidence of full collusion and the collusion index are significantly *higher* in Trio444 than in Duo66. Average prices are also much higher, but this difference is not significant. These results are surprising: if anything, one would expect it to be harder to coordinate on a collusive outcome with 3 rather than 2 players. However, the opposite seems to be true here.

To understand why that may be the case, we analyzed the chat sessions of the subjects

Table 6: Characteristics Trio444 and Duo66.

	Trio444	Duo66
Total periods	340	320
# periods with agreement different from 12	5	25
Period first suggested to all set 12:		
Average	3.71	7.06
Median	1	2.5
Instances of tacit collusion	0	0

"Period first suggested to all set 12" is the first period in which any subject in a market raised the possibility that all players should set their cost level equal to 12. When no subject ever raised that possibility, that observation is set equal to 21. Tacit collusion is defined in this context as all subjects setting cost level 12 without ever having discussed that possibility.

in these two treatments. For this purpose, we had all chats coded independently by two coders. Table 6 gives some summary statistics. The first thing to note is that in markets with 3 firms, there were only 5 instances in which subjects explicitly agreed on setting cost levels different from 12. In markets with 2 firms, there were 25 such instances.[13] Hence, players in 2-player markets more readily agreed on alternative arrangements. Moreover, groups that did figure out that it is a good idea to set cost level 12 took much more time to do so in 2-firm markets than in 3-firm markets. These differences cannot be explained by tacit agreements: in either treatment, there wasn't a single instance in which all subjects set costs equal to 12 without someone raising that possibility. Summing up, having 3 players apparently makes it easier to agree on the focal equilibrium and less tempting to try other scenarios.

Table 7: Comparison of treatments with 2 firms (averages across all rounds and groups).

Measure	Duo66		Duo84
Incidence of full collusion	56.3%	$\approx$	43.4%
Collusion index	73.1%	$\approx$	77.9%
Price	10.3	$\approx$	10.8

Entries between values indicate that the value to the left does not differ significantly ($\approx$) from the value to the right. Differences between treatments are tested using the MWU test for equality.

[13] In the 3-firm case, these alternative agreements all consisted of setting different cost levels and rotating roles. In the 2-firm case, there were 11 such rotating agreements, 2 agreements to set a symmetric cost level different from 12, 11 asymmetric agreements, and 1 partial agreement (that only involved 1 player)

Hypothesis 2 is concerned with the effect of heterogeneity. For the case of 2 firms, Table 7 shows that the incidence of full collusion is higher in Duo66, but the average value of the collusion index is lower. Average prices are also lower. However, none of these differences is significant. Thus, Hypothesis 2(a) is not confirmed.

Table 8: Comparison of treatments with 3 firms (averages across all rounds and groups).

Measure	Trio444		Trio633		Trio642		Trio444	JT
Incidence of full collusion	71.8%	$\approx$	58.1%	$>^{+}$	34.4%	$<^{**}$	71.8%	**
Collusion index	85.8%	$\approx$	74.6%	$\approx$	65.9%	$<^{**}$	85.8%	**
Price	11.0	$\approx$	10.1	$\approx$	9.5	$<^{*}$	11.0	*

Entries between values indicate whether the value to the left is significantly lower (<), significantly higher (>), or does not differ significantly ($\approx$) from the value to the right. Differences between two treatments are tested using the MWU test for equality; differences between all treatments are tested using the Jonckheere-Terpstra test (JT) for equality. $^{+}$: significant at 10%; * at 5%; ** at 1%.

Table 8 looks at the results for three firms. Note that Trio444 is listed twice in this table, to facilitate all pairwise comparisons. All results reported in Table 8 are consistent with Hypothesis 2(b); for any measure, the extent of collusion is always higher if the industry structure is more homogenous. Many of the pairwise comparisons are not significant, but results are highly significant in a Jonckheere-Terpstra test with the ordered alternative hypothesis that Trio444 yields more collusion than Trio633 which in turn yields more collusion than Trio642. Note that we argued in Section 3 that the effect of firm-size heterogeneity on price may be ambiguous, as our model predicts that more heterogeneity makes collusion harder, but the competitive price is also higher. Our experimental results indicate that the effect on collusion is stronger, as market prices do go down with more heterogeneity.

Summing up, in treatments with 2 firms we do not find evidence for an effect of the extent of firm-size heterogeneity on collusion. With 3 firms, however, we find strong support for Hypothesis 2(b): more heterogeneity leads to less collusion.

Table 9 evaluates Hypothesis 3 and looks at the extent to which a merger to symmetric firms facilitates collusion. We find that Duo66 is indeed more collusive than Trio642. Both the incidence of full collusion and the average price is significantly higher

Table 9: Merger to symmetric firms (averages across all rounds and groups).

Measure	Trio642		Duo66		Trio633
Incidence of full collusion	34.4%	$<^*$	56.3%	$\approx$	58.1%
Collusion index	65.9%	$\approx$	73.1%	$\approx$	74.6%
Price	9.5	$<^*$	10.3	$\approx$	10.0

Entries between values indicate whether the value to the left is significantly lower ($<$), or does not differ significantly ($\approx$) from the value to the right. Differences between treatments are tested using the MWU test for equality. *: significant at 5% level.

in Duo66. The collusion index also is, but that difference is not significant. However, the differences between Duo66 and Trio633 are ambiguous and insignificant.

6 Conclusion

In this paper we studied the effect of market structure on collusion among economic agents subject to uniform yardstick competition, an issue particularly relevant for the debate on the effectiveness of tariff regulation. We did so both in a theoretical framework, and in a laboratory experiment.

In our theoretical model, we find that firm-size heterogeneity hinders collusion. More surprisingly, in a symmetric industry, the number of firms does not affect stability of collusion. Different from models with unregulated markets, in our framework defection becomes less attractive if the number of firms increases. That renders the net effect of the number of firms on cartel stability ambiguous. In our parametrization, the lower incentive to defect and the lower incentive to stick to the agreement, exactly cancel out.

The theoretical effects of mergers on collusion are ambiguous. Mergers that do not involve the smallest firm in the industry, hinder collusion, as they improve the competitive outcome for the smallest firm, making it more attractive for the manager of that firm to defect from a cartel agreement. Mergers that lead to symmetric market shares facilitate collusion.

Of course, no theoretical model can always predict what will happen in the real world. That is particularly true for models of collusion, as these assume that cartel agreements are always reached instantaneously and coordination is not an issue. In the real world, coordination problems may be an important obstacle to establishing a cartel. Therefore, we also conducted an experiment in which we allow for unrestricted communication between agents.

In our experiment we find that in triopolies, size heterogeneity indeed hinders collusion. We do not find evidence for this in duopolies. Also, we find some evidence that mergers that lead to symmetric market shares indeed facilitate collusion. Most surprisingly, industries with 3 symmetric firms are more collusive than industries with 2 such firms. Apparently, with 3 firms, the focal equilibrium becomes more salient, and subjects are less tempted to try to explore alternative agreements. We indeed find that 2-firm markets more often reach alternative agreements, and take more time before they start discussing the collusive outcome. The discrepancy between our theoretical and experimental results can largely be explained by the fact that, when compared to the theoretical prediction, subjects in a symmetric duopoly (our Duo66 treatment) are relatively unsuccessful in establishing a cartel, while subjects in an asymmetric duopoly (our Duo84 treatment) are relatively succesful in doing so.

Our counterintuitive results on the number of firms also provide insights relevant for regular cartel experiments. In such experiments, the theoretical prediction is that an increase in the number of firms hinders collusion. In our experimental setup, theory predicts that incentives to collude do not depend on the number of firms. That implies that any effect we find is not due to a change in incentive, but rather to a 'pure numbers effect'. Our results suggest that it is easier for three subjects to reach an agreement than it is for two, when keeping incentives constant. Needless to say, more research is needed for a deeper understanding of this issue.

Summing up, we find that firm-size heterogeneity in an industry subject to yardstick competition has a strong effect on collusion, much more so than the number of firms. Our theory suggests that an increase in heterogeneity increases the regulated price if firms do not collude, but also makes collusion harder, rendering the net effect ambiguous. Our experiment however suggests that the effect of collusion is stronger.

Our conclusions are relevant for the debate on the optimal industry structure. In a competitive market, a more homogeneous industry implies lower tariffs for network users. When also taking the effects on collusion into account, our results suggest that more homogeneity may imply higher tariffs.

A Selected proofs

Proof of Theorem 4 Consider a move from industry structure A to industry structure B, where B is more heterogeneous. Without loss of generality, $\alpha_i^B = \alpha_i^A - \Delta$ and $\alpha_k^B = \alpha_k^A + \Delta$, for some $\Delta > 0$ and $\alpha_i^A \leq \alpha_k^A$, whereas $\alpha_j^A = \alpha_j^B$ for all $j \neq i, k$. Denote the smallest market share of all other firms as $\underline{\alpha}$, so $\underline{\alpha} = \min_{j \neq i,k}\{\alpha_j\}$. From Lemma 2 the smallest firm determines the critical discount factor. We have three possibilities to consider: first, $\alpha_i^B > \underline{\alpha}$; second, $\alpha_i^A < \underline{\alpha}$ and third $\alpha_i^B < \underline{\alpha} < \alpha_i^A$.

In case I, $\alpha_i^B > \underline{\alpha}$, the critical discount factor under industry structure $\kappa \in \{A, B\}$ is given by

$$\hat{\delta}^\kappa = \frac{1}{2}\frac{(1-\underline{\alpha})^2}{1-\underline{\alpha}+\underline{\alpha}^2 - H^\kappa}. \tag{A.1}$$

From Lemma 1, we have $H^B > H^A$, which immediately implies $\hat{\delta}^B > \hat{\delta}^A$.

In case II, $\alpha_i^A < \underline{\alpha}$. Hence, the critical discount factor under industry structure κ is

$$\hat{\delta}^\kappa = \frac{1}{2}\frac{(1-\alpha_i^\kappa)^2}{1-\alpha_i^\kappa+(\alpha_i^\kappa)^2 - H^\kappa}. \tag{A.2}$$

From the proof of Lemma 2, for fixed H, $\hat{\delta}_i(\alpha_i)$ is decreasing in α_i. Hence, as $\alpha_i^B < \alpha_i^A$, for fixed H we have $\hat{\delta}^B > \hat{\delta}^A$. The fact that $H^B > H^A$ only strengthens this result.

The proof for case III, where $\alpha_i^B < \underline{\alpha} < \alpha_i^A$ follows from a combination of the above cases; first consider a decrease from α_i^A to $\underline{\alpha}$. From the analysis for case I, this leads to an increase in $\hat{\delta}$. Next consider a decrease from $\underline{\alpha}$ to α_i^B. From the analysis for case II, this again leads to an increase in $\hat{\delta}$.

Proof of Corollary 1 Part 1 is straightforward. From Lemma 2 the smallest firm has the highest critical discount factor. If (one of the) smallest firm(s) is not involved in a merger, its market share α_i is not affected, so after the merger it is still the smallest firm. However, H will increase, which from (16) implies that $\hat{\delta}_i(\alpha_i)$ increases and a cartel is less stable.

For part 2, suppose that i and k merge; that the merged firm is (among) the smallest on the market; and before the merger i was the smallest. From (24) and Lemma 2, this merger facilitates collusion if

$$\frac{(1-\alpha_i-\alpha_k)^2}{1-(\alpha_i+\alpha_k)-\sum_{j\neq\{i,k\}}^n \alpha_j^2} < \frac{(1-\alpha_i)^2}{1-\alpha_i-\sum_{j\neq i}^n \alpha_j^2}, \tag{A.3}$$

where the LHS gives the critical discount factor after the merger, and the RHS gives the critical discount factor before the merger. Denoting the Herfindahl index before the merger as $H_A \equiv \sum_j^n \alpha_j^2$ and cross-multiplying, this requires

$$(1-\alpha_i-\alpha_k)^2\left(1-\alpha_i+\alpha_i^2-H_A\right) < (1-\alpha_i)^2\left(1-(\alpha_i+\alpha_k)-H_A+\alpha_i^2+\alpha_k^2\right),$$

which we can rewrite as

$$\alpha_k\left(\alpha_i\left(2-3\alpha_i+\alpha_k+2\alpha_i^2\right)+H_A\left(2-2\alpha_i-\alpha_k\right)-1\right) < 0,$$

which in turn implies

$$H_A < \frac{1-\alpha_i\left(2-3\alpha_i+\alpha_k+2\alpha_i^2\right)}{2-2\alpha_i-\alpha_k},$$

where the RHS is a function of α_i and α_k, that we will denote $r(\alpha_i, \alpha_k)$. We will derive a lower bound on $r(\alpha_i, \alpha_k)$. Note that

$$\frac{\partial r(\alpha_i,\alpha_k)}{\partial \alpha_k} = \frac{(1-2\alpha_i)(1-\alpha_i)^2}{(2-2\alpha_i-\alpha_k)^2}.$$

As i is the smallest firm pre-merger, we necessarily have $\alpha_i \leq 1/n$, which implies that this derivative is strictly positive, so the smallest value is reached with α_k as small as possible. Setting $\alpha_k = 0$,

$$\frac{\partial r(\alpha_i,0)}{\partial \alpha_i} = \frac{\partial}{\partial \alpha_i}\left(\frac{1-\alpha_i\left(2-3\alpha_i+2\alpha_i^2\right)}{2-2\alpha_i}\right) = 2\left(\alpha_i-\frac{1}{4}\right).$$

With $r''(a_i, 0) > 0$, this implies that $r(\alpha_i, 0)$ reaches its minimum at $\alpha_i = 1/4$. Taken together, this implies that a sufficient condition for a merger to facilitate collusion is that $H_A < r(1/4, 0) = 7/16$, which establishes the result.

Part 3 follows from part 2. First, if a merger leads to symmetric firms, then there is no firm after the merger that is smaller than the merged firm so the first condition in part 2 is satisfied. Second, if there are n firms before the merger, then all firms outside the merger necessarily have market share $1/(n-1)$. The highest possible pre-merger

H then occurs when one firm that merges is infinitesimally small, whereas the other already has a pre-merger market share close to $1/(n-1)$. In that case, the pre-merger Herfindahl index is

$$H_A = (0)^2 + (n-1)\left(\frac{1}{n-1}\right)^2 = \frac{1}{n-1},$$

which is smaller than 7/16 for any $n > 3$. For $n = 3$, note that the outside firm necessarily has $\alpha_j = 1/2$ so, if i is the smallest firm pre-merger, we have $H_A = \alpha_i^2 + (1/2 - \alpha_i)^2 + (1/2)^2 = 2\alpha_i^2 - \alpha_i + \frac{1}{2}$. From (23) and (24), the merger facilitates collusion if.

$$\frac{1}{2}\frac{(1-\alpha_i)^2}{1-\alpha_i+\alpha_i^2-H^A} > \frac{1}{2}$$

so $(1-\alpha_i)^2 > \frac{1}{2} - \alpha_i^2$ or $\frac{1}{2}(1-2\alpha_i)^2 > 0$ which is always true.

B Instructions Trio633

Introduction
You are going to participate in an experiment in economics. We will first read the instructions aloud. Then you will have time to read them on your own. The instructions are identical for all participants. After reading, there is the possibility to ask questions individually. The experiment is expected to last for approximately 90 minutes. Please refrain from talking during the entire experiment.

You will play with two other players, chosen at random. Together, you and those two other players form a group. You will never learn who the other players are. The experiment lasts for at least 20 rounds. In each round, you will play with the same two players. Before the experiment starts, we randomly determine whether you are player 1, player 2 or player 3 in your group.

In this experiment you can earn points. The number of points you earn depends on the decisions made by you and those made by the other players in your group.

Instructions
In the experiment, each player represents a company. Each player owns a number of production units. In each round, each player has to choose one cost level for all production units that he or she owns. Player 1 owns 2 production units. Player 2 owns 1 production unit. Player 3 owns 1 production unit. At the beginning of the experiment, each player starts with 40 points for each production unit that he or she owns. Player 1 will thus receive 80 points, player 2 receives 40 points and player 3 receives 40 points. In each round, the number of points you earn consists of two components: **profit** and **managerial benefit**. At the end of each round, the points that you earned in that round will be added to your account.

After the experiment the number of points in your account will be converted to euros. Player 1 will receive €1 for every 20 points that he or she has, player 2 will receive €1 for every 10 points, and player 3 will receive €1 for every 10 points.

Each round consists of three steps. These steps are the same in every round.

Step 1: communication
A chat box will appear on your screen. You can discuss anything you want with the other players in your group. However, you are not allowed to identify yourself by name, gender, appearance, nationality, or in any other way. If you do, you will not receive any payment after the experiment. You are only allowed to communicate in English.

You have a limited amount of time to chat. A timer in the top right corner of the screen will inform you of the amount of time you have left. If you prefer not to chat any more, you can leave the chat by pressing the “Leave Chat” button. Once you have left the chat, you cannot return in that round. Once two persons have left the chat, the chat will end automatically.

Step 2: choice of cost level
Each player chooses one cost level for all the production units that he or she owns. You can choose your cost level from the following possibilities:

$$1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20.$$

The cost level you choose will influence the profits in that round for you and the other players. It will also influence your managerial benefit.

Each production unit produces one unit of output. The price you will receive per unit of output equals the average cost level of all production units on the market.

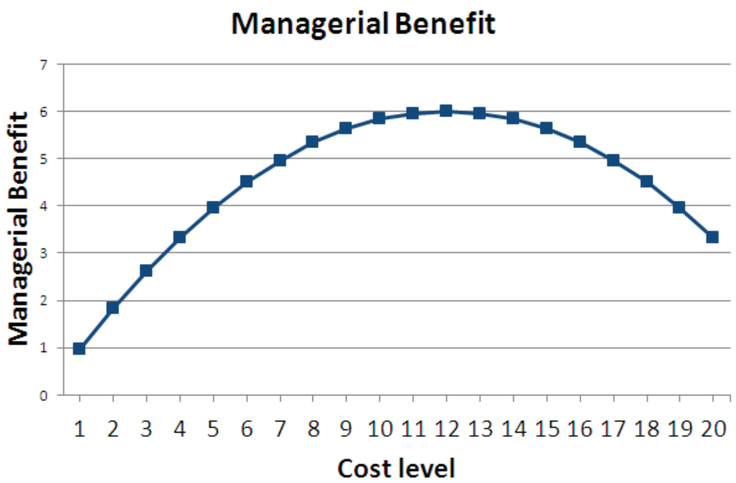
Example. Suppose that player 1 chooses a cost level of 10, player 2 chooses a cost level of 5 and player 3 chooses a cost level of 7. Keeping in mind that player 1 owns 2 production units, player 2 owns 1 production unit, and player 3 owns 1 production unit, the price for each unit of output is then

$$\frac{2 \times 10 + 1 \times 5 + 1 \times 7}{2 + 1 + 1} = \frac{20 + 5 + 7}{4} = \frac{32}{4} = 8. \qquad \blacksquare$$

The profit you earn on each unit of output equals the price minus your cost level. Thus,

$$\text{your profit} = \text{your number of production units} \times (\text{price} - \text{cost level}) .$$

For each of your production units you also receive a managerial benefit. This graph shows how your managerial benefit per production unit depends on your cost level:



The number of points you receive in a round is equal to your profit plus your managerial benefit.

If you prefer, you can also calculate your profit and managerial benefit using a profit calculator that we will provide on screen during the experiment. Alternatively, you can find your profit and your managerial benefit in a table that we provide. These tables are added to these instructions. Please put these tables in front of you now.

Each table reads as follows. Rows represent the possible cost levels you can choose. Columns represent the average cost level per production unit of the other two players. Where a row and a column intersect, you can find your profit. Your managerial benefit is indicated in the last column.

Example. We consider a case in which player 1 chooses a cost level of 10, player 2 chooses a cost level of 5 and player 3 chooses a cost level of 7. As player 1 owns 2 production units and players 2 and 3 each own 1 production unit, the price per unit of output equals $\frac{2\times10+1\times5+1\times7}{2+1+1} = 8$. Profits, managerial benefits, and number of points for all players can be found as follows.

- Consider player 1. Its cost level is 10. The average cost level of the production units owned by players 2 and 3 is $\frac{1\times5+1\times7}{1+1} = \frac{5+7}{2} = 6$. Player 1's profit can be found in Table 1, in the row marked 10, and the column marked 6. You can see that player 1 receives a profit of -4.00 points. Note that player 1 can also calculate this directly. As noted, the price per unit of output in this case equals 8. As player 1 owns two production units, profit is $2 \times (8 - 10) = -4$.

  At the end of the row marked 10, you can see that player 1 receives a managerial benefit of 11.67 points. This can also roughly be seen from the graph. With cost level 10, managerial benefit per production unit is roughly 5.8, which implies total managerial benefit of $2 \times 5.8 \approx 11.6$.

  In total, player 1 thus receives $-4 + 11.67 = 7.67$ points.

- Consider player 2. Its cost level is 5. The average cost level of the production units owned by players 1 and 3 is $\frac{2\times10+1\times7}{2+1} = \frac{27}{3} = 9$. Player 2's profit can be found in Table 2 (the row marked 5, the column marked 9) to equal 3.00 points. Alternatively, note that price per unit in this case equals 8. As player 2 owns one production unit, profit is $8 - 5 = 3$.

  The managerial benefit of player 2 can be found at the end of the row marked 5 to equal 3.96 points. This can also roughly be seen from the graph.

  In total, player 2 thus receives $3.00 + 3.96 = 6.96$ points.

- Consider player 3. Its cost level is 7. The average cost level of the production units owned by players 1 and 2 is $\frac{2\times10+1\times5}{2+1} = \frac{20+5}{3} = 8.33$. If it were 8, player 3's profit could be found in Table 3 (row marked 7, column marked 8) to equal 0.75. If it were 9, player 3's profit could be found in Table 3 (row marked 7, column marked 9) to equal 1.50. As the average cost level of other production units is 8.33, player 3's profit is as in column 8 plus 1/3 times the difference between both columns: $0.75 + \frac{1}{3} \times (1.50 - 0.75) = 1.00$ points. Alternatively, price per unit equals 8. As player 3 owns one production unit, profit is $8 - 7 = 1$.

The managerial benefit of player 3 can be found at the end of the row marked 7 to equal 4.96 points. This can also roughly be seen from the graph.

In total, player 3 thus receives $1.00 + 4.96 = 5.96$ points.

Step 3: summary

After all players have made their decision, you will receive the following information: the cost levels chosen by the other players, the price for each unit of output, your profit, your managerial benefit, and the current state of your account. Throughout the experiment, there will also be a box on your screen where you can observe the decisions made by you and the other players in each previous round.

End of experiment

You will at least play 20 rounds. From round 20 onwards, the experiment ends with a 20% probability at the end of each round. With a probability of 80%, a new round starts. You receive a message on your screen if no further round will take place.

At the end of the experiment the number of points in your account will be converted to euros. Before you can collect your payment in private, you have to hand in the instructions.

After the experiment, please do not discuss the content of the experiment with anyone, including people who did not participate.

Please refrain from talking throughout the experiment.

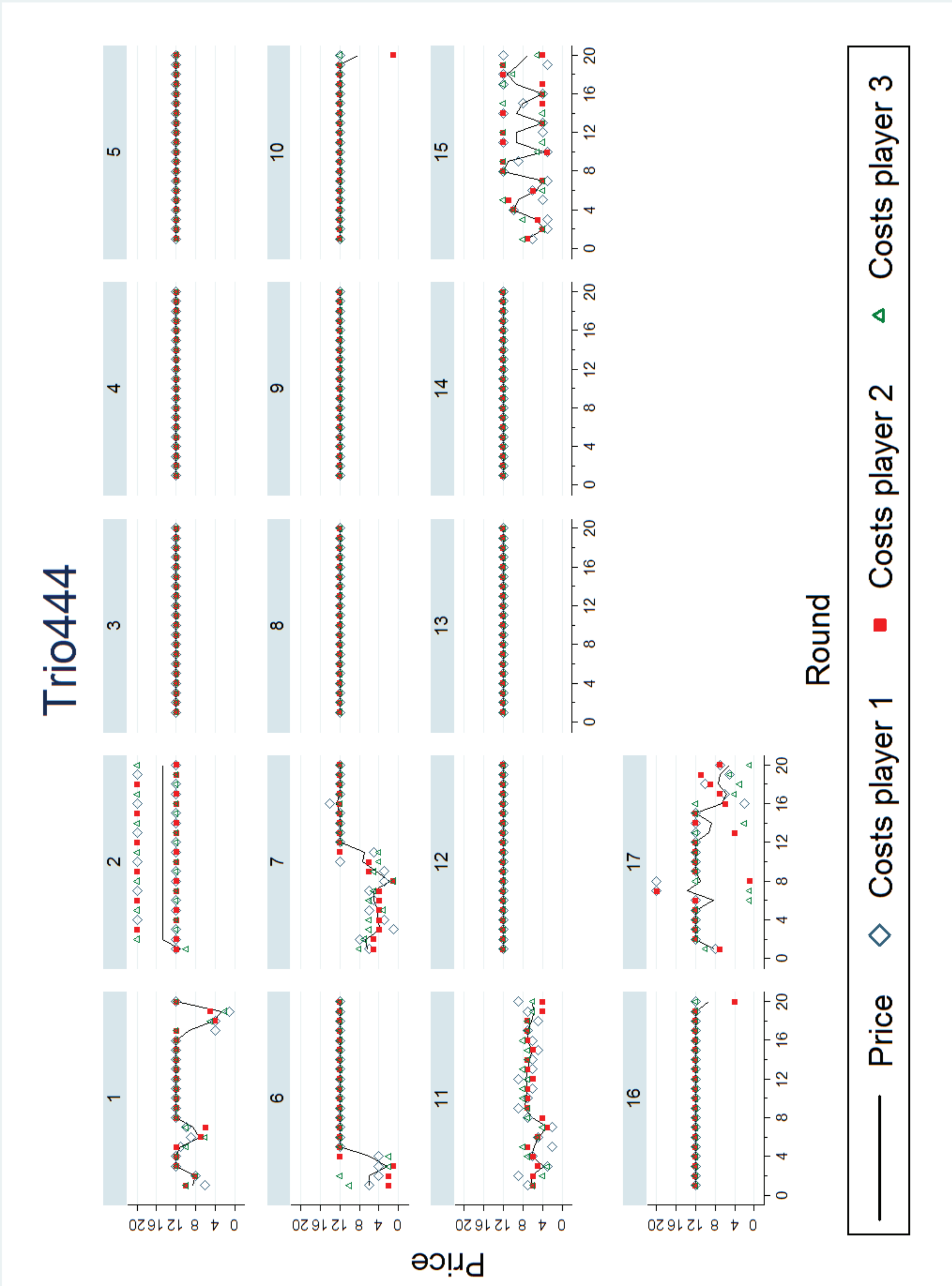


Figure B.1: Cost levels chosen and resulting price in each round per group in Trio444.

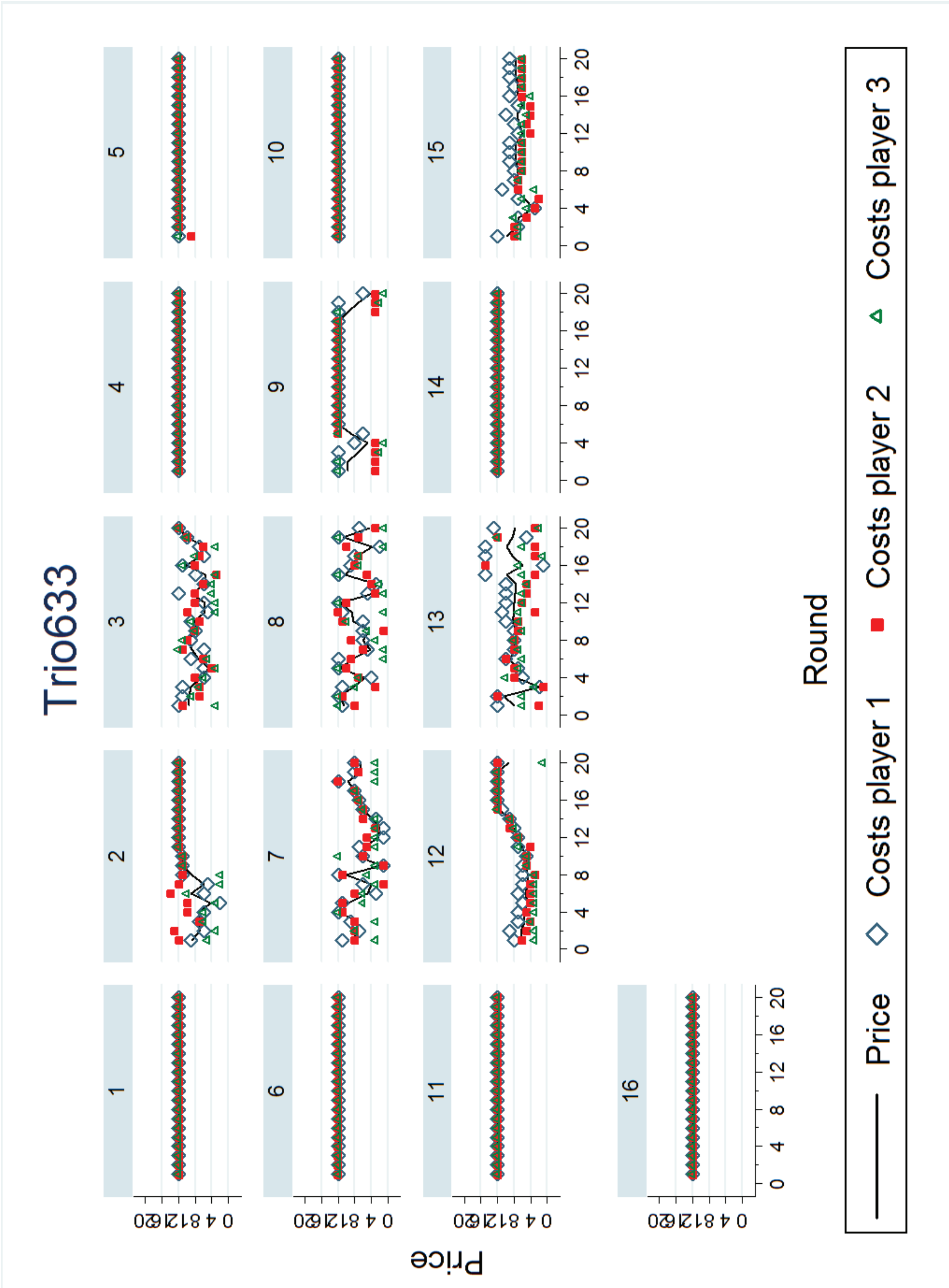


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Figure B.2: Cost levels chosen and resulting price in each round per group in Trio633.

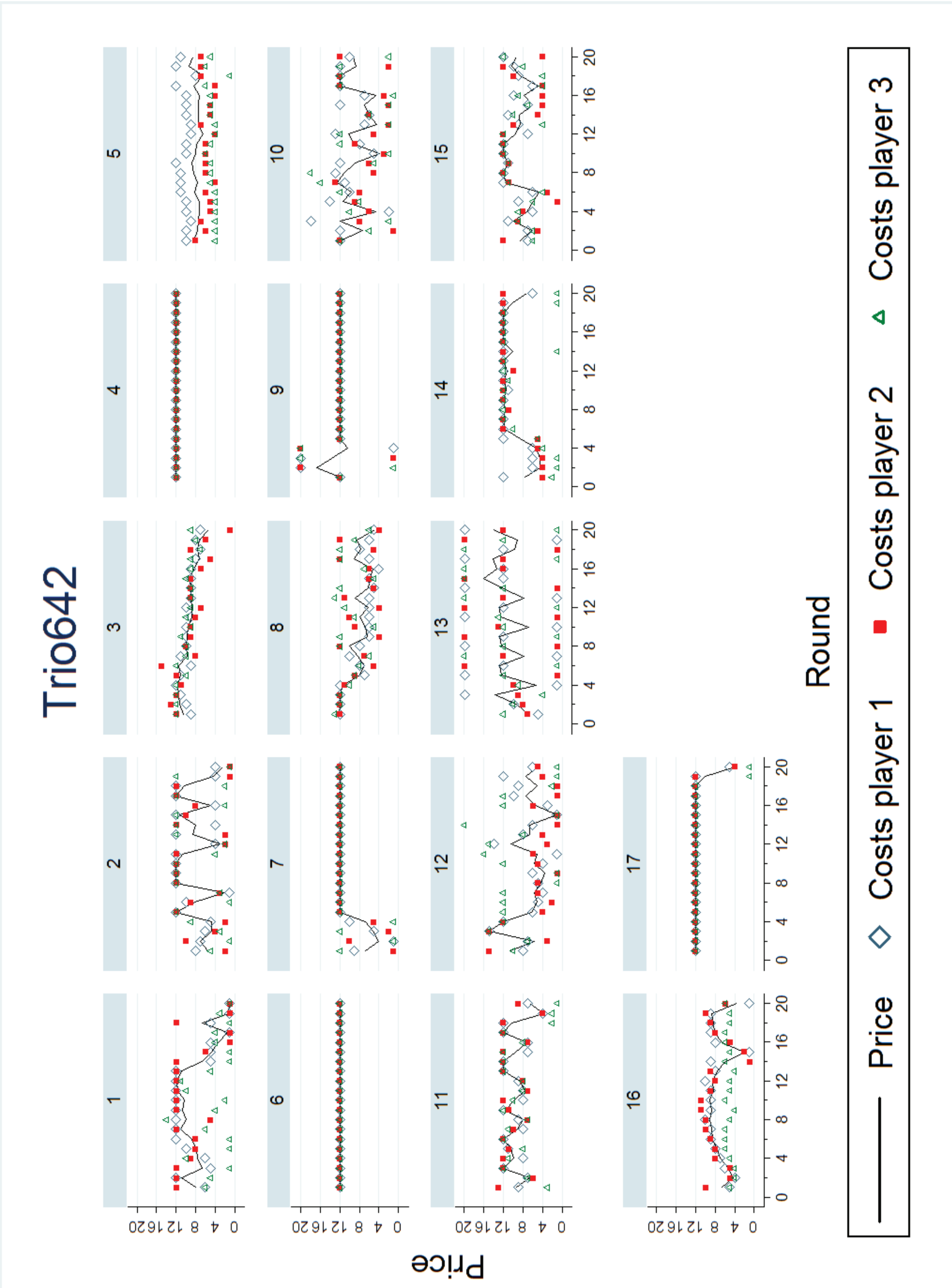

Figure B.3: Cost levels chosen and resulting price in each round per group in Trio642.

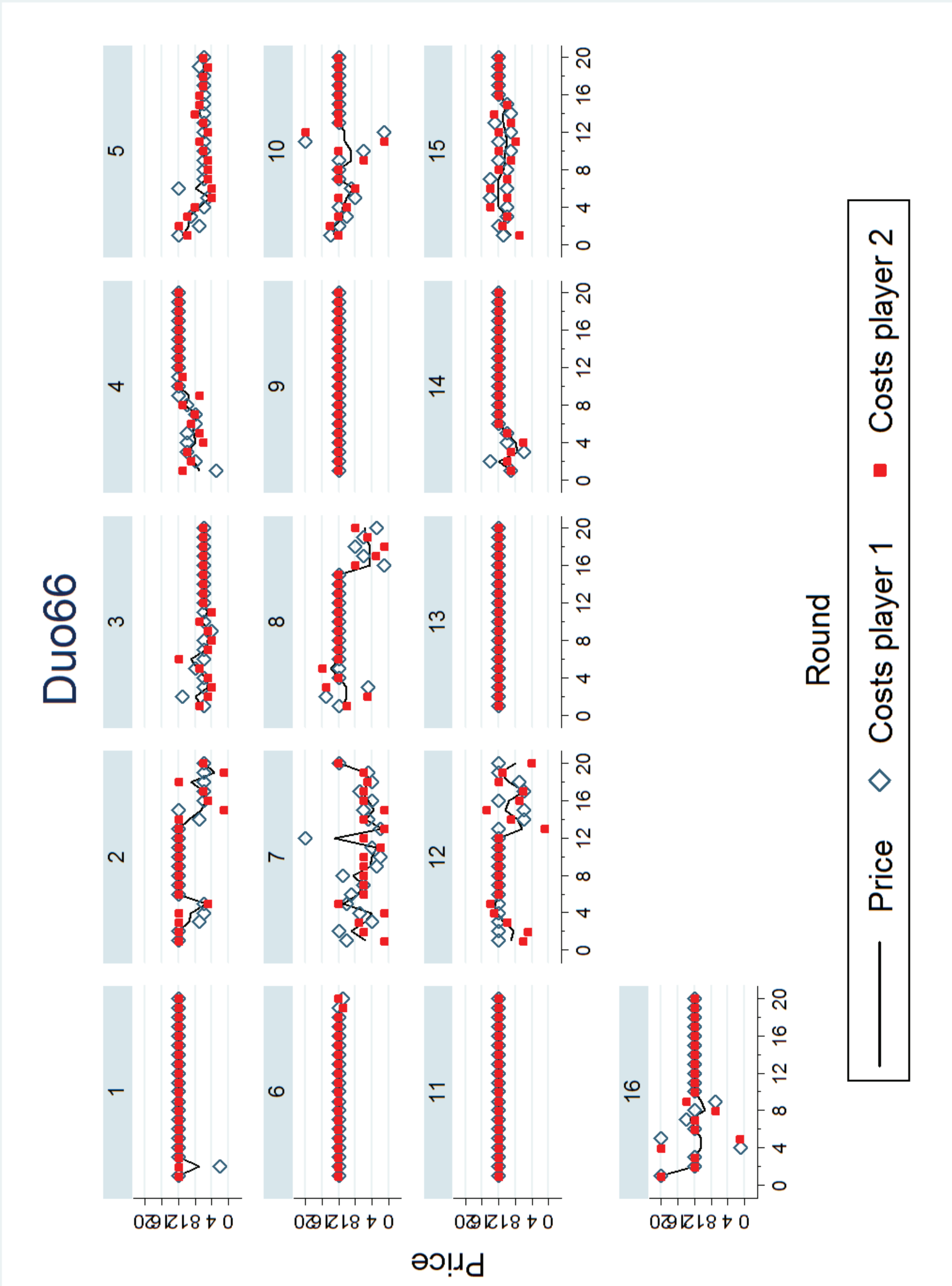

Figure B.4: Cost levels chosen and resulting price in each round per group in Duo66.

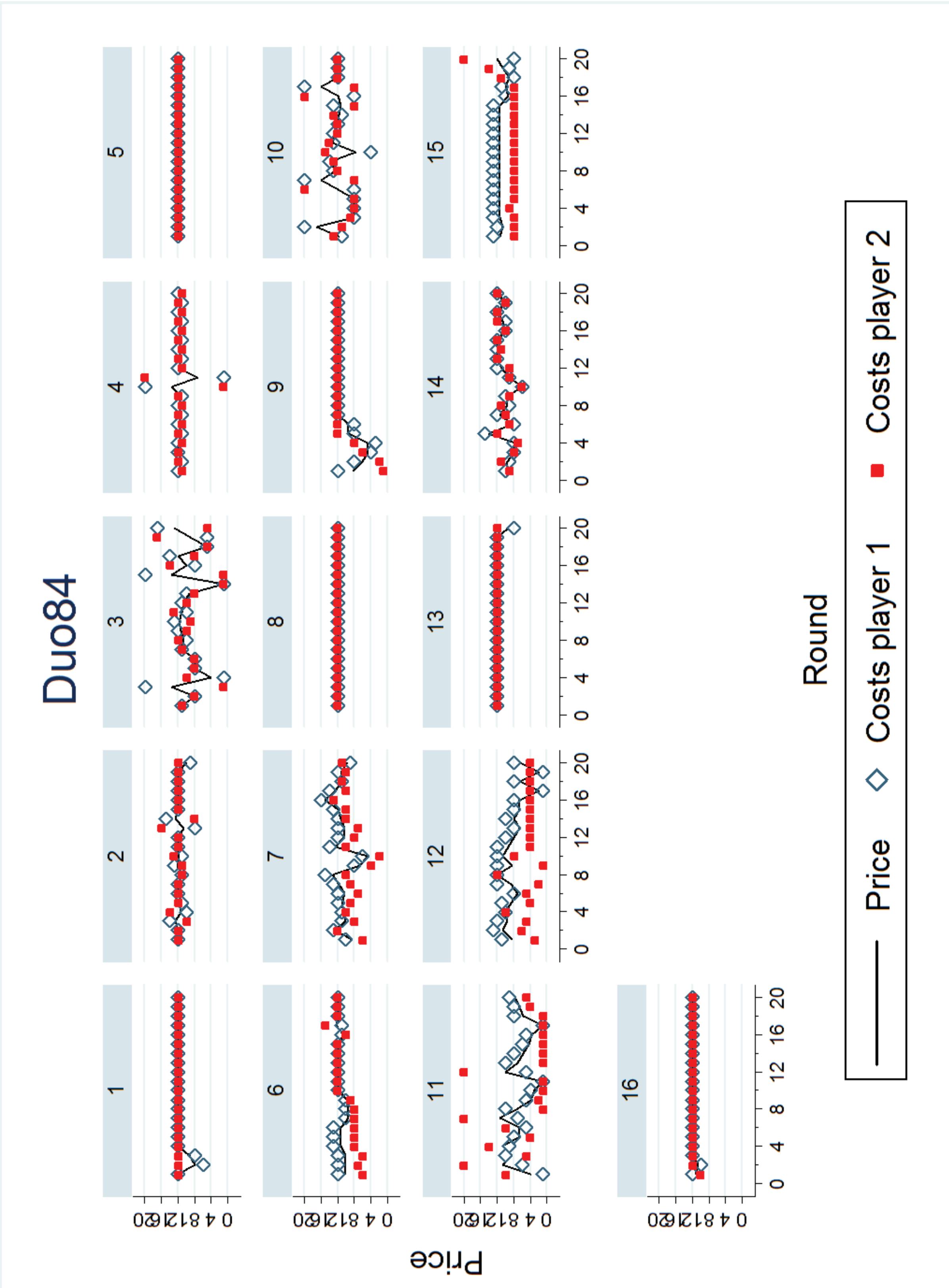

Figure B.5: Cost levels chosen and resulting price in each round per group in Duo84.

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