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## Let's lock them in: Collusion under Consumer Switching Costs

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# Let's lock them in: Collusion under Consumer Switching Costs

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## Abstract

I study consumer switching costs' effect on firms' price setting behavior in a 2x2 factorial design experiment with and without communication. For Bertrand duopolies the price level under consumer switching costs is lower vis-à-vis new consumers but not affected towards old consumers. Markets are overall less tacitly collusive which translates into higher incentives to collude explicitly. Text-mining procedures reveal linguistic characteristics of the communicated content which correlate with market outcomes and communication's effectiveness. The results have antitrust implications especially for the focus of cartel screening.

*JEL Classification:* C7, C9, L13, L41

*Keywords:* Switching Costs, Cartels, Collusion, Experiments.

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# 1 Introduction

Consumer switching costs, even though they are often not explicitly labeled as such, play a crucial role in major competition policy cases especially for market definition and the assessment of market power.<sup>1</sup> Firms use either consumers' inherent or strategic costs of switching to protect their product aftermarkets or create barriers to entry. However, firms' price incentives are twofold. Consumers for whom it is costly to switch are less price elastic and are therefore targeted by firms' higher prices. On the other hand, this prospect facilitates competition for new consumers and creates a downward pressure on prices that may compensate consumers in advance. This state dependent pricing pattern is often referred to as "invest-and-harvest" behavior whose composite effect on prices is seen as ambiguous (Klemperer, 1995).

Firms' market power over locked-in consumers and the potential for consumer harm therefore depend also on the level of competition prior to consumers' lock-in (Farrell and Klemperer, 2007). It is increasingly important to account for this state dependence in form of new and old consumers if firms can indeed price discriminate between the two consumer groups. Neglecting this can lead to an erroneous attribution of high "harvesting" prices to tacit collusion when firms are in fact acting non-cooperative (Che *et al.*, 2007). Hence, it is increasingly difficult to infer from observed prices to the competitiveness of a market, let alone to tacit or explicit collusive outcomes. Theoretical studies of Padilla (1995); Anderson *et al.* (2004) find also countervailing effects of switching costs on the sustainability of collusion which make them also an obstacle for market screening and prosecution of cartel agreements.

This paper studies consumer switching costs' effect on firms' price setting behavior in a laboratory experiment under the presence and absence of firms' ability to communicate. I compare levels and distributions of prices within the 2x2 factorial design experiment and assess the degree of tacit collusion in the way of Ivaldi *et al.* (2003) as the mark-up on equilibrium profits. Firms engage in repeated duopolistic Bertrand competition with homogeneous goods, an environment which is seen as favorable for tacit collusive agreements in the literature (Dufwenberg and Gneezy, 2000) and by the European Commission (Davies *et al.*, 2011). Consumer switching costs enter according to the two period framework of (Klemperer, 1995, Section 3.2). This model captures two distinct characteristics. First, consumers' finite time horizon, meaning they retire from the market after the second period. Second, firms' ability to price discriminate, that is, they can distinguish between both consumer states. Markets that are characterized by these properties are for instance reduced software licenses that are distributed at a discounted price to students or other groups. Once the status as a student voids, a consumer naturally buys a license of a full version only once. This setting translates to any market with finitely living or participating, identifiable consumers in which firms' incentives resemble the "invest-and-harvest"

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<sup>1</sup>See *United States v. Microsoft Corp.*, 253 F.3d 34.; *Ward v. Apple, Inc.*, No. 12-17805.

motive.<sup>2</sup>

There is a strong case to study switching costs' effect on tacit and explicit collusive outcomes in a laboratory environment. The experimenter has complete control over subjects' ability to communicate which allows for a distinct analysis of tacit and explicit collusive outcomes, something economic theory does not incorporate. Further, laboratory experiments can overcome the sample-selection problem the empirical cartel-literature faces (Posner, 1970).

The analysis of the experimental data provides four main results. First, consumer switching costs lead to lower price levels in the model's first market phase, perfectly resembling firms' "investment" behavior, whereas price levels differ not significantly vis-à-vis locked-in consumers. The second result is that communication facilitates firms' coordination on higher prices which is in line with findings of Fonseca and Normann (2012); Cooper and Kühn (2014) who both show that free-form communication is an effective coordination device in dilemma games. However, communication among firms negates competitive effects induced by switching costs as they neither affect the level nor the distribution of prices if firms are in fact communicating. Third, switching costs induce firms' prices towards new consumers to be concentrated at marginal cost level. Firms who initially served all consumers subsequently harvest their customer base through prices in close proximity to the static Nash-equilibrium. The fourth result is that switching costs reduce the degree of tacit collusion as firms' supra-competitive profits are significantly reduced. On the other hand the profit gains from communication are more pronounced making explicit conspiracies more attractive. Additionally, the application of text-mining procedures suggests that the amount of noncommittal language used in subjects' communication limits its effectiveness.

Despite the success of theoretical switching costs models which include a finite time horizon and identifiable consumer groups (see Klemperer, 1995), they often fail to give an unambiguous intuition on the overall competitiveness of switching cost markets. Therefore, many studies withdraw from state dependency and turn to infinite time horizon frameworks to particularly avoid end-game effects and provide predictions for a market steady state (see Beggs and Klemperer, 1992; Padilla, 1995; Dubé *et al.*, 2009). Beggs and Klemperer (1992) investigate duopolistic competition under constant consumer entry and exit in every period. Firms' pricing incentives are primarily determined by the ratio of old and new consumers active in the market. They find that markets are less competitive if switching costs are large enough such that consumers are perfectly locked-in to their initial suppliers. Padilla (1995) relaxes this restrictive assumption but nevertheless finds a relaxing effect on competition. However, a more recent approach of (Dubé *et al.*, 2009) challenges this view and shows a negative effect of consumer switching costs on prices while also allowing for imperfect lock-in. Hence, switching costs' overall competitive effect remains ambiguous independent of the model's time horizon.

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<sup>2</sup>Further examples are age related products like baby or infant products as toys and diapers. But also banking services, consulting services and other durable goods and their after markets exhibit these features.

This study contributes to the literature on the competitiveness of markets under consumer switching costs and, to the best of my knowledge, is the first to investigate tacit and explicit collusive outcomes under state dependency and imperfect lock-in in a laboratory environment. The results raise in fact some doubts about the predominant view that markets are less competitive under switching costs. Significantly reduced prices prior to lock-in stress the importance of a state dependent approach for competition policy. Whereas less tacit collusive markets on the one hand limit the potential for consumer harm they also make the option to collude explicitly on the other hand more attractive. Thus, antitrust authorities should be aware that consumer switching cost markets may be more susceptible to explicit collusive agreements in their market screening practices.

## 2 The Model

The theoretic framework of Klemperer (1995, Section 3.2) incorporates a finite time horizon in form of a two-staged model in which switching costs (SC) emerge only in the second stage, representing the "mature" market. Firms are perfectly symmetric and products are homogeneous. In our implementation, firms compete in Bertrand competition for market shares and do not discount profits from the second stage.<sup>3</sup>

We denote  $\pi_k^i(p_k^i, p_k^j)$  for  $k = 1, 2$  as firm  $i$ 's profit in market stage  $k$ .<sup>4</sup> Goods are produced at constant marginal cost ( $c^i = c^j$ ) in both stages. Although firms are symmetric in costs we hold on to this distinct notation to conserve the intuition on the competitive equilibrium. Consumer mass is of size  $m$  and has inelastic unit demand of one up to a reservation price of  $p^{max}$ . After their initial purchase consumers face switching costs of  $S$  in case of a subsequent switch of suppliers. Switching costs are not too large such that consumers are only imperfectly locked-in. This feature is important in order to preserve firms' pricing incentives in the second stage, in the sense that a firm can still induce consumer switching if it chooses to price aggressively (see Padilla, 1995; Dubé *et al.*, 2009). We therefore impose the following assumption.

**Assumption 1.** *We assume consumer switching costs to be positive and of intermediate size such that  $\frac{p^{max}-c^i}{4} \leq S \leq \frac{p^{max}-c^i}{2}$ , with  $S > 0$ .*

Consumers are myopic and maximize their single market stage utility.<sup>5</sup> Hence, they buy whatever product is cheapest to them, also accounting for switching costs. If consumers are indifferent, their respective demand is split up equally among firms. A firm  $i$ 's profit function is displayed in Appendix A.

We can identify three distinct subgames for the "mature" market. Two of previous monopolization, by the rival or a firm  $i$  itself, and one subgame in which firms shared market

<sup>3</sup>This corresponds to a value of  $\delta = 1$  in equation (1) of Klemperer (1995).

<sup>4</sup>Note that  $\pi_k^F(p_k^i, p_k^j)$  is a step function in our framework and not continuously differentiable in firms' prices.

<sup>5</sup>See also Klemperer (1987a) for a discussion of switching costs under different levels of consumer expectations and future tastes.

demand equally beforehand.

### Monopolization

Given that a firm  $i$  was able to monopolize the market in the first stage, it will either keep its market share, loose one half of it, or loose it entirely in the subsequent competition stage. We can formulate equilibrium prices and profits as follows.

**Proposition 1.** *Let  $p_1^i < p_1^j$ . Then, in equilibrium, a firm  $i$  also monopolizes the mature market under prices of*

$$p_2^{iMI} = p_2^j + S = c^j + S; \quad p_2^{jMI} = c^j, \quad (1)$$

and profits of

$$\pi_2^{iMI} = (c^j + S - c^i)m; \quad \pi_2^{jMI} = 0. \quad (2)$$

*Proof.* See Appendix B. □

This is the price equilibrium also shown in Klemperer (1987b, Section 2) and Farrell and Klemperer (2007, Section 2.3.1). Intuitively, a firm  $i$  who previously served the entire market demand will set a price (just below)  $p_2^i = p_2^j + S$  that maximally exploits its own customer base while securing not to loose any market share over to its rival. Given this pricing strategy, any rival's price of  $p_2^j > c^j$  implies a profitable deviation for firm  $j$  as it can profitably attract at least some demand if it lowers its price.

### Equal split

If firms previously set identical prices they are endowed with a symmetric customer base entering second stage competition. As a consequence they face a trade-off between harvesting their existing customer base with a price just below  $p_2^i = p_2^j + S$  or undercut a rival's price with just below  $p_2^i = p_2^j - S$ . As Farrell and Klemperer (2007, Footnote 31) put it, this setting "generally eliminates the possibility of pure-strategy equilibria if  $S$  is not too large". Indeed, we find an equilibrium in mixed strategies of the following form.

**Proposition 2.** *Let  $p_1^i = p_1^j$ . Then, in equilibrium, a firm  $i$  randomizes over the price set of*

$$p_2^{iS} \in \mathbf{A}^i \cup \mathbf{H}^i, \quad (3)$$

with

$$\mathbf{A}^i = \left[ \frac{p^{max} + 2S + c^i}{2} - S, p^{max} - S \right]$$

$$\mathbf{H}^i = \left[ \frac{p^{max} + 2S + c^j}{2}, p^{max} \right]$$

and earns expected profits of

$$E \left[ \pi_2^{iS} \right] = \left( \frac{p^{max} + 2S + c^j}{2} - c^i \right) \frac{m}{2}. \quad (4)$$

*Proof.* See Appendix B. □

The set of  $\mathbf{A}^i$  contains aggressive prices a firm  $i$  would set in order to win over the rival's customer base, whereas harvesting prices are part of the set  $\mathbf{H}^i$ . This mixed pricing equilibrium is in spirit similar to findings of Padilla (1992); Fisher and Wilson (1995); Shilony (1977) who all find mixed strategy equilibria in single-staged settings with switching costs (or equivalent components). Note that firm  $i$ 's expected equilibrium profits in the split subgame exceed those from  $i$ 's monopolization subgame. The symmetric distribution of market shares induces both firms to compete less fiercely for the rival's customer base, contrary to a monopolization subgame. Firms' behavior can be interpreted in terms of two "fat cats" in the sense of Farrell and Shapiro (1988) who do not compete for rival's imperfectly locked in consumers but rather harvest existing ones. Whereas asymmetric market shares under a monopolization work as a commitment for the outsider to price aggressively.

### Early market & equilibria

Firms maximize combined profits ( $\Pi^i = \pi_1^i + \pi_2^i$ ) from both stages. Obviously, a firm  $i$  does not want to overprice its competitor, since this implies zero profits in either market phase. A monopolization of the early market is always profitable from a single period perspective, but it consequences foregone profits in the following subgame. Given a rival's early price, this trade-off between aiming for monopolization and a split gives rise to the following equilibria.

**Proposition 3.** *There exist multiple subgame perfect Nash-equilibria in pure strategies that include first stage prices over the interval of*

$$p_1^i \in \left[ 2c^i - \left( \frac{p^{max} + 2S + c^j}{2} \right) ; 2c^i - 2(c^j + S) + \frac{p^{max} + 2S + c^j}{2} \right]. \quad (5)$$

*These equilibria are symmetric and pareto-rankable. In equilibrium the market is repeatedly split in both stages. Firms realize total equilibrium profits of*

$$\Pi^{i*} \in \left[ 0, \left( 2 \frac{p^{max} + 2S + c^j}{2} - 2(c^j + S) \right) \frac{m}{2} \right]. \quad (6)$$

*Proof.* See Appendix B. □

A firm  $i$  finds it only optimal to monopolize if it prices high such that early monopolization profits are substantial and make up for fiercer competition in the subsequent subgame. These equilibria are in line with results of Suleymanova and Wey (2011) who also find a market sharing equilibrium in Bertrand competition under switching costs.

### 3 Experimental design

We study price setting behavior in a 2x2 factorial design experiment in which we alter the presence of consumer switching costs and firms' ability to communicate. All markets consist of  $m = 30$  consumers that buy one product up to a reservation price of  $p^{max} = 100$ . The duopolists are symmetric and face constant marginal cost of production of  $c = 40$ . A firm is able to single-handedly serve all consumers in the market. Chosen prices are those of the action set  $p_k^i \in \{0, \dots, 100\}$  and continuity is only limited to eight decimal places by restrictions of the experimental programming software. Subjects choose their prices simultaneously and independently.

We conducted four treatments in total. In NTSC (No-Talk with Switching Costs) and TSC (Talk with Switching Costs) switching costs are of size  $S = 20$ . Whereas in NTSC0 and TSC0 they are of size  $S = 0$ . Subjects are able to communicate in treatments TSC and TSC0. A playing period consists of one iteration of the static game and is played repeat-

Table 1: Treatment overview

	$S = 20$	$S = 0$
Enabled communication	<b>NTSC</b>	<b>NTSC0</b>
Disabled communication	<b>TSC</b>	<b>TSC0</b>

edly.<sup>6</sup> In each of the treatments subjects played a total of three supergames. Subjects were randomly matched to a stranger prior to each supergame. The length of a supergame was determined by a random termination rule, proposed by Roth and Murnighan (1978), for which Fréchette and Yuksel (2013) show that it induces the highest cooperation rates compared to other termination methods in repeated prisoners' dilemma interactions. The incorporated continuation probability was 0.875.<sup>7</sup> Supergame lengths were determined ex-ante and were constant over all treatments. The first supergame lasted for 6 playing periods, the second for 12 periods and 5 for the last.

In TSC and TSC0, subjects were able to communicate for a duration of 120 seconds prior to each supergame via an instant-messenger tool. There was no communication during supergames such that we can perfectly abstract from renegotiation effects. The time limit was sufficiently long to communicate experiment relevant information and subjects were allowed to post as many messages the liked during that time span. Subjects were aware that they communicated only with their rival and not to other participants.

Each treatment was conducted in a separate session with 24 participants. Hence, I observe 12 markets and assess treatment effects between subjects. Instructions were handed

<sup>6</sup>See Appendix C on the infinitely repeated switching cost game.

<sup>7</sup>The continuation probability of 0.875 secures that coordination on any price is a collusive equilibrium of the repeated game if firms punish according to a Nash-reversion trigger. Multiple equilibria and different market phases of the static game provide varying punishments and deviation timings in the indefinitely repeated game. However, for each punishment-deviation pair a continuation probability of 0.4 is sufficient to secure collusive equilibria. Experimental studies of B6 (2005); Fréchette and Yuksel (2013) provide evidence that the continuation probability indeed effects cooperation rates in dilemma games.



out in written form and subjects answered additional control questions on their computer screen prior to the experiment. Subjects used a computer terminal for price and text inputs and they were informed about current own and rival's prices, their own profits and market outcome after each market phase. They had information on their own accumulated profits but not on their rival's. Furthermore, subjects' user interface included a profit calculator that was accessible in all treatments.

Sessions were programmed in z-Tree (Fischbacher, 2007) and were run at the DICE Lab at the Heinrich-Heine University of Düsseldorf in which a total of 96 students participated. Subjects were awarded with a show-up fee of €4 and earned an "Experimental Currency Unit" called "Taler" with an exchange rate of 3,000 Taler : €1. Average payment was €16.03 and session duration reached from 50 up to 70 minutes.

## 4 Treatment effects

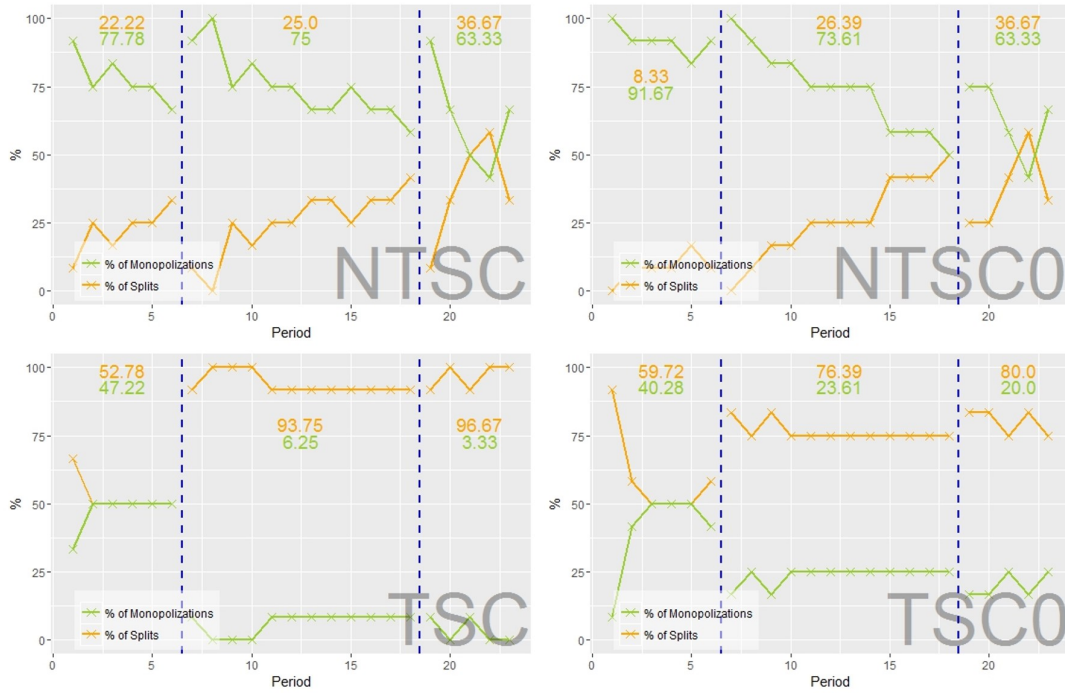
This section reports quantitative results regarding switching costs' and communication's effect on prices, profits and the competitiveness of markets. Prices enter the analyses as posted by subjects and conducted tests are all non-parametric. Test statistics are computed separately over supergames and are based on market level data.

### Subgame frequencies

Coordination on identical prices is naturally easier if one can communicate. Consequently, it is not surprising that subjects share market demand more frequently in talk treatments. In the first supergame markets are averagely split in 53% in TSC and 60% in TSC0 (see Figure 1). These proportions are higher and virtually stable for the subsequent supergames at 94%, 97% and 76%, 80% in TSC and TSC0 respectively. Potential differences between talking treatments that could be driven by switching costs are therefore only minor. Coordination on identical prices in treatments without communication is typically less frequent at the beginning but becomes more present over the duration of a supergame. This process culminates in average market sharing percentages of 37% in either treatment and is independent of the presence of switching costs.

The cause for this trend can be twofold. Either it is driven by an increasing number of markets that manage to coordinate on an identical price and sustain it once they reach it, or by markets on which market states alternate and market sharing becomes just more frequent. The first explanation would relate to somewhat stable states in first-order Markov processes whereas the second implies high transition between states. Table 2 displays the flow matrices for the non-communication treatments. We observe that both states are rather stable in either treatment. Market demand is repeatedly shared in 67% in NTSC and 80% in NTSC0 while repeated monopolization occurs in 83% and 90%. Although almost a third of all shared markets in NTSC move towards monopolization (33%), transitions between states are less frequent and overall mobility is low. Hence, not-moving

Figure 1: Market state proportions



Notes: Observed market state proportions are displayed over the course of each supergame. Annotations provide average empirical probability of occurrence for a market sharing and monopolization outcome. Naturally these add up to one.

Table 2: Market state transition matrices for non-communication treatments

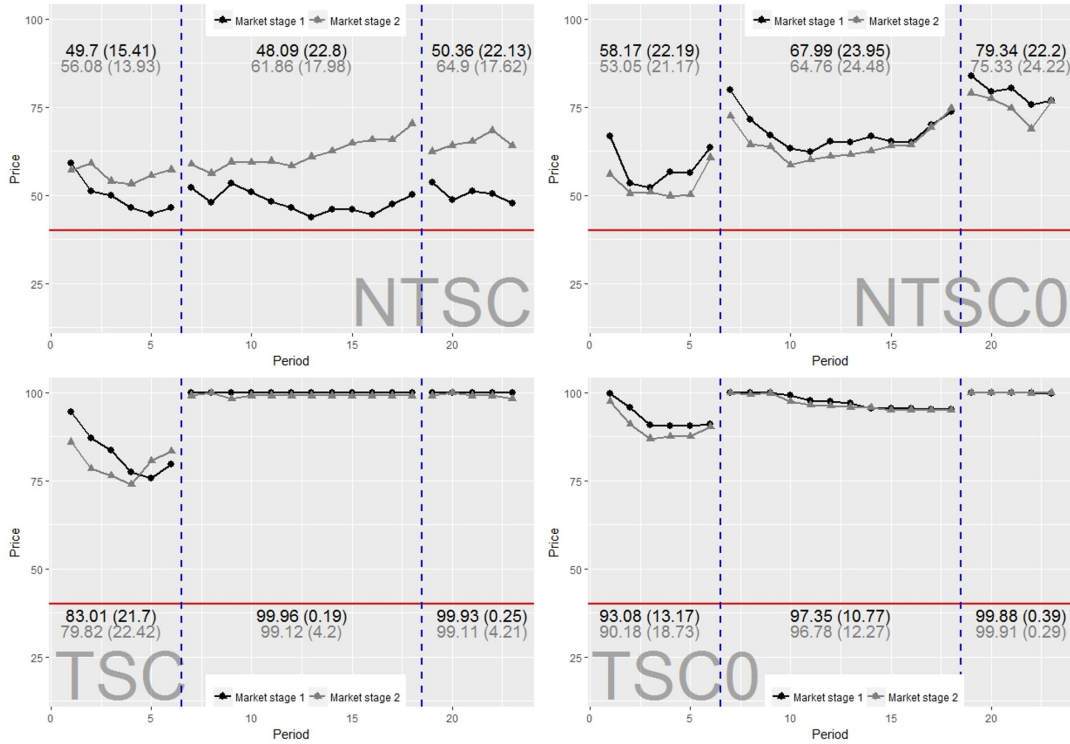
NTSC	to Split	to Monop	NTSC0	to Split	to Monop
from Split	67.21%	32.79%	from Split	80.0%	20.0%
from Monop	16.76%	83.24%	from Monop	10.27%	89.73%

firms are either satisfied with the status quo or want to move but find it difficult to do so. Transition difficulties should however only be an issue if firms want to coordinate on an identical price originating from monopolization. If the market is already split however, firms usually can unilaterally alter this in charging any price other than the previous one (profitably a lower one). Thus, we generally deduce that firms find it indeed profitable to share market demand and compete within a symmetric market environment in the subsequent market phase.

### Price level

Our first result stems from the pairwise comparison of average and subgame specific prices of treatments NTSC and NTSC0. Figure 2 displays the development of aggregate market stage prices in supergames. Average prices are significantly lower in the initial stage of competition if switching costs are active (2-sided Wilcoxon-Mann-Whitney U (WMW), all supergames  $p < 0.05$ ). This downward pressure on prices is not only

Figure 2: Aggregate and mean prices by treatments



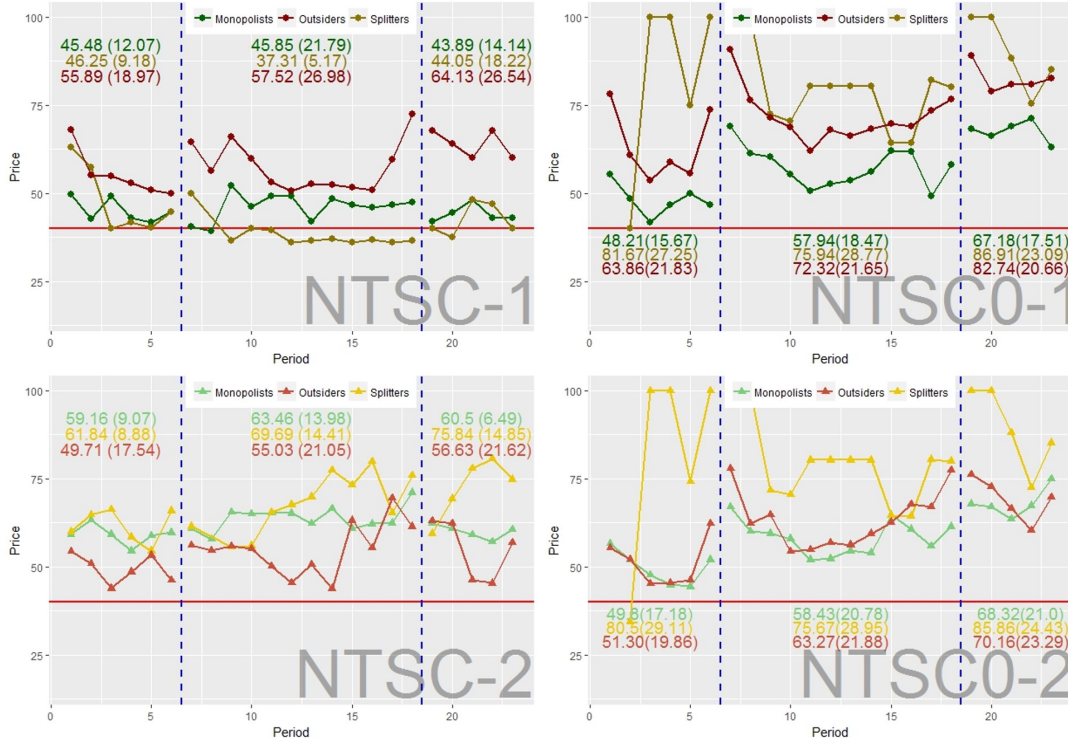
Notes: Aggregate prices in each market stage and period of play for all treatments. Annotations provide mean supergame prices (standard deviations based on market averages in parenthesis).

an aggregate effect but is present in all subgame dimensions. Price levels at which the market is split, monopolized or not served at all, are all significantly lower (WMW, all  $p < 0.01, 0.01, 0.05$ ). Figure 3 shows subgame specific prices in non-communication treatments. Firms' "investment" motive is specifically pronounced in monopolists' average prices who just price above marginal cost and splitters' who even price below that threshold in the second supergame. If switching costs are zero however, firms that coordinate on identical prices do so at prices which even exceed those of outsiders who overprice their fellow competitors.

Although firms do invest in first stage play of NTSC and indeed raise prices in second stage competition, average prices are not significantly different compared to the reference market (WMW, all  $p > 0.1$ ). Monopolists and even more so firms that shared market demand beforehand increase prices, while outsiders who initially overpriced adapt prices downwards. We do not observe this pricing pattern in NTSC0 as monopolists and splitting firms price almost identically as before and only outsiders decrease prices. Further, prices follow a stepwise upward trend over supergames implying a positive restart effect which we do not observe under switching costs.

**Result 1** *Without communication, switching costs induce firms to sell at lower prices early but the subsequent price level is comparable to an otherwise identical market.*

Figure 3: Price levels for non-communication treatments by subgames



Notes: Aggregate prices in each subgame and period of play for non-communication treatments. The graphic labeled "NTSC-1" corresponds to prices from first market stage competition in the treatment NTSC. Annotations provide average supergame prices in each subgame(standard deviation based on market averages in parenthesis).

The pairwise comparison of switching cost treatments and those without produce our second result. We find strong evidence that communication increases firms' ability to sustain a higher price level (WMW, all  $p > 0.01$ ). Although we observe prices significantly declining in the first supergame of either communication treatment, free-form multilateral communication is still effective. This is in line with findings of Cooper and Kühn (2014) in their pre-play chat treatment. Further, switching costs' effect on the price level vanishes if firms are in fact communicating as levels are not significantly different in TSC and TSC0 (WMW, all  $p > 0.243$ ). This holds for subgame specific prices as well as aggregates. Thus, communicating duopolies seemingly manage to overcome competitive effects caused by switching costs.

**Result 2** *Price levels are higher if firms communicate. Switching costs have no competitive effects if firms are communicating.*

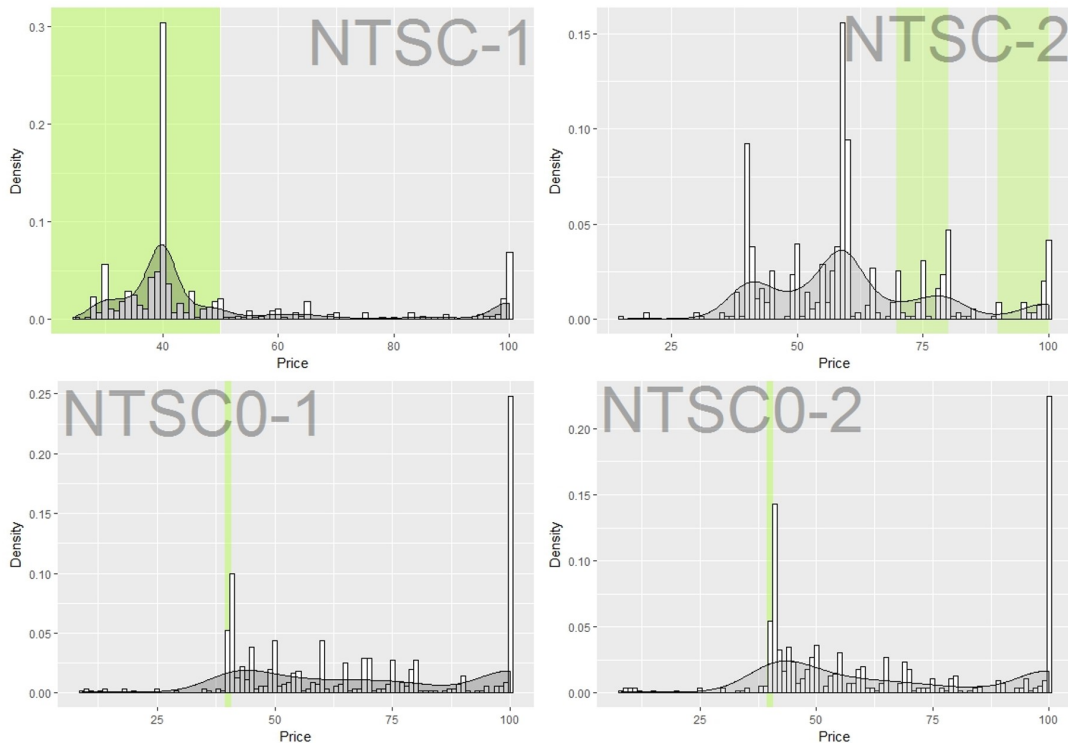
### Distributional characteristics

Although switching costs have no significant effect on the second market phase price level, they do seem to have an effect on the variance of posted prices in NTSC and NTSC0. Standard deviations for monopolists' prices and those on shared markets splitters are reduced if

switching costs are active (see Figure 3). Possibly, switching costs' effect on firms' price setting behavior is simply not fully captured by a rank based statistic and is rather characterized by higher moments of the observed price distribution than just the first.

Our third result is derived by comparisons of empirical CDFs and estimated kernel densities. The observed price distributions in treatments TSC and TSC0 are virtually identical and feature the bulk of probability mass on  $p^{max}$  (Figure 10, Appendix D). Switching costs have no effect on firms' price distribution if communication is active such that we restrict the following analysis to the non-communication treatments NTSC and NTSC0. Figure 4 displays the empirical distribution of all posted prices in non-communication treatments and the corresponding kernel densities.

Figure 4: Price distributions in NTSC & NTSC0 with respective kernels

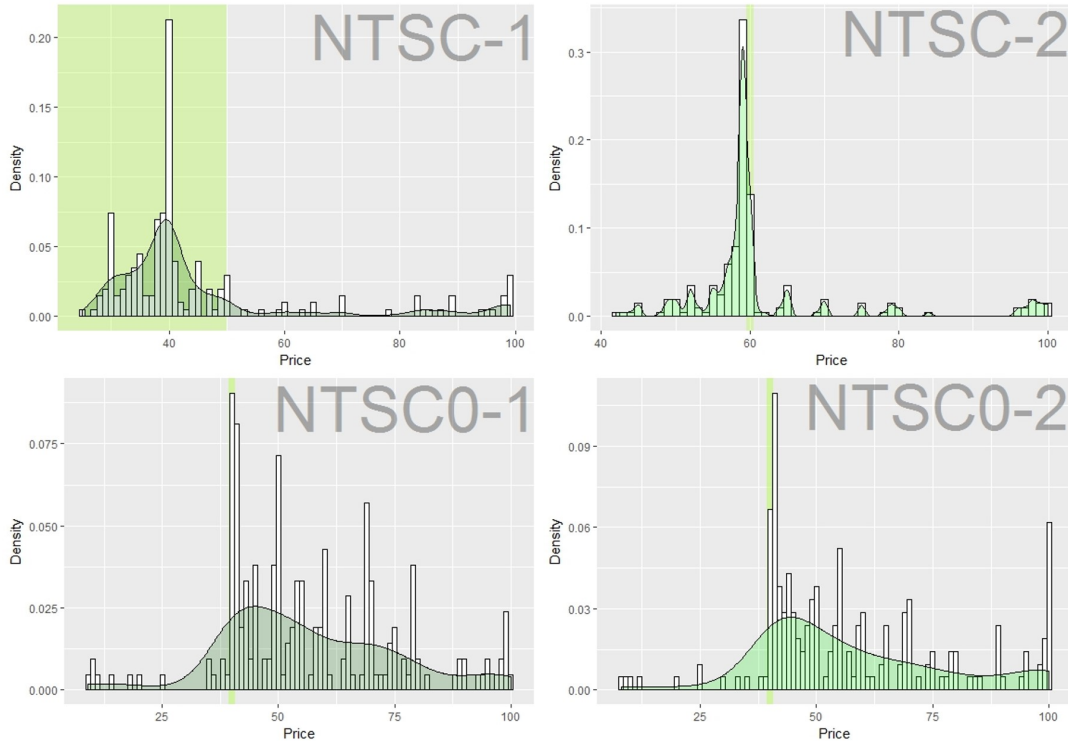


Notes: Displayed distributions incorporate posted prices in all supergames and subgames. Green highlighted areas correspond to prices of the subgame perfect Nash-equilibrium of the static game. Kernel densities are estimated via the Gaussian Kernel function and bandwidth is one standard deviation of the kernel.

Switching costs' effect on first market phase price distributions in NTSC and NTSC0 is two-fold. First, firms post less prices at  $p^{max}$  (6.9%) whereas it accounts for the highest probability mass (24.5%) in NTSC0. Second, prices are more concentrated around the mode of  $c = 40$  with 60.5% of observations smaller or equal to that threshold. In NTSC0 prices are more uniformly distributed above marginal cost level (only 8.7% price such as  $p \leq 40$ ). These distributional differences are significant on a market level (Kolmogorov-Smirnov (KS), all p-values  $< 0.01$ ). The concentration of probability mass around marginal costs is even more pronounced if we filter for prices at which the market is successfully

monopolized (Figure 5) and shared (Figure 6). Monopolists invest in a high market share with 25.2% of prices close to marginal cost level ( $p \in [40, 41]$ ) and even 43.6% below cost. In contrast to this, monopolists in NTSC0 price only in 17.1% of all cases according to the static Nash-prediction within  $[40, 41]$  but manage to monopolize the market with higher prices (81.3%) (KS, all  $p < 0.1$ ). If we consider shared markets, we identify a price of

Figure 5: Monopolists' price distributions in NTSC & NTSC0 with respective kernels



Notes: Displayed distributions incorporate posted prices in all supergames of firms who monopolize the market in the first market stage. Green highlighted areas correspond to prices of the subgame perfect Nash-equilibrium of the static game. Kernel densities are estimated via the Gaussian Kernel function and bandwidth is one standard deviation of the kernel.

$p = c = 40$  as a focal point for coordination (63.5%). An additional 23% of all splits occurred at prices even below  $c$ . This pricing pattern is significantly different (KS, all  $p < 0.01$ ) to shared markets under absent switching costs which are either increasingly collusive at  $p^{max}$  (63.64%) or competitive at  $p \in [40, 41]$  (27.27%).

In the second market stage of NTSC0, firms price almost as identical as in the previous one. Distributions of prior monopolists and also firms who previously split market demand exhibit no significantly different price frequencies. The only exception are firms who initially served no demand and adapt their prices downwards. Their kernel density exhibits now more probability mass on lower prices and resembles more closely the distribution of prior monopolists' (see Figure 11, Appendix D). In NTSC however, we identify a trimodality in the unfiltered price distribution which we did not observe in previous competition (Figure 4). We identify its concentrations in proximity to  $p = 40, 60, 80$  as a composite effect that corresponds to the pricing incentives in the three different subgames

of market stage two.

Prices of  $p \in [59, 60]$  are frequently chosen by monopolists who price according to the static Nash-prediction (Figure 5). Precisely, 47.5% of all monopolists, price in this interval and even 80.2% choose a price of  $p \leq 60$ . Given a rival's rationality, the majority of monopolists therefore effectively harvest their locked-in customers while not losing demand over to its rival. If switching costs are absent however, only 18.3% of prior monopolists choose a price of  $p \in [40, 41]$  which would correspond to static equilibrium play. We find these distributional differences to be significant (KS, all  $p < 0.1$ ). Additionally, the condensing of probability mass is also reflected in lower variances in all supergames (Fligner-Killeen, all  $p < 0.05$ ). This however has implications for cartel screening in antitrust policy. Screens often take small variances as signal for potential cartel activities (Abrantes-Metz *et al.*, 2006). Switching costs could then lead to an increased number of false positives whereas firms are acting in fact competitive.

Monopolists' virtual optimal play, in terms of game theory, coincides with the pricing behavior of firms that were previously driven out of the market (Appendix D). 33.66% of these firms price indeed such as  $p \in [40, 41]$  and are restricting the monopolist maximally while securing themselves a non-negative payoff in case they win over some customers. The majority (56.93%) prices above that corridor following no systematic pattern. However, outsiders' price distributions are not significantly different from those of the reference market.

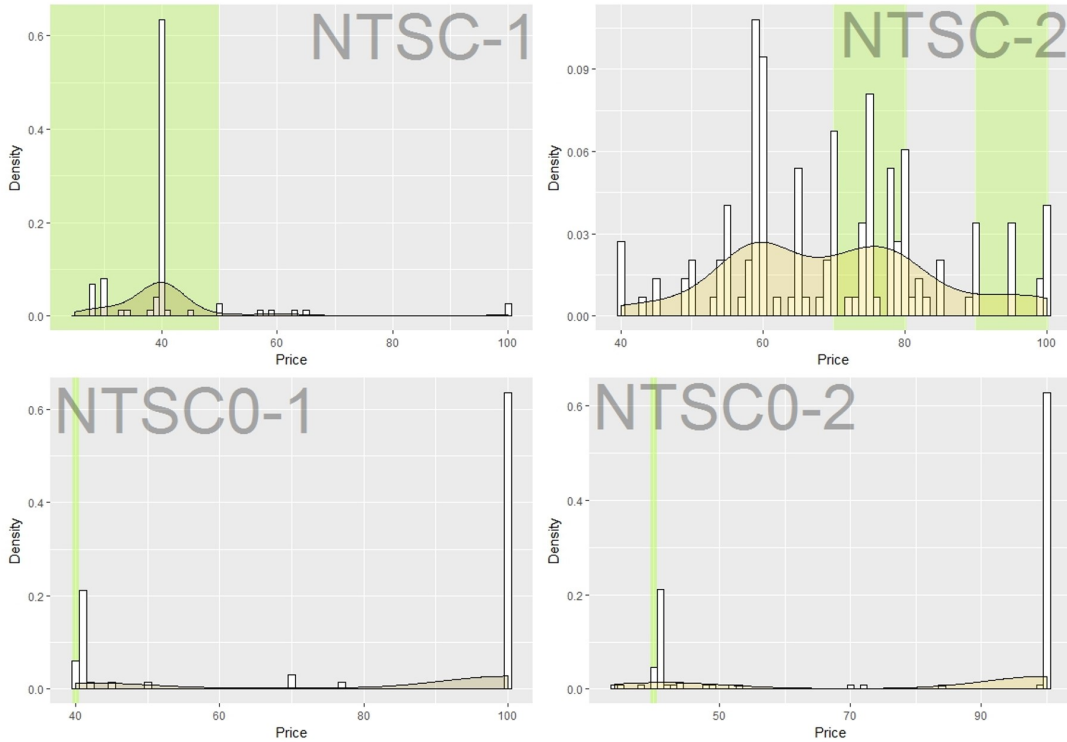
While estimated kernel densities for monopolists and outsiders are unimodal, shared markets exhibit a bimodal estimate. Probability mass agglomerates around values of  $p = 60, 80$  (Figure 6) and corresponds to maxima of the unfiltered kernel estimate. 62.2% of market sharing firms choose subsequent prices of  $p > 60$  and therefore price higher as the vast majority of monopolists. Apparently, subjects notice a rival's increased opportunity costs if both firms are equipped with an existing customer base. However, the observed bimodality does not coincide with price intervals of the static mixed-strategy equilibrium. Interestingly, the concentrations could be explained instead by the level-k approach in the field of behavioral economics.<sup>8</sup> Although kernel densities of NTSC and NTSC0 visually look very different in the second market phase, differences are statistically not significant.<sup>9</sup>

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<sup>8</sup>Seminal contributions of (Nagel, 1995) and (Stahl and Wilson, 1995) in the concept of level-k reasoning assume that a subject's decision making process can be characterized by specific levels of strategic reasoning. The zero level corresponds to a decision-maker whose decisions are made independent of beliefs about an opponent's behavior. In our setting the zero level would correspond to an own price of  $p = c = 40$  that would result in non negative profits. Level-1 decision makers then believe that their opponents are of type zero and play accordingly. Analogously, subjects of level-2 reasoning play a best response given the belief that their opponents are of level-1. In a split subgame under switching costs these would correspond to prices of  $p = c + S = 60$  for level-1 reasoning and  $p = c + 2S$  for level-2. Hence, according to the level-k approach the majority of observed splitters in our sample would be of level-1 or 2.

<sup>9</sup>Since we do not observe split subgames on every market in every supergame the statistical test is performed on a reduced sample size. We observe Split subgames in NTSC on 8 markets in the first supergame, 9 in the second and 8 in the third. In NTSC0 we observe 3, 9 and 8 markets that exhibit split subgames.

Figure 6: Splitters' price distributions in NTSC & NTSC0 with respective kernels



Notes: Displayed distributions incorporate posted prices in all supergames of firms who shared market demand in the first market stage. Green highlighted areas correspond to prices of the subgame perfect Nash-equilibrium of the static game. Kernel densities are estimated via the Gaussian Kernel function and bandwidth is one standard deviation of the kernel.

**Result 3** *Without communication, switching costs cause firms' price distribution to be concentrated at marginal cost level in the early market stage while they induce monopolists to price more frequently at the static equilibrium price level in the subsequent stage.*

### Competitiveness & Collusion

The competitiveness of a market is mainly determined by the profits firms are able to realize. Given that the demand specification of the underlying model secures cleared markets, firms' profits are only driven by selling prices. Although we analyze treatment effects based on posted prices, our first two results with respect to the price level carry over to the profit dimension. Table 6 in Appendix D displays firms' average market phase profits.

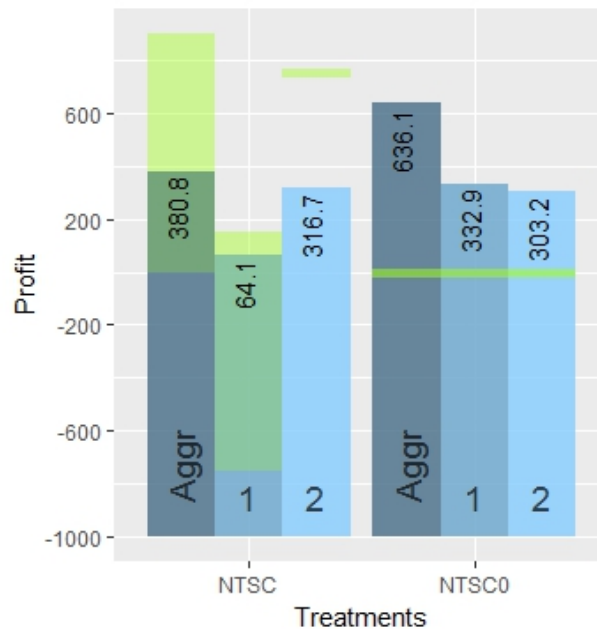
Firms earn significantly less in early market stages of NTSC whereas later profits are equivalent to those of the reference market. Apart from this we observe differences in profits for monopolists and outsiders in communication treatments. However, these can be explained by subjects' choice of coordination strategy.<sup>10</sup>

<sup>10</sup>In TSC0 more subjects adapt a collusive strategy of alternating monopolization (take-it-in-turns) rather than coordinate on an identical price. Additionally, a firm who applies this strategy and monopolizes the market in the second stage in TSC has to undercut by a high margin whereas in TSC0 already a marginally lower price is sufficient. Outsiders' profits in TSC0 are therefore lifted upwards.



From these we can now infer to the competitiveness of switching cost markets. Especially to answer the question whether profits are realized competitively or whether the market environment is rather tacitly collusive? As Ivaldi *et al.* (2003, p.5) put it “..., tacit collusion is a market conduct that enables firms to obtain supra-normal profits, where ‘normal’ profits corresponds to the equilibrium situation...”. We therefore measure the intensity of tacit collusion as the amount of profits that exceed the equilibrium level. Following this notation a profit around the equilibrium level would not be collusive whereas a negative equilibrium mark-up would indicate a somewhat over-competitive environment. Figure 7 displays firms’ mean and equilibrium profits of one playing period in the non-communication treatments. We exploit the variation in firms’ supra-competitive

Figure 7: Mean and equilibrium period profits in NTSC and NTSC0



Notes: Profit bars display firms’ mean period profits in each market phase and aggregated. Green shaded areas correspond to the equilibrium profits of the Subgame-perfect Nash-equilibria of the respective game.

profits to evaluate switching costs’ effect on the market’s competitiveness. In NTSC0, firms manage to establish a tacit collusive environment in either market phase. If switching costs are active however, firms manage to realize profits that are for one below the mixed strategy equilibrium profit in market phase two and for another within the set of equilibrium profits of early competition. Hence, profits in the second market stage under switching costs are rather realized competitively as tacit collusive intensity is significantly lower (WMW, all  $p < 0.01$ ). We cannot provide such clear cut evidence for the competitiveness in the first market stage as it depends on the choice of a competitive reference point within the interval of equilibrium profits. If we take the upper interval profit as reference we assume a somewhat "friendly" competitive benchmark and find evidence that also supra-competitive profits in the early market stage are significantly lower (WMW, all

$p < 0.01$ ). If the median or lower bound profit of the interval are taken as reference, intensity of tacit collusion either does not differ or is significantly higher (WMW, all  $p < 0.1$ ). Switching costs' effect on the overall level of tacit collusion however is unambiguous as we find strong evidence that firms realize less supra-competitive profits if we take the median equilibrium profit as reference (WMW, all  $p < 0.01$ ). Even if we assume equilibrium profits of fierce competition (lower interval border) we find the degree of tacit collusion to be lower in the third supergame of NTSC (WMW,  $p < 0.05$ ).

However, the question why firms are not able to establish a comparable degree of tacit collusion, although higher profits can be sustained even in the static equilibrium, remains puzzling. Seemingly, consumer switching costs induce firms to behave more competitively in general, whereas the atmosphere is more cooperative in NTSC0. The prospect of looming asymmetries and the opportunity to gain a competitive advantage could drive the perception as rivals between the duopolists whereas firms being symmetric throughout contributes to a more cooperative view of the fellow duopolist.

The presence of untapped tacit collusive potential under switching costs is most pronounced in the second market phase. Splitters could price more bravely at higher prices given symmetric customer bases while monopolists almost perfectly settle for safe equilibrium profits rather than trying to establish a tacit collusive outcome above equilibrium level. Opportunities for monopolists to do so are plenty however, as outsiders do not maximally restrict the monopolist in most of the cases and charge prices above marginal cost (56.93%). On the other hand, outsiders also have an incentive to raise a monopolist's profits since market interactions take place repeatedly and one time outsiders become monopolists themselves eventually.

This good news in terms of consumer harm however should also influence a firm's decision whether to form a cartel and collude explicitly in the field. Naturally, a limited scope for tacit collusion makes the prospect of high profits under explicit collusion even more attractive. As Shapiro (1989, p.357) puts it "Anything...that makes more competitive behavior feasible or credible actually promotes collusion". Hence, consumer switching costs should also make explicit collusion more attractive. A realistic way to measure a firm's incentive to collude explicitly is the profit it would gain through such an agreement. Fonseca and Normann (2012) therefor assess profit differences between communication and non-communication treatments. In a difference-in-difference OLS-regression (Table 5, Appendix D) we find indeed that in supergames two and three the increase in firms' profits under communication is more pronounced if switching costs are active. Hence, firms would profit more from communication and have a stronger incentive to collude explicitly. The contrary result in the first supergame can be mainly explained by subjects' inexperience and a lower price level in TSC relative to TSC0. Whereas tacit collusion is less present under consumer switching costs, they may make profits from explicit cartel agreements even more attractive.

**Result 4** *Consumer switching costs reduce firms' supra-competitive profits and therefore the intensity of tacit collusion. On the other hand, after some learning, gains in profits from communication are more pronounced making explicit agreements more attractive.*

In the field this trade-off between tacit and explicit collusion should be highly relevant as firms who cartelize coincidentally reject the option to collude tacitly. Hence, consumer switching costs could not only facilitate competition but also make markets more susceptible to cartel agreements. Our results suggest that firms' prices in mature or aftermarket are less crucial for a firms' potential cartelization decision as they indeed differ in their competitive intensity under which they are realized but still remain comparable. Considerably more effected by switching costs is the competition for new consumers. Industries in which new consumers initially buy at relatively high prices although a subsequent switch of suppliers is costly, could indicate the existence of potentially dominant firms or those who behave anti-competitive. While the experiment data confirms that switching costs indeed induce firms to invest in customer bases and harvest them later on, the overall scope for consumer harm if firms do not communicate is however reduced. In reverse an increased focus on switching cost markets and especially "soft" investment stages for cartel screening could be promising.

## 5 Text Analysis

The analysis in this section covers the second dimension of input subjects made during the experiment, that is chat content. We employ different approaches and metrics to quantify communication among subjects that contain descriptive statistics based on unsupervised message counts as well as text mining procedures. These results accompany findings of the prior quantitative analyses and should not be interpreted as causal relationships. We are primarily interested in whether communicated content differs in the presence of switching costs and even more so between the first supergame and the latter two of the respective treatments since these differ in distribution of market states and price level.

### Descriptives

In this section we provide descriptive statistics assessable by simply counting *messages* in the raw, unsupervised chat log.<sup>11</sup> We define a *message* as a line of text that is written by subject  $i$  and is sent coherently to subject  $j$  within an experimental market. Therefore, a message is interpreted as an unilateral contribution to the within market communication. Table 3 displays mean message counts within a market for each supergame ( $\overline{C_{SG}}$ ) and treatment. While we observe more overall interactions between duopolists in TSC0, the

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<sup>11</sup>The text data is unsupervised in the sense that that neither punctuation and misspellings are corrected nor are *stopwords* filtered out. Stopwords are language specific and include words that are naturally used very frequently while not bearing any analytic value for the specific research question. For the English language these can be "a", "and", "also" or "the" among others. They are usually removed prior to text mining

Table 3: Mean messages per market and supergame

Means of within market <i>messages</i>	TSC	TSC0
$\bar{C}$	<b>12.83</b>	<b>14.5</b>
$\bar{C}_1$	10.75	11.5
$\bar{C}_2$	12.58	15.25
$\bar{C}_3$	15.17	16.75
Observations	462	522

number of messages sent per supergame increases over the course of the experiment in both treatments. Especially in TSC0 chat interactions become more frequent after the first supergame. In the light of the market outcomes in the first supergames of both communication treatments, the lower amount of messages seems not surprising. Possibly subjects' communication simply was not extensive enough to establish stable collusion.

### Text Mining

Whereas simple message counts only display how reciprocal a conversation might be, text mining methods allow a somewhat objective analysis of the communicated content. Based on our quantitative findings of *Section 4* we are particularly interested whether communicated content differs between treatments and even more so whether content can indicate why collusion breaks down so frequently in the first supergame compared to supergames two and three.

For this purpose we use the *Relative Rank Differential* (RRD) of Huerta (2008) which measures words that are relative more frequent in one corpus of text compared to another.<sup>12</sup> Text mining methods so far have been mostly used in fields of computational linguistics and health sciences but recently also for the analysis of chat content in economic experiments (Möllers *et al.*, 2017).

The RRD statistic is calculated on word ranks according to their frequency in the respective corpus. For the ordinal measurement of words within a corpus we adopt the frac-

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procedures in order to avoid any bias.

<sup>12</sup>The compared corpora of text however do not necessarily correspond to text of different treatments but can also capture subsets of different market outcomes or other dimensions. In our case the respective first supergame and supergames two and three.

tional ranking method ("1 2.5 2.5 4") for the RRD which is calculated according to (7).<sup>13</sup>

$$RRD_{w,t1} = \frac{r_{w,t2} - r_{w,t1}}{r_{w,t1}} \quad (7)$$

The expression  $r_{w,t1}$  corresponds to the rank of word  $w$  in the base corpus  $t1$  whereas  $r_{w,t2}$  is the rank of the same word  $w$  in the comparison corpus  $t2$ . The RRD therefore accounts not only for the rank differential but also for the frequency of the respective word in the base corpus. Consequently, rank differences for common words are weighted higher than those that are only used rarely. The least common words of a corpus are sparse words which have zero frequency in that respective corpus but are used in the comparison one and have the rank of  $r_w$  of the ordinal spectrum. Naturally, a word  $w$  with a positive RRD value corresponds to a word which is ranked higher in the base corpus and the magnitude of the metric determines the salience or "keyness" of the respective word.

As with other text mining procedures the RRD is calculated on supervised chat data to prevent any bias of the metric. For this we conduct the following modifications and filtration during a preprocessing stage. We remove any *punctuation* and *special characters* such as ("@" or "/" ). Since capital letters are pretty common in the German language it is crucial to transform all letters to *lower case* to avoid a twofold listing of the identical word. Our vector of german specific *stopwords* which are filtered out include all variations of conjunctions, definite and indefinite articles, and prepositions of location. Finally, we correct common *misspellings*, *typos* and merge *colloquial words* accordingly.<sup>14</sup> We report keywords in Tables 7-9 of Appendix D whose original rank in the base corpus and rank differential satisfies  $r_{w,t1} \leq 50$  and  $RRD_{w,t1} \geq 3$  respectively.

The keyword comparison between both communication treatments in Table 7 exhibits an almost identical number of total words ( $W_{TSC,TSC0}$ ) in both corpora. Keywords used under switching costs contain statements of affirmation like "sure" or "absolutely" and words corresponding to the experimental environment as "market", "bet" or "say". The same is true for keywords used in TSC0 as we find affirmations "perfect" or "deal" and words that are used to communicate strategies like "per" and "time" as in the expression "each time". Further, the phrase of "1800" is also salient and corresponds to a firm's period profit if the market is repeatedly split at  $p^{max}$ . This could indicate that subjects use

<sup>13</sup>The applied ranking method within the corpora naturally effects the ordinal spectrum  $O = [r_w, \bar{r}_w]$  and consequently the RRD. To conveniently compare ranking methods we provide a ranking of four items in which the first is ranked ahead while the last is ranked behind the second and third which are tied based on the ranking criteria. The standard competition ranking ("1224") and its modified version ("1334") are less condensing on  $O$  than the dense ranking ("1223") but the sum of assigned ranks varies with the number of ties. Especially for corpora containing only a limited amount of total words, like experiment chat, the probability of words having the same (low) frequency is quite high and the condensing effect is quite prevalent. Dense ranking would therefore severely reduce the ordinal spectrum to the number of different word frequencies we observe and consequently reduce the magnitude of the RRD. Therefore, we use fractional ranking ("1 2.5 2.5 4") as it is not only the least condensing method with respect to  $O$  but has also the property that the sum of all ranks is the same as in ordinal ranking ("1234") and independent of the number of ties which is needed for statistical tests.

<sup>14</sup>Colloquial speech that is transformed mostly contains all variations of negations ("nope", "nah") , affirmations ("yep", "yup" "yessir") and interjections of laughing and giggling ("haha", "tee-hee").

explicit calculations and profit targets to communicate a strategy and compare between them.<sup>15</sup> However, we consider the keywords of both corpora as somewhat neutral in a sense that it is difficult to deduct any indication from them on observed outcomes that are not significantly different anyhow.

By contrast, market outcomes, namely market state proportions as well as the price level, do differ between the first supergame and the latter two in both treatments. Table 8 and 9 display the keywords of the within treatment comparisons of supergames. What has already been indicated by the lower amount of *messages* sent in the respective first supergames translates also into total words used. Subjects do not only interact less prior to their first pricing decision but also use far fewer words on average compared to subsequent communication. To be precise, the amount of words increases by 28,37% in TSC and 38,86% in TSC0 on average.

For keywords in TSC we find again somewhat neutral words such as "product", "costs" in  $SG_1$  or affirmations, "super", in  $SG_{2,3}$  which were prevalent in the previous treatment comparison. However, the most salient keywords in the first supergame are either subjunctive, "were" or "(we) might", or noncommittal like "attempt", "suggest" or "(I) believe". Whereas in the subsequent supergames more binding words like "(we) both" and "always" are more salient. Apparently, communicated content in  $SG_1$  is less definite and may indicate that subjects could be more uncertain about pricing decisions and the desirability of certain market outcomes due to somewhat vague communication.

We observe the same increased keyness for subjunctive expressions and noncommittal language in the supergame comparison of TSC0. Again words like "would", "suggest", "test" and "idea" can be found at the top of the RRD ranking indicating that the lack of definite language is not treatment specific. It is rather driven by subjects' inexperience of what specifically needs to be communicated to create an environment of stable collusion. However, subjects seem to gain that experience after the first supergame. Keywords are then again "per", "always" and "1800" characterizing a more profound payoff evaluation but also "collusion" and "if" indicate more contingent price strategies. This is in line with findings of Cooper and Kühn (2014) who find that especially contingent messages including a punishment facilitate collusion.

Hence, the salient noncommittal language together with fewer interactions in the respective first supergames provide an intuition on why market outcomes are less collusive. It seems that subjects need to learn how to use communication effectively in order to establish stable collusion.

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<sup>15</sup>Interestingly, the word "switching costs" is more salient in NTSC0 in which they are zero. However, this is due to one market in which subjects talk about the framing of the respective treatment and consequently use the specific word more frequently rather than the word being used in communication on pricing strategies.

## 6 Conclusion

Consumer switching costs impose a challenge for antitrust authorities in assessing firms' market power or cartel detection. Screening methods mostly focus on mean prices or the variance of the observed pricing distribution (Abrantes-Metz *et al.*, 2006). However, it is increasingly difficult to infer from these two moments to the competitiveness of the market if consumers face costs of switching their supplier. This is especially true if firms can distinguish new from old consumers and will price according to an "invest-and-harvest" pattern in equilibrium (Klemperer, 1995). A screen would then perceive prices to new consumers as potentially predatory and vis-à-vis old consumers as collusive (Che *et al.*, 2007).

While finite time horizon models provide ambiguous results on switching costs' effect on the overall competitiveness, infinite frameworks established a somewhat conventional wisdom of a negative competitive effect. However, recent findings challenge this view (Dubé *et al.*, 2009).

This study sheds light on switching costs' competitive effects and scope for collusion on markets that exhibit finitely participating, identifiable consumers. I investigate these issues by studying Bertrand duopolies in a laboratory environment which is seen as favorable for collusive behavior (Dufwenberg and Gneezy, 2000; Davies *et al.*, 2011).

The experimental data shows that firms price indeed lower and invest in a high market share early. However, subsequent prices do not differ to those of the reference market since firms manage to establish a tacit collusive environment which they fail to do if switching costs are present. Since the duopolistic environment is seemingly more competitive, firms' ability to collude tacitly is limited and their supra-competitive profits plummet. This is especially present for firms who initially served all consumers. The price distribution of these prior monopolists is centered around the equilibrium "harvesting" level and also exhibits a lower variance.

The implications of these results for antitrust policy are manifold and an increased focus on switching cost markets might be rewarding for several reasons. A lesser scope for tacit collusion naturally translates into markets that are more susceptible for explicit conspiracies. This illegal communication is indeed an effective coordination device on pareto-superior outcomes and additionally negates competitive effects induced by switching costs. Increased competition for new consumers make high cartel profits even more tempting. Hence, suspiciously soft "investment" stages could be a promising starting point for cartel screening. However, the choice of the specific cartel screen should consider switching costs' effect on all moments of the price distribution to avoid false positives.

## Appendix A: Profit function

We define a firm  $i$ 's profits in the respective market phases as

$$\pi_1^i = \begin{cases} (p_1^i - c^i)m & \text{if } p_1^i < p_1^j, \\ \frac{(p_1^i - c^i)m}{2} & \text{if } p_1^i = p_1^j, \\ 0 & \text{if } p_1^i > p_1^j. \end{cases}; \quad \pi_2^i = \begin{cases} (p_2^i - c^i)m & \text{if } p_1^i < p_1^j \wedge p_2^i < p_2^j + S, \\ \frac{(p_2^i - c^i)m}{2} & \text{if } p_1^i < p_1^j \wedge p_2^i = p_2^j + S, \\ 0 & \text{if } p_1^i < p_1^j \wedge p_2^i > p_2^j + S, \\ (p_2^i - c^i)m & \text{if } p_1^i = p_1^j \wedge p_2^i < p_2^j - S, \\ \frac{(p_2^i - c^i)3m}{4} & \text{if } p_1^i = p_1^j \wedge p_2^i = p_2^j - S, \\ \frac{(p_2^i - c^i)m}{2} & \text{if } p_1^i = p_1^j \wedge p_2^j - S < p_2^i < p_2^j + S, \\ \frac{(p_2^i - c^i)m}{4} & \text{if } p_1^i = p_1^j \wedge p_2^i = p_2^j + S, \\ 0 & \text{if } p_1^i = p_1^j \wedge p_2^i > p_2^j + S, \\ (p_2^i - c^i)m & \text{if } p_1^i > p_1^j \wedge p_2^i < p_2^j - S, \\ \frac{(p_2^i - c^i)m}{2} & \text{if } p_1^i > p_1^j \wedge p_2^i = p_2^j - S, \\ 0 & \text{if } p_1^i > p_1^j \wedge p_2^i > p_2^j - S. \end{cases}$$

while corresponding profits of the rival  $j$  are derived analogously.

## Appendix B: Proofs

### Proof of Proposition 1.

*Proof.* Intuitively, a firm  $i$  who previously served the entire market demand will set a price of  $p_2^i = p_2^j + S - \gamma$  that maximally exploits its own customer base while securing not to lose any market share over to its rival as long as  $p_2^j \geq c^i - S + \gamma$  with  $\gamma \rightarrow 0$ . If a rival prices below this threshold a firm  $i$  will rather serve no consumers since maintaining some market share would result in negative profits. Hence, there exist multiple equilibria in pure strategies

$$p_2^i = p_2^j + S \in [c^i, c^j + S[; \quad p_2^j \in [c^i - S, c^j[$$

in which the monopolist realizes non-negative payoffs and the outsider zero profits. However, weak dominance or the trembling-hand equilibrium refinement produces the known price equilibrium of Klemperer (1987b, Section 2) and Farrell and Klemperer (2007, Section 2.3.1)

$$p_2^{iMI} = p_2^j + S = c^j + S; \quad p_2^{jMI} = c^j. \quad (8)$$

This completes the proof.  $\square$

### Proof of Proposition 2.

*Proof.* Given a firm  $i$ 's installed customer base, its options are to optimally "harvest" existing customers with  $p_2^i = p_2^j + S - \gamma$ , win over half of the rival's customers with  $p_2^i = p_2^j - S$



or monopolize the entire market at  $p_2^i = p_2^j - S - \gamma$  for  $\gamma \rightarrow 0$ . However, profits in the states in which a firm  $i$  serves  $\frac{1}{4}$  ( $\pi_2^{iS, \frac{1}{4}}$ ) or  $\frac{3}{4}$  of market demand ( $\pi_2^{iS, \frac{3}{4}}$ ) can be characterized as irrelevant alternatives in terms of equilibria finding. Losing all prior market share due to overpricing its rival serves as an ever-present critical zero profit benchmark for a firm  $i$ .

Figure 8 displays firm  $i$ 's profits in a split subgame as a function of rival  $j$ 's price ( $\pi_2^i(p_2^j)$ ). Intersections of the profit functions determine the relevant cut-offs for firm  $i$ 's best response.

A firm  $i$  will find it profitable to undercut any rival's price above  $p_2^{j'}$  which satisfies

$$\pi_2^{iS, MI} \geq \pi_2^{iS, S} \Leftrightarrow (p_2^j - S - \gamma - c^i)m \geq (p_2^j + S - \gamma - c^i)\frac{m}{2}.$$

The above condition however implies that  $p_2^{j'} = 3S + c^i + \gamma < p^{max} - S + \gamma$  and a firm  $i$  can fully "harvest" its existing consumers with a mark-up of  $S$  while it does not exceed the reservation price. Given **Assumption 1** this condition is however violated and firm  $i$  will set a price of  $p_2^i = p^{max}$ . This ,consequently, shifts the rival's price for which undercutting is profitable ( $p_2^{j''}$ ) downwards . It is defined as a solution to

$$\pi_2^{iS, MI} \geq \pi_2^{iS, S^{max}} \Leftrightarrow (p_2^j - S - \gamma - c^i)m \geq (p^{max} - c^i)\frac{m}{2}$$

with  $\pi_2^{iS, S^{max}}$  as the maximum profit a firm  $i$  can realize if the market is repeatedly split. The solution to this inequality is  $p_2^j \geq \frac{p^{max} + 2S + c^i + 2\gamma}{2} = p_2^{j''}$  and  $[p_2^{j''}, p^{max}]$  defines rival's prices for which firm  $i$  finds it profitable to undercut.<sup>16</sup> Hence, for  $\gamma \rightarrow 0$  a firm  $i$  will find it optimal to undercut rival's prices of

$$\frac{p^{max} + 2S + c^i}{2} \leq p_2^j \leq p^{max}.$$

The uniqueness of derived intercepts and cut-offs is secured by  $\frac{\partial \pi_2^{iS, MI}}{\partial p_2^j}, \frac{\partial \pi_2^{iS, \frac{3}{4}}}{\partial p_2^j}, \frac{\partial \pi_2^{iS, S}}{\partial p_2^j}, \frac{\partial \pi_2^{iS, \frac{1}{4}}}{\partial p_2^j} > 0$ .

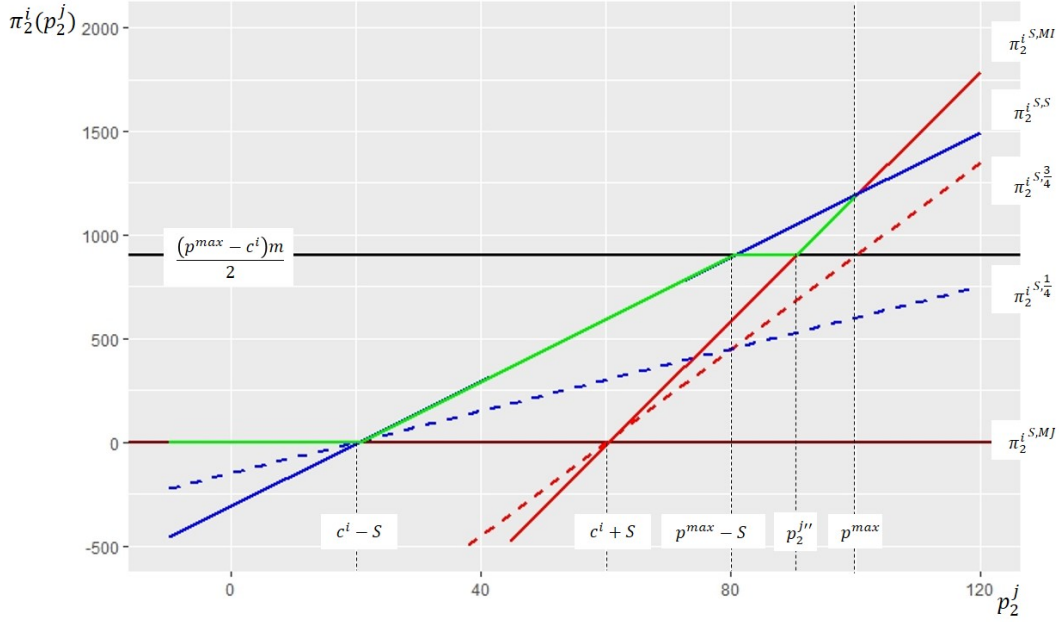
Following this, one can state firm  $i$ 's best response function as follows.

$$BR^{iS}(p_2^j) = \begin{cases} p_2^j - S & \text{if } \frac{p^{max} + 2S + c^i}{2} \leq p_2^j \leq p^{max}, \\ p^{max} & \text{if } p^{max} - S < p_2^j < \frac{p^{max} + 2S + c^i}{2}, \\ p_2^j + S & \text{if } c^i - S \leq p_2^j \leq p^{max} - S, \\ p_2^j \in [c^i, p^{max}] & \text{if } p_2^j < c^i - S. \end{cases} \quad (9)$$

Applying the strict dominance criterion, we can derive two sets of non-dominated prices a firm  $i$  chooses with different intention. First, the range of "aggressive" prices  $\mathbf{A}^i = [\underline{\alpha}^i, \bar{\alpha}^i]$

<sup>16</sup>The condition of  $S \leq \frac{p^{max} - c^i}{2}$  in **Assumption 1** secures that there is at least one price for which it is profitable to price aggressively and that  $[p_2^{j''}, p^{max}]$  is a non-empty set.

Figure 8: Firm  $i$ 's profits and best responses in a split subgame



Notes: The displayed profit line are those for the experiment parameter values of  $S = 20$ ,  $c^i, c^j = 40$ ,  $m = 30$ ,  $p^{max} = 100$ . Intercepts are provided for  $\gamma \rightarrow 0$ . A firm  $i$ 's best response profits are colored in green.

defined as

$$\mathbf{A}^i = \left[ \frac{p^{max} + 2S + c^i}{2} - S - \gamma, p^{max} - S - \gamma \right]$$

a firm  $i$  would set in order to win over market share. Second, the set of "harvesting" prices  $\mathbf{H}^i = [\underline{\epsilon}^i, \bar{\epsilon}^i]$  is then given as

$$\mathbf{H}^i = \left[ \frac{p^{max} + 2S + c^j}{2} - \gamma, p^{max} \right]$$

since it includes mainly the best responses on rival's aggressive prices. Please note that a price of  $\bar{\epsilon}^i = p^{max}$  is firm  $i$ 's best response on a rival's harvesting price that is just not profitable to undercut ( $p_2^j = \underline{\epsilon}^j$ ). For every rival's harvesting price, except for  $\underline{\epsilon}^j$ , there exists a price for firm  $i$  to optimally undercut its rival. Thus, for  $\gamma \rightarrow 0$  the interval length of  $\mathbf{A}^i$  corresponds to the length of  $\mathbf{H}^j$  and vice-versa. Equation (10) then defines a firm  $i$ 's best response after the iterated elimination of strictly dominated prices  $BR^{iS^*}(p_2^j)$  and consequently constitutes firm  $i$ 's set of rationalisable price strategies in a split subgame.

$$BR^{iS^*}(p_2^j) = \begin{cases} \mathbf{A}^i & \text{if } p_2^j \in ]\underline{\epsilon}^j; \bar{\epsilon}^j], \\ [\underline{\epsilon}^i; \bar{\epsilon}^i[ & \text{if } p_2^j \in \mathbf{A}^j, \\ \bar{\epsilon}^i = p^{max} & \text{if } p_2^j = \underline{\epsilon}^j. \end{cases} \quad (10)$$

The price spectrum of aggressive and harvesting prices does not exhibit any states of mutual best responses in pure pricing strategies. Hence, a firm  $i$  randomizes among its set of rationalisable strategies  $p_2^i \in \mathbf{A}^i \cup \mathbf{H}^i$  which constitutes an equilibrium in mixed strategies we define as  $\Gamma$ . Since  $p_2^i = \underline{\epsilon}^i$  is not profitable to undercut, a firm  $i$  will always retain its market share and will realize the same profit, even if the rival optimally responds with  $p_2^j = \bar{\epsilon}^j$ . As a consequence, it must retain the same expected profit as well in the mixed strategy equilibrium such that  $E[\pi_2^i(\Gamma)] = \pi_2^i(p_2^i = \underline{\epsilon}^i)$  which converges to

$$\pi_2^{iS} = \left( \frac{p^{max} + 2S + c^j}{2} - c^i \right) \frac{m}{2} \quad (11)$$

for  $\gamma \rightarrow 0$ . This completes the proof. □

### Proof of Proposition 3.

*Proof.* Firms are anticipating market outcomes of the subsequent period early on and maximize combined profits from both the early and the mature market. We define  $\Pi^{iMI} = \pi_1^{iMI} + \pi_2^{iMI}$  as firm  $i$ 's total profits if it monopolizes the market in the first period. Total profits of  $\Pi^{iS}$ ;  $\Pi^{iMJ}$  are defined analogously. It is obvious that a firm wants to avoid overpricing its competitor if possible in the first period, since this implies zero profits in either market phase. However, this case is highly relevant as it always secures a non-negative payoff and serves as a minimum profit benchmark. The intercepts of total profits given rival's prices constitute the following proposition. A firm  $i$ 's total profits are defined as

$$\begin{aligned}\Pi^{iMI} &= \pi_1^{iMI} + \pi_2^{iMI} = \left( (p_1^j - \gamma) - c^i \right) m + (c^j + S - c^i) m \\ \Pi^{iS} &= \pi_1^{iS} + \pi_2^{iS} = \left( p_1^j - c^i \right) \frac{m}{2} + \left( \frac{p^{max} + 2S + c^j}{2} - \gamma - c^i \right) \frac{m}{2} \\ \Pi^{iMJ} &= \pi_1^{iMJ} + \pi_2^{iMJ} = 0 + 0.\end{aligned}$$

The intercepts of (i)  $\Pi^{iS}(p_1^j) \geq \Pi^{iMJ}$ , (ii)  $\Pi^{iMI}(p_1^j) \geq \Pi^{iMJ}$  and (iii)  $\Pi^{iMI}(p_1^j) \geq \Pi^{iS}(p_1^j)$  then determine, for which rival prices respective profits are greater than zero (rival monopolization) or it is profitable to monopolize rather than split the market early. The solutions to the above inequalities for  $\gamma \rightarrow 0$  are as follows.

(i)

$$p_1^j \geq 2c^i - \left( \frac{p^{max} + 2S + c^j}{2} \right)$$

(ii)

$$p_1^j \geq 2c^i - (c^j + S)$$

(iii)

$$p_1^j \geq 2c^i - 2(c^j + S) + \left( \frac{p^{max} + 2S + c^j}{2} \right)$$

One can show that the derived thresholds can be ordered such as (i) < (ii) < (iii) given Assumption 1 and switching costs' size. Since  $\Pi^{iMI}$  and  $\Pi^{iS}$  are both monotonically increasing functions in  $p_1^j$  the derived intercepts are unique. Hence for rival prices of

$$p_1^j \in \left[ 2c^i - \left( \frac{p^{max} + 2 + c^j}{2} \right) ; 2c^i - 2(c^j + S) + \frac{p^{max} + 2S + c^j}{2} \right] \quad (12)$$

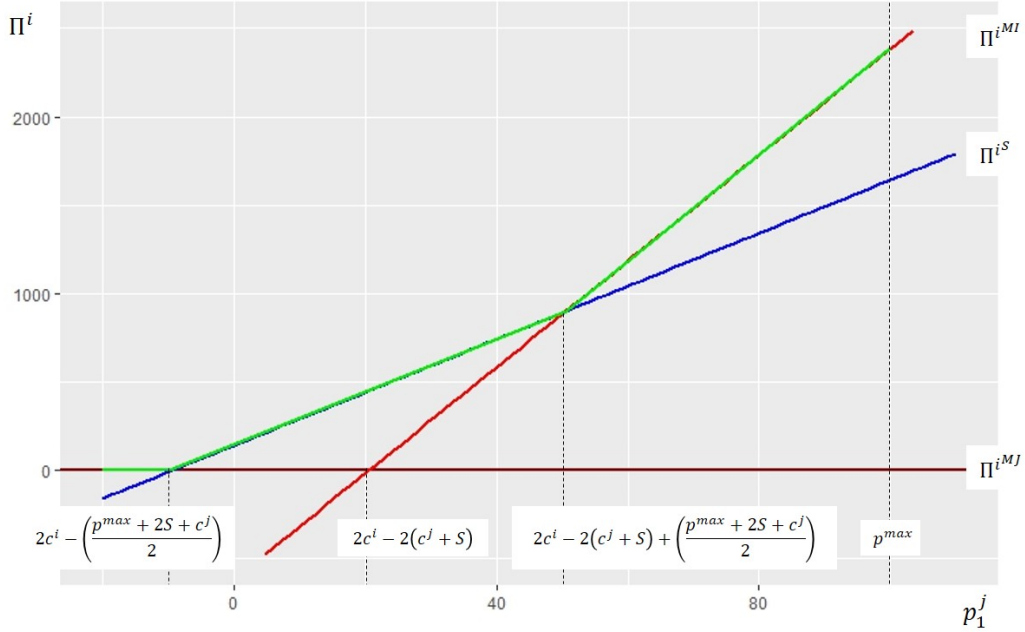
total profits of repeated market sharing exceed those from own monopolization. Consequently a firm  $i$  wants to price identical  $p_1^i = p_1^j$  resulting in multiple price pairs within this range on which firms want to coordinate on early. This implies the existence of multiple subgame perfect Nash-equilibria of the present SC game. In equilibrium profits are

of the interval

$$\Pi^{i*} \in \left[ 0, \left( 2 \frac{p^{max} + 2S + c^j}{2} - 2(c^j + S) \right) \frac{m}{2} \right]. \quad (13)$$

Figure 9 illustrates firms' total profits of the reduced game and relevant intercepts. This completes the proof.  $\square$

Figure 9: Profits of the reduced switching costs game



Notes: Firms' total profits of the reduced form game in case of market sharing ( $\Pi^{iS}$ ), own and rival's monopolization ( $\Pi^{iMI}$ ,  $\Pi^{iMJ}$ ) as a function of rival's price ( $p_1^j$ ). Firm  $i$ 's best response function is highlighted.

The symmetric distribution of market shares in a split subgame severely decreases price competition compared to a monopolization subgame. Although monopoly profits exceed those from market sharing in the first stage, they will not necessarily make up for reduced profits in the second market phase. Only for rivals prices that lie above the interval of (12) monopolization is optimal. Hence, for prices within the interval firms want to coordinate and price identically rather than aggressively to take advantage of relaxed subsequent price competition in a split subgame. If however the rival prices such as  $p_1^j < 2c^i - \left( \frac{p^{max} + 2S + c^j}{2} \right)$  even splitting marked demand early is not profitable. A firm  $i$  then optimally overprices since early market phase discounts could not be recouped by profits of the mature market.

## Appendix C: Dynamic competition

For equilibria finding of the repeated game we assume collusive firms to coordinate on prices that maximize joint cartel profits irrespective of switching costs. Hence, firms charge the reservation price and share market demand twice. An explicitly collusive firm  $i$  then sets prices of  $p_1^{iC}, p_2^{iC} = p^{max}$  under switching costs and  $p_B^{iC} = p^{max}$  under the Bertrand benchmark.

Given the structure of the static game, cartel sustainability and equilibria of the repeated game differ in two dimensions. First, the static switching cost game exhibits multiple Nash-equilibria in pure strategies. Therefore, a firm  $i$  has the opportunity to employ either of these as a competitive threat as part of a grim trigger punishment. Therefore, firms can either punish *harshly* in setting the lowest equilibrium price of  $p_1^i = 2c^i - \left(\frac{p^{max} + 2S + c^j}{2}\right)$  or more *smoothly* in granting positive competitive profits. Second, the two competition stages within a playing period enable firms to deviate in the first or the second stage. Given Assumption 1, a deviation in the first market stage is however always preferable to a deviation during later competition if switching costs are present. In treatments NTSC0 & TSC0 deviating firms do so rather in the second stage of Bertrand competition. Table 4 displays the minimum discount factors for which all prices up to  $p^{max}$  can be sustained in a symmetric collusive equilibrium.

Reasonably, a firm who wants to deviate will do so optimally in the first market stage. Then it depends on the punishment intensity whether switching costs facilitate cartel sustainability or not. If firms employ indeed a harsh punishment scheme that implies competitive profits of zero, collusion is easier to sustain under switching costs. The contrary applies if firms in fact punish rather smoothly. For the specific experiment parameters the highest discount factor required for collusive equilibria is that of early deviation under a smooth punishment regime of  $\delta_{SC}^{iS,E} = \frac{2}{5}$ . If subjects perceive the game's continuation probability of  $\frac{7}{8}$  in fact as a discount factor, then coordination on every price of the spectrum is an equilibrium outcome of the repeated game. Bó (2005) finds for repeated prisoner's dilemma games that the continuation probability has indeed an effect on subjects' play.

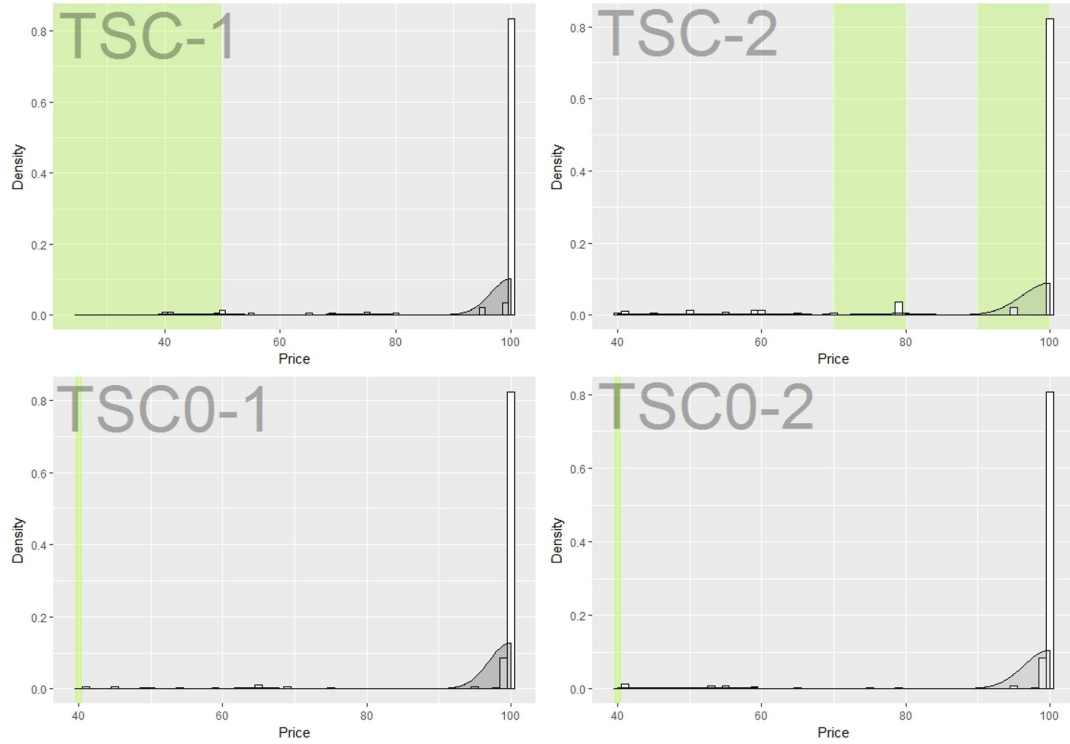
Table 4: Minimum discount factors by punishment intensity and deviation timing

	Early deviation	Late deviation
Bertrand competition	$\frac{1}{1-\delta}\Pi^{i2C} \geq (p^{max} - c^i)m$ $\delta_B^i \geq 0$	$\frac{1}{1-\delta}\Pi^{i2C} \geq \Pi^{iC} + (p^{max} - c^i)m$ $\delta_B^i \geq \frac{1}{3}$
Switching costs		
Harsh punishment	$\frac{1}{1-\delta}\Pi^{i2C} \geq [(p^{max} - c^i)m + (c^j + S - c^i)m]$ $\delta_{SC}^{i,H,E} \geq 1 - \frac{p^{max}-c^i}{p^{max}-2c^i+c^j+S}$ $0, \delta_{SC}^{i,H,L} < \delta_{SC}^{i,H,E} < \frac{1}{3}, \delta_{SC}^{i,S,E}$	$\frac{1}{1-\delta}\Pi^{i2C} \geq [\Pi^{iC} + (p^{max} - S - c^i)m]$ $\delta_{SC}^{i,H,L} \geq 1 - \frac{p^{max}-c^i}{\frac{3}{2}(p^{max}-c^i)-S}$ $0 < \delta_{SC}^{i,H,L} < \frac{1}{3}, \delta_{SC}^{i,H,E}, \delta_{SC}^{i,S,L}$
Smooth punishment	$\frac{1}{1-\delta}\Pi^{i2C} \geq [(p^{max} - c^i)m + (c^j + S - c^i)m]$ $+\frac{\delta}{1-\delta} \left[ \left( \frac{p^{max}+2S+c^j}{2} - 2(c^j + S) \right) \frac{m}{2} \right]$ $\delta_{SC}^{i,S,E} \geq \frac{(c^j+S-c^i)}{\left( \frac{p^{max}+3c^j-4c^i}{2} + S \right)}$	$\frac{1}{1-\delta}\Pi^{i2C} \geq [\Pi^{iC} + (p^{max} - S - c^i)m]$ $+\frac{\delta}{1-\delta} \left[ \left( \frac{p^{max}+2S+c^j}{2} - 2(c^j + S) \right) \frac{m}{2} \right]$ $\delta_{SC}^{i,S,L} \geq \frac{\frac{1}{2}(p^{max}-c^i)-S}{\left( \frac{p^{max}+c^j-3c^i}{2} - S \right)}$ $\frac{1}{3}, \delta_{SC}^{i,H,E}, \delta_{SC}^{i,S,L} < \delta_{SC}^{i,S,E} < \frac{1}{2}$

Notes:  $\Pi^{iC} = (p^{max} - c^i) \frac{m}{2}$  is defined as the cartel profit of on market stage and is identical for competition with and without switching costs.  $\Pi^{i2C} = 2 \cdot \Pi^{iC}$  is then the cartel profit of two market stages and an entire playing period. Under "harsh punishment" the smallest competitive equilibrium profit of zero is used as a punishment threat, whereas "smooth punishment" corresponds to the highest competitive equilibrium profit. For the ordering of the discount factors  $c^i = c^j$  is imposed as is the case in the experiment.

## Appendix D: Figures & tables

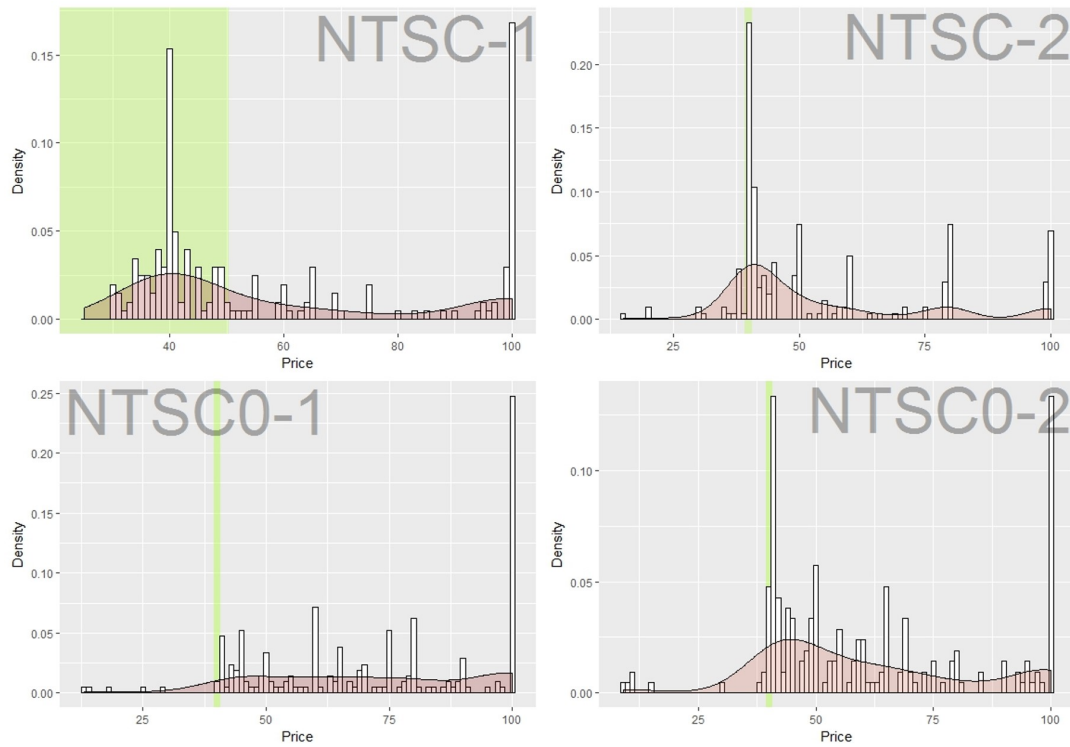
Figure 10: Aggregate price distributions of communication treatments



Notes: Displayed distributions incorporate posted prices in all supergames and subgames. Green highlighted areas correspond to prices of the subgame perfect Nash-equilibrium of the static game. Kernel densities are estimated via the Gaussian Kernel function and bandwidth is one standard deviation of the kernel.



Figure 11: Suckers' price distributions of non-communication treatments



Notes: Displayed distributions incorporate posted prices in all supergames of firms who overpriced in the first market stage and consequently served no demand initially. Green highlighted areas correspond to prices of the subgame perfect Nash-equilibrium of the static game. Kernel densities are estimated via the Gaussian Kernel function and bandwidth is one standard deviation of the kernel.

Table 5: Difference-in-difference estimation

	Dependent variable: <i>Mean market period profit</i>		
	$SG_1$	$SG_2$	$SG_3$
Communication dummy	1,200.42*** (87.48)	1,048.44*** (52.46)	795.75*** (69.64)
SCost dummy	35.31 (87.48)	-266.30*** (52.46)	-577.75*** (69.64)
Comm-SCost-Interaction	-344.06*** (123.71)	337.86*** (74.18)	561.25*** (98.48)
Constant	296.67*** (61.86)	654.89*** (37.09)	998.25*** (49.24)
Observations	288	576	240
Adj. R <sup>2</sup>	0.499	0.657	0.695

Notes: Estimated OLS regression coefficients with robust standard errors in parenthesis. The dependent variable is the mean profit of a market in a playing period. *Communication dummy* is a dummy, which takes the value 1 for observations from communication treatments TSC & TSC0. *SCost dummy* is a dummy, which takes value 1 if observations are from treatments with Switching Costs NTSC & TSC. *Comm-SCost-Interaction* is an interaction of the previous two dummies. Significance levels of the coefficients are indicated according to \*p<0.1; \*\*p<0.05; \*\*\*p<0.01.

Table 6: Firms' average profits by period and market phase

Profits (Taler /Period) (Taler /Market phase)	Aggregate		Monopolist		Outsider		Splitter	
	NTSC	<b>380.8</b> 64.08	316.68	<b>714.7</b> 161.44	553.22	<b>3.71</b> 0	3.71	<b>439.7</b> 18.65
NTSC0	<b>636.1</b> 332.9	303.2	<b>743.8</b> 496.7	247.1	<b>180.8</b> 0	180.8	<b>1189.1</b> 601.8	587.3
TSC	<b>1622.4</b> 819.6	802.8	<b>1266.7</b> 836.7	430.0	<b>292.7</b> 0	292.7	<b>1786.6</b> 897.8	888.8
TSC0	<b>1669.2</b> 842.4	826.8	<b>1608.2</b> 1376.4	231.8	<b>1053.0</b> 0	1053.0	<b>1795.6</b> 899.9	895.7

Notes: Bold values display average profits of a total playing period, plain values refer to average profits firms realize in the respective market stages.

Table 7: Keywords in whole treatments TSC and TSC0

<i>TSC</i>		$W_{TSC} = 1476$		<i>TSC0</i>			$W_{TSC0} = 1458$
Word	Freq.	Rank	RRD to <i>TSC0</i>	Word	Freq.	Rank	RRD to <i>TSC</i>
many	8	30.5	16.62	deal	10	26.5	19.57
market	8	30.5	16.62	switching costs	6	44	11.39
absolutely	6	42	11.80	per	17	11	8.45
bet	8	30.5	8.93	(each) time	13	17.5	8.40
say	6	42	6.21	I	7	37.5	7.56
sure	11	21.5	4.05	perfect	12	20	7.23
go	9	24.5	3.43	1800	10	26.5	5.21
have	7	36.5	3.21	shall	12	20	4.20
give	12	19	3.16				

Notes: Words are ordered according to the *RRD* towards the respective treatment which is calculated according to (8). Only words whose original rank in the base corpus ( $t1$ ) and rank differential satisfies  $r_{w,t1} \leq 50$  and  $RRD_{w,t1} \geq 3$  are displayed. Punctuation, articles, conjunctions and prepositions of location are omitted. Words are translated from German.

Table 8: Keywords in the first supergame and the latter two of TSC

$SG_1$				$W_1 = 393$				$SG_{2,3}$				$W_{2,3} = 1083$			
Word	Freq.	Rank	RRD to $SG_{2,3}$	Word	Freq.	Rank	RRD to $SG_1$	Word	Freq.	Rank	RRD to $SG_1$	Word	Freq.	Rank	RRD to $SG_1$
attempt	3	26.5	18.30	many	8	21	18.76	many	8	21	18.76	many	8	21	18.76
(I) see	4	19.5	12.69	to me	8	21	18.76	to me	8	21	18.76	to me	8	21	18.76
know	2	45	10.37	none	8	21	18.76	none	8	21	18.76	none	8	21	18.76
were	2	45	10.37	has	8	21	18.76	has	8	21	18.76	has	8	21	18.76
suggest	2	45	10.37	absolutely	6	29	13.31	absolutely	6	29	13.31	absolutely	6	29	13.31
our	2	45	10.37	(we) both	6	29	13.31	(we) both	6	29	13.31	(we) both	6	29	13.31
get	2	45	10.37	super	13	12	8.83	super	13	12	8.83	super	13	12	8.83
half	2	45	10.37	total	8	21	4.62	total	8	21	4.62	total	8	21	4.62
(I) believe	2	45	10.37	always	39	3	4.50	always	39	3	4.50	always	39	3	4.50
900	4	19.5	5.59	have	6	29	3.07	have	6	29	3.07	have	6	29	3.07
choose	2	45	4.93												
already	2	45	4.93												
product	2	45	4.93												
costs	2	45	4.93												
(we) might	2	45	4.93												
you're welcome	2	45	4.93												
(I) think	2	45	4.93												
agree	3	26.5	3.85												

Notes: Words are ordered according to the *RRD* towards the respective supergame(s) which is calculated according to (8). Only words whose original rank in the base corpus ( $t1$ ) and rank differential satisfies  $r_{w,t1} \leq 50$  and  $RRD_{w,t1} \geq 3$  are displayed. Punctuation, articles, conjunctions and prepositions of location are omitted. Words are translated from German.

Table 9: Keywords in the first supergame and the latter two of TSC0

$SG_1$				$W_1 = 386$				$SG_{2,3}$				$W_{2,3} = 1072$			
Word	Freq.	Rank	RRD to $SG_{2,3}$	Word	Freq.	Rank	RRD to $SG_1$	Word	Freq.	Rank	RRD to $SG_1$	Word	Freq.	Rank	RRD to $SG_1$
would	3	28	17.21	has	13	11.5	34.78								
that	4	18.5	13.00	have	7	27.5	13.96								
price	7	10	10.70	more	6	31	12.27								
suggest	2	49.5	9.30	exactly	6	31	12.27								
test	2	49.5	9.30	per	16	9	12.11								
idea	2	49.5	9.30	collusion	5	39	9.55								
had	2	49.5	9.30	(it) worked	5	39	9.55								
alternate	2	49.5	9.30	go	5	39	9.55								
second	3	28	8.25	first	5	39	9.55								
most	3	28	8.25	(I) am	5	39	9.55								
switching costs	4	18.5	5.32	many	10	17	5.94								
none	5	14	4.29	1800	9	20.5	4.76								
probably	2	49.5	4.23	(we) both	8	24.5	3.82								
kidding	2	49.5	4.23	if	13	11.5	3.30								
reverse	2	49.5	4.23	always	34	4.5	3.11								
tip	2	49.5	4.23												
next	2	49.5	4.23												
sounds (good)	2	49.5	4.23												
highest	2	49.5	4.23												
equally	2	49.5	4.23												
sense	3	28	3.18												
thanks	3	28	3.18												

Notes: Words are ordered according to the *RRD* towards the respective supergame(s) which is calculated according to (8). Only words whose original rank in the base corpus ( $t_1$ ) and rank differential satisfies  $r_{w,t_1} \leq 50$  and  $RRD_{w,t_1} \geq 3$  are displayed. Punctuation, articles, conjunctions and prepositions of location are omitted. Words are translated from German.

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